Design and implementation of WoBaLearn - a work-based context-aware mobile learning system

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Contents

1 Introduction

1.1 Introduction

The use of technology for learning and teaching brings optimism and opportunities for education. It frees both the teacher and the learner by removing traditional boundaries and restrictions to knowledge via the open and ubiquitous access that it offers (Katz, 2010). Particularly in professional environments where learning occurs randomly and spontaneously, technology enhanced learning can provide more learning opportunities and better learning effects.

In this chapter, we first introduce and identify the relative definitions in the Technology Enhanced Learning field and the definitions of learning occurring in professional environments. Then, we indicate the necessities, challenges and contributions of this research. Finally, we define the organization of this dissertation.

1.2 Definitions in the Technology Enhanced Learning Field

The rapid co-development of technology and learning offers new ways to represent knowledge, new educational practices, and new global communities of learners. This has attracted increasing attention in the research field known as Technology Enhanced Learning.

The term Technology Enhanced Learning (TEL) is used extensively throughout the educational world. It is an assortment of terms that have been used to describe the application of information and communication technologies (ICT) to learning and teaching (Price et al., 2010). TEL explores learning futures that incorporate digital technologies in innovative and transformative ways. Research in TEL includes issues such as: design of learning experiences that connect formal and informal context; evolution of learning and technology; new social and cultural context for learning with technology; novel questions of design, computational expression, collaboration and intelligence; social exclusion and inclusion in an age of personal and mobile technology; and attempts to broaden practical and theoretical perspectives on cognition, community and epistemology (Goodyear et al., 2010).

In recent years, researchers have evolved the research issues in TEL from electronic learning to mobile learning, and now to context-aware mobile learning. In what follows, these three TEL research domains are introduced in detail.

1.2.1 Electronic Learning

In a broad sense, electronic learning (e-learning) comprises all forms of electronically supported learning and teaching (Behera, 2013). It is an approach to facilitate and enhance learning through and based on both computer and communication technology. In a narrow sense, e-learning can be defined as instructions delivered on a digital device, mostly computers and laptop computers, with the purpose of supporting individual learning or organizational performance goals (Clark et al., 2011).

E-learning is the means of education that incorporates self-motivation, communication, efficiency, and technology. It offers learners control over content, learning sequences, pace of learning and learning objectives (Behera, 2013). E-learning applications and processes include web-based learning, computer-based learning, virtual classroom and digital collaboration. Learning contents are delivered via Internet, intranet/extranet, wireless telephonic, audio or video tape, satellite TV, and CD-ROM (Behera, 2013). E-learning can be self-paced or instructor-led and includes media in the form of text, image, animation, streaming video and audio. To sum up, e-learning is the use of the Internet and related technologies for the development, distribution and enhancement of learning resources.

In recent years, some e-learning researchers have noticed the progress of wireless communication and sensor technologies, and thus have changed their research issues from e-learning to mobile learning.

1.2.2 Mobile Learning

Mobile learning (m-learning) combines e-learning and mobile computing. Compared with e-learning, m-learning benefits from its flexible mobile support. It is a means to enhance a broader learning experience, and to engage learners on their own terms.

(Traxler, 2009; Kukulska-Hulme et al., 2009) defined mobile learning as the process of learning and teaching that occurs with the use of mobile devices, such as PDA, Smart phones and Tablets, which provide flexible on-demand access (without time and device constraints) to learning resources, experts, peers and learning services from any place. In this definition, a mobile learning learner can carry multiple heterogeneous wearable and handheld devices, and can learn continually wherever he is moving without any location, time or other restrictions. The learner can move and interact unrestricted with other people, hardware and software resources in his neighborhood or in remote locations via networks (Economides, 2009).

The former work in our laboratory (David et al., 2008) identified a mobile learning cartography in relation to e-learning, ubiquitous computing, mobile computing and wearable computing. This mobile learning cartography is shown in Figure 1.1.

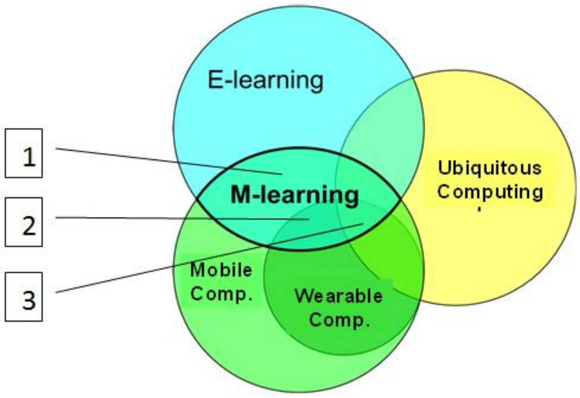

Figure 1.1 Mobile Learning Cartography

In this cartography, four essential characteristics were proposed to describe mobile learning situations, including: devices, mobility, context and location. Three categories of mobile learning, as shown in Figure 1.1, can be identified based on variations of these four characteristics.

- Case 1: This case represents the intersection between e-learning and mobile computing. Mobile technologies can be divided in nomadic use. One situation is mobility without personal computer, and is based on devices proposed in different situations, such as the classroom and in-environment computer on which the user accesses his working / learning environment. Another situation is the mobile technologies provided by personal devices which allow the user to access his working / learning environment installed on his computer wherever he is. This second situation is extracted and discussed as in case 2.

- Case 2: This case represents the mobile learning which is based on wearable computers, such as tablet PC, smartphone, etc. In this case, learning is accessible anywhere in mobility, which means not only sitting somewhere but also while moving.

- Case 3: This case is the intersection between e-learning, wearable computing and ubiquitous computing. Mark Weiser proposed the pioneering notion of ubiquitous computing in 1991 (Weiser, 1991), as mobile and embedded processors can communicate with each other and the surrounding infrastructure, seamlessly coordinating their operation to provide support for a wide variety of everyday work practices. Furthermore, David Lay describes ubiquitous computing as “a vision of computing power ‘invisibly’ embedded in the world around us and accessed through intelligent interfaces” (Lay, 2007). Important features of ubiquitous computing environments are wireless communication between objects as well as the sensors, which allow the objects to sense user information and environment information in the real world and provide users with personalized services (Hwang et al., 2006). Compared with the other two cases, the importance of case 3 is to take context into account.

We consider that it is very important to separate mobile learning into two categories in relation to the context.

- The first category is the learning activity which is totally independent of the learner’s context, such as his personal characteristics, location, surroundings, etc. This category only takes into account the mobile devices used, such as the knowledge acquisition tools.

- The second category is the learning activity relating to the learner’s context. This category focuses on providing learning supports according to the diversity of learners’ characteristics, location, surroundings, as well as mobile devices.

Our work mainly concerns the second category of mobile learning, which is also called context-aware mobile learning.

1.2.3 Context-aware Mobile Learning

Due to the rapid development of sensing technology, combining real-world context with digital systems has become an important learning mode (Wu et al., 2012). Many researchers have attempted to combine sensing technology with mobile technology to build up context-aware mobile learning. Processing context-aware characteristics, a mobile learning system has the capacity to detect real-world situations, and guide students to learn through mobile devices in the actual context (Uden, 2007, Hwang et al., 2008).

1.2.3.1 *What is Context?*

Context in mobile computing is different from that in common life. In literature, the term "context" first appeared in Schilit and Theimer's paper (Schilit et al., 1994a). They defined context as location, identities of nearby people and objects, and changes to those objects. Since then, many researchers have made efforts to define context in mobile computing. Brown et al. (Brown et al., 1997) give context definition as location, identities of the people around the user, the time of day, season, temperature, etc. Context defined by Ryan et al. (Ryan et al., 1998) is the user's location, environment, identity and time. However, when considering a potential new type of context information, these definitions expressed by the examples are hard in helping us to decide whether to classify the information as context.

Other definitions have provided synonyms for context, referring to context as the environment or situation. Some consider context to be the user's environment, whereas others consider it to be the application environment. For example, Brown defined context to be the elements of the user's environment that the computer knows about (Brown, 1996). Franklin and Flaschbart saw it as the situation of the user (Franklin et al., 1998). Ward, Jones, and Hopper viewed context as the state of the application surroundings (Ward et al., 1997), while Rodden, Cheverst, Davies, and Dix defined it as the application setting (Rodden et al., 1998). Hull, Neaves, and Bedford-Roberts included the entire environment by defining context to be aspects of the current situation (Hull, R., et al., 1997). These definitions are clearly more general than enumerations, but provide little guidance in analyzing the constituent elements of context, much less identify them.

Abowd and Dey (Abowd et al., 1999) summarize previous works and provide a more general definition of context with the following statement: Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves. This definition of context enjoys widespread acceptance by researchers. In this thesis, we also adopt Abowd and Dey's definition of context.

For the expression in this thesis, we use “context” as a collective noun to present the groups, and use “one context” to express a specific element of the group.

1.2.3.2 *What is Context Awareness?*

The first definition of the term “context-aware” was given by Schilit and Theimer (Schilit et al., 1994a). They described context awareness as the capacity to adapt according to the location of use, the collection of nearby people and objects, as well as those objects over time. From then on, there have been numerous attempts to define context awareness.

Hull et al. (Hull, R., et al., 1997) and Pascoe et al. (Pascoe et al., 1998) have described context-aware computing to be the ability of computing devices to detect and sense, interpret and respond to aspects of a user's local environment and the computing devices themselves. Ryan (Ryan, 1997) viewed context awareness as applications that monitor input from environmental sensors and allow users to select from a range of physical and logical context according to their current interests or activities. In a similar definition, Fickas et al. (Fickas et al., 1997) gave the context-aware application (called an environment-directed application) a definition saying that the application can monitor changes in the environment and adapt their operation according to predefined or user-defined guidelines. The context-aware application defined by Brown (Brown, 1998) was the application that automatically provides information and/or takes actions according to the user’s present context as detected by sensors.

In 1999, Abowd and Dey (Abowd et al., 1999) provided a widely acceptable definition of context awareness: A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task.

A precise definition of context awareness is an efficient method for telling whether an application is context-aware or not, and has provided researchers with a useful way for determining what types of applications to focus on.

1.2.3.3 What is Context-aware Mobile Learning?

The highly personalized nature of digital mobile devices provides an excellent platform for the development of contextual, learner-centric learning experiences. By taking advantage of the context-aware feature, a mobile learning system can better understand the just-in-time learning situation, and then provide the learner with adaptive and personalized learning supports. During the learning process, the mobile device can sense, track and monitor the surrounding environment and transmit the information to the learning system. The system uses this contextual information to make dynamic learning adaptation decisions for the benefit of the learner. In this way, the system providing supports would be auto-configured and tailored to learner's needs, learner's interests, environment limitation and device capabilities (Economides, 2008a).

Context-aware mobile learning is an essential learning approach in terms of both learning attitude and learning effectiveness (Hwang et al., 2008). The main benefits of context-aware mobile learning are reported by Demetrios G. Sampson (Sampson et al., 2013) in 2013, as follows:

- Enabling on-demand access to learning resources and services, as well as instant delivery of notifications and reminders (Ogata et al., 2004);
- Offering new opportunities for learning that extend beyond the traditional teacher-led classroom-based activities (Kukulska-Hulme et al., 2009);
- Encouraging learners to participate more actively in their learning process by engaging them in experiential learning such as learning by doing (Kukulska-Hulme et al., 2009);
- Enabling learning and performance support by exploiting real-life context (Kukulska-Hulme et al., 2009);
- Supporting on-demand access, communication and exchange of knowledge with experts, peers and communities of practice (Sharples et al., 2010).

Many existing efforts have been undertaken regarding designing and implementing context-aware mobile learning systems. Some significant examples of context-aware mobile learning systems are: mCALS (Yau et al., 2008), which was developed for supporting Java programming; CAMLES (Nguyen et al., 2010), which aims to support foreigners in English learning; LOCH (Paredes et al., 2005), which can be applied in supporting informal language learning outside the classroom; UoLmP (Gómez et al., 2013), which was developed for delivering adapted activities and contents through every step in the learning flow, and was presented by a language learning scenario; P-LearNet (Pham-Nguyen, C. et al, 2008) project, which is concerned with TEL (Technology Enhanced Learning) systems integrating context-aware corporate learning and working activities for e-retail in shops and hypermarkets. We will present in detail the application field, the functions and the architecture of these systems in section 2.1.

1.3 Definitions of Learning in Professional Environments

Learning is a process of changing or transforming, in the sense of expanding the range of possibilities and actions for individuals and for groups (Fenwick, 2005). Focusing on learning particularly by professionals, two phases can be identified, and are shown in Figure 1.2:

- Academic phase: this phase focuses on learning before starting a professional activity, which happens mainly during school or university studies or pre-professional training periods,

- Working phase: this phase focuses on learning during a professional occupation, which happens in the workplace.

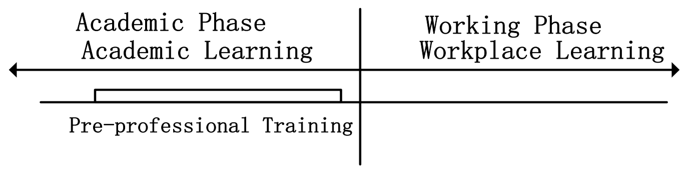

Figure 1.2 Two Phases Identified in Professional Learning

The knowledge generated and acquired in the workplace differs greatly from that generated and sustained by academic institutions (Boud et al., 2000a). In the academic phase, studies form an appropriate period devoted to assimilation of important theories and generic methodologies which are more difficult to acquire in the workplace. On the contrary, in the working phase, learning is devoted to practical, precise behaviors, and operation and gesture acquisitions which are difficult to acquire at university. More specifically, in the working phase, learning is focused on a job and may be associated with training to gain the skills, experimental learning from doing a job, or reflection about the context of that job.

It is important to take into account assimilation and mastering of these two phases of learning. Theories and main approaches through typical case studies can be learned in the academic phase before starting to work, and precise commands of special methods, tools and gestures can be naturally mastered during workplace practice. In this thesis, our work mainly focuses on the professionals' learning during their working phase.

1.3.1 Workplace Learning

Workplace learning, the learning occurring during the professionals' working phase, is seen as a flexible form of learning which enables employees to engage in the regular processes of updating and continuing professional development which have been increasingly emphasized (Reeve et al, 1999). Workplace learning is concerned not only with immediate work competencies, but also with potential competencies. Also, it is about investment in the general capabilities of employees as well as specific and technical capabilities (Boud et al., 1999).

Workplace learning is considered to be a key strategy in meeting challenges both from the perspective of enterprise competitiveness and from the perspective of individuals' employability (Ellström, 2001; Mills et al., 2003). The enterprises benefit because workplace learning is a potential to promote production, effectiveness and innovation; and the professionals benefit because workplace learning supports them to learn knowledge, skills and capacity, timely and effectively (Boud et al., 1999). What's more, the workplace is a good environment for the development of professional generic skills, such as communication, problem solving, teamwork, customer service, etc.

Workplace learning comes from a range of study fields, such as adult education, higher education, cultural anthropology, organizational theory, innovation studies, industrial economies, management studies, vocational education, etc. It contains a variety of theoretical perspectives, including behaviorism, interpretivism and critical theory. Workplace learning servers are used in a variety of environments, such as, manufacturing or production-based industries, knowledge-based or service-based organizations, the public sector, universities, professional practice etc. Also, it uses every imaginable methodology, from surveys and interviews, to diaries and participant observation (Candy et al., 1998).

Based on the degree to which "learning" and "work" are separated, workplace learning can be divided into three phases (Stern et al., 1999):

1) **Workplace as a site for learning**
   This approach involves the spatial separation of learning from work, where learning activities, typically in the form of "in-company training", will take place "off-the-job" and outside the immediate working environment.

2) **Workplace as a learning environment**
   In this approach, learning is still planned and organized but takes place within the working environment and is largely "on-the-job".

3) **Learning and working inextricably linked – work-based learning**
   In this phase, the workplace is structured to maximize processes of learning where employees learn how to become learners and learn skills related to their own jobs and those of other workers. Work is organized according to a "high performance" model where learning occurs "informally" within the workplace and through team work, problem solving and social interaction with colleagues and clients/customers. This learning is work-related, informal, location-based and just-in-time.

1.3.2 Work-based Learning

Work-based learning is the third phase of workplace learning. More specifically, work-based learning refers to a form of learning activity that occurs on a day-to-day basis at work as professionals acquire new knowledge and skills or develop new approaches to solving problems (Boud et al., 2000b). In the process, work activities cause learning to occur, determine the needs and provide the context; learning activities arise from work practice, provide supports and ensure that work continues. Work-based learning is a facilitating form of learning in that it supports professionals with particular knowledge and skills which are relevant to the work in which professionals are engaged.

A survey in 2001 presented the specific learning methods used in work-based learning. By interviewing 80 professionals from 20 different professions and based on a questionnaire survey of 372 professionals from six selected professions, professionals' work-based learning approaches and their ratings are listed in Table 1.1 (Cheetham et al., 2001). Based on this survey result, we can identify that acquiring just-in-time work-related instructions and collaborating with others (discuss or get help) are professionals' essential work-based learning approaches.

Table 1.1 Professionals' Work-Based Learning Approaches and Ratings in 2001

Work-Based Learning Approach	Average Rating (out of 5) for contribution to competence
Reading manual and book on the job	4.2
Working alongside more experienced colleagues	3.9
Working as part of a team	3.7
Self-analyzing or reflecting	3.6
Learning from clients/customers/patients/etc.	3.5
Networking with others doing similar work	3.4
Getting support from mentors	3.2
Using a role model	2.6

With the development of technology, especially network technology, the learning methods used in work-based learning have changed. Technology provides the new services to help professionals collaborate with others and access knowledge, thus increasing learning opportunities. Both traditional approaches and new technology approaches in work-based learning were identified in 2006, and are listed in Table 1.2.

Table 1.2 Traditional and New Technology Work-Based Learning Approaches in 2006

The traditional approaches	The new technology approaches
• Ask a neighbor • See the boss • Talk to an expert • Look at a manual or a book	• Learn in workflow • Search the Internet or Intranet to find online knowledge sources • Email an individual • Instant Message or Skype someone • Listen to a Podcast • Interact with others online via discussion forums

As Engeström reported (Engeström, 2001), work-based learning is a crucial approach to increasing professionals' working and learning efficiency. However, as a result of its characteristics, such as spontaneity and informality, more attention and efforts are required to promote work-based learning.

The learning systems, used to support the design, development and delivery of learning programs in companies, encompass five types of applications (Carliner, 2012), including: Learning Management Systems (LMSs) (Peter, 2013), Course Management Systems (Malikowski et al., 2007), Learning Content Management Systems (LCMSs) (Brennan et al, 2001), Content Management Systems (Baxter, S. et al., 2002), and Talent Management Systems (Tarique et al., 2010). Although these systems were designed originally to support formal learning, each has capabilities useful for some specific aspects of professionals' learning during their work, such as distributing learning materials or allowing communication among learners and helpers in a company. The details concerning these learning systems are:

- **Learning Management Systems (LMSs)**: LMSs for professionals can automate many of the administrative functions involved in managing courses and training and development groups. LMSs let instructors and learners communicate with one another, while many also provide course catalogs and related career-planning materials.

- **Course Management Systems**: Course Management Systems were designed originally for the academic environment and were intended to support classroom courses. For professionals, they could facilitate communication among learners in an enterprise as well as distribution of learning materials.

- **Learning Content Management Systems (LCMSs)**: LCMSs for professionals can store, organize, retrieve and present electronic learning materials, such as professionals' individual lessons, brief passages, videos, and illustrations.

- **Content Management Systems**: Content Management Systems can help professional organizations to track and manage all the contents they produce, such as reports, plans, policies and procedures, references, and user's guides.

- **Talent Management Systems**: Talent management systems for professionals provide templates for creating and monitoring performance and career development plans, as well as reminders about advice for conducting appraisals. Some let managers and human resources staff evaluate skill bases and use that information to determine individual and group needs for learning.

However, none of the above-mentioned systems is designed for providing just-in-time, personalized and work-related learning supports in real working situations. The original design principle means these systems are hard to cater totally to professionals' work-based learning needs.

On the other hand, EPSS, the electronic performance support system, aims to offer professionals just-in-time, just enough information and tools to enable optimum performance when and where needed (Bezanson, 2002). By using an EPSS, employees will receive the additional support often required during their everyday tasks. However, most EPSS are accessed by computers, and few can be accessed by mobile devices. This cannot ensure continuation of learning when professionals change their workplace. What's more, few contexts are considered in EPSS, for example, the environment context sensed by sensors and personal learning characteristics are rarely considered. This cannot ensure that EPSS offers completely adaptive learning contents according to the different learning situations.

The deficiencies in the above-mentioned systems and the significance of work-based learning call for a specifically designed system to provide proper and comprehensive learning supports. More specifically, the system should be designed according to professionals' practical working processes, to cater to their just-in-time learning needs, to take into account essential contexts, and to integrate comprehensive learning resources, services and tools required to provide sufficient, necessary and adaptive learning supports.

1.4 Work-based Context-aware Mobile Learning

In the field of work-based education, mobile technologies such as cellphones, smartphones and tablets are currently generating considerable interest. However, surprisingly there is little systematic knowledge available about how mobile devices can be used effectively for learning and competence development in the workplace except for initial empirical studies (Pachler et al., 2011a, Pachler et al., 2011b) and theoretical and conceptual discussions (Pimmer et al., 2010).

(Pimmer et al 2014) expressed the notion of “work-based mobile learning” as: the processes of coming to know, and of being able to operate successfully in, and across, new and ever changing contexts, including learning for, at and through work, by means of mobile devices.

To emphasize the “context aware” characteristics of mobile learning, we propose “work-based context-aware mobile learning” as a kind of learning method by taking advantage of context-aware mobile learning to facilitate professionals’ work-based learning. The goal of work-based context-aware mobile learning is to provide work-related, personalized and just-in-time learning supports to assist professionals to solve problems, grasp skills or enhance knowledge, thus promoting personnels’ and also enterprises’ competitiveness.

1.4.1 How Context-aware Mobile Learning can Improve Work-based Learning?

In certain work-based learning scenarios, mobile learning is applied to provide important theoretical and technical support by assisting professionals in achieving or facilitating work-based learning without the limitation of place and time. With the benefits of mobile learning, professionals can continually contact experts, look at a digital manual or book, search the internet to find online sources or interact with others online even if he / she changes workplace. (Pimmer et al 2014) summarized the differences between traditional learning approaches and mobile learning approaches in work contexts based on five aspects, including content, proximity to work processes, social form, degree of formality and educational paradigm. The result is shown in Table 1.3. This result shows that, in work contexts, compared with traditional learning approaches, mobile learning can provide more inspiring benefits.

Table 1.3 Traditional Approaches to Mobile Learning in Work Contexts

Aspects	Traditional Approaches	Excerpts from the Mobile Learning Case Study
Content	Delivery	Standardized: compliance training courses via BlackBerry. Reductionist: Replace video and audio segments with photos or photo series and transcripts. Push: courses were pushed out.
Proximity to Work Processes	Learning for work	Place-independent: to deliver learning anytime and anywhere: 32% completed the learning during business travel, 24% while commuting to work, 26% at home and 18% in the office or elsewhere.
Social Form	Individual	Human-computer interaction: allow the leaner to communicate back and forth with the internal LMS.
Degree of Formality	Formal	Highly structured: standards, such as SCORM, helped guide the methodology for the technology design; tools for reporting, troubleshooting, course and learner-level permission structures.
Educational Paradigm	Cognitive, Behavioral	Outcome/summative assessment: 1.21 percent increase in average competency score. Duration: a more timely completion of compliance training, including a 12 percent higher completion rate.

Furthermore, profiting from the context-aware characteristic of mobile learning, a context-aware mobile work-based learning system has the ability to fit its behavior and functionalities to professionals' learning needs (such as their learning goals and interests), their personal characteristics (such as learning styles and different prior knowledge) and the particular workplace circumstances (such as the current location and illumination level of the workplace). That is to say, with the support of context-aware mobile learning, professionals wearing multiple heterogeneous wearable and handheld devices are able to continually learn contents adapting to his / her learning needs, personal profile and environment conditions, etc., and move and interact unrestricted with other appropriate professionals, hardware and software resources in his / her neighborhood or in remote locations via networks.

Compared with the learning approaches listed in Table 1.2, the enhanced work-based learning by context-aware mobile learning method can be characterized as listed in Table 1.4.

Table 1.4 Enhanced Work-based Learning by Context-aware Mobile Learning Method

Former Work-based Learning Approaches	**Enhanced Approach by Context-aware Mobile Learning Method**
Ask a neighbor	Find available and experience-related neighbor
See the boss	Make an appointment with the boss according to his available time
Talk to an expert	Find related and available experts
Look at a manual or a book	Decrease the range of manuals and books according to current activity
Learn in workflow	Find most-related contents according to current workflow.
Search the internet or intranet or find online knowledge sources	Save online sources' searching time, and increase results' accuracy
Email an individual	Establish communication with a related and available person, provide appropriate communication platform according to their status
Instant Message or Skype someone	
Interact with others online via discussion forums	
Listen to a Podcast	Provide related podcast contents

What's more, from the pedagogical viewpoint, context-aware mobile learning could provide personalized scaffolding, and support professionals to observe and experience real-world situations so as to construct personal knowledge. Professionals, as a result of interaction with work-related context, can conduct independent thinking and enhance their learning motivations to further promote learning achievements.

1.4.2 Relative Learning Approaches

Several learning approaches related to work-based context-aware mobile learning can be identified, including: informal learning, just-in-time learning, problem-based learning, learning and doing, collaborative learning. By analyzing these learning approaches, we can identify the main characteristics of work-based context-aware mobile learning. Meanwhile, these relative learning approaches also provide us with the design principles for a proper work-based context-aware mobile learning system.

1) Informal Learning

Learning is commonly perceived as formal processes or activities that are planned and organized in order to foster change or transformation (of a situation) as a primary (Hager, 2004). However, for the past 20 years researchers have increasingly been focusing their attention on learning as informal processes or activities. Broadly defined, the term "informal" refers to learning outside formally structured, institutionally sponsored, classroom-based activities (Marsick et al., 1990; Garrick, 1998). It is not structured in terms of learning objectives, learning time, or learning support. Most often it is not planned by the learner, it may be intentional, but in most cases it is non-intentional. Also, it typically does not lead to certification (European Commission, 2001).

10 informal learning characteristics are identified (Sarah, 2012): informal learning is never organized; informal learners are often highly motivated to learn; informal learning is often spontaneous; there is no formal curriculum; the "teacher" is someone who cares and who has more experience than the learner; the world is the classroom; informal learning is difficult to quantify; often dismissed by academics and skeptics as being worthless; essential to a child's early development; essential to an adult's lifelong learning.

According to a 2009 Conference Board of Canada study (Bloom, 2009), 56 percent of work-related learning occurs in informal situations. Other authors, such as Jay Cross (Cross, 2007), suggested that this percentage is closer to 70 percent. Given these findings, it's no surprise that learning professionals are keenly interested in trying to understand informal learning so they can harness their power in their organizations (Carliner, 2012).

2) Just-in-time Learning

Just-in-time learning describes the learning in which knowledge is delivered to learners when and where they need it, rather than sitting through hours in traditional classroom training. The aim is that learners can get just the information they need to solve problems, perform specific tasks or quickly update their skills (Sambataro, 2000). Just-in-time learning is strongly related to learning context. It provides learners with effective learning supports which enable learners to solve problems quickly. Nowadays, just-in-time learning is facilitated by information and communication technologies. For example, mobile computing technology allows learners to learn about a topic or to solve a practical problem just-in-time for them but anywhere and anytime.

Just-in-time learning has increasingly attracted the attention of companies, and has been widely applied in working environments. Rather than having employees take time away from work to sit through traditional classroom training, many companies are using just-in-time, technology-based, self-guided tutorials and databases that allow users to focus on “nuggets” of information as needed to perform specific tasks and solve problems as they crop up (Sambataro, 2000).

3) Problem-based Learning

Problem-based learning is recognized as a methodology which promotes integration of knowledge and fosters a deeper approach to lifelong learning (Koschmann et al., 1996). Problem-based learning focuses on learners as constructors of their own knowledge in a situation similar to that in which they would apply that knowledge. In problem-based learning, learners can actively engage in working at tasks and activities that are authentic to the environment in which they would be used (Savery et al., 1995).

Problem-based learning is one of the best examples of a constructivist learning environment in which understanding occurs based on the interactions between learner and environment. In problem-based learning, the learner’s cognitive conflict or puzzlement is his stimulus for learning, and determines the organization and nature of what is learned. During this learning, the learner’s knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings.

4) Learning and Doing

Learning and doing provides learners with “authentic activities” in which learners can work with problems from the real world (Bruner, 1986; Ogata et al., 2004). Learning and doing has two aspects of meaning: (1) learning by doing, in which “learning” is the objective of activity, and doing facilitates the effect of learning; (2) doing by learning, in which “doing” is the objective of activity, and new information supports “doing” to continue until the goal is reached. This process, in which new information integrates with the actor’s experience and cognition, forms learning.

The learning and doing approach has the advantage of discovery and identification of problems. This is because, before the action, the existing problems are difficult to identify, and some new problems may emerge during the action. Specifically, in consideration of the work environment, doing is required particularly for learning when we are confronted with appliances or products, because the interactions between the machines and their use environment are sometimes complex to predict (Habermeier, 1990).

5) Collaborative Learning

The most popular definition of collaborative learning is that several people are learning or trying to learn together. It allows learners to solve one or more issues in common. Collaborative learning is a variety of educational approaches involving joint intellectual efforts of learners, or learners and tutors (Smith et al., 1992).

The necessities of collaborative learning can be identified as:

- Firstly, collaborative learning enables knowledge acquisition from collaborative partners, and stimulates cognitive processes such as articulation and internalization (Dillenbourg, 1999).

- Secondly, better learning occurs when students are given the opportunity to learn skills in authentic environments and to communicate their understanding to others (Rieger et al., 1997);

- Thirdly, learning most naturally occurs, not in isolation but with individuals working together to solve problems, thus denoting the inherent social nature of solutions (Roschelle, 1992).

The development of information technologies allows users to remotely collaborate synchronously. Computer-supported collaborative learning (CSCL) allows support of collaborative learning with ICT. In CSCL, the interactions between individuals or groups are connected to the information environment (Stahl et al., 2006).

In the above statement, we have reviewed 5 learning approaches. Each of these approaches is primarily focused on certain aspects of work-based context-aware mobile learning: informal learning focuses on spontaneity; just-in-time learning focuses on timeliness; problem-based learning focuses on pertinency; learning and doing focuses on authenticity; collaborative learning focuses on interactivity. All these learning approaches can provide us with the design principles for a proper work-based context-aware mobile learning system.

1.5 Research Area

The work of this thesis focuses on: (1) researching into the learning theories related to work-based context-aware mobile learning; (2) researching into the approaches for designing a work-based context-aware mobile learning system; (3) researching into the technologies and methodologies for implementing and testing the designed learning system.

1.5.1 Necessities of Research

Work-based learning is a crucial approach for promoting personnels' and enterprises' competitiveness. It is just-in-time, work-related, informal and spontaneous. As a result of its characteristics such as spontaneity and informality, more attention and efforts are required to promote work-based learning.

As stated above, the learning systems, widely used in companies for supporting the design, development and delivery of learning programs, include LMSs, Course Management Systems, LCMSs, Content Management Systems and Talent Management Systems. However, these systems were designed originally to complement formal learning. This original principle makes these systems hard to totally cater to professionals' just-in-time, work-related learning needs. What's more, EPSS, aiming at offering professionals just-in-time, just enough information and tools to enable optimum performance when and where needed, are accessed mostly by computers, and only a few by mobile devices. Also, few context considered in EPSS, for example, environment context sensed by sensors and personal learning characteristics are rarely considered.

On the other hand, context-aware mobile learning systems, which aim to provide just-in-time learning experiences delivered by mobile devices and tailored to educational needs, personal characteristics and particular circumstances, were initially conducted as part of natural science courses and language training courses (Hwang et al., 2009). For example, mCALS, CAMLES, LOCH and UoLmP, which are stated in section 1.2. Skills training with the support of context-aware mobile learning systems, attracted scholars' attention until recently. The experimental results from a learning environment, which guides inexperienced researchers in practicing single-crystal X-ray diffraction operations, show that the context-aware mobile learning mechanism can benefit the cultivation of learners' problem-solving abilities and operational skills (Hwang et al., 2009). However, limited application fields, and few learning scenarios for skills training and problem-solving have been considered. Nevertheless, the characteristics of context-aware mobile learning systems, such as being aware of context, can provide just-in-time learning supports, and predict that this kind of learning approach can play an important role in skills training and problem-solving.

In this thesis, we aim to apply the context-aware mobile learning method to facilitate professionals' work-based learning. This research work has potential advantages for promoting professionals' learning motivation, effectiveness and cognitive competence. With the benefits of work-based context-aware mobile learning, professionals use their mobile devices to access personalized, adaptive and just-in-time learning supports in the real working environment, which is important from both the learning attitude and learning effectiveness aspects. From the perspective of pedagogy, context-aware mobile learning can provide a fine platform for promoting work-based learning with learning theories, such as situated and authentic learning, which praise the importance of actual experience with the objects and situations to be learned and can be taken as "cognitive apprenticeship" (Paredes et al., 2005). Therefore, the research work in this thesis concerning designing and implementing work-based context-aware mobile learning is necessary and significant.

1.5.2 Research challenges

Given the focus on theories and application of work-based context-aware mobile learning, it is important to understand the main issues in this research theme. Research challenges can be identified from two progressive phases: identifying the challenges in designing and implementing a context-aware mobile learning system, and identifying the challenges in designing the system functionalities and system process to cater to professionals' habits and needs in their work-based learning.

Four major challenges were considered when conducting research in context-aware mobile learning, including:

1) Extracting the metadata for labelling learning contents.

2) Extracting and describing the contextual information for characterizing learning situations.

3) Designing the adaptation strategies which adapt learning contents, learning partners and learning activities according to the contextual learning information.

4) Designing the adaptation engine to execute the adaptation strategies.

Furthermore, considering the characteristics of professionals' work-based learning, five specific research challenges were identified, including:

1) Which metadata should be considered for characterizing the learning contents required in professionals' work-based learning?

2) Which context information should be considered in the particular situation of professionals' work-based learning?

3) When catering to professionals' work-based learning habits and needs, which adaptive learning supports should be designed in adaptation strategies?

4) How to design the adaptation engine to implement the adaptation strategies stated above?

In the former work of our laboratory, efforts were made to extract the metadata to label the learning contents in a particular professional field. In the PhD thesis of Chuantao (Yin C. T., 2010), which was defended in 2010, AM-LOM metadata were proposed with the definitions of nine metadata fields, including: general information, lifecycle, metaMetadata, technical information, educational information, rights, the relation, the annotation and the classification. One or more learning contents, which are related to one professional knowledge or skill, are labeled with these metadata fields, and are formed as a learning unit.

The research in this thesis reused and extended Chuantao's research work. Construction of learning contextual information and generation of adaptation strategies referred to the elements defined in the AM-LOM metadata.

Also, in our user study for evaluating the system, we collected all the required learning contents from professional manuals and the Internet. We then reorganized the relative learning contents into a learning unit and labeled it with AM-LOM metadata according to the definition and specification presented in Chuantao's thesis (Yin C. T., 2010).

In this thesis, for the expression aspect, "learning content" is used to express the single element for explaining or demonstrating knowledge or skill; "learning resource" is used to express the collection of all the necessary learning contents; "learning unit" is a single learning content or a combination of several relative learning contents, which explains a theory or provides a solution of a problem, and is labeled with AM-LOM metadata.

1.5.3 Research Contributions

The main contribution of the work in this thesis is to propose a design scheme and an implementation of a context-aware mobile learning system dedicated to professionals' work-based learning, named WoBaLearn. This system complies with professionals' practical working processes, and provides professionals' with just-in-time, work-related, personalized, environment-adapted learning units, partners and activities delivered by mobile devices.

More specifically, the contributions of the thesis are:

1) **The architecture of WoBaLearn**
By identifying professionals' needs and habits in work-based learning from our online survey results, we proposed the system architecture with the learning activities, complying with professionals' practical working processes and with the functions facilitating professionals' essential learning needs (Zhang, 2013).

2) **An ontology-based hierarchical context model for work-based learning**
We defined an initial context model for describing contextual information in work-based mobile learning, named WbML (Yin C. T., 2014). This model adopts a hierarchical design approach which classifies context into a common layer and a domain layer. This approach improves reusability of the context model. What's more, the WbML context model is built based on ontology for describing context semantically in

a way which is independent from programming language, underlying operation systems or middleware.

3) **A set of adaptation strategies for work-based learning and a learning engine to execute these strategies**
We proposed a set of adaptation strategies for learning units selection, learning units sequence, learning units navigation, learning partners communication, and learning activities generation. These strategies adapt learning supports depending on professionals' just-in-time learning context. We also proposed an adaptation engine which executes these proposed strategies to implement learning adaptations

4) **An implementation of WoBaLearn**
We implemented the proposed system with modern technologies, and set a user study to evaluate this WoBaLearn system. Evaluation results provided us with the evidence that this designed system can offer professionals a satisfactory learning experience and facilitate their work activities.

1.6 Organization of the Dissertation

This dissertation focuses on the design and implementation of a work-based context-aware mobile learning system, which aims to provide professionals with just-in-time, work-related, personalized and environment-adapted learning units, learning partners and learning activities delivered by mobile devices.

In chapter 2, we review the state of the art and the research conducted relevant to context-aware mobile learning systems. Moreover, we enter into an in-depth discussion about the existing contextual information modeling approaches, learning adaptation strategies and adaptation engine design approaches.

In chapter 3, we state and analyze the results of our online survey about work-based learning, which can provide the basis for designing a work-based learning system. Then, we propose our system general design based on four aspects: design principles, design of learning activities in the system, design of system overall structure and design of system architecture.

In chapter 4, we describe in detail the design of learning context model. Based on the specialties of work-based learning, we propose an ontology-based hierarchical context model, named WbML. The context model framework, the context model structure, the description and the values of each context element in this model are presented in this chapter. Then, we introduce the ontology development tools used for building and manipulating the WbML context model. Finally, we interpret the specific methods for collecting the context aspects defined in this model.

In chapter 5, we describe specifically the design of learning adaptation strategies and the adaptation engine. We propose five adaptation strategies for professionals' work-based learning, including adaptation of learning units selection, adaptation of learning units sequence, adaptation of learning units navigation, adaptation of learning partners communication and adaptation of learning activities generation. The design of each adaptation strategy is described in detail in this chapter. Then, an adaptation engine for applying these adaptation strategies in the WoBaLearn system is presented.

By following the system design described in Chapters 3, 4 and 5, we have implemented the WoBaLearn system. In chapter 6, we present first the concrete technologies and development tools used to implement the system. Then, we introduce in detail the functionalities of WoBaLearn with the support of the user interfaces at runtime.

In chapter 7, we present a user study for evaluating our WoBaLearn system. This evaluation contains three aspects, including: users' learning achievement with this system, users' attitudes and acceptance of this system, and users' cognitive load imposed by this system. We introduce the participants, instruments and procedure of this user study. Also, we analyze and discuss the results obtained from this evaluation.

In chapter 8, we summarize the main contributions of this thesis, and discuss future work.

2 State of the Art

2.1 Introduction

Many efforts have been made to design and implement context-aware mobile learning systems. Furthermore, two aspects need to be focused on when aiming at providing learners with adaptive and personalized learning supports in this kind of system (Graf et al., 2008). One aspect incorporates what kind of learning information should be used for adaptation, while another considers what can be adapted in these systems based on the specific information.

In the remainder of this chapter, first we introduce the application fields and functions of a number of context-aware mobile learning systems; second, we state the research work concerning modeling contextual information for characterizing learning situations; then, we list the adaptation strategies designed in typical systems used for adapting learning supports according to current context, and also the adaptation engines employed for executing the corresponding adaptation strategies.

2.2 Context-aware Mobile Learning Systems

Context-aware mobile learning systems are designed with the aim of providing learning supports delivered via mobile devices and tailored to learning needs, personal characteristics and the particular circumstances of the individual learners or a group of interconnected learners. With the benefit of context-aware mobile learning systems, learners can be provided with adaptive and personalized learning supports that are tailored to their particular learning needs and personal characteristics to optimize their satisfaction, learning speed and learning effectiveness.

In this section, we present the application field, functions and architecture of 5 typical context-aware mobile learning systems, including: mCALS (Yau et al., 2008), CAMLES (Nguyen et al., 2010), LOCH (Paredes et al., 2005), UoLmP (Gómez et al., 2013) and P-LearNet (Pham-Nguyen, C. et al, 2008).

1) mCALS

mCALS is a context-aware mobile learning system developed for supporting Java programming learning. The goal of the system is to select appropriate learning objects for learners based on their current context and preferences. User context attributes include their location, and user preference attributes include their knowledge level for the topic (in this case Java) and their available time (Yau et al., 2008).

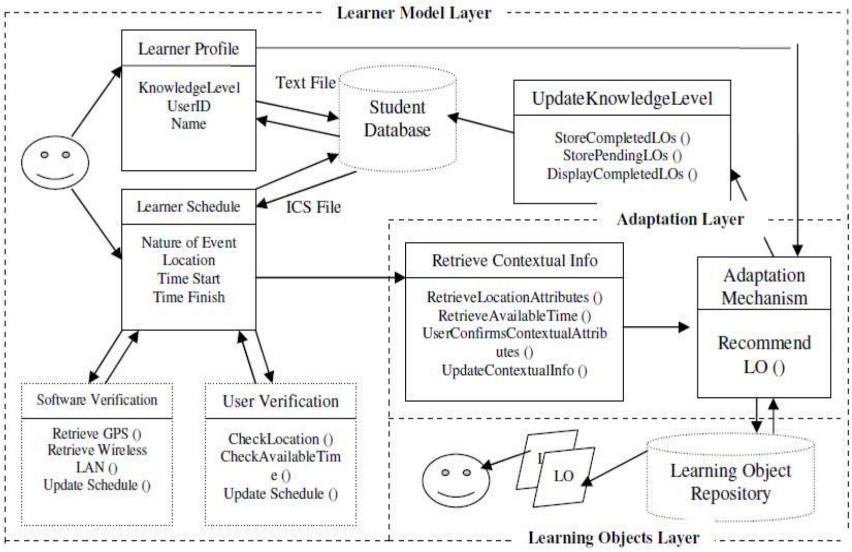

Figure 2.1 System Architecture of mCALS (From (Yau et al., 2008))

The system architecture is designed as shown in Figure 2.1. This architecture is made up of three layers: Learner Model Layer, Adaptation Layer and Learning Objects Layer.

- **Learner Model Layer**: This layer collects, organizes and manages the learner's context, which can characterize the learning situation for learning objects adaptation.

- **Adaptation Layer**: This layer is in charge of selecting appropriate learning objects based on the learner's current context with a series of adaptation mechanisms.

- **Learning Objects Layer**: This layer stores and manages learning objects in a learning object repository, with which learners are provided during their learning.

2) CAMLES

CAMLES is a context-aware mobile learning system that aims to support English language learning and adapts the sequence and navigation of its educational contents based on the combination of the learner's previous knowledge, needs, preferences, availability, current location and temporal information (Nguyen et al., 2010).

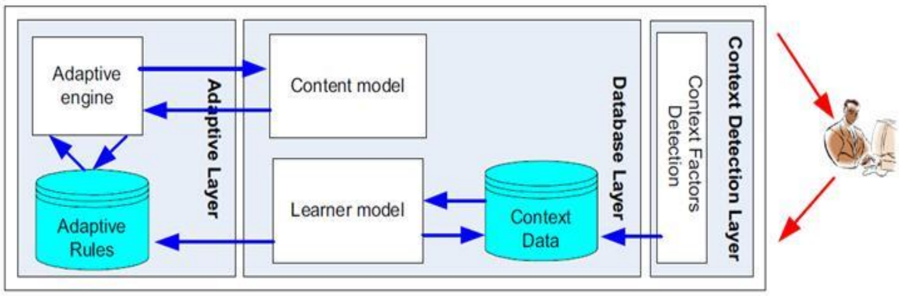

Figure 2.2 CAMLES Architecture (From (Nguyen et al., 2010))

The system architecture of CAMLES is shown in Figure 2.2. This architecture includes three layers: Context Detection Layer, Database Layer and Adaptive Layer.

- **Context Detection Layer**: This layer identifies the context factors such as location, time interval, manner of learning and learner's knowledge that impact selection of adapted learning contents for different learners.

- **Database Layer**: This layer consists of context data, content data, the learner's profile and test.

- **Adaptive Layer**: This layer includes an adaptive engine which selects learning contents according to the learner's learning context based on a set of if-then rules stored in the rules repository.

3) LOCH

LOCH is a context-aware mobile learning environment for supporting informal language learning outside the classroom (Paredes et al., 2005). In the environment, the teacher assigns field activities to the learners, and the learners go around the town to carry out the activities and share their individual experiences. This system can provide learners with personalized hints at the right time and suggest suitable learning activities depending on criteria like location and current task.

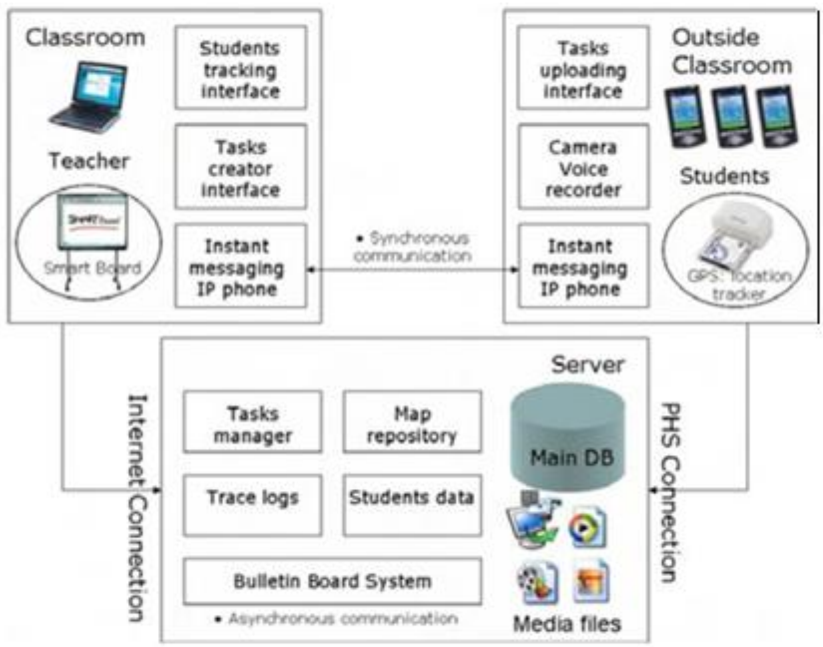

Figure 2.3 System Architecture of LOCH (From (Paredes et al., 2005))
(In the figure, PHS stands for Personal Handy System)

The system architecture of LOCH is shown in Figure 2.3. The system is designed as a central server with two user interfaces, one for the teacher and one for the learners. The central server has a repository of the learner's information, tasks provided by teachers, and data gathered outside the classroom. Learners can operate on mobile devices to annotate, record questions, take pictures and report back to the teachers. Teachers can monitor the position of the learners and establish communication with them.

4) UoLmP

UoLmP (Units of Learning mobile Player) is a context-aware adaptive and personalized mobile learning system (Gómez et al., 2013). The system aims to support learners by delivering adapted activities and contents through every step in the learning flow of a mobile educational scenario. UoLmP focuses on generating adapted individual learning activities, as well as offering adaptations to supportive educational contents, tools and services, based on processing different criteria derived from learners' contextual elements in the aspects of learning design, learner profile, learner temporal information, people, place, artifact, time and physical conditions.

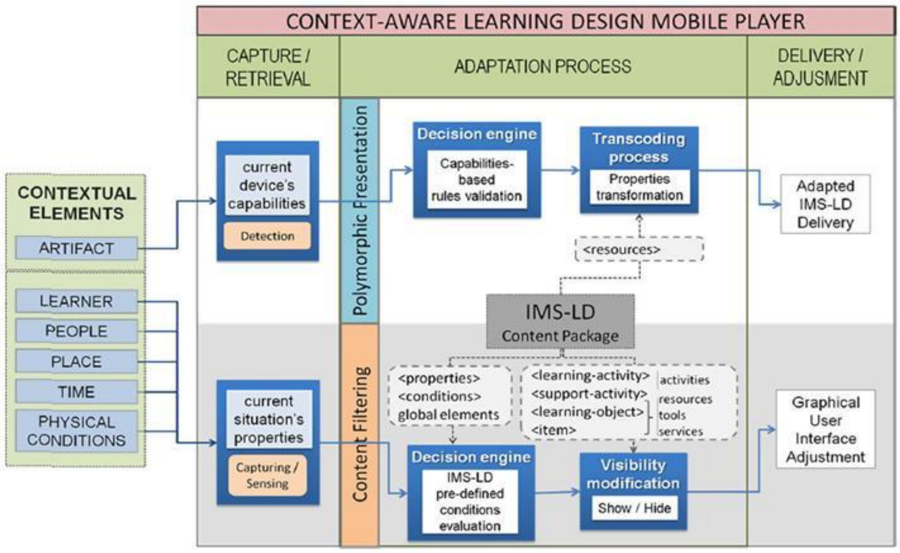

Figure 2.4 Architecture of UoLmP (From (Gómez et al., 2013))

The system architecture of UoLmP is shown in Figure 2.4. This architecture includes three parts: capture/retrieval part, adaptation process part, and delivery/adjustment part.

- **Capture/retrieval part**: This part captures or senses the current situation properties for filtering learning contents, and detects current device capabilities for presenting the filtered contents polymorphically.

- **Adaptation process part**: This part executes the adaptation mechanisms, including the filtering mechanism and the polymorphic presentation mechanism, based on the IMS Learning Design Specification (IMS-LD).

- **Delivery/adjustment part**: This part delivers the adapted learning contents and learning activities to learners.

5) **P-LearNet**

P-LearNet: Pervasive learning network. This project is concerned with TEL systems integrating context-aware corporate learning and working activities for e-retail in shops and hypermarkets (Pham-Nguyen, C. et al, 2008). The main issues of the P-LearNet project are: provide work-integrated learning and customer learning support whatever the place, the time, the organizational and technological contexts of the individual or collective learning and working processes.

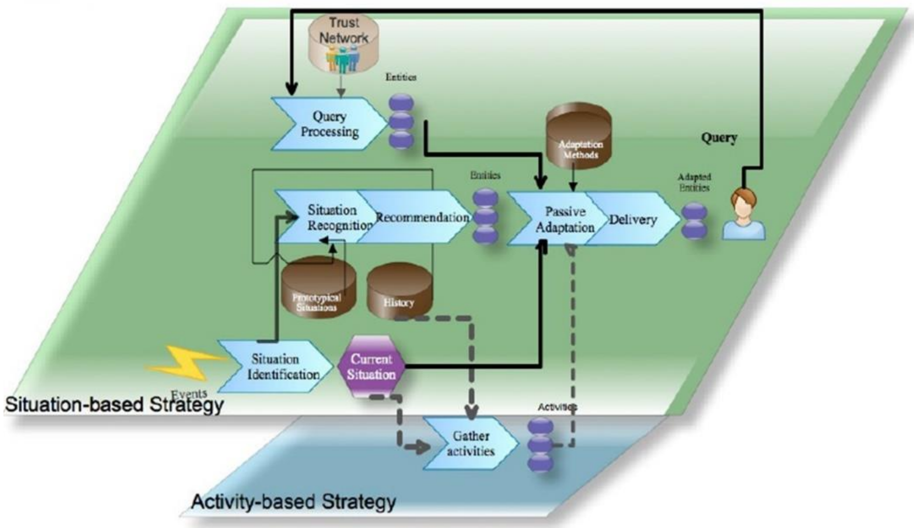

Figure 2.5 Architecture of P-LearNet (From (Bouzeghoub et al., 2011))

The system architecture of P-LearNet is shown in Figure 2.5. The main parts of this architecture can be identified from this figure, including: the current situation, which characterizes learner's current learning situation and learning activities; entities, which contain the learning materials needed during the learning process; the adaptation method, which adapt entities according to the current situation.

The first four systems were designed to support students in conducting specific course learning, such as Java programming learning, language learning, etc., which have the pre-defined learning goals and pre-planned learning process. The adaptive learning supports provided by these systems cannot satisfy the goal of this thesis which aims to facilitate professionals' work-based learning with work-related and just-in-time learning supports. P-LearNet has the same goal as this thesis. However, P-LearNet rarely considers the personal learning characteristics in its adaptation. That means, for example, that different people may have different learning styles, and in different conditions, they may prefer different learning strategies. But, in this system, it will provide the same learning supports if the learning needs are the same.

However, the in-depth analysis of these systems can benefit in guiding us to propose our specific learning system with a proper architecture and functions. By synthesizing these listed system architectures, three essential elements of context-aware mobile learning systems can be identified: the learning resource containing all the learning contents, the learning context characterizing the essential learning situation information, and the adaptation mechanism which adapts the learning contents according to the learning context information. These three elements and their relationships are presented in Figure 2.6.

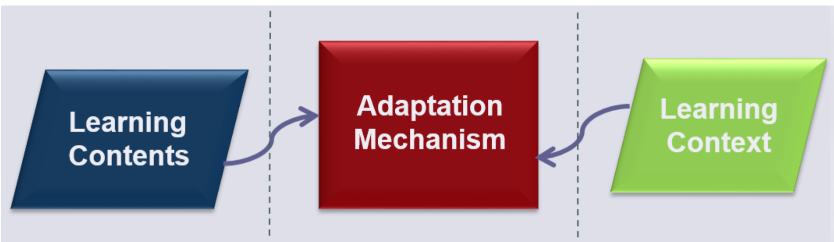

Figure 2.6 A General Architecture of Context-aware Mobile Learning Systems

Our research work complied with this general system architecture. The work for extracting the metadata for labeling learning contents was carried out as part of the former work of our laboratory (Yin C. T., 2010). In what follows, we focus on discussing the other two elements in more detail, including: modeling contextual learning information, and developing the learning adaptation strategies and constructing the adaptation engine.

2.3 Modeling Contextual Learning Information

Modeling context information is to formulate a way to decide which aspects of context should be concerned in the situation and how to describe them. Research into modeling context has been undertaken for a long time now, and various context models are proposed. Analyzing the existing context models is conductive to understand: which context information should be concerned for representing a situation comprehensively and compactly, and how to store and organize the context information in an appropriate format.

2.3.1 Which Contextual Information should be concerned?

Research work into extracting context information tends from general to domain-specific. Initially, major works focus on proposing context models used in ubiquitous computing which try to cover all situations. By analyzing these models, we can acquire guidance about which context information is more important for characterizing a situation and how to extract and classify it. However, in a particular situation, some information should be emphasized, while other information should be ignored, a fact which is hard to cover by a general context model. Recently, more and more works focus on constructing context models for specific domains. Context models for learning emphasize particular aspects of context, such as learning needs, learning method, etc., which are more important in learning situations. By analyzing the existing learning context models, we can determine which characteristics should be involved in learning.

1) **Context Models for Ubiquitous Computing**

(Schilit et al., 1994b) proposed that the context model should include computing context (devices accessible for user input and display, network capacity, connectivity, cost of computing), user context (user location, collection of nearby people, social situation) and physical context (light level, noise level, temperature). However, this context model does not include time aspects. (Chen, G. et al., 2000) extend the context model with "Time Context" (such as time of day, week, month, and season of the year). (Ryan et al., 1998) summarized context information into four categories: Location, Identity, Environment and Time. Later, Abowd (Abowd et al., 1999) considered that "Environment" should be changed to "Activity", because activity answers a fundamental question of what is occurring in the situation. (Gu et al., 2005) proposed a hierarchical context model with the upper layer context as Person, Location, Activity and CompEntity. The work of (Krogstie, 2001) and (Kofod-Petersen et al., 2003) emphasized the mobile situation, and proposed a context model with main categories including the following aspects: personal, task, social, spatio-temporal and environmental.

The previous studies, in the pervasive and ubiquitous computing field, provide different classification methods for context. However, (Dourish, 2004) argues that context is an emergent property of occasions of interaction, rather than being a stable, objective set of features that externally characterize activity. Context has the nature of being continually negotiated and redefined. The major design opportunity should concern not use of predefined context within an ubiquitous computing system, but how ubiquitous computing supports the process by which context is continually manifested, defined, negotiated, and shared. From this viewpoint, we should use the context model for ubiquitous computing as a reference and propose the context model for the specific situation.

2) Context Models for Learning

A commonly used definition for context information in Technology-enhanced Learning was given by (Luckin, 2010), defining Learning Context as: "the current situation of a person related to a learning activity". For learning, more specific context should be concerned and emphasized, for example, learning objective, learning style, pedagogical method, etc. (Economides, 2009) concluded by several open research questions about learning context, including: identifying the relevant learning characteristics, modeling the learner, and changing the learning environment for users with different learning characteristics.

Several standardization efforts have been made regarding learner models and learning objects. IEEE PAPI (Public and Private Information) characterized the learner with the context concerning contact information, relation information, security information, preference information, performance information and portfolio information (PAPI, 2002). IMS LIP (Learner Information Package) encompassed learner context including identification, accessibility, goal, qcl (qualifications, certifications and licenses), activity, transcript, competency, interest, affiliation, security key, relationship, content type, referential, temporal, and privacy (Smythe et al., 2001).

(Economides, 2009) defined the context for ubiquitous learning, which consists of learner's state, education activity state, infrastructure state and environment state. In more detail, the context concerned in learner's state includes: demographics, education & profession, previous results & achievement, preferences, favorites, interests, objectives, health, current biological & physiological needs, physical abilities, cognitive abilities, social abilities, cultural abilities, feelings & emotions, motivation & conation, learning styles, cognitive styles, intelligence, personality, related people, time & schedule, location, mobility, restrictions & constraints and current status.

The more variables described in a context model, the more accurate the context model would be. However, this accuracy also increases the complexity of the context model and the requirements for collecting data. Harmonious integration of all these input data is an open research problem. There should be a balance between the number of variables, the accuracy of the context model and the complexity of the context model. It is necessary to reduce context model complexity by extracting the essential context information according to a specific learning situation.

Several works for extracting the context model from a specific learning situation have been proposed. (Das et al, 2010) summarized the context considered in existing context-aware e-learning systems, and classified them into three aspects:

- **Personal Context**: Personal information (name, id, DOB, gender, address, email-id, phone number, technologies known, knowledge level, OS experience, internet usage), Personality type, Level of expertise.

- **Abstraction Context**: Learning preference, Learner intention, Learning style.

- **Situation Context**: Learner situation, network, Device, PoLS.

(Martín et al., 2006) proposed a mechanism to support the creation of adaptive collaborative m-learning environments in which the activities to be proposed to a user at a certain time can depend on the context, such as:

- **Static user features**: This information is stable throughout time. For example, personal data information (such as name, address, email, and telephone number), personal characteristics (language, background, abilities, etc.), preferences (learning style, type of information required), role of the user (teacher, student).

- **Actions**: The information about the actions performed by the user, such as the activities started but not finished (pending), the activities already finished, the results obtained during the accomplishment of these activities, etc.

- **Context**: The context of a user includes information related to his/her location, the available devices at that moment and the idle time.

- **Agenda**: Used for checking the expected availability of each user at a certain time.

Table 2.1 Mobile Learning Context Model (From (Sampson et al., 2013))

Learning Context	
Dimensions	Elements
Learning design	Learning objectives, pedagogical models, learning activities, participating roles, tools and resources.
Learner	Competence profile (knowledge, skills, etc.), role, semi-permanent personal characteristics (learning style, physical disabilities, etc.).
Mobile context	
Dimensions	Elements
Learner	Temporal personal information (preferences, needs, mood, etc.).
People	Role, relationship, contributions and constraints.
Place	Location, interactive space, cultural background and learning setting.
Artifact	Technological: physical and digital properties, and non-technological.
Time	Task duration, task scheduled, action happens, availability.
Physical conditions	Illumination, noise level, weather conditions, etc.

(Sampson et al., 2013) proposed a context model for modeling learner's contextual information in the m-Learning system shown in Table

2.1. This context model includes two main parts: learning context, relating to the structure of learning design, considering the learning paths and activities that learners follow and perform, respectively, in order to acquire knowledge, and mobile context, relating to the ubiquitous and mobile environment in which learners and teachers interact while performing those activities.

The existing work helps us to obtain an overview of the various aspects to be considered for learning context, and to present the approach for extracting particular aspects of context according to different learning situations, such as e-learning, m-learning, collaborative learning, etc.

2.3.2 How to Describe Contextual Information?

(Strang et al., 2004) and (Baldauf et al., 2007) analyzed and identified a broad range of approaches for describing context information. According to different data structures of context information represented and exchanged, the approaches can be classified into six main types:

1) **Key-value model**
(Schilit et al., 1993) models contextual information in a key-value pair, with an environmental variable acting as the key and the value of the variable holding the actual context data. This is the most simple model but one that is practical in allowing pattern-matching queries. For example, the key-value pair [identity, string, "Mark"] means, a string type key "identity" has value "Mark". However, the model will be too complicated and even impossible if it is used to express complex context information, and the search algorithm based on this model is low-effective.

2) **Markup scheme model**
This model type adopts a hierarchical data structure. It uses makeup languages which have hierarchical ability, for example XML, to express context information. The context aspects are modeled as tags and corresponding fields. Profiles (CC/PP, 2007) (UAP, 1999) are the most classic markup scheme models. Compared with key-value models, this model type is able to describe the type and data structure of information conveniently and accurately, but cannot express the relationships between information.

3) **Graphic model**
Unified Modeling Language (UML) is also suitable for modeling context. Based on graphics, this model type is intuitive and has strong expression. Various approaches are available where contextual aspects are modeled using UML (Sheng et al., 2005) (Van den Bergh et al., 2005) (Derntl et al., 2005). However, surveyed by Thomas Strang (Strang et al., 2004), this model type is evaluated as having poor action with respect to the capacities of distributed composition, partial validation and incompleteness and ambiguity.

4) **Object-oriented model**
This model type takes advantage of the object-oriented method, such as encapsulation, reuse and inheritance. The contextual information is embedded as the states of the object, and the object provides methods to access and modify the states. The context model in project TEA (Schmidt et al., 2001) represents object oriented models. However, due to this high encapsulation, the representation and disposal of context information are independent.

5) **Logic-based model**
This model method is proposed by McCarthy (McCarthy, 1993) (McCarthy et al., 1997). Context data are expressed as facts in a rule-based system. It is possible to add new rules as well as submit queries to the database, and also to infer unknown facts and expressions from the known ones. Jean Bacon proposed a location-oriented multimedia system which expresses contextual information by a logic-based model (Bacon et al., 1997). However, the system based on this model type cannot verify data incompleteness, noisiness and inconsistency.

6) **Ontology-based model**
According to the Semantic Web led by W3C (World Wide Web Consortium), ontology is a way to describe knowledge systematically, and a typical and explicit specification on concepts and conceptualization. It also defines concepts and relations required to describe meaning and information (Berners-Lee et al., 2001) (Gruber, 1995). Typical languages to describe ontology are as follows: XML, RDF, OWL, etc. OWL is a web ontology language proposed by the Web Ontology Working Group of W3C. OWL is much more expressive than other languages. Furthermore, OWL is divided into OWL-Lite, OWL-DL and OWL-Full according to its ability to describe. Otztürk and Aamodt (Otztürk et al., 1997) proposed the first ontology-based context model.

Due to its effective descriptive power and integrated inference rules, a number of context-aware systems (Chen, H. et al., 2003) (Chen, H. et al., 2004a) (Chen, H. et al., 2004b) (Lin, X. et al., 2005) (Xu, 2013) adopt the ontology-based model. Reference (Lin, X. et al., 2005) suggested an ontology-based model in intelligent environments as well as service-oriented context-aware systems, middleware and architectures through OWL.

Reference (Di Z., 2008) analyzed and compared comprehensive indexes of each model type. Several important characteristics are listed in Table 2.2. Inside this table, the simple "-" stands for "un-supported", "*"stands for "partly supported" and "**"stands for supported.

Table 2.2 Comparison of the Principle Context Model Types (From (Di Z., 2008))

Index / Model Type	Combination	Efficiency	Ambiguity	Extendibility	Automation	Flexibility	Manageability	Independence	Cell	Fineness
Key-value	*	-	-	-	-	*	-	-	-	-
Markup scheme	*	**	-	*	*	*	-	-	*	*
Graphical	-	-	-	-	-	-	-	-	-	-
Object-oriented	**	*	*	*	*	*	**	**	*	-
Logic-based	**	-	-	**	*	**	*	*	**	**
Ontology-based	**	**	**	**	**	**	**	**	*	**

By comparing the expression ability and conciseness of each model type, the ontology-based model is an outstanding method which can represent context detail, in logic, relational and explicit terms. Based on this model type, a system could possess abilities like semantic context description, context reasoning, knowledge sharing, context classifications, context dependency, and so on.

2.4 Developing Learning Adaptation Strategies

A context-aware mobile learning system could provide multiple learning supports adapting to the current learning context. It could support learners by interacting with them through mobile devices, guiding them to suitable places, presenting them with appropriate learning contents and activities, helping them to interact with proper peers and experts, etc. (Graf et al., 2008).

Several research works have been carried out to analyze the adaptation strategies used in context-aware mobile learning systems (Economides, 2009; Graf et al., 2008). Two main adaptation categories were identified as:

- **Adaptations related to learning resources**
  These adaptations adapt the selection, presentation, navigation and sequence of learning resources according to just-in-time learning context.

- **Adaptations related to learning activities**
  These adaptations adapt the supporting services, tools, activity feedbacks, location navigation and peers' communication in learning activities.

To distinguish the lexical expression set out in chapter 1 which uses "learning resource" to express the collection of all necessary learning contents, we use "learning materials" to replace "learning resources" when we state the "adaptations related to learning resources".

2.4.1 Adaptations Related to Learning Materials

The adaptations related to learning materials can be classified into three categories: selection, presentation, and navigation and sequencing.

1) **Adaptation of learning materials selection**

   This type of adaptation deals with selecting appropriate learning materials and presenting them to learners based on different selection criteria derived from learners' contextual elements. Several existing works adopting this kind of adaptation are:

   - mCALS aims to select appropriate learning materials for students based on their current location, availability, previous knowledge.

   - (Chen et al., 2010) proposed a learning system which recommends English vocabulary based on learner's current location, availability, schedule tasks, duration of tasks and previous knowledge.

2) Adaptation of learning materials presentation

This type of adaptation considers that learning materials are adaptively structured for access via mobile devices. Different presentation forms of learning materials include (Zhao et al., 2008; Bomsdorf, 2005):

- Changing the format for the same type of learning materials (e.g. from wav files to mp3 files).

- Changing the type of the learning materials (e.g. visual or audio presentation instead of textual presentation).

- Changing the dimensions of the learning materials (e.g. scaling down or scaling up the dimensions of the learning materials).

Several existing works adopting this kind of adaptation are:

- Birgit Bomsdorf proposed a system with the function of transforming the format, type and dimensions of educational materials based on learner's learning preferences, learning style and mobile device parameters (Bomsdorf, 2005).

- (Zhao et al., 2008) provided an architecture to adapt learning materials' presentation based on device capabilities and learner's experience and preference.

3) Adaptation of learning materials navigation and sequencing

This type of adaptation rearranges or reorders the navigation and sequencing possibilities of different learning materials that are linked to each other to create personalized learning paths, by taking into account different criteria derived from learners' contextual elements. Several existing works adopting this kind of adaptation are:

- CAMLES supports learners in learning English as a foreign language in order to prepare for the TOEFL test (Nguyen et al., 2010). This system provides adaptive topics as well as test questions based on learner's location, time, manner and knowledge.

- (Cui et al., 2005) introduced TenseITS, a language learning environment, with the aim to support English learning in learner's leisure time. This system creates courses (including learning topics and after tests) according to learner's location, available time, concentration level and former learning records.

2.4.2 Adaptations Related to Learning Activities

Context-aware mobile learning systems could be able to provide personalized hints at the right time or suggest suitable learning activities for a learner, depending on the current environment and the needs of the learner. The adaptations related to learning activities can be sorted into four categories: adaptation of automatic generation of learning activities, adaptation of feedback and support (scaffolding), adaptation of navigation to locations, and adaptation of communication and interaction.

1) Adaptation of automatic generation of learning activities

This type of adaptation deals with automatic generation of individual learning activities based on different criteria derived from learners' contextual elements. More precisely, automatic generation of learning activities includes: (a) adaptations to the learning materials, tools and services that support the learning activities, (b) adaptations to the roles that participate in the learning activities.

This adaptation strategy includes several other adaptation strategies, such as adaptations related to learning materials, adaptation related to communication, etc., which seems to be misclassified. However, this adaptation strategy focuses on not only one specific adaptation aspect but on a general learning process which includes the aspects of learning materials, learning partners, learning sequence, etc. An example of this kind of adaptation is:

- UoLmP creates adaptation decision processes using IMS-LD conditional statements to evaluate the characteristics of context in order to show or hide available learning activities, learning materials and tools and services, and to transcode contents based on the technical capabilities of user's devices and the user's characteristics (Gómez et al., 2012).

2) Adaptation of feedback and support (Scaffolding)

This type of adaptation includes personalized hints at the right time and suggests suitable learning activities depending on different criteria derived from learner's contextual elements. Several existing works adopting this kind of adaptation are:

- (Yin C. J. et al., 2010) proposed the JAPELAS2 system for overseas learners learning Japanese polite expressions. Depending on learner's location (e.g. university, family, party, etc.) and information (age, position, social relation, etc.) of the learner and his/ her conversation goal, the system supports the learner with appropriate polite expressions and corresponding feedbacks.

- LOCH guides learners in fulfilling field activities assigned by teachers (Paredes et al., 2005). Learners can make use of their handhelds for writing down annotations, recording questions, taking pictures and reporting back to the teacher. The teachers monitor and guide the learners through the task activities, and give suggestions or hints.

- (Ogata et al., 2005) proposed the TANGO (Tag Added LearNinG Objects) system for vocabulary learning, which detects the objects around the learner using RFID (Radio Frequency Identification) tags, and provides the learner with the right information for language learning.

3) Adaptation of navigation to locations

This type of adaptation includes mostly location-awareness and planning of suitable learning activities in a real-world situation. This adaptation benefits learning while visiting a museum or conducting an experiment in a laboratory. The existing work adopting this kind of adaptation is:

- (Hwang et al., 2009) developed a context-aware learning environment to assist novice researchers in learning a complex science experiment by automatically navigating learners to conduct learning activities within a laboratory. The context aspects concerned include learner's location and previous knowledge.

4) Adaptation of communication and interaction

This type of adaptation helps learners during execution of learning activities to:

- Find peers based on their location with whom they can meet virtually, build learning groups for sharing knowledge, and communicate with experts to ask for advice or help with specific issues.

- Select appropriate communication and collaboration tools based on learners' preferences and needs. Communication can be asynchronous and synchronous. Regarding asynchronous communication, components such as discussion forums, question and answer services, and knowledge sharing services can be made more personal and adaptive to the learners' situation, characteristics, and needs. Synchronous communication can assist learners in forming learning groups or showing them who might be able to answer their questions.

An example of this kind of adaptation is:

- Economides (Economides, 2008b) suggested adaptation of the collaborative learning environment to the learner's culture profile, consisting of beliefs, norms, knowledge, sets of practice, etc. This is because different learners' cultures affect their participation, motivation, satisfaction, and performance during learning.

- (Tan et al., 2009) proposed a location-based adaptive mobile learning system. This system can help learners to find learning peers and organize them in a learning group. The context aspects considered in the adaptation include learner's age, learning progress, subject to be learnt, learning style, learning interest and learner's location.

2.5 Constructing the Adaptation Engine

The adaptation engine, the core of a context-aware mobile learning system, is the carrier of the adaptation strategies. The input of an adaptation engine is learning context, while the output of an adaptation engine would be the adapted learning materials and/or the adapted learning activities. Based on the input variables and adaptation decision rules, the adaptation engine produces the adaptive learning supports.

2.5.1 Adaptation Engines in Related Work

There are several approaches in the field of context-aware mobile learning for implementing an adaptation engine. Generally, these approaches can be classified into two types, including: rule-based approach and algorithm-based approach (Gómez et al., 2013).

1) Adaptation engine based on rules

The adaptation engine based on rules is the engine used when the resultant types of adaptation are derived from conditional structures of IF / THEN / ELSE statements, based on the instances of learning context dimensions (Gómez et al., 2013). Adaptation strategy is selected by the adaptation engine if the predicates in the IF-part match the current learning context.

Table 2.3 Rules for "Selecting a crystal through an optical microscope" (Hwang et al., 2009)

R01: IF Location (student) = Location (R204) THEN Phase (student) = "Selecting a crystal"
R02: IF Phase (student) = "Selecting a crystal" AND Location (student) = Location R204.Microscop) THEN Inquiry "Selecting crystals by transparency"
R03: IF Phase (student) = "Selecting a crystal" AND "Quality of selected crystal is good" = TRUE THEN Phase (student) "Limit the size of crystal"
R04: IF Phase (student) = "Limit size of crystal" AND Location (student) = Location (R204.Microscop) THEN Inquiry "Limit size of crystal <0.5 mm3"
R05: IF Phase (student) = "Limit size of crystal" AND Crystal size <0.5 mm3 THEN Phase (student) "Fix the crystal"
R06: IF Phase (student) = "Fix the crystal" AND Location (student) = Location (R204) THEN Inquiry "Cut the fiber size to 0.5 cm"
R07: IF Phase (student) = "Fix the crystal" AND Fiber size = 0.5 cm AND Location (student) = Location (R204) THEN Inquiry = "Fix crystal on the fiber"
R08: IF Phase (student) = "Fix the crystal" AND "Crystal fixed on fiber" = TRUE AND Location (student)! = Location (R126) THEN Inquiry "Move to R126" and Phase (student) = "Operating the X-ray diffractometer"

For example, in (Hwang et al., 2009), a set of IF-THEN rules are made for deciding a suitable guide for experiment operation based on learner's location and previous knowledge. The eight rules defined for guiding learners to select a crystal through an optical microscope are illustrated in Table 2.3.

Another example, (Arai et al., 2011) proposed an adaptation engine based on adaptation rules. The adaptation and intelligent process within the engine contain 4 modules: Analysis, Adaptation, Restructuring and Delivering. Each module implements its adaptation capability by IF / THEN / ELSE statements illustrated in Table 2.4. The learning activities and learning materials are pre-defined in the adaptation rules. The just-in-time learning context is taken as the rules' conditions. According to different conditions, different learning activities and materials would be selected and provided to the learner.

Table 2.4 Adaptation Rules in the Adaptation Engine of (Arai et al., 2011)

Analysis
(1) System get request e-Learning web page (E) from user (U) with device (D). (2) Check if E+D is already adapted before. If "yes" then load previous adaptation data (ETD) and jump to last process (10). If "no" then process the next step. (3) Extract contents from E: main information (I), style information (S) & learning object (O). (4) Store content data (I, S, O) as new structure in XML (EX)
Adaptation:
(5) Get profile (DP) and capabilities (DC) of D from CDE (6) Rule Based System to determine transcoding process for each of (O) based on DP and DC. (7) Process transcoding and store the results in cache (OT)
Restructuring:
(8) Compose adaptation (ETD) using template (T), EX and OT.
Delivering:
(9) Save E, D, U and ETD. (10) Send ET to U.

2) Adaptation engine based on algorithms

The adaptation engine based on algorithms is the engine used when the resultant types of adaptation are derived from different types of algorithms such as heuristic algorithms, similarity algorithms, decision-based algorithms, etc., which process the instances of learning context dimensions (Gómez et al., 2013).

For example, (Su et al., 2011) were concerned with how to efficiently manage a large number of historical learners' requests while delivering learning material that is precisely tailored to meet the individual needs of each user and to fall within the scope of various mobile device requirements. A Personalized Learning Content Adaptation Mechanism (PLCAM), used to manage historical learners' requests and deliver appropriate learning materials, has been proposed. PLCAM consists of two phases: the Adaptation Data Format Definition Phase and the Personalized Learning Content Delivery Phase. The former phase defines an adaptation data format based on Composite Capabilities/Preference Profiles and User Agent Profile. These profiles identify constructive information about the requesting learner, applicable hardware, network capabilities, and media during the learning content adaptation process. The latter phase applies distance-based clustering and decision tree approaches to create a working relationship among a cache of historical learners' requests. At this stage, the proposed adaptation decision and material synthesis processes can resourcefully identify and organize a precise and suitable version of the learning material to meet the specific request.

In addition to the approaches stated above, (Gómez et al., 2012) proposed an adaptation engine in UoLmP based on IMS-LD Level B, which implements the adaptations of learning activities, learning materials selection and presentation, as shown in Figure 2.4. IMS Learning Design Specification (IMS-LD) is a standard notation language for the description of educational scenarios, which is a series of learning activities performed by one or more actors/roles in an environment consisting of tools and services (IMS, 2003). Level B of IMS-LD adds properties (storing information about a person or group), and conditions (placing constraints on flows) to the description of learning scenarios. The adaptation process in the UoLmP engine makes decisions based on the evaluation of a pre-defined structured decision tree that considers contextual elements. More specifically, IMS-LD conditional statements are considered for making decision processes. By assessing learner's contextual information, the adaptation engine shows or hides learning activities, learning materials and tools and services. Conditional statements are pre-defined at design-time and consist of IF / THEN / ELSE structures that form a decision tree for selecting and delivering the adaptation results.

2.5.2 Criteria for Evaluation of the Adaptation Engine

(Economides, 2007) defined 17 criteria to evaluate the effectiveness of a designed adaptation engine, including: Input Comprehensiveness; Input

Harmonious Integration; Output Comprehensiveness; Prioritization; Correctness & Accuracy; Flexibility & Adjustability; Usefulness & Effectiveness; Meaningfulness & Rationality; Seamlessness & Transparence; Learner Control; Speed; Convergence & Stability; Consistency; Scalability & Extensibility; Portability & Interoperability; Security & Privacy; Cost. The details of these criteria are listed as follows:

1) **Input comprehensiveness (context)**
The adaptation engine should base its decisions on a variety of input data. However, the more input data are used in the system, the more accurate but complicated the context becomes. The question arises as to the right amount and variety of useful input data.

2) **Input Harmonious Integration**
The adaptation decisions should be based on the full context. If they are based on partial input data, then discrepancies and contradictions may occur. For example, one adaptation decision may call for video and picture presentation, while another calls for low bandwidth communication lines. However, video cannot be transmitted over low bandwidth communication lines.

3) **Output Comprehensiveness**
This criterion describes the capacity of the learning system to produce adapted learning materials and activities. The output of the adaptation engine should be comprehensive and useful.

4) **Prioritization**
The various features of the learning materials and learning activities may vary in importance for the learner. So, there should be prioritization among the features in the event of constraints or conflicts. The adaptation engine may decide to adapt some features and not others.

5) **Correctness & Accuracy**
The adaptation decisions should be accurately based on the context. The adapted educational materials and learning activities should be correct. If the adaptation engine cannot tailor exactly the learning materials and / or learning activities to the context, then the difference in tailoring should be very small, otherwise wrong decisions may be made. For example, if the mobile device terminates a text or video communication and establishes only an oral communication due to insufficient

bandwidth, a learner with low verbal and linguistic abilities may perform lower than his true abilities.

6) **Flexibility & Adjustability**
This criterion describes that if the adaptation engine cannot produce a precise output due to constraints, then an acceptable approximation should be available. For example, if there is not sufficient communication bandwidth for video transmission, then at least text communication should be provided.

7) **Usefulness & Effectiveness**
The results of the adaptive learning system should be useful and effective. This criterion states that the learning system should provide adaptations which can improve learning, equity, learner's satisfaction, learner's motivation, while, at the same time, reduce cost, learner's anxiety, learner's drop out, etc.

8) **Meaningfulness & Rationality**
The adaptation results should be meaningful, rational and intuitive. The learner should trust and not wonder about the correctness and validity of the adaptations.

9) **Seamlessness & Transparence**
The learner should not be disturbed by the adaptations. The adaptation engine should decide and produce the adaptations in a seamless and transparent way. There should be no need for the learner to manually make changes in configurations, run programs, etc. Also, transitions from one state to another should take place as smoothly as possible.

10) **Learner Control**
On the other hand, the learner may be allowed to have control over the adaptations. So, the learner would determine the degree, quantity, form and type of adaptation. For example, the adaptation engine could propose adaptation alternatives, and the learner could select only those that he agrees with and likes.

11) **Speed**
After sensing and measuring the context, the sooner the adaptation is implemented, the better. The adaptation engine should fast track the context and make appropriate adaptations.

12) **Convergence & Stability**
The adaptations should be based on the current context and not on outdated and obsolete input data. So, the convergence speed of the adaptation rules to the optimal is significant. Furthermore, the adaptation rules should converge and be stable.

13) **Consistency**
The adaptation engine should produce similar results for similar input data. The adaptations should be consistent. Similar context should result in similar adaptations. For example, similar learners in the same situation should see similar learning activities. Also, the same learner in similar situations should see similar learning activities.

14) **Scalability & Extensibility**
The adaptation engine should be scalable and efficiently incorporate many learners, learning activities, objects, devices, networks, etc. Also, it should be easily extended and upgraded to manage other types of context.

15) **Portability & Interoperability**
The adaptation engine should easily interoperate with other systems in order to receive or provide information about the context. Based on an open architecture and standards, it should easily connect to other hardware and software systems. It should accept input data from a variety of sources and export data to a variety of destinations.

16) **Security & Privacy**
The adaptation should also comply with security and privacy issues of the learning system. It should not bypass any security and privacy restrictions on the hardware and software resources.

17) **Cost**
The decision and implementation of the adaptation has some cost. If this cost is prohibitively high, then a question arises about implementing the adaptation. Of course, the cost is related to the achieved results. If the results (e.g. learning) justify the cost, then the adaptation should be implemented.

These evaluation criteria give us the guidelines when we begin to design the adaptation engine of a context-aware mobile learning system. It is important to take these criteria into consideration to avoid design deficiencies and improve design efficiency.

2.6 Conclusion

In this chapter, we reviewed the state of the art of context-aware mobile learning systems. First, in section 2.2, we presented 4 typical systems for demonstrating the architecture of a context-aware mobile learning system. Then, in the following three sections, we analyzed more precisely the sub-work of designing a context-aware mobile learning system, including modeling the contextual learning information, developing the learning adaptation strategies and constructing the adaptation engine.

As presented in section 2.2, most systems were designed for guiding students in specific course learning which have the pre-defined learning goals and pre-planned learning process. However, work-based learning has characteristics such as informal, location-based, work-related and just-in-time, which are hard to fulfill by these course learning systems. A context-aware mobile learning system, which is addressed to fit professionals' practical work processes and cater to their specific learning needs, is designed and implemented in this thesis work. However, analysis of the existing systems could help us to plan the system functions and construct the system architecture in a proper way. What's more, analysis of the existing context models in section 2.3.1 provides us with an overview about should-be concerned context in different situations, which helps us define the context for representing professionals' work-based learning. Also, by comparing the different context modeling approaches in section 2.3.2, the ontology-based model approach, which can represent context detail, in logic, relation and explicit terms, is selected for constructing our context model for work-based learning. Besides, analysis of the existing learning adaptation strategies helps us identify the multiple learning supports that could be provided by a context-aware mobile learning system. Finally, analysis of the existing adaptation engines forms the basic guidelines for designing and implementing the adaptations in our system.

3 The General System Design of WoBaLearn - A Work-based Context-aware Mobile Learning System

3.1 Introduction

This chapter presents the general design of WoBaLearn, a work-based context-aware mobile learning system. General system design is the design process of the overall program and the overall technical approach in the completion of a system. It is an important stage in the system development process.

In this chapter, first, we state the results of an online survey we carried out, which aims at identifying professionals' habits, needs and processes in work-based learning. Then, according to these results, we propose the schema of the general design for WoBaLearn. We state this general design based on two aspects: the design of work-based learning activities in the system, and the design of the system architecture.

3.2 Analysis of the Online Survey on Work-based Learning

To design a proper work-based learning system, we prepared a questionnaire for identifying professionals' actual work-based learning needs and behaviors at the beginning of our research.

This questionnaire addressed four main inquiry aspects:

1) What are the main difficulties professionals get into?
2) What are professionals' usual and expected learning processes?
3) Where do professionals get their work-based knowledge and skills from?
4) Which approaches do professionals use for collaborating with their learning partners?

This questionnaire was posted on line, and can be accessed from the site identified in the reference (Zhang, 2014). It is also presented in Appendix 1. 164 professionals participated in the survey. These participants' professions comprised 35% information technology, 27% industry, 5% teachers and researchers, 4% bank and assurance, and other professions with few people in each. A chart presenting profession breakdown in the survey is shown in Figure 3.1.

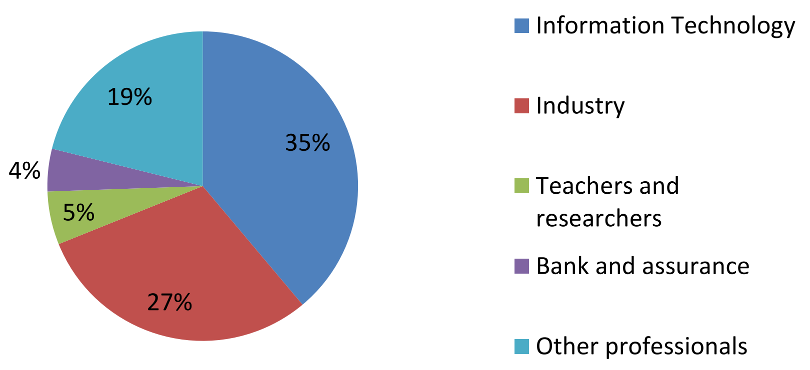

Figure 3.1 A chart for presenting profession breakdown in the survey

From the analysis of the questionnaire results, we could:

1) Construct the system architecture aiming at solving high frequency difficulties.

2) Arrange work-based learning activities in the system for leading professionals to carry out a proper learning process.
3) Identify learning resource scope concerned in the system.
4) Identify collaborating functions supported by the system.

In the following sections, we analyze the findings from the survey in detail.

3.2.1 Main Difficulties in Work-based Learning

The questionnaire results show that, during the work-based learning process, professionals mainly get into four kinds of difficulties, shown in Figure 3.2.

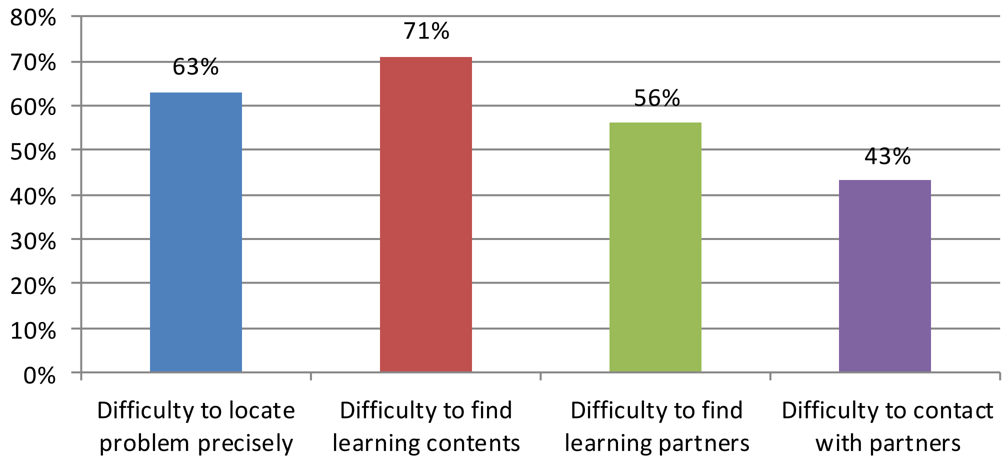

Figure 3.2 Four main kinds of difficulties occurring in work-based learning

The main difficulties include:

- Difficulty to locate the problem precisely, which has 63% positive answers;
- Being aware of the problem, but it is difficult to find appropriate learning contents, which has 71% positive answers;
- Difficulty to find appropriate learning partners, which has 56% positive answers;
- Difficulty to know the appropriate way to contact their learning partners, which has 43% positive answers.

Besides, a few answers point out that the problems existing in enterprises' management cause difficulties during learning. While this is a real difficulty impacting considerably professionals' work efficiency, it exceeds the scope of the design of a learning system.

3.2.2 Usual and Expected Learning Processes

By classifying the answers concerning surveying of professionals' usual learning process, we can identify professionals' main work-based learning activities, including:

- Learning through learning contents: Such as, reading manuals and books on the job, searching the internet or intranet to find online knowledge, listening to a podcast, etc.

- Learning from others: Such as, working alongside more experienced colleagues, learning from clients / customers, networking with others doing similar work, supporting from mentors, working as a part of a team, interacting with others online via discussion forums / social networks, etc.

Furthermore, with respect to the expected activities for supplementing work-based learning, 74% of participants agree that it is necessary to find a review time to go over the new knowledge or skills learned to consolidate their learning, and 76% of participants agree that it is necessary to learn other related knowledge and skills to extend their learning, such as the knowledge and skills related to that just learned, and the knowledge and skills learned by their learning partners.

3.2.3 Scope of the Learning Resources

To identify the scope of the learning resources used in work-based learning, the questionnaire surveys professionals' attitudes concerning the importance of nine types of learning content. The results are listed in Table 3.1. In the table, the positive column summarizes the participants' choices of "Very important" and "Important" options, the neutral column summarizes the participants' choices of the "Somewhat important" option, and the negative column summarizes the participants' choices of the "Not important" option.

Table 3.1 Survey results for the Scope of the Learning Resources

Types of Learning Content	Positive	Neutral	Negative
Books	59%	27%	17%
Article in professional magazine	51%	32%	17%
Employee manuals	66%	27%	8%
Materials at professional meeting	73%	24%	3%
Lesson materials used in professional training	73%	24%	3%
Information recordings of your organization. (e.g., the supplier lists for a retail company.)	75%	19%	5%
Professional articles, reference materials on blogs and websites	77%	18%	5%
News, policies, procedure online	67%	24%	7%
Discussions or opinions online	53%	37%	10%

In addition to this, a few participants answered the open question to supplement the learning resource scope. However, most of these answers point out the importance of learning from other people, such as experienced colleagues, experts or near-by people, already considered in the fourth survey aspect. Thus, the listed items in Table 3.1 could be taken as the scope of the learning resources used in work-based learning. Besides, during system design, the recommendation priority of learning content could be set according to the percentage of the positive answers illustrated in the table above.

3.2.4 Supported Collaborating Functions

Collaborating with learning partners is an important activity during work-based learning, from which professionals could acquire timely and effective instructions and suggestions. Our questionnaire surveyed the utilization frequency of 8 collaborating approaches. The results are listed in Table 3.2. In the table, the positive column summarizes the participants' choices of "Very often", "Often" and "Occasionally" options, the neutral column summarizes the participants' choices of the "Rare" option, and the negative column summarizes the participants' choices of the "Never" option.

According to the percentage of positive answers shown in Table 3.2, we can identify the collaborative functions that should be provided by the WoBaLearn system. For example, the function for finding the available near-by colleagues to encourage face-to-face collaborating, and the function for providing the remote expert's telephone numbers to promote consulting.

Table 3.2 Survey Results for Collaborating Approaches

Collaborating Approaches	Positive	Neutral	Negative
Face to face	90%	9%	1%
On-line Chat	29%	31%	40%
Forum	48%	27%	26%
Email	91%	5%	3%
Social Network	20%	25%	55%
Video Conference	46%	24%	30%
Phone	90%	7%	4%
SMS	23%	20%	57%

In addition to this, a few participants answered the open question to supplement the collaborating approaches. Some of them added that the Email and the chatting tools in their enterprises' internal systems are useful. This could be taken into account in accordance with the specific enterprises.

3.3 System Design

According to the online survey analysis stated above, in this section we present the general design of our WoBaLearn system.

According to the difficulties in professionals' work-based learning, which have been identified from our online survey, we conclude that the main principle for designing our work-based learning system is: to sequence professionals' activities in the system by following their actual work process and learning needs, and to provide task-relevant learning units, learning partners and learning activities for assisting them to complete a specific task. Furthermore, the run-time environment should integrate knowledge management functions and communication platforms to help professionals to gather, store, retrieve and acquire sufficient knowledge and also to contact their learning partners in the current learning context.

Furthermore, the design objectives of WoBaLearn can be specified as follows:

- To integrate sufficient learning contents.
- To classify the learning contents into learning units, and to describe the learning units with metadata.
- To enable a learner to get the right learning units at the right time.

- To take not only learning units, but also knowledgeable people as learning resources.
- The information about a role and individual role members should be used to help a learner to find appropriate knowledgeable people: such people may be a local supervisor, a co-worker, and even a co-learner when the learner needs to learn how to perform an activity.
- To integrate necessary communication tools.
- To enable a learner to contact the right people at the right time with the proper communication tool.
- To assist the reflective process by enhancing professionals' review and practice to encourage them to reflect.
- To assist the learner to access the extensive knowledge artefacts with which the learner could better understand the just-learned knowledge or skills and also extend his learning area.

According to the relevance to a specific knowledge or skill, learning contents identified in the learning resource scope can be classified into learning units which are applied in the WoBaLearn system. Each learning unit can provide a more complete theory explanation or problem solution. Based on the former research work in our laboratory, in this thesis we label and describe the learning units with comprehensive AM-LOM metadata. The definition and specification of AM-LOM and the details of how to generate learning units can be found in Chuantao's PhD thesis (Yin C. T., 2010), and are not specified in this thesis.

Hereafter in this section, we present the system general design in detail based on two aspects, including the design of work-based learning activities in the system, and the design of system architecture.

3.3.1 Design of Work-based Learning Activities in the System

Because work-based learning is usually unstructured and spontaneous, it is necessary to sequence work-based learning activities in the system into a proper process to promote professionals' learning and working efficiency.

In a broad sense, learning activities include all the activities related to learning, for example, teaching, assessing, etc. The concept of learning activity design refers to planning, structuring and sequencing the learning activities to help learners to achieve a predefined teaching objective. This learning activity design principle is adjusted to reflect the formal learning process. However, in the field of work-based learning, copying the existing approach directly to design work-based learning activities is inappropriate. For the work-based learning process, we cannot predict when the learning happens, and we cannot force professionals to complete a course. In addition, professionals themselves, not instructors, have primary responsibility for their work-based learning, and determine whether they succeed in their learning. Thus, the evaluation approach used for evaluating formal training, for example, assessing learner's reaction and behavior transfer, is inappropriate for evaluating work-based learning.

The goal of the design of work-based learning activities is to make sure that professionals have access to appropriate learning supports when the need arises and receive help in learning to complete the current work. Furthermore, the design should be able to provide professionals with the cognitive apprenticeships, which have features including situated learning, scaffolding, reflection and exploration (Collins, M., 1991; Collins, A. et al., 1989; Wilson et al., 1991).

To design effective work-based learning activities in the system, our research consists, first, in identifying the actors involved in work-based learning and also the duties of each actor. Then, for the main actor, according to the usual and expected learning processes identified by the online survey, we propose several just-in-time and supplementary learning activities to support them in performing their work or consolidating their learning. Finally, according to the practical work process, we sequence these proposed work-based learning activities.

In the work-based learning process, professionals encountering a problem during their work and wanting to acquire new knowledge or skills to find a solution, act as learners. Another role is that of the learning partner, who collaborates with the learner to give instructions or suggestions. The learner's main activities can be identified as:

- Locating problems encountered during his work.
- Finding the knowledge or skills which are work-related, personalized and environment-adapted.
- Finding and collaborating properly with the appropriate learning partners.
- Learning the new knowledge and skills, and, at the same time, finding a solution to solve the work problem.

Moreover, two additional activities for helping learners to consolidate or expand their knowledge and skills can be identified as:

- To remind learners to review the newly-acquired knowledge and skills at an appropriate time several days later.
- To provide learners with extended but task-related knowledge and skills to help them to progress further, such as the topics related to the ones just learned or the topics learned by their learning partners.

Because work-based learning is always spontaneous, these supplementary activities cannot be forced to happen. However, they must be designed in work-based learning activities to remind professionals that, by following these supplementary activities, their knowledge and skills can be consolidated, and their future work enhanced.

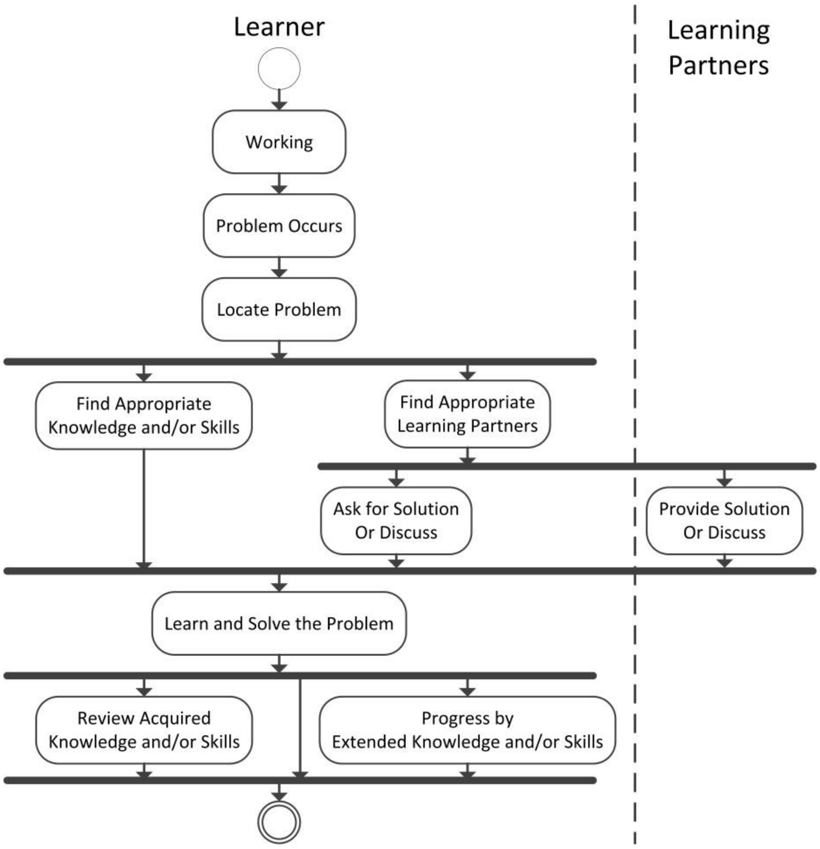

Figure 3.3 Learning Sequence in the WoBaLearn System

According to the professionals' practical work process, we sequence the designed work-based learning activities into a learning sequence, shown in Figure 3.3. The learning sequence is triggered by professionals' need to solve a work-based problem. Work and learning activities take place at the same location within the same period. Learning appropriate knowledge and skills or collaborating with appropriate learning partners provides the learner with the necessary supports to complete his current work. Once the learner completes his work, he can choose to learn further by extended knowledge or skills, reserve a time to review learned knowledge and skills later, or finish his learning directly.

This design of work-based learning activities can provide systematic guidance and supports for learners, opportunities to practice knowledge and skills with the real tasks, and review and extension of the learning process, which matches the concept of cognitive apprenticeship.

3.3.2 Design of System Architecture

Through analysis of the relative work stated in chapters 1 and 2, three essential elements of a context-aware mobile learning system are: the context model, the learning units, and the adaptation engine with designed learning strategies. According to this structure, we proposed the overall structure of the WoBaLearn system as shown in Figure 3.4.

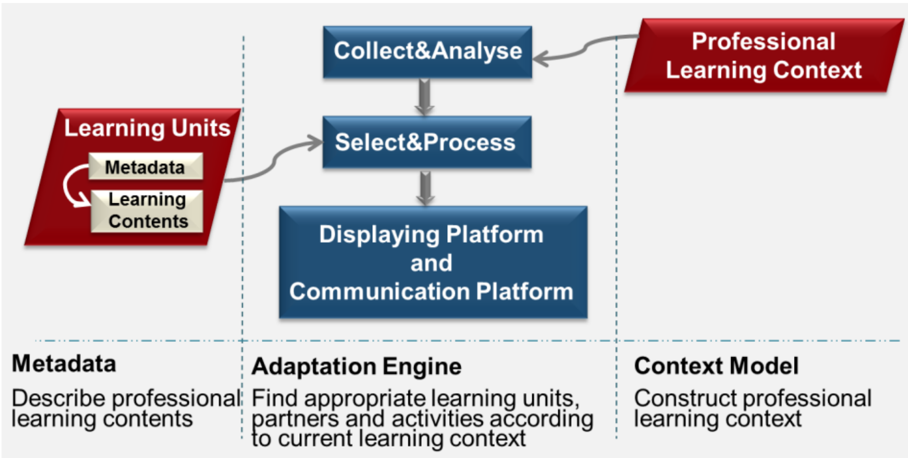

Figure 3.4 Overall Structure of WoBaLearn

Shown in Figure 3.4:

- **Learning context**
  The professionals' learning context is the system input and is constructed into a context model.

- **Learning units**
  Learning contents are classified into learning units which are described by AM-LOM metadata.

- **The adaptation engine**
  The adaptation engine collects and analyzes professionals' learning context, and then selects and processes learning units. Finally, it displays the selected learning units to the professional and builds a communication platform between him and appropriate learning partners.

More specifically, to achieve the design objectives and support professionals in accomplishing the work-based learning activities as shown in Figure 3.3, we proposed the overall architecture of the WoBaLearn system as shown in Figure 3.5. This architecture can support the system in adapting learning units, partners and activities according to professionals' learning needs, personal characteristics and particular circumstances, and ensure that professionals acquire personalized, just-in-time and problem-based learning supports in real working situations.

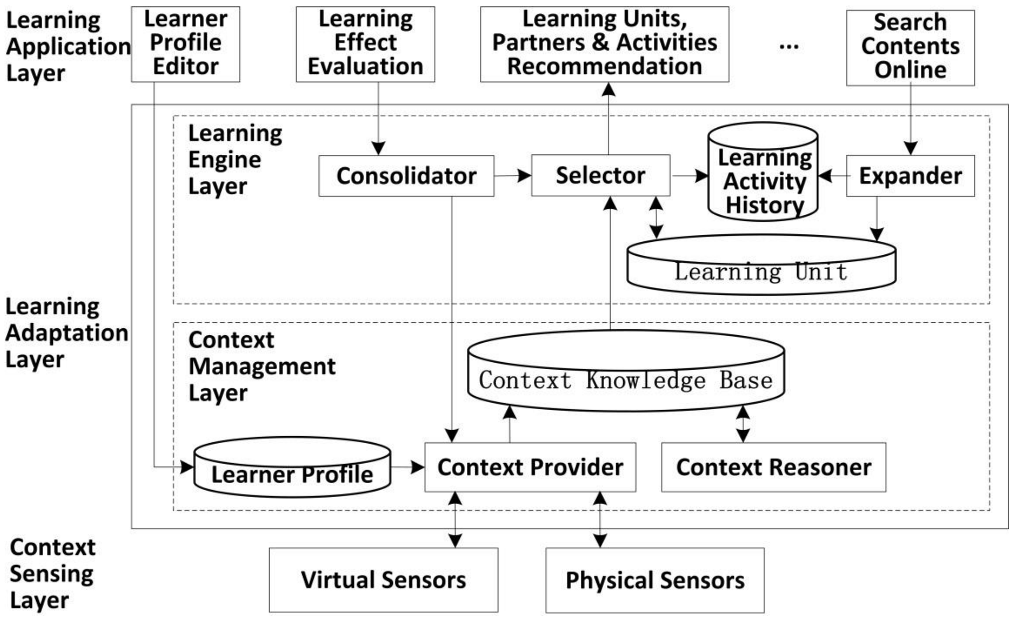

Figure 3.5 Overall Architecture of WoBaLearn

The overall architecture of WoBaLearn consists of three layers:

1) **Context Sensing Layer**

This layer contains various sensors for sensing the context aspects concerning activity, device and environment. The context aspects which should be collected in the system are predefined in the context model. Some of these aspects are transmitted by the sensors actively, while the others are requested by the upper layer. The sensors in this layer can be classified into two types:

- **Virtual Sensors**: Virtual sensors refer to other information services and web services, such as location services and calendar services. These can provide the service results, such as user's location and user's available time, as the required context aspects.

- **Physical Sensors**: Physical sensors contain the smart tag sensors, the environment sensors, the device and gadget sensors, etc. These can provide the sensed information as the required context aspects.

2) **Learning Adaptation Layer**

The goal of the Learning Adaptation Layer is to provide appropriate learning supports, including learning units, learning partners and learning activities, in relation with the current learning context. The Learning Adaptation Layer contains two sub layers:

- **Context Management Layer**: in charge of collecting, transforming, expanding and storing professionals' learning context. These functions are implemented by four components:

  a. **Learner Profile Database**: stores the learner's profile inputted by the learner from the system interface.

  b. **Context Provider**: collects the aspects concerning the Learner context from the Learner Profile Database and other context aspects from the Context Sensing Layer, and then converts them to a uniform representation for further processing.

c. **Context Reasoner**: in charge of reasoning new context aspects from these collected context aspects with ontology reasoning and user-defined rule-based reasoning.

d. **Context Knowledge Base**: stores the context aspects collected by the Context Provider and those reasoned by the Context Reasoner.

- **Learning Engine Layer**: makes use of the just-in-time learning context stored in the Context Knowledge Base, and then adapts the learning supports. The Learning Engine Layer contains five components:

a. **Selector**: in charge of selecting learning units, proposing learning partners and organizing learning activities according to a series of selection rules, as well as sequencing the selected learning units in a learner preferred order. What's more, Selector stores the learning recordings in the Learning Activity History Database.

b. **Consolidator**: in charge of modifying the context aspects concerning learner profile, as well as recollecting the context aspects concerning device, activity and environment, as the conditions to reselect the learning supports. What's more, Consolidator is also in charge of modifying the sequence rules for reordering the selected learning units.

c. **Expander**: in charge of expanding the Learning Unit Database with the learner's contents found online. More specifically, Expander reorganizes the learning contents found into a learning unit by labeling it with AM-LOM metadata, and stores the new learning unit in the Learning Unit Database.

d. **Learning Unit Database**: stores the learning contents labeled with metadata. The scope of the learning resources could refer to the items listed in Table 3.1.

e. **Learning Activity History Database**: records all the professionals' learning histories, thus enabling professionals to review their learning later and ensuring that the system can offer appropriate learning supports more quickly in the future.

3) **Learning Application Layer**

This layer is in charge of interacting with learners, such as: collecting their information and requirements, displaying to them the adaptive learning units, building the appropriate communication platforms between them and the selected learning partners, helping them to complete proper learning activities, etc. The actual services provided by this layer include: Learner Profile Editor, Learning Effect Evaluation, Learning Units Recommendation, Learning Partners Recommendation, Learning Activities Recommendation, Search Contents Online, etc.

As in the design above, this architecture can support the WoBaLearn system with an efficient infrastructure, and ensures that the system possesses the following abilities:

- Able to handle the adaptation rules and match them with the values of contextual information automatically, so as to enable the learning units adaptation mechanism, which provides the solution for the learner's current work problem, as well as displaying the solution in a format by balancing learner preference, device capacities and environment factors.

- Provide the learner with the opportunity to modify his / her learning context and the learning units sequence rules, so as to enable the learning units to be reselected and reordered, thus consolidating the learning process.

- Able to increase the number of learning units by the learner evaluated learning contents from online searching.

- Provide the learner with the appropriate learning partners who are experienced and available, or nearby and able to give immediate suggestions.

- Build a collaborative platform between the learner and his / her learning partners by considering learning partners' availabilities.

- Provide the learner with the complete learning process with necessary supplementary activities, such as reviewing and progressing.

3.4 Conclusion

In this chapter, we focused on presenting the general system design of WoBaLearn. First, by analyzing the survey results obtained from an online questionnaire, we gained a clear idea about four design bases, including: the main difficulties professionals get into during their work-based learning, professionals' usual and expected work-based learning processes, the learning resource scope and the frequently used collaborating approaches in work-based learning. Based on this, we proposed the design of work-based learning activities in the system, which aims to enable professionals to access appropriate learning units, learning partners, and learning activities when learning needs arise and to be supported to learn how to complete the current work. Then, we presented the design of the system architecture, which aims to enable the system to achieve the goals and to enable professionals to accomplish the designed work-based learning activities.

The following two chapters, 4 and 5, present the system design in more detail. Chapter 4 focuses on the design of the learning context model, while chapter 5 focuses on the design of adaptation strategies and the adaptation engine.

4 The In-depth Design of WoBaLearn – Learning Context Model Design

4.1 Introduction

This chapter describes the system design in detail, and in particular the design of the learning context model. Modeling context, formulating a way to decide which context aspects should be concerned in the situation and how to describe them, is an essential work when constructing a context-aware mobile learning system. A system collects the necessary context aspects defined in the model, and infers new context aspects based on the context relationships expressed by the model. Then, these aspects are provided as the conditions for adapting the learning units, the learning partners and the learning activities.

As stated in chapter 2, several context models for learning have been proposed. However, building a context model that adapts to all aspects of different learning scenarios, such as language learning, experiment learning, etc., is no easy task. In this chapter, based on the specialties of work-based learning, we propose an ontology-based hierarchical context model, named WbML. We first propose the framework of WbML context model with the hierarchical approach, and then we elaborate the design of this context model by describing the context ontology design method, illustrating the value of each context and introducing the tools for building the model. At the end of this chapter, we state the approach for collecting and applying the context defined in the WbML context model.

4.2 Framework of the WbML Context Model

The WbML context model adopts the hierarchical design approach. This context model consists of a common layer and a domain layer. According to the domain requirement, a particular domain can be divided into a domain general layer and a domain specific layer. In each layer, we express the context information in ontology. The framework of the WbML context model is shown in Figure 4.1.

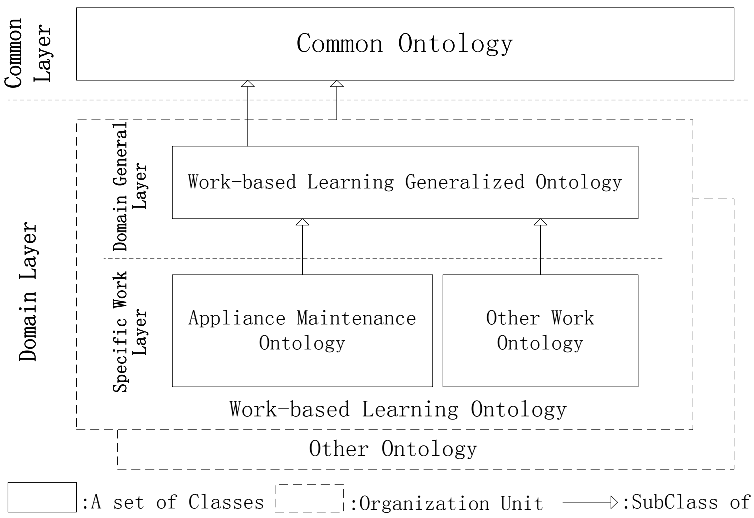

Figure 4.1 Framework of the WbML Context Model

The common ontology generalizes the common context in ubiquitous computing, as well as their inherent properties. The common ontology is fixed once defined, and will be shared among different particular domains. All the particular domain ontologies inherit from the common ontology, thus enabling information and service sharing among the different domains. For example, "Person" is defined as a common context, and its properties, like name, gender, etc., are available in all the domains.

The particular domain ontology captures the context which can characterize a particular domain, such as transportation, medical service, etc. This should be defined by the domain-related model designer. The domain ontology inherits and specializes from the common ontology. For example, for the learning domain, the context "Person" is specialized as a "Learner", by which a person's learning behaviors should be emphasized. For work-based learning, in order to design a context model adapting to all works, we structure the domain ontology of the model into two layers: the work-based learning generalized ontology, which captures the general context in all works, and the specific work ontology, which collects the specific context varying from one kind of work to another. The specific work ontology should be defined by the experts in this specific work, which ensures that the context aspects can characterize comprehensively the actual work situation.

This framework design can improve the reusability of the WbML context model. The common layer of the framework is generic enough to provide the possibility for sharing information and services among different application domains. What's more, the framework is extendable in the particular domain layer, so that it is able to cover all the work-based learning situations. In addition, separation of the application domains significantly reduces the context scale, and thus eliminates the burden of context processing.

4.3 Design of Context Ontology in WbML

By comparing different context modeling formats stated in chapter 2, we choose to describe the WbML context model by ontology written in OWL-DL. OWL-DL is one of the species of OWL (Web Ontology Language) proposed by the W3C Web Ontology Working Group (Deborah L. M., et al., 2004). W3C defined, in OWL, ontology consists of three elements, including: individuals, properties and classes.

- **Individuals**: Individuals represent objects we are interested in, and are the instances of classes.

- **Properties:** OWL properties are sets of binary relations which link two individuals together. According to different connection objects, OWL properties can be divided into object properties, which represent the relationships between individuals, and data properties, which describe the relationships between an individual and its data values.

- **Classes:** Classes are sets of individuals with the same properties and behaviors.

The WbML context model is recorded in OWL format in the file named “WbML_Context_Model.owl”. A partial file is shown in Figure 4.2.

```
<rdf:RDF
xmlns="http://www.semanticweb.org/snow/ontologies/2013/11/Context_Model_WbML#"
    xml:base="http://www.semanticweb.org/snow/ontologies/2013/11/Context_Model_WbML"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:owl2xml="http://www.w3.org/2006/12/owl2-xml#"
    xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
……

<Class rdf:about="#Learner">
      <rdfs:subClassOf rdf:resource="#Person"/>
</Class>
……

<DatatypeProperty rdf:about="#hasLearning_Preference">
      <rdfs:domain rdf:resource="#Learner"/>
      <rdfs:range rdf:resource="&xsd;string"/>
</DatatypeProperty>
……

<ObjectProperty rdf:about="#learn">
      <rdfs:domain rdf:resource="#Learner"/>
      <rdfs:range rdf:resource="#LearningActivity"/>
</ObjectProperty>
```

Figure 4.2 A Partial WbML Context Model in OWL Format

Modeling context using an ontology-based approach allows us to describe context semantically in a way which is independent from programming language, underlying operating systems or middleware (Gu et al., 2005). The ontology-based hierarchical context model for work-based learning is shown in Figure 4.3 by describing classification of classes, the data properties of classes and the major object properties between the relevant classes.

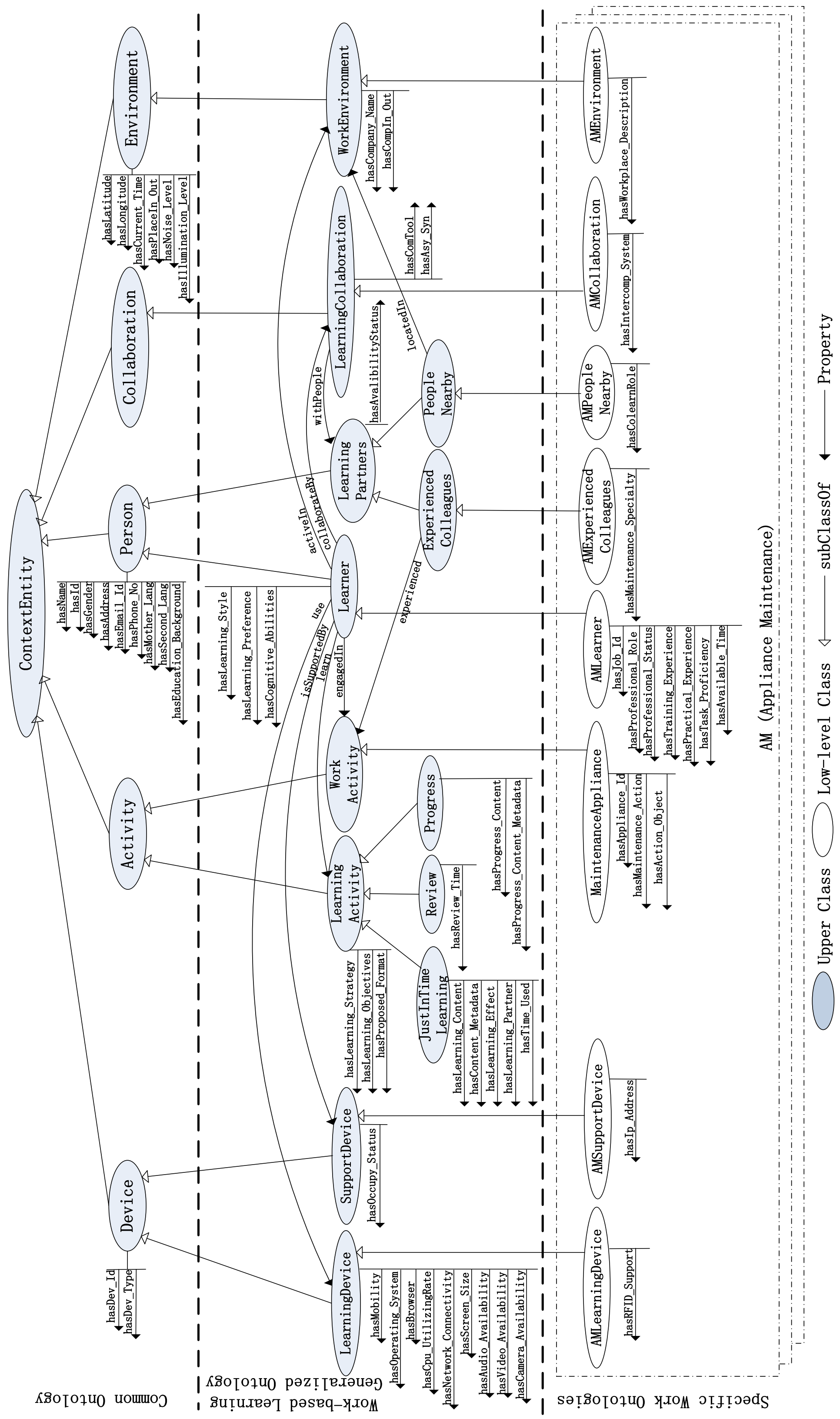

Figure 4.3 WbML – An Ontology-based Hierarchical Context Model for Work-based Learning

As shown in Figure 4.3, the common ontology consists of a parent class Context_Entity and its five subclasses. The Context_Entity provides an entry point of reference for declaring the common ontology. By balancing comprehensiveness and representativeness with the context defined in the existing ubiquitous computing models, we define five classes for modeling the common ontology, including: Person, Activity, Device, Collaboration and Environment.

The classes of the work-based learning generalized ontology inherit from those of the common ontology, and are concretized with professionals' behaviors in work-based learning. These classes include:

- **Learner**
  The person who needs to learn.

- **Learning Partners**
  The person with whom the learner could collaborate to ask for learning supports. This class has two subclasses: Experienced Colleagues, the learning partners who carried out the same work before and can provide the learner with instructions, and People Nearby, the learning partners who are located near the learner and can provide him / her with suggestions.

- **Learning Collaboration**
  The communication approaches by which the learner can contact his / her learning partners.

- **Learning Device**
  The equipment which the learner uses to search for the learning contents or to communicate with others.

- **Support Device**
  The equipment that surrounds the learner and can be used to support his / her learning.

- **Work Activity**
  The task in which the learner engages and confronts a problem.

- **Learning Activity**
  This activity relates to acquiring the new knowledge and skills to develop the new approaches to solve the problem occurring in the work

activity. This class has three subclasses: Just-In-Time Learning, Review and Progress.

- **Work Environment**
  The physical circumstances in which the learner acts and in which the working and learning activities take place.

Table 4.1 Object Properties in the Work-based Learning Generalized Ontology Layer

Property	**Domain**	**Range**	**Meaning of the Object Property**
engagedIn	Learner	WorkActivity	Learner is engaged in WorkActivity.
learn	Learner	LearningActivity	Learner learns LearningActivity.
supportBy	Learner	SupportDevice	Learner is supported by SupportDevice.
use	Learner	LearningDevice	Learner uses LearningDevice.
activeIn	Learner	WorkEnvironment	Learner active in WorkEnvrionment.
collaborateBy	Learner	LearningCollaboration	Learner has LearningCollaboration.
withPeople	LearningCollaboration	LearningPartners	LearningCollaboration is with LearningPartners.
experienced	ExperienceColleagues	WorkActivity	ExperienceColleagues did WorkActivity.
locatedIn	PeopleNearby	WorkEnvironment	PeopleNearby located in WorkEnvrionment.

The specific work ontology describes the context aspects which differ in each specific work. For example, in a firm specialized in appliance maintenance, a repairman's work activity is to maintain an appliance, in which the appliance identity and the maintenance action (repair, install, etc.) are the essential context aspects to be collected. In another scenario, for example the clinic, the doctor's work activity is to consult the illness of the patient, in which the medical records and the patient's physical status are the context aspects concerned.

As stated above, in different work-based learning scenarios, context aspects in specific work ontology should be defined by the specific domain experts. Also, correspondingly, the adaptation strategies of the WoBaLearn system, designed for adapting context-related learning supports, should be modified according to these specific work context aspects. In this thesis, we take "appliance maintenance" as an example of work-based learning scenarios. We defined the context aspects concerned, specifically during appliance maintenance as shown in the specific work ontology of Figure 4.3. Moreover, in chapter 5, we present the design of learning adaptation strategies with the example of learning during appliance maintenance.

The WbML context model is applied in the WoBaLearn system as a reference for the system to construct the just-in-time work-based learning situation. The WbML context model enables the WoBaLearn system to achieve the enhanced learning services, such as establishing a communication platform among the appropriate people according to context LearningPartners and context LearningCollaboration, delivering the work-related and personalized learning units according to context WorkActivity and context Learner, adapting the units displaying format according to context LearningSevices and context WorkEnvironment, and so on.

4.4 Illustration of Context and Values

In this section, we illustrate the description, instances and data source of the context defined in the WbML context model. The details of aspects defined in the Person, Activity, Device, Collaboration and Environment classes are described separately in Table 4.2, Table 4.3, Table 4.4, Table 4.5 and Table 4.6.

Table 4.2 Contextual Elements and Instances Considered in the Person Class

Context	Description	Data (Instances)	Data Source
Class: Person			
Name	The person's name.		By inputting.
Id	The person's Id in the WoBaLearn.		By inputting.
Gender	The person's gender.		By inputting.
Address	The person's address.		By inputting.
Email_Id	The person's email.		By inputting.
Phone_No	The person's phone No.		By inputting.
Mother_Lang	The person's mother language.	English, French, Chinese, etc.	By inputting.
Second_Lang	The person's second language. (This could be a list.)	English, French, Chinese, etc.	By inputting.
Education_Background	The person's educational background.		By inputting.
Class: Learner			
Learning_Style	The learner's innate pattern of thinking and problem solving when approaching a learning task.	Active, Reflective.	Own instances definition.
Learning_Preference	The learner's inclination for content displaying format.	Image, Audio, Video.	Own instances definition.
Cognitive_Abilities	The learner's capacity for higher mental processes of reasoning, remembering, understanding, and problem solving.	Working memory capacity, Critical thinking, Inductive reasoning, reflective thinking, Associative learning.	Cognitive Trait Model (Lin, T. et al., 2003)
Class: AMLearner			
Job_Id	The professional's job Id.		By inputting.
Professional_Role	The professional's role.	Programmer, Dealer, etc.	By inputting.
Professional_Status	The professional's status.	Manager, Worker, etc.	By inputting.
Training_Experience	The professional's training experience.	Java Programming, English, etc.	By inputting.
Practical_Experience	The professional's practical experience.	Java develop, Repair a PC, etc.	By inputting.
Task_Proficiency	The professional's proficiency with the current work.	Beginner, Experienced, Expert.	Own instances definition.
Available_Time	Professional's available time for learning and solving the problem.	In minutes	Professional's planned time.
Class: LearningPartners			
Availability_Status	The co-learner's status in the WoBaLearn system.	Online & Available, Online & Unavailable, Offline	Own instances definition.
Class: ExperiencedColleagues			
This class is an inheritance Class without the elements.			
Class: People Nearby			
This class is an inheritance Class without the elements.			
Class: AMExperiencedColleagues			
Maintenance_Specialty	The maintenance specialty of the experienced colleague.		By inputting.
Class: AMPeopleNearby			
LearningPartners_Role	The role of the people nearby.	Colleague, Client, etc.	By inputting.

Table 4.3 Contextual Elements and Instances Considered in the Activity Class

Context	Description	Data (Instances)	Data Source
Class: Activity			
This class is an inheritance Class without the elements.			
Class: LearningActivity			
Learning_Strategy	The learning strategy recommended by the system.	Fast, Systematic, Intensive, Extended.	Own instances definition.
Learning_Objectives	The learning objective for solving the problem occurring in the current work.	Maintenance_Action + Action_Object + Appliance_Id	Organized by the other three context aspects of work activity.
Proposed_Format	The learning content format recommended by the system based on the other context aspects.	Image, Audio, Video	Own instances definition.
Class: JustInTimeLearning			
Learning_Content	The name of the learning content selected by the system.		Learning unit database.
Content_Metadata	The metadata file of the selected learning content.	A XML file.	Learning unit database.
Learning_Effect	The learner's evaluation of the selected learning content.	Satisfied, Not Satisfied.	Own instances definition.
Learning_Partner	The id of the learning partners recommended by the system and selected by the learner.		User database.
Time_Used	The time used for the learning process.	In minutes.	Count by the system clock of the device.
Class: Review			
Review_Time	Time reserved for reviewing.	In the format "dd-mm-yyyy hh:mm".	Learner's planned time.
Class: Progress			
Progress_Content	The name of the extension contents recommended by the system and selected by the learner.		Learning unit database.
Progress_Content_Metadata	The metadata file of the selected extension contents.		Learning unit database.
Class: WorkActivity			
This class is an inheritance Class without the elements.			
Class: MaintenanceAppliance			
Appliance_Id	The id of the appliance which the professional operates on.		By the manufacturer.
Maintenance_Action	The description of the professional's maintenance action.	Repair, Install, Maintain, Test, Problem Solving.	Own instances definition.
Action_Object	The object of the maintenance action.	E.g. Screen, SIMM Board, etc.	By inputting.

Table 4.4 Contextual Elements and Instances Considered in the Device Class

Context	Description	Data (Instances)	Data Source
Class: Device			
Device_Id	The device Id.		By the manufacturer.
Device_Type	The device functional type.		By the manufacturer.
Class: LearningDevice			
Mobility	The learning device mobility.	E.g. Portable, Fixed, etc.	(W3C-MBP, 2008) (WURFL, 2008)
Operating_System	The operating system of the learning device.	E.g. Windows, Android, iOS, etc	
Browser	The browser type of the learning device.	E.g. Firefox, Chrome, Safari, Android, etc.	
Cpu_Utilizing_Rate	The CPU utilizing rate of the learning device.		
Network Connectivity	Whether the learning device is connected with the network.	Yes, No.	
Screen_Size	The screen size of the learning device.		
Audio_Availability	Whether the audio of the mobile device is available.	Yes, No.	
Video_Availability	Whether the video of the mobile device is available.	Yes, No.	
Camera_Availability	Whether the camera of the mobile device is available.	Yes, No.	
Class: AMLearningDevice			
RFID_Support	Whether the learning device has RFID support.	Yes, No.	(W3C-MBP, 2008) (WURFL, 2008)
Class: SupportDevice			
Occupy_Status	Whether the support device is occupied.	Yes, No.	Own instances definition.
Class: AMSupportDevice			
Ip_Address	The IP address of the support device.		Protocol of IP address.

Table 4.5 Contextual Elements and Instances Considered in the Collaboration Class

Context	Description	Date (Instances)	Data Source
Class: Collaboration			
This class is an inheritance Class without the elements.			
Class: LearningCollaboration			
ComTool	The name of the collaboration tool.	E.g. Email, Online Chat, SMS, etc.	Own instances definition.
Asy_Syn	Whether the collaboration is asynchronous or synchronous.	Asynchronous, synchronous.	Own instances definition.
Class: AMCollaboration			
Intercomp_System	The name of the collaboration tool used specially in the company.		By inputting.

Table 4.6 Contextual Elements and Instances Considered in the Environment Class

Context	Description	Date (Instances)	Data Source
Class: Environment			
Latitude	Spatial coordinates.		Mobile device integrated GPS.
Longitude	Spatial coordinates.		Mobile device integrated GPS.
Current_Time	Current time.	In the format “dd-mm-yyyy hh:mm”.	Mobile device integrated system clock.
PlaceIn_Out	Whether the learner is located indoors or outdoors.	In, Out.	Own instances definition.
Noise_Level	State of the noise level in the place where the people are located.	Low, High.	Own instances definition.
Illumination_Level	State of the illumination level in the place where the people are located.	Low, High.	Own instances definition.
Class: WorkEnvironment			
Company_Name	Name of the learner’s company		By inputting.
CompanyIn_Out	In the company or out of the company.	In, Out.	Own instances definition.
Class: AMEnvironment			
Workplace_Description	One-word physical description of where the professional is located.	Office, Meeting Room, etc.	Own instances definition.

4.5 Building and Manipulating the Context Model with Development Tools

In our research, we selected Protégé as the editing tool to build the ontology of the WbML context model. Also, we use Jena API to manipulate the context aspects defined in the WbML context model in the Java program

4.5.1 Building the WbML Context Model with Protégé

Protégé editor, developed by the Stanford Center for Biomedical Informatics Research, is a free, open source ontology editor and knowledge-based framework (Protégé, 2004). It is supported by a strong community of developers and academic, government and corporate users, who use Protégé for knowledge solutions in areas as diverse as biomedicine, intelligence gathering, and corporate modeling.

The Protégé platform supports two main ways of modeling ontologies: Protégé-Frames editor and Protégé-OWL editor. The Protégé-Frames editor enables users to build and manipulate ontologies that are frame-based, in accordance with the Open Knowledge Base Connectivity protocol (OKBC). The Protégé-OWL editor enables users to build ontologies for the Semantic Web. The Protégé-OWL editor implements a rich set of knowledge-modeling structures and actions that support creation, visualization, and manipulation of ontologies in various representation formats including OWL, RDF(S), and XML Schema. It can be customized to provide domain-friendly support for creating knowledge models and entering data. The Protégé-OWL editor enables users to: load and save OWL and RDF ontologies; edit and visualize classes, properties, and SWRL rules; define logical class characteristics as OWL expressions; execute reasoners such as description logic classifiers; edit OWL individuals for Semantic Web markup.

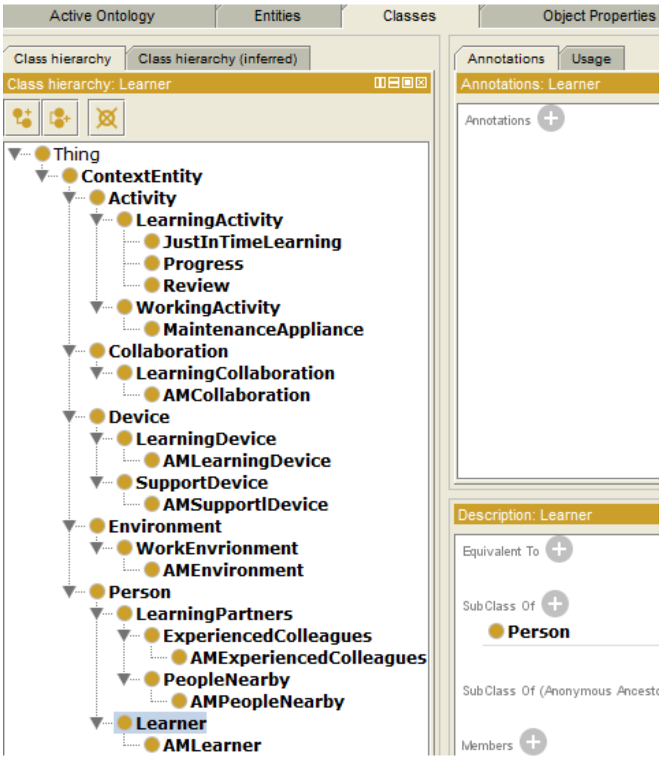

Figure 4.7 Build Classes for the WbML Context Model with Protégé

When implementing the WoBaLearn system, the Protégé Ontology Editor is used to construct the initial WbML context model. Figure 4.7 shows hierarchical class building with Protégé. Figure 4.8 shows data property setting with Protégé by identifying the domain and range of each data property.

Figure 4.9 shows object property setting with Protégé by identifying the domain, range and relative properties of each object property.

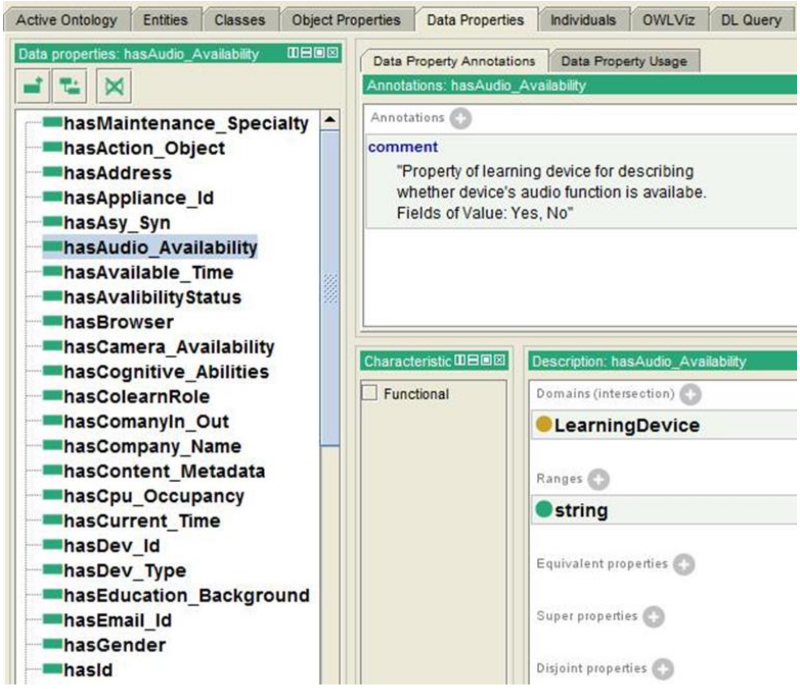

Figure 4.8 Set Data Properties of the WbML Context Model with Protégé

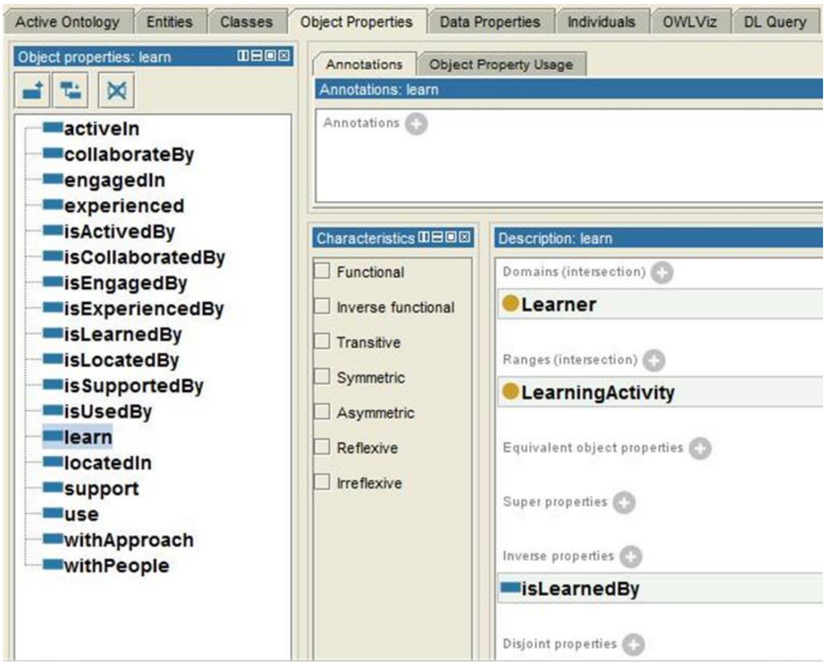

Figure 4.9 Set Object Properties of the WbML Context Model with Protégé

4.5.2 Manipulating Context in WbML with Jena

Jena, supported by the Apache Software Foundation, is a Java framework for building Semantic Web applications by providing a collection of tools and Java libraries to help developers to develop semantic web and linked-data apps, tools and servers (Apache Jena, 2010). Jena provides a set of Java APIs for creating and manipulating RDF and OWL graphs, including representation, parsing, database persistence, querying and some visualization tools. Applications use Jena to deal with ontology, just as we use Protégé to deal with ontology.

For RDF, Jena uses the object classes to represent graphs, resources, properties and literals. A graph is called a model, and is represented by the Model interface. The interfaces for representing resources, properties and literals are called Resource, Property and Literal, respectively. The Jena OWL model is an extension of the Jena RDF model. It provides extra capabilities for handling ontologies. The OWL models are created via the Jena ModelFactory. The fundamental concepts in ontology are class, property and individual.

When implementing the WoBaLearn system, we use Jena API to manipulate the context aspects defined in the WbML context model in the Java program. More specifically, the manipulations include:

- Opening, creating and saving an OWL file;
- Representing the WbML context model in the Java program;
- Querying the value of a specific context;
- Reasoning the potential correlations between the context;
- Reasoning the values of unknown context aspects from the known ones;
- Inserting or modifying the value of a context.

The specific code of each operation can refer to (Apache Jena, 2010). Below, we focus on introducing the reasoning supports of Jena.

Jena supports two kinds of reasoning, including: ontology reasoning, reasoning based on OWL semantic structure; and user-defined rule-based reasoning, reasoning based on user-defined rules.

1) Ontology reasoning

Ontology reasoning is responsible for checking class consistency and implied relationships, and for asserting inter-ontology relations when integrating or switching specific work ontology. It is implemented using a rule-based reasoning engine.

Ontology reasoning includes RDFS reasoning and OWL reasoning. RDFS reasoning supports all the RDFS entailments described by the RDF Core Working Group. OWL reasoning supports OWL/lite, which includes constructs such as relations between classes, cardinality, equality, characteristics of properties, and enumerated classes. Several examples of reasoning rules based on ontology are illustrated in Table 4.7.

Table 4.7 Reasoning Rules Based on Ontology

Reasoning Rules	Example
subClassOf	(?A rdfs:subClassOf ?B) ^ (?B rdfs:subClassOf ?C) -> (?A rdfs:subClassOf ?C)
transistiveProperty	(?P fdf:typowl:TransitiveProperty) ^ (?A ?P ?B) ^ (?B ?P ?C) -> (?A ?P ?C)
subPropertyOf	(?A rdfs:subPropertyOf ?B) ^ (?B rdfs:subProertyOf ?C) -> (?A rdfs:subPropertyOf ?C)
disjointWith	(?C owl:disjointWith ?D) ^ (?X rdf:type ?C) ^ (?Y rdf:type ?D) -> (?X owl:differentFrom ?Y)
inverseOf	(?P owl:inverseOf ?Q) ^ (?X ?P ?Y) -> (?Y ?Q ?X)

2) User-defined rule-based reasoning

User-defined rule-based reasoning is responsible for matching the known fact and the pre-defined rules to generate the values of some context aspects. User-defined rule-based reasoning provides forward chaining, backward chaining and a hybrid execution model. The forward-chaining rule engine is based on the standard RETE algorithm (Forgy, 1982), while the backward-chaining rule engine uses a logic programming engine similar to Prolog engines. A hybrid execution mode performs reasoning by combining both forward-chaining and backward-chaining engines.

The rule is defined by a Java Rule object with a list of body terms (premises), a list of head terms (conclusions), and an optional name and optional direction. An informal description of the simplified text rule syntax is shown in Figure 4.10.

```
Rule := bare-rule . or [bare-rule] or [ruleName : bare-rule]
bare-rule := term, ··· term -> hterm, ··· hterm // forward rule
          or bhterm <- term, ··· term // backward rule
hterm := term or [bare-rule]
term := (node, node, node) or (node, node, functor) or builtin (node, ··· node)
bhterm := (node, node, node)
functor := functorName (node, ··· node)
node := uri-ref or prefix:localname or <uri-ref> or ?varname or ‘a literal’
      or ‘lex’ ^^ typeURI or number
```

Figure 4.10 Description of the Rule Syntax

For example, a rule can be defined as [rule1: (?f pre:father ?a) (?u pre:brother ?f) -> (?u pre:uncle ?a)], which describes the meaning that: if f is father of a, and u is brother of f, then u is uncle of a.

The ontology reasoning rules and the user-defined reasoning rules are called and written in a rule file with the extension of ".rules". An example of a rule file named "Family.rules" is shown in Figure 4.11. In the Java program, relative Jena APIs are called to execute the reasoning based on the rule file and the owl data file.

```
@prefix pref: <http://www.semanticweb.org/user/ontologies/2013/11/Family#>.
@include <RDFS>.
@include <OWL>.

[rule1:
(?f pre:father ?a) (?u pre:brother ?f)
-> (?u pre:uncle ?a)]
```

Figure 4.11 Example of a Rule File

4.6 Collecting the Context Defined in the WbML Context Model

The technique and approach to be adopted to collect a context depend on the category of the specific context. Based on the means by which a context is collected, we classify the context aspects concerned in the WbML context model into two main categories: direct context and indirect content.

- **Direct context**: Direct context is the context which can be acquired or obtained directly. More specifically, direct context can be divided into sensed context and defined context.
    - **Sensed context**: Sensed context is acquired from physical sensors, such as the RFID installed at the entrance of a meeting room to detect whether a user enters the room, or from virtual sensors, such as a web service.
    - **Defined context**: Defined context is typically defined by a user and collected by form filling, such as learning preference, which reflects learner preferred display format of learning units, and is specified by a particular learner.
- **Indirect context:** Indirect context is the context which cannot be acquired directly from the physical and visual sensor. An indirect context aspect can be obtained by reorganizing or inferring from several direct context aspects. For example, the proposed display format of learning units should be inferred with a set of reasoning rules by considering the learner's learning preference, the mobile device capacities and the workplace situations.

Below, we present several typical examples for clarifying the specific techniques and approaches used to collect context.

1) Collecting sensed context

Sensed context, for example, the context aspects related to learner's location, such as latitude, longitude, workplace description, etc., can be collected directly from the sensors.

The Global Positioning System (GPS) integrated in mobile devices is used to collect the learner's latitude and longitude. GPS is a space-based satellite navigation system that provides location and time information in the military, civil and commercial application fields. Recently, the US Government turned off degradation of the civil GPS signal to allow an accuracy of 10 meters, which is 10 times more accurate than before. Benefiting from this policy, GPS can provide the WoBaLearn system with acceptable data on the learner's latitude and longitude, which are the most important context aspects considered when the system selects the location-based learning services.

However, when the learner is located indoors, data accuracy and signal strength limit utilization of the GPS. RFID (Radio-frequency identification) is one of the possible solutions used in this situation. RFID is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. Tags contain electronically stored information. In our application, RFID tags store the information of the company rooms, and are installed at the entrance to the corresponding rooms. A learner carrying the mobile device integrated with the RFID reader can receive the workplace description delivered by the RFID tag.

The other sensed context can be collected from other sensors, such as the current time obtained by the integrated system clock of the mobile device, the illumination level obtained from the light sensor, the noise level obtained from the sound sensor, etc.

2) Collecting defined context

Defined context, such as learner's basic information, learning preference, learning style, training experience, practical experience, etc., should be inputted in the WoBaLearn system by the actual learner.

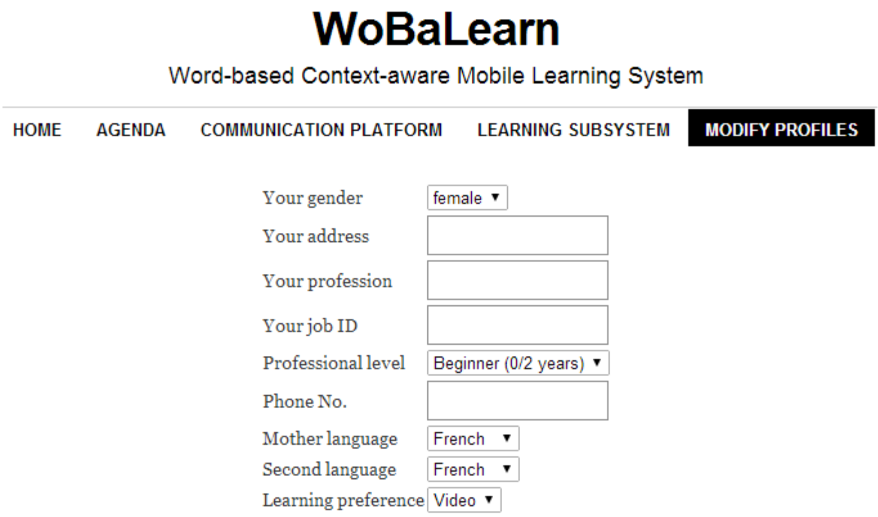

Figure 4.12 WoBaLearn interface for collecting and updating defined context

The defined context aspects are relatively fixed, for example, the learner's basic information. Once these context aspects are inputted by the learner, they are recorded in the system database, which means that the system does not have to collect them each time. In addition, defined context may be changed, for example the learner's practical experience could be expanded during his work. So, these context aspects can also be modified and updated in the corresponding system interface by the learner. The WoBaLearn system interface for collecting and updating some defined context aspects is shown in Figure 4.12.

3) Inferring indirect context

When implementing the WoBaLearn system, we set out the reasoning rules in the file named "Rule.rules" for inferring the indirect context aspects defined in the WbML context model.

For example, the rule set defined for "hasProposed_Format" reasoning in the "LearningActivity" class consists of three rules, including Present_Video, Present_Image and Present_Audio. They are defined in the "Rule.rules" file as shown in Figure 4.13.

```
[Present_Video:
(?L rdf:type pref:AMLearner),(?L pref:hasLearning_Preference ?P),equal(?P,'Video'),
(?LD rdf:type pref:AMLearningDevice),(?LD pref:hasVideo_Availability ?VA),equal(?VA,'Yes'),
(?E rdf:type pref:AMEnvironment),noValue (?E pref:hasWorkplace_Description 'Meeting_Room'),
(?JL rdf:type pref:JustInTimeLearning),
->(?JL pref:hasProposed_Format 'Video')
]

[Present_Image:
(?L rdf:type pref:AMLearner),(?L pref:hasLearning_Preference ?P),equal(?P,'Image'),
(?E rdf:type pref:AMEnvironment),noValue(?E pref:hasIllumination_Level 'High'),
(?JL rdf:type pref:JustInTimeLearning),
->(?JL pref:hasProposed_Format 'Image')
]

[Present_Audio:
(?L rdf:type pref:AMLearner),(?L pref:hasLearning_Preference ?P),equal(?P,'Audio'),
(?LD rdf:type pref:AMLearningDevice),(?LD pref:hasAudio_Availability ?AA),equal(?AA,'Yes'),
(?E rdf:type pref:AMEnvironment),noValue (?E pref:hasWorkplace_Description 'Meeting_Room'),
(?E rdf:type pref:AMEnvironment),noValue(?E pref:hasNoise_Level 'High'),
(?JL rdf:type pref:JustInTimeLearning)
->(?JL pref:hasProposed_Format 'Audio')
]
```

Figure 4.13 Rules for "hasProposed_Format" reasoning in "LearningActivity"

The rules listed in Figure 4.13 can be formulated as:

- **Present_Video**: If L is the instance of the AMLearner class and L has a video learning preference; And LD is the instance of the AMLearningDevice class and its video function is available; And

E is the instance of the AMEnvironment class and E is not a meeting room; Then, the format proposed by the system should be video.

- **Present_Image**: If L is the instance of the AMLearner class and L has an image learning preference; And E is the instance of the AMEnvironment class and its illumination level is not high; then, the format proposed by the system should be image.
- **Present_Audio**: If L is the instance of the AMLearner class and L has an audio learning preference; And LD is the instance of the AMLearningDevice class and its audio function is available; And E is the instance of the AMEnvironment class, and E is not a meeting room and also its noise level is not high; then, the format proposed by the system should be audio.

Another example is the rule set defined for "hasLearning_Strategy" reasoning in the "LearningActivity" class. The rule set consists of four rules, including Strategy_Fast, Strategy_Systemetic, Strategy_Intensive and Strategy_Extended. They are defined in the "Rule.rules" file as shown in Figure 4.14.

```
[Strategy_Fast:
(?L rdf:type pref:AMLearner),(?L pref:hasAvailable_Time ?M),le(?M,30),
(?LA rdf:type pref:LearningActivity)
->(?LA pref:hasLearning_Strategy 'Fast')
]
[Strategy_Systematic:
(?L rdf:type pref:AMLearner),(?L pref:hasAvailable_Time
?M),greaterThan(?M,30),
(?L pref:hasTask_Proficiency 'Beginner'),(?LA rdf:type pref:LearningActivity)
->(?LA pref:hasLearning_Strategy 'Systemic')
]
[Strategy_Intensive:
(?L rdf:type pref:AMLearner),(?L pref:hasAvailable_Time
?M),greaterThan(?M,30),
(?L pref:hasTask_Proficiency 'Experienced'),(?LA rdf:type pref:LearningActivity)
->(?LA pref:hasLearning_Strategy 'Intensive')
]
[Strategy_Extended:
(?L rdf:type pref:AMLearner),(?L pref:hasAvailable_Time
?M),greaterThan(?M,30),
(?L pref:hasTask_Proficiency 'Expert'),(?LA rdf:type pref:LearningActivity)
->(?LA pref:hasLearning_Strategy 'Extended')
]
```

Figure 4.14 Rules for "hasLearning_Strategy" reasoning in "LearningActivity"

The rules listed in Figure 4.14 can be formulated as:

- **Strategy_Fast**: If L is the instance of AMLearner and L has available time of less than or equal to 30 minutes; then, the learning strategy should be fast.

- **Strategy_Systematic**: If L is the instance of AMLearner and L has available time of more than 30 minutes, and its task proficiency is a beginner; then, the learning strategy should be systematic.

- **Strategy_Intensive**: If L is the instance of AMLearner and L has available time of more than 30 minutes, and its task proficiency is experienced; then, the learning strategy should be intensive.

- **Strategy_Extended**: If L is the instance of AMLearner and L has available time of more than 30 minutes, and its task proficiency is expert; then, the learning strategy should be extended.

The collected context aspects are recorded in an instance of the model file "WbML_Context_Model.owl" with the name format as "LearnerID_Current_Time.owl", which indicates the learning context of a learner at a particular time. These context aspects are used in the WoBaLearn system as the conditions for selecting personalized and adaptive learning units, learning partners and learning activities.

4.7 Conclusion

In this chapter, we described in detail the design of WbML, a context model for work-based learning. This model adopts the hierarchical design approach and is described by ontology written in OWL-DL. In this chapter, first, we introduced the hierarchical framework of the WbML context model and identified the function of each layer. Second, we presented the context ontology design of the model by describing its class classifications, data properties and major object properties. Third, we illustrated the description, instances and data source of each context aspect defined in the WbML context model. Then, we introduced the approaches for building the model ontology with Protégé and manipulating the context aspects defined in WbML in the Java program with Jena. Finally, we described the collecting approaches for particular context aspects with examples.

In the next chapter, we present another important aspect in WoBaLearn system design – the design of adaptation strategies and the adaptation engine.

The content of this chapter was published in:

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5 The In-depth Design of WoBaLearn - Adaptation Strategies and Engine Design

5.1 Introduction

This chapter describes the system design in detail, and, particularly, the design of adaptation strategies and of the adaptation engine. The adaptation strategy is the mechanism to implement adaptivity and personalization in WoBaLearn system. Based on adaptation strategies, the system can fit its behavior and functionalities to professionals' learning needs, personal characteristics, particular circumstances, etc. The adaptation engine applies the adaptation strategies to produce appropriate learning units, learning partners and learning activities based on just-in-time learning context.

As stated in section 4.3, in this thesis we take "appliance maintenance" as an example of work-based learning scenarios. In this chapter, we describe the designed adaptation strategies under the example of "appliance maintenance". These strategies can be reused widely in different work-based learning scenarios by changing a few specific work context aspects in these strategies.

Analyzing the effect of each adaptation strategy stated in chapter 2, and considering the proposed learning sequence stated in section 3.3.1 in Figure

3.3, we decide to take into account five learning adaptation strategies in the WoBaLearn system, including adaptation of learning units selection, adaptation of learning units sequence, adaptation of learning units navigation, adaptation of learning partners communication, and adaptation of learning activities generation. In this chapter, we first present these five adaptation strategies in detail, and then we introduce the design of the adaptation engine which implements these proposed adaptation strategies.

5.2 Design of Learning Adaptation Strategies

To facilitate professionals' work-based learning, by examining the effect of each adaptation strategy stated in chapter 2, and by considering the proposed learning sequence stated in section 3.3.1 in Figure 3.3, we implemented five learning adaptation strategies in the WoBaLearn system as listed in Table 5.1. The remainder of this section presents the design of each learning adaptation strategy in detail.

Table 5.1 Learning Adaptation Strategies Implemented in WoBaLearn

Adaptation Types	Adaptation Strategies
Learning Units Selection	Select appropriate learning units for professionals based on their work-based learning context in the domains of learner, work activity, learning device and work environment.
Learning Units Sequence	Reorder the sequence of the selected learning units by taking into account the learner's personalized settings.
Learning Units Navigation	Rearrange the navigation between the proposed learning unit and other relative units for making adaptive pedagogical units.
Learning Partners Communication	Help the learner to find his learning partners and build the communication platforms based on three context aspects: learner, learning partners and work activity.
Learning Activities Generation	Deal with automatic generation of individual learning activities, including the just-in-time activity, the review activity and the progress activity.

5.2.1 Adaptation of Learning Units Selection

This adaptation strategy is used for selecting the learning units which are most relative to the learner's current work, and which are also in a display format adapted to the learner's preference, mobile device capacities and workplace situations.

We describe the design of this adaptation strategy based on three aspects: the considered learning context, the considered metadata of learning units, and the selection rules defined for choosing the learning units according to the learning context.

1) The considered learning context

The context aspects considered in this adaptation strategy include two parts:

- The context for identifying the learner's current work, which can be used to select the contents of learning units for providing the learner with the work-related supports. The considered context aspects include the elements of the "WorkActivity" class defined in the WbML context model, shown in Figure 4.3. For the specific work as appliance maintenance, the considered context includes: Appliance Id, Maintenance Action and Action Object.

- The context for identifying the learner's preference, device capacities and environment situations, which can be used to determine an appropriate display format of learning units. More specifically, the context aspects considered include: Learning Preference, Video Availability, Audio Availability, Workplace Description, Illumination Level and Noise Level. With the context instances and the user-defined reasoning rules stated in chapter 4, the indirect context "Proposed Format" can be inferred. The value of "Proposed Format" could be video, audio or image. This value is taken as the most appropriate display format for the learner.

2) The considered metadata of learning units

In the former work of our laboratory, Dr. Chuantao YIN proposed AM-LOM metadata for describing the metadata of learning contents used specially in work-based learning (Yin C. T., 2010). He defined AM-LOM with nine types of metadata, including: general information, lifecycle, metaMetadata, technical information, educational information, rights, relation, annotation and classification. Relative learning contents are reorganized into a learning unit which is labeled with AM-

LOM metadata. Each learning unit is recorded in a XML file and stored in the system Learning Unit Database, thanks to which the WoBaLearn system can be aware of each learning unit and choose the one adapted to the just-in-time context.

Corresponding with the context aspects stated above, two metadata elements are considered in this adaptation:

- **General->Keyword**
  In AM-LOM, General->Keyword is used to identify the main contents described in a learning unit. In the metadata file of a learning unit, these metadata can be either one or multiple, which represents single or multiple keywords of the learning unit.

- **Technical->Format**
  In AM-LOM, Technical->Format is used to identify the display format of a learning unit. The value of these metadata can be Video, Audio or Image. "Image" is the default value of these metadata.

3) The selection rules

The selection rules defined for this adaptation aim to select the appropriate learning units according to the values of the considered learning context aspects above. The rules are executed in two steps:

(1) Searching in the system learning unit database, matching the metadata "General->Keyword" of each learning unit with the collected context for identifying the learner's current work, then selecting the learning units that have the most keywords catering to the current context.

(2) Searching in the learning units selected by the first step, choosing the ones that have the metadata "Technical->Format" equaled with the reasoned context "Proposed Format". If none of the learning units is in the display format catering to the context, then the ones in the default format "Image" will be selected.

As stated above, the adaptation strategy of learning units selection can be summarized in Table 5.2. The result of this adaptation has at least one selected learning unit, and it is possible to have several learning units.

Table 5.2 Adaptation Strategy of Learning Units Selection

Context	Metadata	Selection Rules
Appliance Id Maintenance Action Action Object	General->Keyword	Select the learning units stored in the Learning Unit Database that have the most keywords catering to the context of the learner's current work.
Proposed Format (Reasoned from: Learning Preference, Video Availability, Audio Availability, Illumination Level, Noise Level, Workplace description)	Technical->Format	In the result of the first step, select the learning units in the format as the value of context "Proposed Format". If nothing is found, the one(s) in the default format "Image" will be selected.

5.2.2 Adaptation of Learning Units Sequence

Based on the adaptation strategy of learning units selection, one or multiple learning units have been selected. Since the result can be a large set, the adaptation strategy for sequencing the learning units has been designed. This adaptation strategy reorders the learning units by taking into account the learner's personalized settings.

1) The considered learning context

In adaptation of learning units sequence, for the current design of WoBaLearn, we consider only three aspects of the learning context, including: Learning Style, Task Proficiency and Mother Language. The context aspects considered in this adaptation strategy would be extended in our further research.

- **Learning Style**
  Learning Style, with a reflective or active value, represents a learner's innate pattern of thinking and problem solving when approaching a learning task, which shows that the learner inclines towards the learning unit interactive type.
- **Task Proficiency**
  Task Proficiency, with a beginner, experienced or expert value, represents a learner's proficiency with his work, which shows that the learner inclines towards the learning unit difficulty level.

- **Mother Language**
  Mother Language, with the value like En, Fr, etc., inputted by the learner, which shows that the learner inclines towards the language of learning unit.

More context aspects defined in WbML can be used as the conditions to sequence the learning units. More emphasis will be placed on this work in our future research.

2) The considered metadata of learning units

Corresponding with the context aspects above, three metadata elements defined in AM-LOM are considered in this adaptation:

- **Education->Interactive Type**
  In AM-LOM, Education->Interactive is used to identify the interactive type of a learning unit, with the value of static (e.g. to identify a reading material) or task (e.g. to identify a group collaborative activity).

- **Education->Difficulty**
  In AM-LOM, Education->Difficulty is used to identify the difficulty of a learning unit for average learners, with the value of easy, medium or difficult.

- **General->Language**
  In AM-LOM, General->Language is used to identify the language of a learning unit. The value could be En, Fr, etc.

3) The sequencing rules

The sequencing rules reorder the selected learning units by four steps:

(1) Compare the values of these three context aspects and the corresponding metadata of the selected learning units. If they are matchable, the value of M_Context_Metadata (matching parameter of Context and Metadata) is assigned as 1. For example, if the value of Learning Style is "Reflective", and the Interactive Type of a learning unit is "Static", then the value of M_LS_IT (matching parameter of the learner's Learning Style and Interactive Type of the learning unit) equals 1. Similarly, M_TP_D refers to the matching

parameter of a learner's Task Proficiency and Difficulty of a learning unit, and M_ML_L refers to the matching parameter of a learner's Mother Language and Language of a learning unit.

(2) Obtain the values for the importance of these three context aspects. The values are set to 1 by default and can be modified from the system interface by the learner according to his practical situation. These values reflect the learner's inclination of choosing the learning units. The scale of the values is 5. The higher value indicates that this context aspect has a greater impact on sequencing units order. In the sequencing rules, I_LS is used to represent the importance of context Learning Style. Similarly, I_TP is the importance of context Task Proficiency, and I_ML is the importance of context Mother Language

(3) Calculate the sequence value of each selected learning unit by the following formula:
SequenceValue = M_LS_IT * I_LS + M_TP_D * I_TP + M_ML_L * I_ML

(4) Order those learning units according to their sequence values, where that with the highest value is the most appropriate learning unit.

As stated above, the adaptation strategy of learning units sequence can be summarized in Table 5.3. This strategy finds the learning unit with the highest priority.

Table 5.3 Adaptation Strategy of Learning Units Sequence

Context	**Metadata**	**Sequencing Rules**
Learner->Learning Style Value: Reflective Value: Active	Education->Interactive Type Value: Static Value: Task	Calculate the SequenceValue of each selected learning unit, and order them from highest priority to lowest by the SequenceValue from big to small.
Learner->Task Proficiency Value: Beginner Value: Experienced Value: Expert	Education->Difficulty Value: easy Value: medium Value: difficult	
Learner->Mother Language	General->Language	

5.2.3 Adaptation of Learning Units Navigation

Adaptation of learning units navigation can guide the learner in accessing other relative learning units according to his / her available time and work proficiency. More specifically, this adaptation strategy produces adaptive pedagogical units based on the proposed learning unit along with its prior knowledge, extended knowledge, and / or intensive knowledge. This adaptation strategy organizes the individual learning unit into a knowledge system which can satisfy the person's need for cognition.

1) The considered learning context

The context aspect considered in this adaptation is Learning Strategy of the Learning Activity class. Learning Strategy indicates the instructional strategy proposed by the system for assisting the learner to better achieve his learning goal. The value of Learning Strategy could be Fast, Systematic, Intensive, or Extended.

Learning Strategy is an indirect context, and is reasoned from two direct context aspects: Available Time and Task Proficiency. The user-defined reasoning rules for Learning Strategy have been presented in chapter 4 and can be summarized in Table 5.4.

Table 5.4 User-defined Reasoning Rules for Learning Strategy

Available Time	Task Proficiency	Learning Strategy
< = 30 min	Any value	Fast
> 30 min	Beginner	Systematic
> 30 min	Experienced	Intensive
> 30 min	Expert	Extended

2) The considered metadata of learning units

In this adaptation, the metadata considered are Relation->Kind. In the metadata file of a learning unit, Relation->Kind indicates the relationships between this unit and other units. In a metadata file, Relation->Kind can be single or multiple. Its value can be basedon, haspart or extendedwith. We list the meaning and the example of each value in Table 5.5.

Table 5.5 Values of the metadata Relation->Kind

Value of Relation->Kind	Meaning	Example
basedon	Indicate the prior knowledge.	A basedon B: B is A’s prior knowledge
haspart	Indicate the intensive knowledge.	A haspart C: C is A’s intensive knowledge.
extendedwith	Indicate the extended knowledge.	A extendedwith D: D is A’s extended knowledge.

3) The navigation rules

The principles for defining the navigation rules are:

- If the value of Learning Strategy is Fast, which means the learner does not have enough time to learn other knowledge but just that for solving the problem at hand, then the rule presents the individual learning unit selected by the adaptation strategies above.

- If the value of Learning Strategy is Systematic, that means the learner has enough time to learn not only the selected learning unit but also other relative units. As the learner is a beginner in his current work, the rule presents additionally prior knowledge for replenishing the learner’s insufficiency and intensive knowledge for enhancing his ability.

- If the value of Learning Strategy is Intensive, similarly, the learner has enough time to learn. As the learner is experienced in his current work, the rule hides the prior knowledge, and just presents the selected learning unit and its intensive knowledge.

- If the context Learning Strategy is Extended, similarly, the learner has enough time to learn. As the learner is an expert in his current work, the rule presents the selected learning unit, its intensive knowledge and also the extended knowledge for expanding his ability.

As the statement above, the adaptation strategy of learning units navigation can be summarized in Table 5.6. This strategy organizes adaptive pedagogical units with the learning unit selected by the strategies above and also its relative knowledge.

Table 5.6 Adaptation Strategy of Learning Units Navigation

Value of the Context Learning Strategy	Navigation Rules	Value of the Metadata Relation->Kind
Fast	Individual unit selected by the strategies above.	none.
Systematic	Selected learning unit; Prior knowledge; Intensive knowledge.	none; basedon; haspart.
Intensive	Selected learning unit; Intensive knowledge.	none; haspart.
Extended	Selected learning unit; Intensive knowledge; Extended knowledge.	none; haspart; extendedwith.

5.2.4 Adaptation of Learning Partners Communication

The learning supports considered in WoBaLearn come not only from the learning units stored in the Learning Unit Database, but also from the knowledge of people who can offer instructional or suggestive opinions to help the learner achieve his / her learning goal. Adaptation of learning partner communication assists the learner in finding his appropriate learning partners, and also proposes adaptive communication approaches by considering partners' locations and availabilities.

Two kinds of people are considered in WoBaLearn as potential learning partners: experienced colleagues and people located near the learner. Although experienced colleagues may be located in different places, they can be contacted by multiple communication tools and give effective instructions according to their experiences. Nearby people maybe have no experience with the learner's work, but they can provide immediate feedback or discuss with the learner for finding a solution.

In what follows, we describe the design of this adaptation strategy based on three aspects: the considered learning context, the rules for selecting the learning partners, and the rules for selecting the communication approaches.

1) The considered learning context

The learning context aspects considered in this adaptation include two parts:

- The context aspects for identifying the learner's learning objective, which can be used to select the experience-related learning partners. In the WbML context model, we defined Learning Objective to record the learner's current learning objective. Learning Objective is an indirect context. It should be organized from the direct context aspects used for identifying the learner's current work. For example, considering the specific work of appliance maintenance, the direct context aspects include: Appliance Id, Maintenance Action and Action Object.

- The context aspects for identifying the learner's location, which can be used to find the nearby learning partners. Several context aspects for describing information about the learner's location have been defined in the WbML context model, such as Latitude, Longitude, Workplace Description, etc. However, for now, in implementation of the WoBaLearn system, we only consider the context Workplace Description.

2) Rules for selecting the learning partners

The scope of the learning partners provided by the WoBaLearn system is limited to system registered users. The system can obtain their profiles and current statuses from the Learner Profile Database, and also their learning histories with the WoBaLearn system from the Learning Activity History Database.

- To select the experience-related learning partners, the rule compares the learner's learning objective, which is recorded in the Learning Objective context, with other users' former learning objectives, which are recorded in the Learning Activity History Database. The matching users are taken as the learner's potential learning partners. Their basic information, including names, system statuses, professional roles, training experience, practical experience, etc., are obtained from the Learner Profile Database, and are listed as references for the learner to choose his / her learning partners.

- To find the nearby learning partners, the rule compares the learner's current workplace, which is recorded in the Workplace Description context, with other users' current workplaces, which are sensed by RFID installed at the rooms' entrances when users enter rooms. The matching users are recommended to the learner as his / her nearby learning partners. Also their basic information can be obtained from the Learner Profile Database and provided to the learner before starting a discussion.

3) Rules for selecting the communication approach

The learner can choose more than one person as his / her learning partners. According to the chosen person's locations and their system statuses, different communication approaches are recommended.

- If the learner chooses experience-related colleagues as his / her learning partners, the rule recommends that the learner contacts them by communication tools. The specific tool is selected according to the learning partner's status on the system. Three statuses have been defined, including: Online & Available, Online & Unavailable and Offline. If the learning partner is Online & Available, an online chat room is created between them which can facilitate a just-in-time question-and-answer session. If the learning partner is Online & Unavailable, the learner is transferred to a mail application with the partner's mail address already inputted in the address bar. If the learning partner is Offline, the learner is provided with the partner's telephone number, which enables consultation by phone or SMS.

- If the learner chooses nearby people as his / her learning partners, once he / she knows their basic information, the learner can discuss with them face-to-face.

As stated above, the rules for selecting communication approaches between the learner and his / her learning partners can be summarized in Table 5.7.

Table 5.7 Rules for Selecting the Communication Approaches

Type of Learning Partner	System Status	Communication Approach
Experience-related colleagues	Online & Available	Online chat room
	Online & Unavailable	Email
	Offline	Phone and SMS
Nearby people	Any	Face-to-face

5.2.5 Adaptation of Learning Activities Generation

This adaptation strategy aims, according to learning context, to generate abundant and comprehensive learning activities to accompany professionals' entire learning process. The generated learning activities can be classified into three parts: just-in-time activity, review activity and progress activity. These learning activities not only provide the learner with a solution to overcome the work problem at hand, but also help the learner to enlarge his / her knowledge and skills within an adaptive and personalized learning cycle.

Below, we present the adaptations of these three learning activities respectively.

1) Adaptation of just-in-time activity

Adaptation of just-in-time activity adapts pedagogical units, learning partners, and learning summary. This adaptation contains the adaptations of learning units and learning partners, so that they seem to cross with each other. However, from our research perspective, the adaptations stated before this section focus on the specific aspect of the learning process, while adaptation of just-in-time activity focuses on the general process by organizing all necessary activities together to provide totally just-in-time learning supports.

Adaptations of learning units and learning partners have been described in detail above. Adaptation of learning summary summarizes the learner's just-in-time learning activity by identifying the objective of the learning, the time used for the learning, the learned units titles and also the non-learned ones.

2) Adaptation of review activity

Adaptation of review activity adapts learning review time to help the learner reinforce his / her learning. Once the learner has finished his / her just-in-time learning activity, the system proposes that he / she reserves a learning review time. According to his / her agenda recorded in the system, this adaptation finds and lists the future arranged activities and the occupied periods. According to these listed activities, the learner chooses the review time him / herself by avoiding those occupied periods. The reserved time, the learning objective and the just learned units are organized into a review activity, and are recorded in the learner's agenda.

3) Adaptation of progress activity

Adaptation of progress activity selects and provides the learning units which might interest the learner by helping him / her make progress by learning more. These learning units are different from the ones selected for forming pedagogical units. They do not have the necessary relationship with the learner's work problem. Two types of learning units are considered in this adaptation, including:

- **Learning units followed by the learner's learning partners**
  During the learning process, the learner chooses one or more users as his / her learning partners. These learning partners are recorded in the system. Adaptation of progress activity searches for these learning partners' learning histories which are stored in the Learning Activity History Database, and finds and lists the learning units which they have learned but not followed by the learner.

- **Learning units followed most by all**
  Adaptation of progress activity searches in the Learning Activity History Database, counts the number of repeats of each listed learning unit, and then lists the one with the largest number as the learning unit followed most by all.

As stated above, the adaptation strategy designed for generating adaptive learning activities can be summarized in Table 5.8.

Table 5.8 Adaptation Strategy of Learning Activities Generation

Learning Activities	**Adaptations**
Just-in-time Activity	To form adaptive pedagogical units. To recommend experience-related colleagues or the nearby person as learning partners, and to provide the proper communication approaches. To make a summary for this just-in-time activity.
Review Activity	To adapt learning review time, and to reserve review activity in the learner's agenda.
Progress Activity	To select the learning units for facilitating learner progress. The considered units include: those followed by his / her learning partners and those followed most by all.

5.3 Design of the Adaptation Engine

The adaptation engine, which implements the learning adaptation strategies, is the major system component for implementing the adaptive and personalized learning process.

The input of the adaptation engine is learning context. The output of the adaptation engine would be adapted learning units, learning partners and learning activities. Although adaptation of learning activities includes the two adaptations above, these two adaptations focus on two essential learning aspects respectively, which need to be extracted and explained separately. Combining learning context and adaptation strategies, the adaptation engine produces the learning adaptations. The adaptation engine can also receive feedback from the learner. Feedback concerns the learner's satisfaction with his / her learning process with the produced adaptations. According to this feedback, the engine consolidates its adaptations by modifying learning context and / or by modifying adaptation strategies. Focusing only on the adaptation process of WoBaLearn, the system overall architecture, which is shown in Figure 3.5, can be simplified as shown in Figure 5.1.

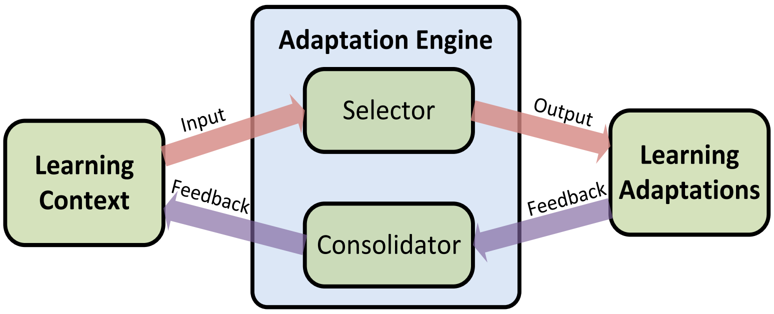


Figure 5.1 Simplified WoBaLearn Architecture Focusing on the Adaptation Process

The implemention approach of this adaptation engine is based on rules, which produce adaptations by the conditional structures of the IF / THEN / ELSE statement. Here, we list the IF-THEN-ELSE rule set in Table 5.9 which was produced to select the appropriate learning units.

As listed in this table, the first six rules are applied to count the matching keyword number of each learning unit considering current learning context, and then find and get the units with the maximum value. From seven to nine, the rules search the units which are in the preferred display format from the selected ones. If no units match, rules ten to twelve continue to search the units in Image which is the default display format in the system. Else, rule thirteen chooses the ones found by the first six rules.

Table 5.9 Rule Set for Selecting Learning Units

Rule1: Search in the system Learning Unit Database. If Learning Unit 1 (LU1) has metadata General->Keyword equals context Appliance Id, then set its Matching Number (MN1) to 1, else set MN1 to 0.
Rule2: If LU1 has metadata General->Keyword equals context Maintenance Action, then add 1 to MN1, else add 0.
Rule3: If LU1 has metadata General->Keyword equals context Action Object, then add 1 to MN1, else add 0. Now, MN1 represents the degree of content correlation between LU1 and the learner's current work.
Rule4: Repeat Rule1, Rule2 and Rule3 on all the learning units, LU2, LU3… LUn, get MN2, MN3 … MNn.
Rule5: Compare MN1, MN2, MN3 … MNn and find the maximum value MNmax.
Rule6: Get the learning units with MNmax.
Rule7: Search in the result of Rule6. If Learning Unit a (LUa) has metadata Technical->Format equals context Proposed Format, then LUa is recorded in the result set RS.
Rule8: Repeat Rule7 on all the items of Rule6's result.
Rule9: If RS has one or more items, then go to Rule14. Else go to Rule10.
Rule10: Search again in the result of Rule6. If Learning Unit a (LUa) has metadata Technical->Format equals "Image", then LUa is recorded in the result set RS.
Rule11: Repeat Rule10 on all the items of Rule6's result.
Rule12: If RS has one or more items, then go to Rule14. Else go to Rule13.
Rule13: Set the items of Rule6's result in RS.
Rule14: Return RS.

According to the designed learning adaptation strategies, in the adaptation engine, there are seven rule sets, including the rule sets of learning units selection, learning units sequence, learning units navigation, learning partners communication, summary, review and progress. The execution sequences of these rule sets in the adaptation engine are shown in Figure 5.2.

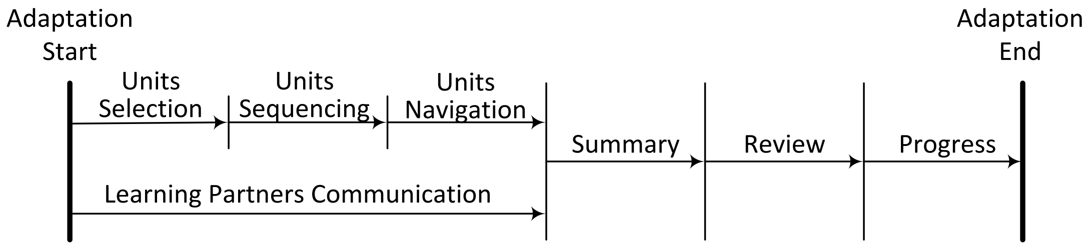


Figure 5.2 Execution Sequences of the Rule Sets in the Adaptation Engine

For each learning adaptation process, the engine executes first the rule set for learning units selection, followed by the rule set for units sequencing, and by the rule set for units navigation. At the same time, the engine executes the rule set for establishing learning partners' communication. All the rule sets above are applied for generating just-in-time learning activities. This phase ends with the rule set for summary. Then, the engine executes the rule set for generating review activity, and, finally, the rule set for generating progress activity.

This adaptation engine can base its decisions on a variety of input context combining the domains of person, device, activity, collaboration and environment. Also, it has the capacity to produce comprehensive outputs, including just-in-time activity, review activity and progress activity. What's more, its adaptation process is flexible and adjustable, which is embodied in the provision of an acceptable approximation when the engine cannot find a precise output due to constraints: for example, selection of learning resource display format.

5.4 Conclusion

In this chapter, we focused on presenting the in-depth design of WoBaLearn, including the adaptation strategies and the adaptation engine. Five learning adaptation strategies have been proposed. By adaptation of learning units selection, the learning units which relate to the learner's current work activity can be selected. By adaptation of learning units sequence, these selected units can be ordered by the priority of the leaner's personalized settings. By adaptation of learning units navigation, adaptive pedagogical units are made based on the highest priority learning unit and its relative learning units. By adaptation of learning partners communication, the people near to the learner and the colleagues who are experience-related are recommended to the learner as his / her learning partners. Also, different communication approaches can be selected according to the partners' locations and statuses on the system. Finally, by adaptation of learning activities generation, the adaptations above were organized into a just-in-time learning activity ending with an adaptive learning summary. Also, a review activity and a progress activity were carried out to help the learner reinforce his / her learning and progress by learning more. An adaptation engine which implements these five learning adaptation strategies was presented at the end of this chapter. The operational process of the engine, the design of IF-THEN-ELSE rules in the engine, and the execution sequence of these rules were described in detail.

In the next chapter, we present the system implementation approach based on the design stated in chapters 3, 4 and 5.

6 System Implementation of WoBaLearn

6.1 Introduction

Based on the design explained in chapters 3, 4 and 5, we implemented the WoBaLearn system with appropriate technologies. In this chapter, we present first the concrete technologies and development tools that we used to implement the WoBaLearn system. Then, we introduce the functionalities of WoBaLearn in detail with the support of user interfaces at runtime.

6.2 Techniques Used for Implementing WoBaLearn

WoBaLearn is implemented in the form of a website and published in a web server on a B/S (Browser and Server) structure. Learners access the system by their mobile devices via a wireless network. The system network structure is shown in Figure 6.1.

The system interfaces are achieved through a WWW browser. The system main business logic is implemented on the web server side. This structure greatly simplifies the system load, and also reduces the cost and effort of system maintenance and upgrading. This structure allows a one-time place, different people, from different locations, with different access methods (such as LAN, WAN, Internet / Intranet, etc.) to access and manipulate the common database.

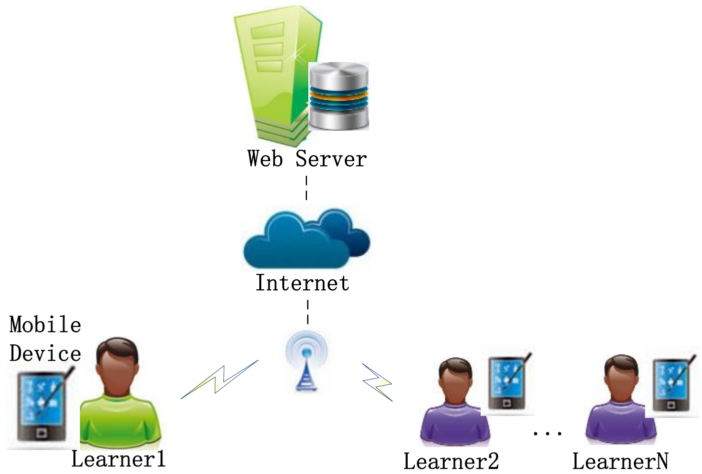


Figure 6.1 The Network Structure of WoBaLearn

The functionalities of WoBaLearn are implemented according to three layers: presentation layer, logic layer, and data layer, shown in Figure 6.2.

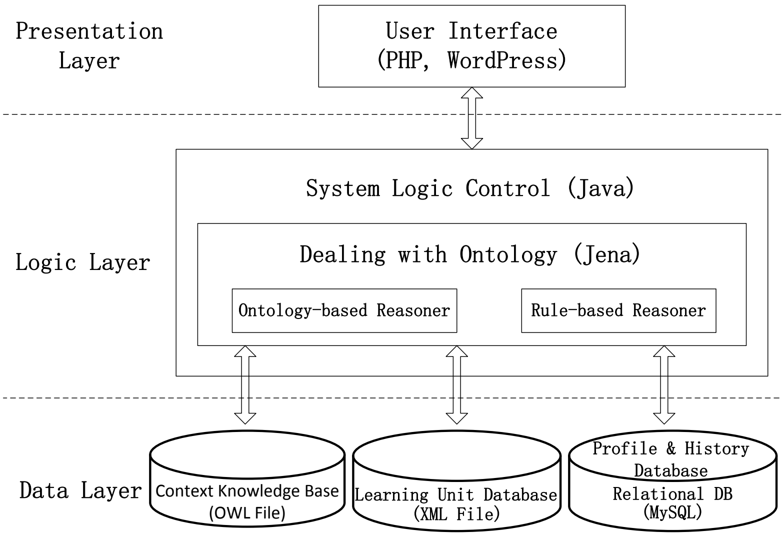


Figure 6.2 Technical Architecture of WoBaLearn

- **Presentation Layer**
  This layer provides learner-oriented services which are responsible for delivering learning supports to the learner and managing learner interaction with the system. Also, this layer is in charge of transmitting and formatting learner's operation information to the logic layer for further processing.

- **Logic Layer**
  This layer implements the core functionality of WoBaLearn, and encapsulates the relevant logic. It receives information from the presentation layer and accesses the data stored in the data layer. It executes the pre-defined logic to process the information and data, then generates appropriate learning supports and delivers them to the presentation layer.

- **Data Layer**
  This layer provides access to data that are hosted within the boundaries of the system. The data stored in the layer contain context information, learning units, learners' profiles and learning histories.

Each layer is based on different implementation issues to achieve its specific functionalities. The considered implementation issues include: PHP and WordPress in the presentation layer, Java and Jena in the logic layer, and OWL, XML and MySQL in the data layer.

- **PHP**
  PHP is a server-side scripting language designed initially for web development. PHP code can be simply mixed with HTML code, or it can be used in combination with various web frameworks. After the PHP code is interpreted and executed, the web server sends resulting output to its client in the form of part of the generated web page. In implementation of WoBaLearn, PHP is applied to create system interfaces for interacting with learners and displaying contents to learners, and is also used to achieve several system logics, such as registering, logging in, managing learner information, etc.

- **WordPress**
  WordPress is a free and open source blogging tool and a content management system based on PHP and MySQL, which runs on a web hosting service. It has abundant plugins and templates which make it easy and effective to create one's own website or blog (WordPress, 2013). Because WordPress has ready-existing functions like register, login, etc., in implementation of WoBaLearn, we used WordPress to construct the learner's personal space, which means redevelopment is not required. Also, we developed several functions required particularly in WoBaLearn as WordPress plugins by following the corresponding development rules. For example, we developed the learner agenda plugin,

which is used for creating and managing the learner's working and learning activities.

- **Java**
  Java is a computer programming language that is concurrent, class-based, object-oriented, and specifically designed to have as few implementation dependencies as possible. Thanks to the JVM (Java virtual machine), the code programmed with Java, after running on one platform, does not need to be recompiled to run on another. In implementation of WoBaLearn, Java is applied to implement system logic control, including manipulating data bases, adapting learning supports, managing learners' interfaces, etc.

- **Jena**
  Jena is an open source Semantic Web framework for Java. It provides a Java API to create, add, and search for ontology and its instances. What's more, Jena provides inference supports by ontology-based reasoner and rule-based reasoner. In implementation of WoBaLearn, Jena is applied for manipulating the learner's contextual information written in OWL (Web Ontology Language), as well as being used for inferring indirect context aspects and a part of learning supports by rule-based reasoner. The details of applying Jena were presented in Chapter 4.

- **OWL**
  Web Ontology Language (OWL) is a family of knowledge representation languages or ontology languages for authoring ontologies or knowledge bases. Languages are characterized by formal semantics and RDF/XML-based serializations for Semantic Web. In implementation of WoBaLearn, the WbML context model is expressed by ontology written in OWL-DL language, and is stored in an OWL file. According to the elements defined in the context model, the system collects the necessary learning context and stores it in a new OWL file with the file name as LearnerID_CurrentTime.owl.

- **XML**
  Extensible Markup Language (XML) is a markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable. In implementation of WoBaLearn, the metadata of learning units are written in XML, and are stored in XML files. Depending on the machine-readable format, the system can find

the required learning unit by searching for the values of relative metadata recorded in XML files.

- **MySQL**
  MySQL is an open-source relational database management system, widely used in web applications. In implementation of WoBaLearn, the learner's registration information, profile and learning histories are stored in MySQL.

The tools used for developing and running the WoBaLearn system are:

- **Eclipse**
  Eclipse is an integrated development environment (IDE). It can be used to develop applications in Java and PHP. Eclipse can make it easier for developers to manage, run and debug their programs.

- **JDK**
  The Java Development Kit (JDK) is a software development environment used for developing Java applications and applets. It includes the Java Runtime Environment (JRE), and interpreter/loader (java), a compiler (javac), an archiver (jar), a documentation generator (javadoc) and other tools needed in Java development.

- **Protégé**
  Protégé is a free, open source ontology editor and a knowledge acquisition system. Protégé enables developers to build ontologies for Semantic Web. In system implementation, Protégé is used to construct the WbML context model. The details of applying Protégé were presented in Chapter 4.

- **WampServer**
  WampServer is a Windows web development environment. It allows developers to create a web application with an Apache, PHP and MySQL database. The WoBaLearn system was implemented as a website, and runs on the WampServer.

6.3 Functionalities of WoBaLearn

The functionalities of WoBaLearn are implemented by the learning adaptation function module and other supporting function modules.

- **The learning adaptation function module**
  This module performs the main functions of the WoBaLearn system, which aims to adapt the learning units, learning partners, and learning activities according to just-in-time learning context. It is implemented by Java, and runs as an Applet.

- **Other supporting function modules**
  The supporting function modules include two types: modules for managing user information, such as modules for registering, logging in, and setting learner profile, and modules for supporting learning process, such as the agenda and communication modules. Implementations of these modules are based on WordPress by making use of the existing WordPress plugins and developing new ones for the specific functions.

These function modules are integrated together, and can be accessed from the webpage of WoBaLearn. In this section, we present each function module in detail with the support of the user interfaces at runtime.

6.3.1 Supporting Function Modules

The WoBaLearn system has five supporting function modules: the modules, Register, Login, and Learner Profile Setting, are applied to manage user's information, while the modules, Agenda and Communication, are applied to support user's learning process. The structure of the supporting function modules is shown in Figure 6.3.

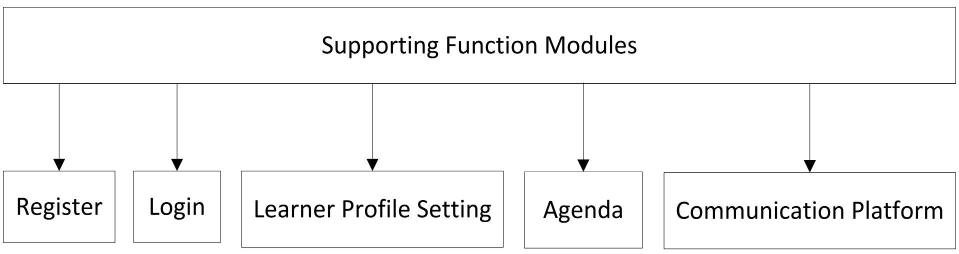
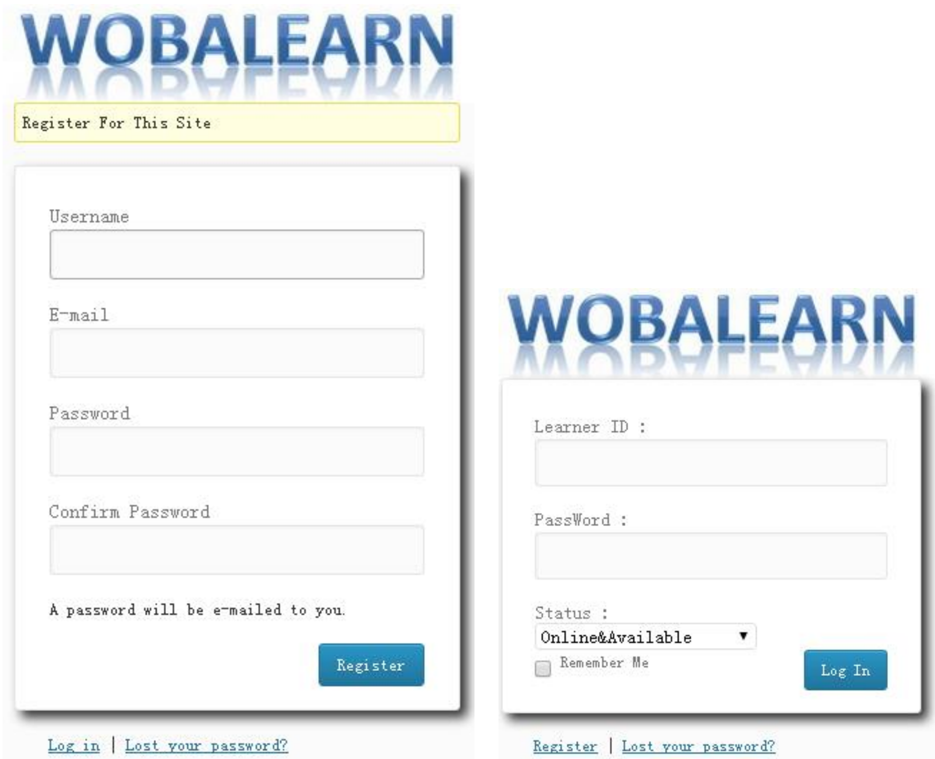


Figure 6.3 Structure of the Supporting Function Modules

To register as a WoBaLearn user, you must fill in the blanks on the register page as shown in Figure 6.4 (1). A confirmation message will then be sent to your register email with the Learner ID distributed by the system automatically. With the Learner ID and the preset password, you can log into the WoBaLearn system. The login page is shown in Figure 6.4 (2). In addition, on the login page, the user can choose his status to indicate his / her availability, which is an important condition for the system to propose the proper learning partners. The options of a learner's status include Online & Available, Online & Unavailable and Offline.



(1) (2)

Figure 6.4 Interfaces of the Register and Login Function Modules

The interface of the learner profile setting function module is shown in Figure 6.5. On this page, the learner can set and update different aspects of his / her learning profile, such as, learning preference, learning style, educational background, training experience, practical experience, etc. His / her learning profile is recorded in the system database, and is applied by the system as the values of the Learner context for selecting the personalized learning supports.

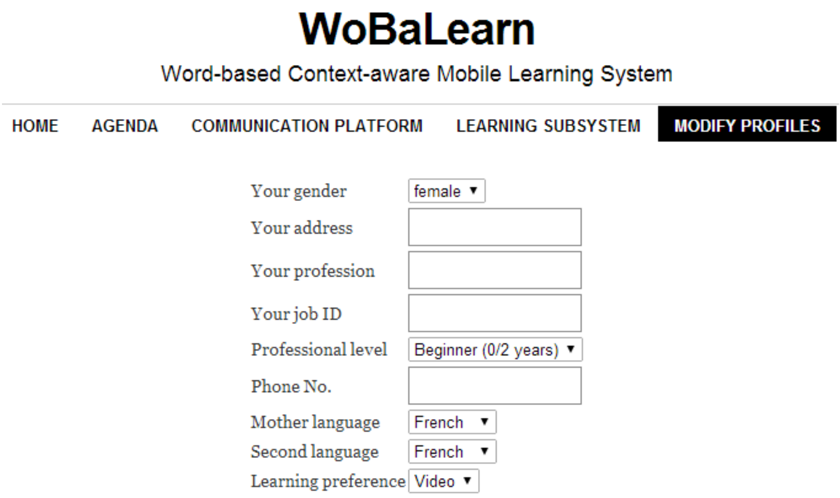


Figure 6.5 Interface of the Learner Profile Setting Function Module

The interface of the agenda function module is shown in Figure 6.6. On this page, the learner can arrange his / her activities by occupying a time period. Also, the learner can modify and delete his / her activities. With the support of the agenda function, the WoBaLearn system can identify the learner's available time and propose to review his / her reserved learning units at that time.

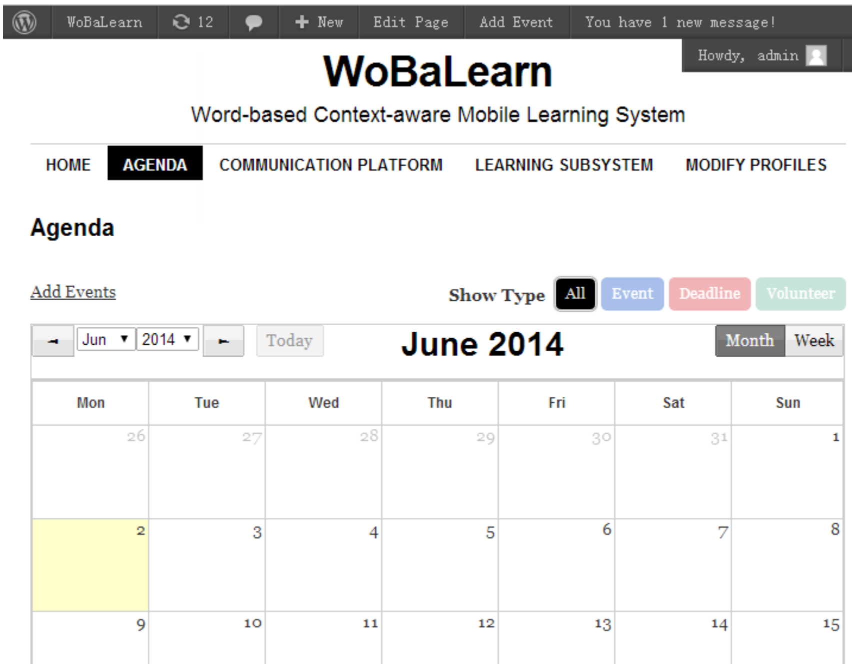


Figure 6.6 Interface of the Agenda Function Module

The interfaces of the communication function module are shown in Figure 6.7 and Figure 6.8.

Figure 6.7 Interface of the Email Function

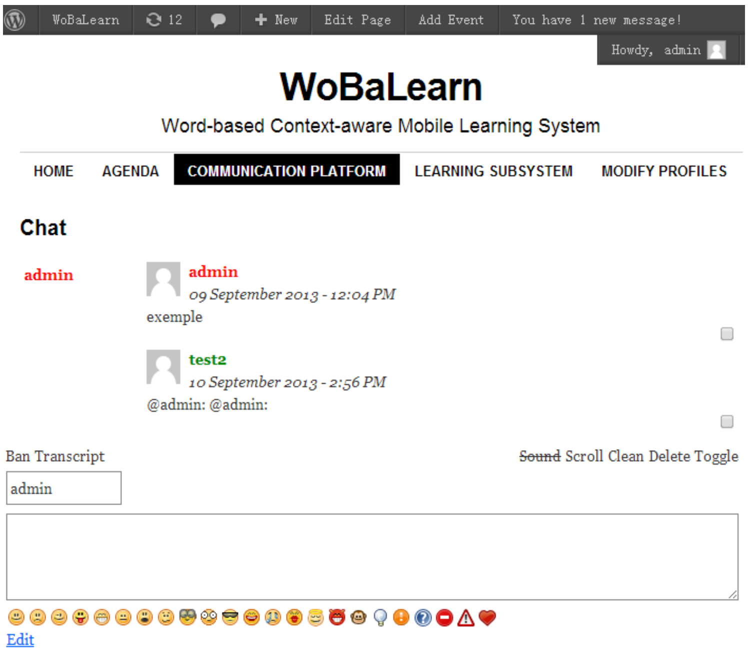


Figure 6.8 Interface of the On-line Chat Function

During a learning process, the learner can communicate with his / her learning partners according to different communication approaches depending on his / her learning partners' availabilities. The Email function enables the learner to contact his / her learning partners who are online but unavailable, or offline, as shown in Figure 6.7. The on-line chat function facilitates just-in-time communication between the learner and his / her online and available learning partners, as shown in Figure 6.8.

6.3.2 Learning Adaptation Function Module

The learning adaptation function module runs as a Java Applet, and can be accessed from the website as shown in Figure 6.9. The lower part of Figure 6.9 shows the learning history review page which is the entrance page of this module. The functions and operations of this entrance page will be described in detail in the following section.

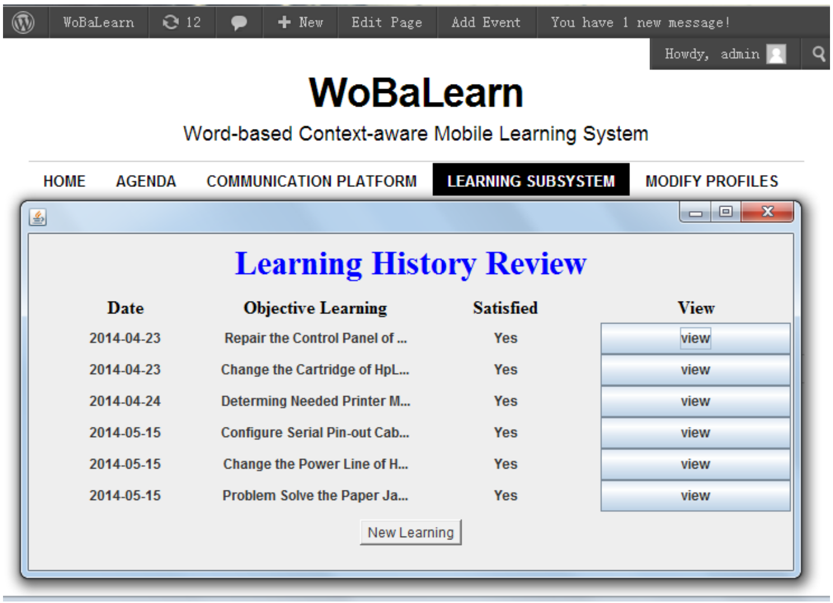


Figure 6.9 Interface of the Learning Adaptation Function Module

The learning adaptation function module performs the main functions of the WoBaLearn system. It chooses and offers the adaptive and personalized learning units, learning partners and learning activities according to the learner's current learning context. The flow chart of the learning adaptation function module is shown in Figure 6.10.

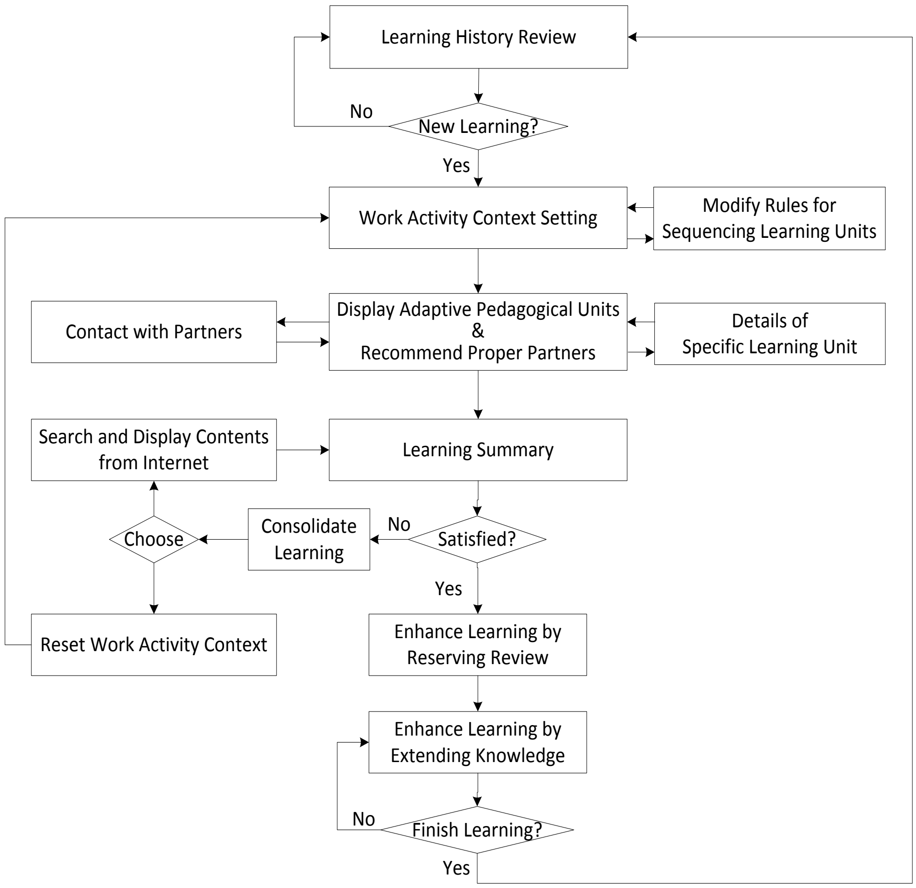


Figure 6.10 Flow Chart of the Learning Adaptation Function Module

By entering the learning adaptation function module, the learner can review his / her particular learning histories recorded in the system database. The module starts a new learning process when the learner sends his / her requirement. At the beginning of a new learning process, the learner sets the context values for his / her current work activity which will be used to select work-related learning units and experience-related learning partners. In addition, the learner can also set the parameters of units sequencing rules which can influence the display order of the selected learning units. After operation of the system adaptation engine, this module displays and recommends the context-adapted learning units and learning partners. The learning units are organized into pedagogical units, which include not only the necessary knowledge and skills, but also the learning objective, the expected learning time, and a learning outline of the proposed learning units, the prerequisite knowledge and the intensive knowledge, etc. At the same time as learning the pedagogical units, the learner can contact his / her learning partners by the system proposed communication approaches. When the learner completes units learning, the module displays a learning summary by illustrating the time taken, the learning units titles learned, and those not learned. Then, according to personal learning experience, the learner can evaluate his / her learning process. If the learner is not satisfied with the learning process, this module proposes that the learner consolidates the learning by resetting his / her work activity context and profile, or by searching for the learning contents him / herself from the Internet. If the learner is satisfied, this module proposes that the learner enhances his / her learning by reserving a review time and/or by extending it with some relative knowledge. When the learner decides to finish this learning process, this module records the necessary information in the system database and returns to the module entrance page. During the learning process, the learner can interrupt his / her learning, and his / her learning recording can be recorded in the system database. When the learner wishes to resume his / her learning, this module reloads his / her learning recording, and the learning continues.

Hereafter in this section, we describe each function of this module in detail with the support of the Applet interface at runtime.

1) Learning History Review

The interface of the learning history review is shown at the lower part of Figure 6.9. This function lists a particular learner's previous learning histories which were recorded in the system database. This function lists the items, including learning date, learning objective, and learner's learning evaluation. The learner can check to review each learning recording.

The learner can require a new learning process by clicking the button "New Learning". At this time, using the WbML context model, a new OWL file is created and named in the format "LearnerID_Date_Time.owl". This OWL file is applied for recording the learner's just-in-time learning context. Also, the learner's profile, which is inputted by the learner from the Profile Setting Function Module and stored in the system database, is entered in this OWL file as the Learner context values.

2) Work Activity Context Setting

The interface for setting the work activity context is shown in Figure 6.11.

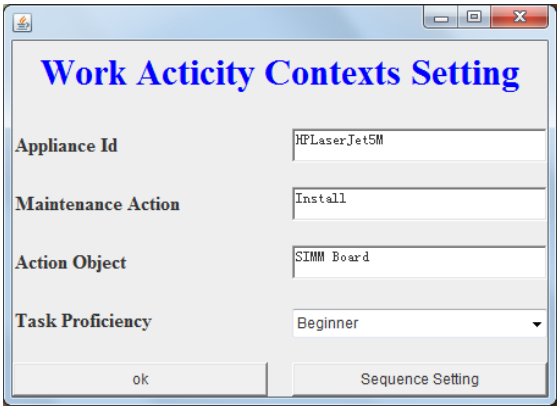


Figure 6.11 Interface for the setting work activity context

This function collects the context aspects about the learner's current work activity. Considering the specific work of "appliance maintenance", the considered context aspects include: appliance id, action, action object and learner's proficiency about this work. The first three aspects should be inputted by the learner him / herself, while the fourth aspect can be selected from a list with the values as beginner, experienced and expert. For example, a professional encounters a problem when he / she installs for the first time a SIMM board in a printer marked as HPLaserJet5M. He / she can set the work activity context as shown in Figure. 6.11.

By clicking the button "OK", the values of the work activity context, mobile device context, environment context, etc., are collected and entered in "LearnerID_Date_Time.owl". Also, according to context relationships defined in the WbML context model and the user-defined reasoning rules stated in chapter 4, the values of indirect context aspects are reasoned and entered in the OWL file. Then, the system adaptation engine is required for adapting learning units, learning partners and learning activities according to just-in-time learning context which is recorded in "LearnerID_Date_Time.owl".

3) Modify Learning Units Sequence Rules

The interface for modifying learning units sequence rules is shown in Figure 6.12.

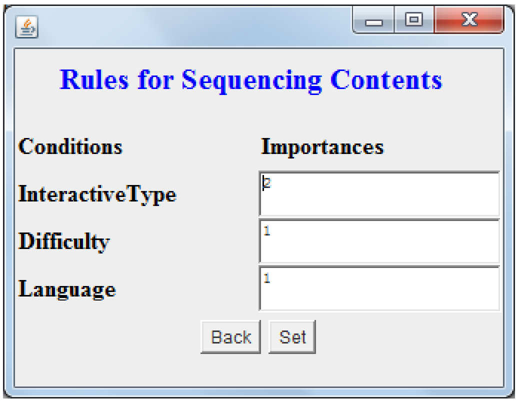


Figure 6.12 Interface for Modifying Learning Units Sequence Rules

This function provides the learner with the ability to modify the coefficient importance of sequence conditions for changing the display order of the selected learning units. Three conditions are considered in current research work, including the interactive type of learning unit, the difficulty of learning unit, and the language of learning unit. The scale of each sequence condition is 5, by which "5" stands for "very important" and "1" stands for "not important". The details of learning units sequence rules have been presented in detail in chapter 5.

4) Display Adaptive Pedagogical Units

The interface for displaying the adaptive pedagogical units function is shown in Figure 6.13.

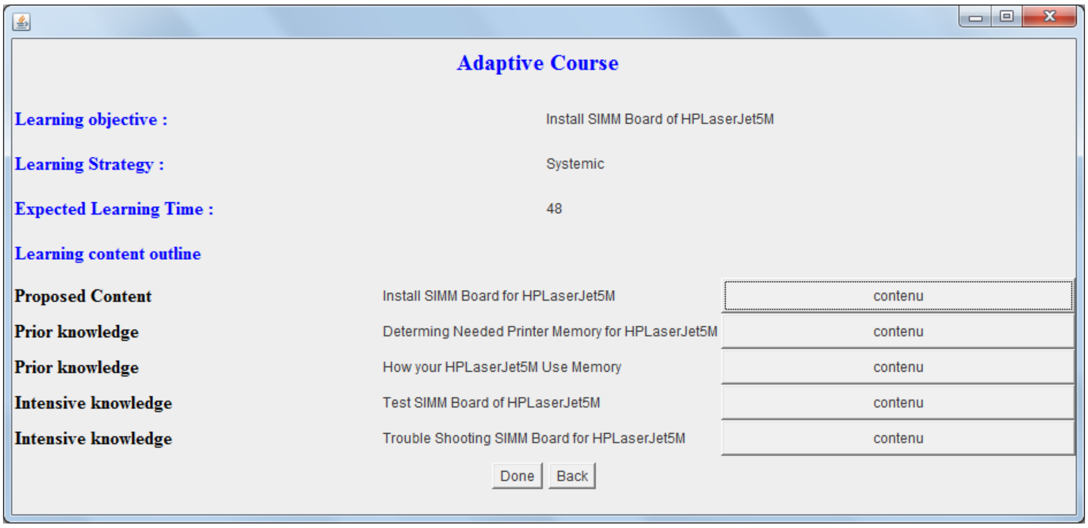


Figure 6.13 Interface for Displaying Adaptive Pedagogical Units

This function displays adaptive pedagogical units to the learner by identifying the learning objective, the learning strategy proposed by the system, the expected learning time and the outline of pedagogical units.

- **The learning objective**
  The learning objective is obtained from the learner's settings for his work activity context as shown in Figure 6.11.

- **The learning strategy**
  The learning strategy could be fast, systematic, intensive or extended. It is determined by the learner's task proficiency and availability. The approach detail to determine learning strategy has been described in chapter 5.

- **The outline of pedagogical units**
  According to different learning strategies, the selected learning unit is organized with corresponding learning units and made into pedagogical units. For example, a "systematic" learning strategy organizes the selected learning unit with its prerequisite knowledge and intensive knowledge. If the selected learning unit is "SIMM Board Installation", and has relationships with other learning units as shown in Figure 6.14, then the outline of pedagogical units can be created as shown in Figure 6.13. The detail for creating pedagogical units has been described in chapter 5.

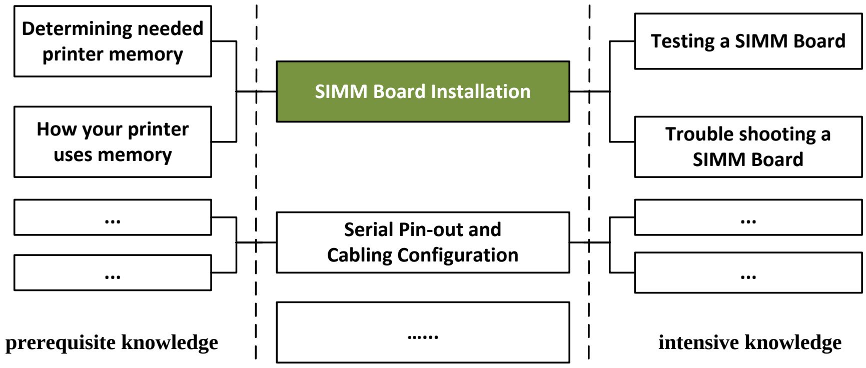


Figure 6.14 Relationships between "SIMM Board Installation" and Other Learning Units

- **Expected learning time**
  This time is obtained by summing the expected learning time of each unit listed in the outline.

For each item listed in the outline, the learner can click the "view" button next to the item title to check the detail of each learning unit. The display format of the learning unit is adapted by the system adaptation engine and recorded in "LearnerID_Date_Time.owl" as the value of the "proposed_format" context. The display format is adapted depending on the context aspects such as: learner's preference, mobile device capacities, illumination level of environment, etc. The reasoning rules of the display format have been described in chapter 4. According to different formats, different interfaces are required to display checked units. The interfaces for displaying the learning unit "Install SIMM Board of HPLaserJet5M" are shown in Figure 6.15 and Figure 6.16. Figure 6.15 displays the learning unit on video format, while Figure 6.16 displays the learning unit on image format.

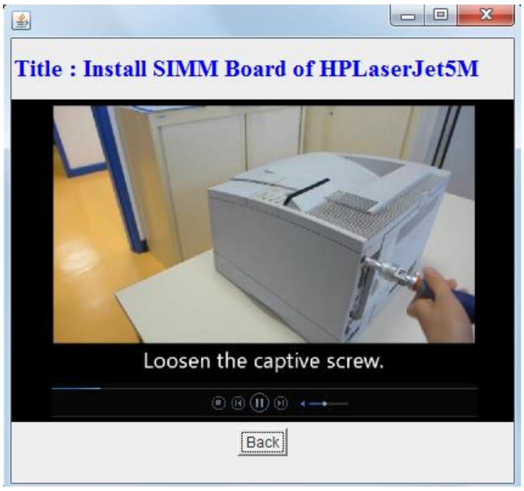


Figure 6.15 Interface for Displaying "Install SIMM Board of HPLaserJet5M" on Format Video

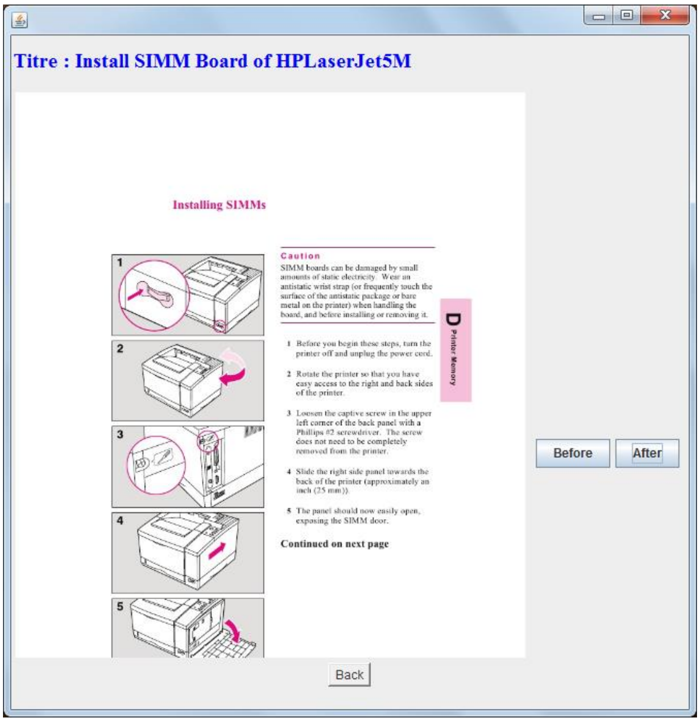


Figure 6.16 Interface for Displaying "Install SIMM Board of HPLaserJet5M" on Format Image

5) Contact with Learning Partners

The interface for contacting learning partners is shown in Figure 6.17.

Figure 6.17 Interface for Contacting Learning Partners

This function lists the users who carried out the same work as the learner's current work activity. In this example, as shown in Figure 6.17, the listed users are the ones who carried out the work for installing the SIMM board in HPLaserJet5M. These users are taken as the learner's potential learning partners. The users' relative information is listed on this interface, including names, system statuses, jobs, training experiences and practical experiences. The learner is provided with this information as selection conditions to choose his / her learning partners. According to the status of the chosen learning partner, a different communication approach is applied. If the learning partner is online but unavailable, the learner can be led to send an e-mail to him / her as shown in Figure 6.7. If the learning partner is online and available, the learner can be led to chat on line with him / her as shown in Figure 6.8. And if the learning partner is offline, the learner can be given the learning partner's phone number which enables a SMS or phone communication, as shown in Figure 6.18.

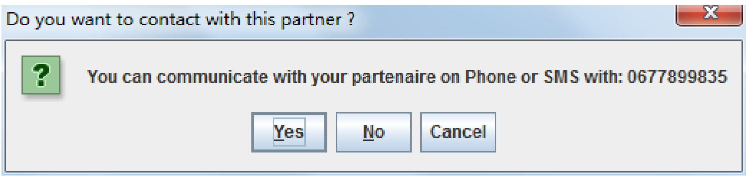


Figure. 6.18 The Interface for Providing the Learning Partner's Phone Number

6) Learning Summary

The interface for displaying the learning summary is shown in Figure 6.19.

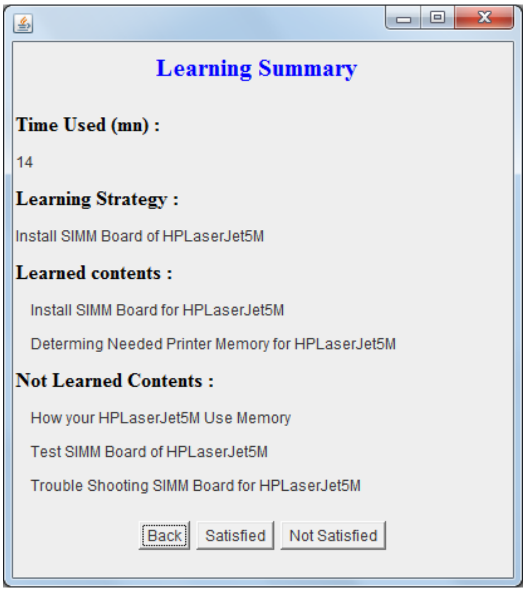


Figure 6.19 Interface for Displaying the Learning Summary

When the learner completes his / her learning, the learning summary function summarizes this learning by identifying the time used for learning, the learning objective, the learned learning units' titles and the not learned ones. Then, the learner can evaluate his / her learning process by clicking the button "Satisfied" or "Not Satisfied". If the learner is not satisfied, he / she can be led to consolidate his / her learning by resetting the learning context and / or by modifying the learning units sequence rules. Also, the learner is offered the opportunity to find appropriate learning contents him / herself by searching on the Internet. If the learner is satisfied, he / she is led to enhance learning by reserving a learning review time and / or by extending learning with relative knowledge.

7) Search for and Display Learning Contents on Internet

The interface for searching for and displaying learning contents on Internet is shown in Figure 6.20.

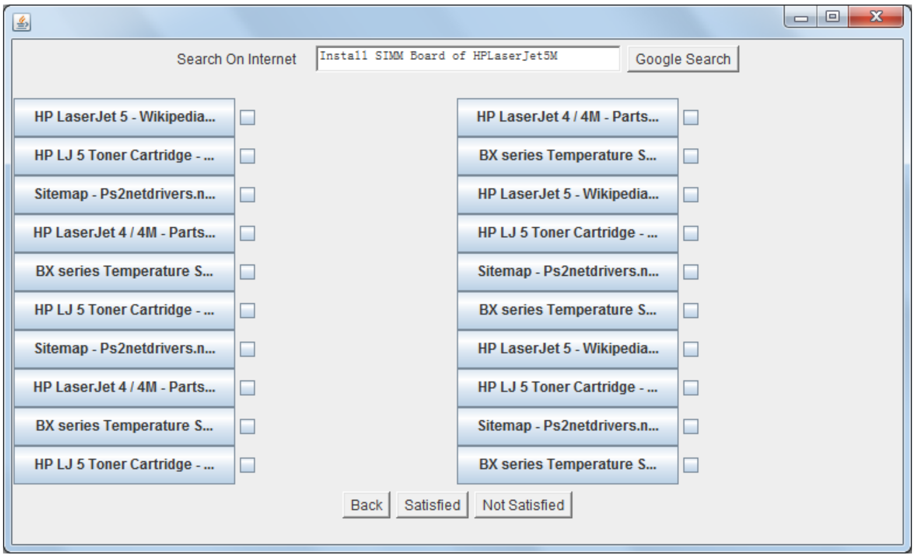


Figure 6.20 Interface for Finding Learning Contents on Internet

With the use of the Google search engine, this function searches for contents on Internet with the keywords in the search box. These keywords are derived from the learning objective, and are inputted automatically by the system. The contents found are listed in this interface. The learner can check each content by clicking the correspondent button. Then, the learner can evaluate the contents which are beneficial for his / her learning by ticking the corresponding check boxes and clicking the button "Satisfied". These beneficial contents will be formed into a learning unit by labeling with AM-LOM metadata automatically by the system, and will be added to the learning unit database. This learning unit will be recommended with a higher priority to the learners who learn in the same learning context.

8) Enhance Learning by Reserving a Review Time

The interface for enhancing learning by reserving a review time is shown in Figure 6.21.

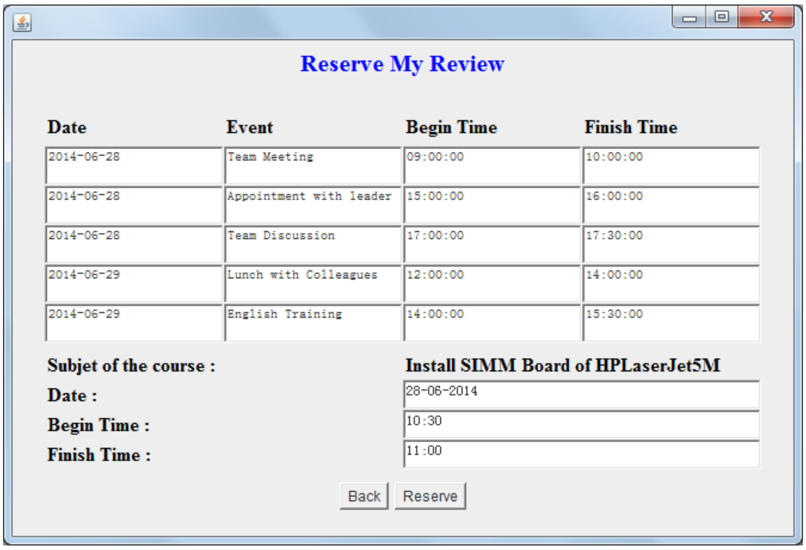


Figure 6.21 Interface for Enhancing Learning by Reserving a Review Time

This function assists the learner in enhancing his / her learning by reserving a review time. It checks the learner's agenda, and finds and lists the future arranged activities and the occupied periods. According to these listed activities, the learner reserves his / her review time by avoiding these occupied periods. Then, this review activity is recorded in the learner's agenda.

9) Enhance Learning by Extending Knowledge

The interface for enhancing learning by extending knowledge is shown in Figure 6.22.

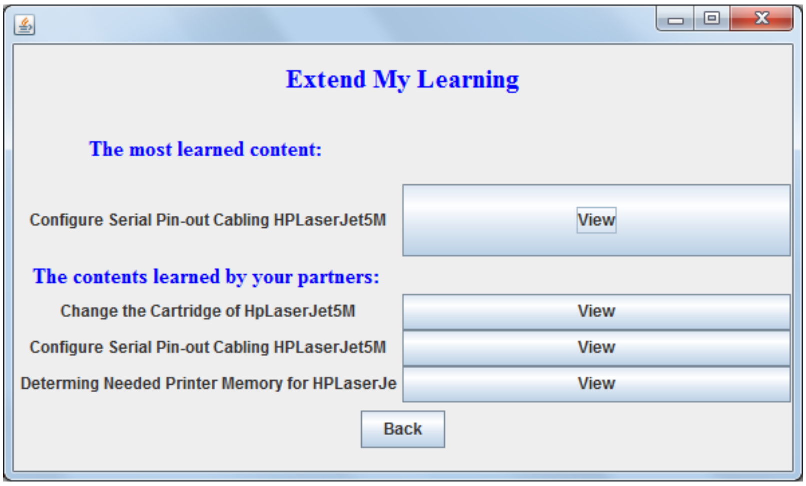


Figure 6.22 Interface for Enhancing Learning by Extending Knowledge

This function helps the learner enhance his / her learning by extending his / her knowledge with related learning contents. Two types of related learning units can be recommended and listed, including: the learning units learned by the learner's learning partners, and those learned most by all.

This learning adaptation function module provides the learner with a learning cycle with pedagogical units, the summary, the extension and the review. What's more, when the learner decides to finish his / her learning process, this function module records all learning data in the "LearnerID_Date_Time.owl" file, including information like the learning units selected for achieving the learning objective, the learner's evaluation for these selected units, the learning partners contacted by the learner, the time used for learning, the time reserved for reviewing, the relative units learned for the extension, etc. Finally, this function module records the "LearnerID_Date_Time.owl" file and the learner's evaluation concerning this learning process in the system database. This recorded information can be used by this learner for reviewing his / her learning histories and also by the other learners for searching for experience-related learning partners.

During execution of this function module, generation of the learning context file "LearnerID_Date_Time.owl" is an essential task. This file records all the information related to the learning process, including the learner's profile, the descriptions of work activity, the mobile device capacities, the environmental conditions, the learning partner's status, and the details of his / her total learning activities.

The generation process of this file has been introduced in a disorganized manner along with the descriptions of each function. For a clearer presentation, we extract the file generation process as shown in Figure 6.23, and focus on describing it as follows:

- The file is created when the learner's learning need arises. The file is formed with the WbML context model as a template.

- The newly created file is entered with the learner's profile which is stored in the system database as Learner context values. This file is named in the format as "LearnerID_Date_Time.owl".

- During the learning process, the real-time context values, including mobile device, work activity and environment, are collected and recorded in the "LearnerID_Date_Time.owl" file.

- With all these recorded context aspects and the user-defined reasoning rules file, the system adaptation engine can infer the values of indirect context aspects and store them in the file.

- According to all these context aspects, including learner profile context, real-time context and inferred context, the system adaptation engine adapts the learning units, learning partners and learning activities, then, offers them to the learner.

- The information concerning the learner's just-in-time learning, review and extension is recorded in the file.

- At the end of the learning process, the "LearnerID_Date_Time.owl" file is stored in the Learning History Table of the system database.

- During the learning process, if learning context and / or performed learning activities have been changed, the file can be modified with the updated information.

- During the learning process, if the learner wants to interrupt his / her learning, the file is stored in the system database temporarily and can be reopened when the learner resumes this learning process.

- During the learning process, if the learner wants to stop his / her learning, this learning process will not be recorded in the system database, and this "LearnerID_Date_Time.owl" file will be destroyed.

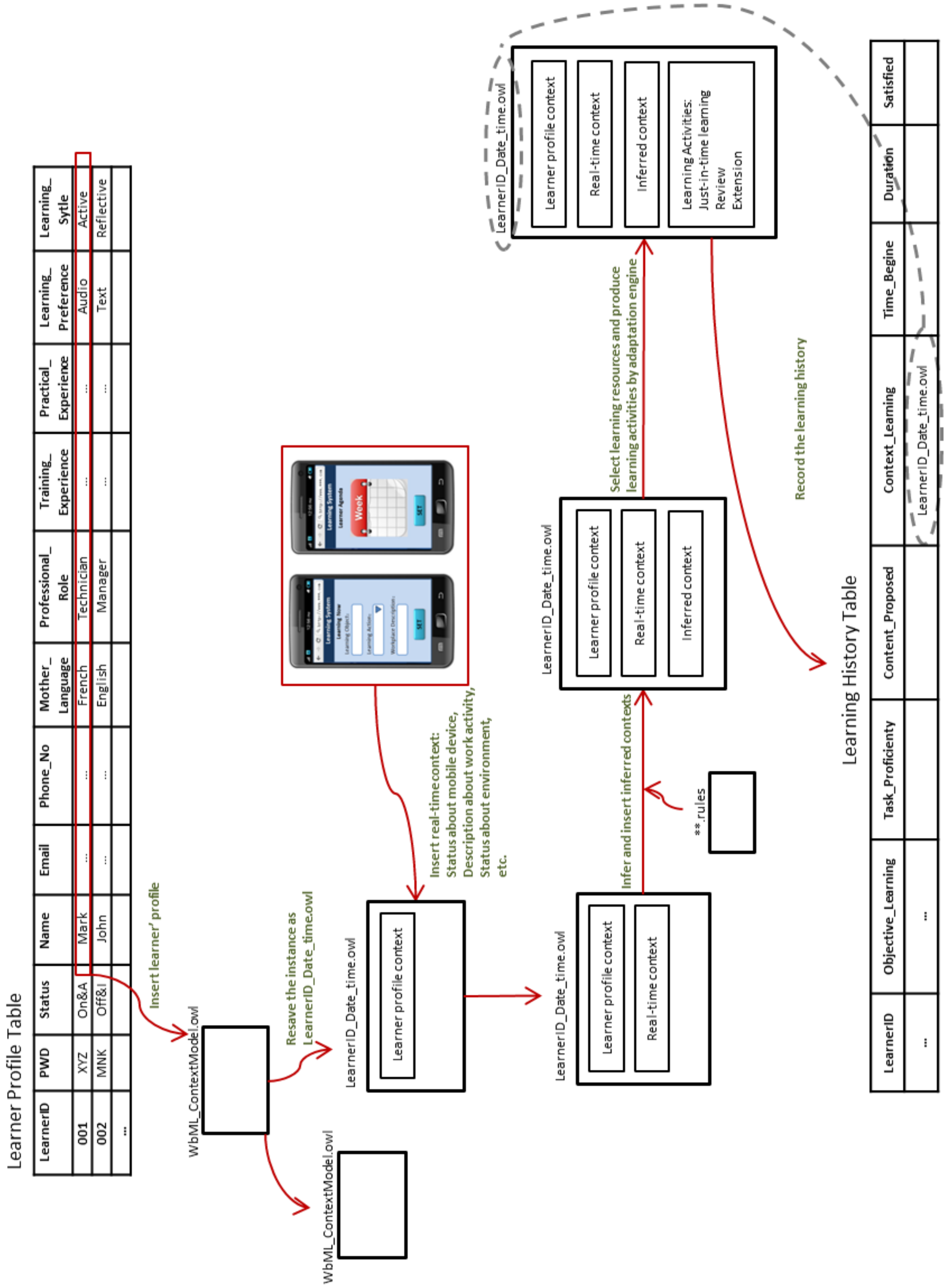


Figure 6.23 Generation Process of the Learning Context File

6.4 Conclusion

In this chapter, we described system implementation in detail, including a description of the system network structure, an introduction to the techniques and development tools used for developing the system, and a presentation of the system functionalities. We detailed user operations in each function, corresponding feedbacks, and run-time interfaces, which help better understand the system.

To evaluate the implemented system, a user study, which required professionals to perform a work-based task with the support of the WoBaLearn system, was proposed and carried out. In the next chapter, we describe this user study in detail.

7 Case Study and Evaluation

7.1 Introduction

In our research, after designing and implementing, we conducted a user study of the WoBaLearn system. With the evaluation of this case study, we aimed to explore and analyze three main aspects of the WoBaLearn system, including: users' learning achievement with the system, users' attitudes and acceptance of the system, and users' cognitive load imposed by the system.

To achieve the evaluation target above, in this case study, we designed a work-based learning scenario, and implemented a prototype of WoBaLearn which aims at providing professionals with learning supports to solve the work problems designed in this scenario. Considering the limitation of the experimental environment and the complexity of carrying out the experiment, in the case study, this designed work-based learning scenario can be characterized by few variables. Correspondingly, the system prototype is implemented by taking into account part of the context aspects defined in the WbML context model, as well as by executing part of the designed learning adaptation strategies.

In this chapter, we first introduce the case study by presenting the work-based learning scenario and the system prototype for supporting professionals in learning and working in the scenario. Then we describe the evaluation experiment in detail, including the participants involved, the instruments used, the procedure carried out, and the results obtained.

7.2 Case Study

Our case study assumes a specific work-based learning scenario. The scenario describes that a maintenance engineer needs to learn new knowledge and / or new skills to complete a task to reconfigure the IP address of a printer according to the new intranet setting of his / her company. For avoiding the task too simple to achieve, and to ensure that a learning process takes place, in the scenario, a control panel empty problem, caused by panel cable disconnection, is set. To complete the assigned task, the maintenance engineer first needs to locate the problems precisely, find the solution to repair the control panel empty problem, and then finish reconfiguration of the printer IP address.

In this scenario, the maintenance engineer's learning and doing can be supported by the prototype of the WoBaLearn system. The experimental environment is shown in Figure 7.1. The system is published on the web server. The maintenance engineer can access the system with his / her mobile device via a wireless network.

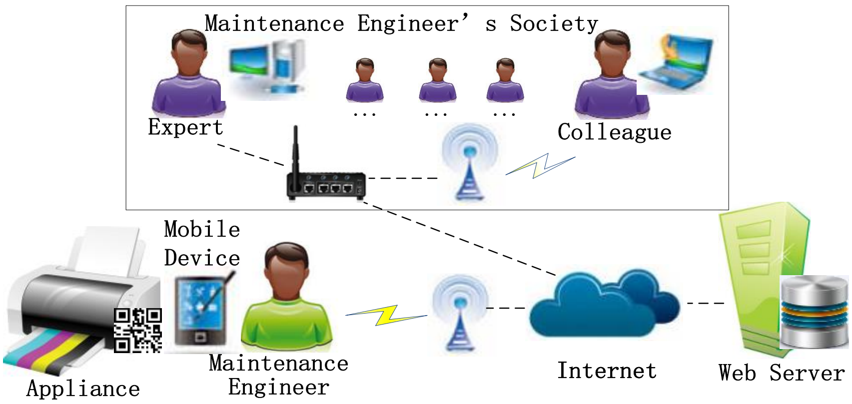
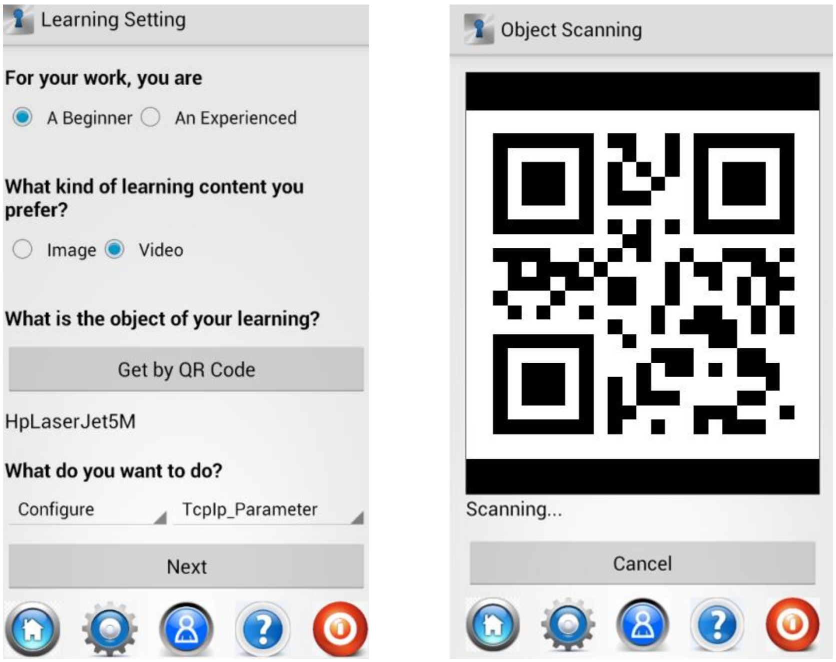


Figure 7.1 A Work-based Learning Scenario Supported by WoBaLearn

During the maintenance engineer's work-based learning process, the system first collects the direct learning context aspects inputted from the system interfaces or sensed by the mobile device's sensors, and infers the necessary indirect context aspects based on these direct aspects and the defined reasoning rules. Then, the system adaptation engine starts to execute, and generates automatically and displays the adaptive learning supports. Considering the objective of this evaluation and the complexity of the experiment process, in this system prototype, the provided learning supports are limited to the task-related and personalized pedagogical units. Finally, according to the maintenance engineer's feedback, the system readapts and reoffers the consolidated learning supports, or records and finishes the learning process.

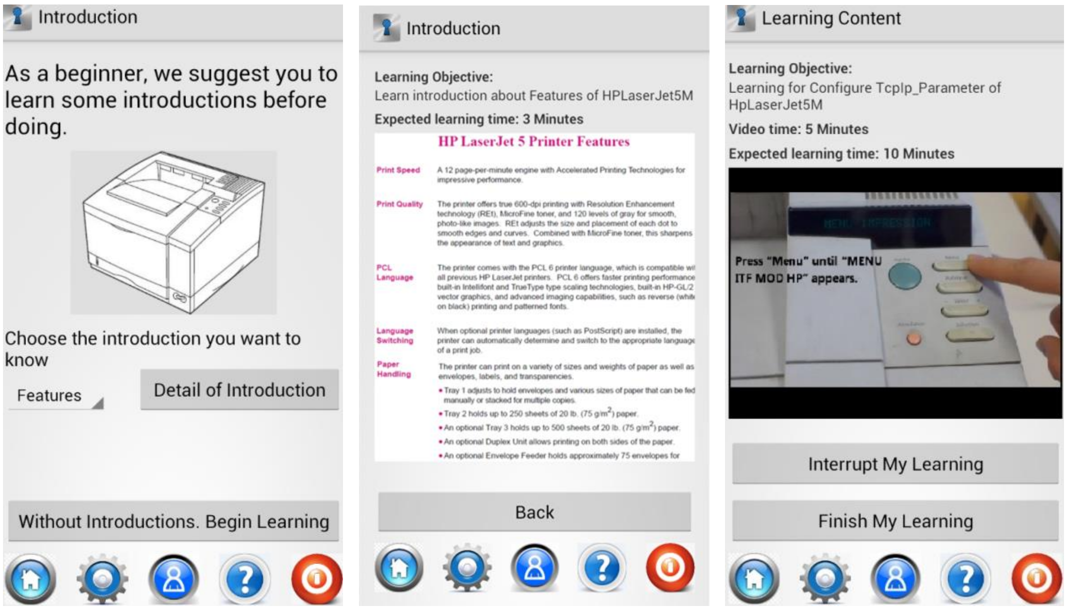
In this system prototype, the interface for collecting the learning context is shown in Figure 7.2 (a). Five context aspects can be indicated on this interface, including: Task Proficiency, with the value options Beginner and Experience; Learning Preference, with the value options Image and Video; Appliance Id, obtained by scanning the QR Code stuck on the printer; Maintenance Action, with the value options in a list, such as Install, Configure, Repair, etc.; Action Object, with the value options in a list, such as Software, Cartridges, SIMM Board, etc. The interface for scanning the Appliance Id from the QR Code is shown in Figure 7.2 (b).



(a) (b)

Figure 7.2 Interfaces for Collecting the Learning Context in the Prototype

According to the learning context setting, the adaptation engine of the system prototype selects appropriate learning units and organizes them into adaptive pedagogical units. For example, if the learning context values are set like Figure 7.2 (a), then the generated adaptive pedagogical units are displayed as shown in Figure 7.3.



(a) (b) (c)

Figure 7.3 Interfaces of the Adaptive Pedagogical Units in the Prototype

In this example, as the maintenance engineer considers that he / she is a beginner for the current work, the system suggests he / she learns some prior knowledge before beginning the assigned task, as shown in Figure 7.3 (a). By choosing the introduction options in the list, the maintenance engineer could get to know the features, the accessories options, the structure parts, etc., about the printer. The detail of the printer features is shown in Figure 7.3 (b). Once he / she has finished learning about prior knowledge, the maintenance engineer begins to follow the task-related learning units. As he / she indicates in the context setting that he / she prefers to learn with video material concerning configuring the TCP / IP parameter of the HPLaserJet5M printer, the selected learning unit is shown in Figure 7.3 (c) by displaying the learning objective, the video time, the expected learning time and the specific content on video.

7.3 Evaluation and Results

In this section, we present the experiment which evaluated the professionals' learning attitudes in the case study described above. We present this experiment based on four aspects: the participants involved, the instruments used, the procedures carried out, and the results obtained.

7.3.1 Participants

The participants in this experiment include the PhD students and the post-graduates from different departments of the Ecole Centrale de Lyon, INSA Lyon, and Lyon 1, in France. A total of 17 students voluntarily participated in this experiment. According to their major backgrounds and their practical experience about using and maintaining a printer, these participants can be taken as the maintenance engineers with a professional level as a Beginner or Experienced.

(a) (b) (c)

Figure 7.4 Snapshots of a Participant's Operations in the Experiment

To analyze the participants' learning processes in this case study, with their consent, a video for recording learning behavior during the experiment is shot for each participant. As shown in Figure 7.4, a participant carries out the experiment. Figure 7.4 (a) shows that she is learning the prior knowledge about the printer with the system. Figure 7.4 (b) shows that she is repairing the control panel empty problem after learning the instructions. Figure 7.4 (c) shows that she is configuring the TCP / IP parameter of the printer by following the pedagogical units proposed by the system.

7.3.2 Instruments

Three approaches are normally applied for evaluating a learning system, including, pre-test and post-test, log, and questionnaire (Wu, P. H. et al., 2012; Motiwalla, L. F., 2007; Georgieva, E. S. et al., 2011). Unlike course learning, the performance of work-based learning cannot be assessed only by the score differences of the pre-test and the post-test. In our research, we used a log tool to record users' learning behaviors to analyze their learning achievement. Also, we used four questionnaires to explore, respectively, the aspects relating to users' learning attitude, cognitive load imposed by learning system, acceptance of learning system and learning influence.

These questionnaires contain 3, 6, 9 and 4 questions respectively, and were presented using a five-point Likert scale, in which "5" stood for "strongly agree" and "1" stood for "strongly disagree". The questions proposed in these questionnaires referred to the relative existing work (Wu, P. H. et al., 2012; Gómez et al., 2013; Angeli, C. et al., 2002). They are listed as follows.

The learning attitude questionnaire consists of three questions, namely:

1) I am comfortable with this learning approach.
2) I think this learning approach is effective.
3) I prefer to learn using this approach in the future.

The questionnaire concerning cognitive load imposed by the learning system consists of six questions, namely:

1) I feel comfortable with my abilities to grasp how to use the system.
2) I feel comfortable learning with the new system.
3) I found that the learning procedure offered by the system is easy.
4) Use of the system in the scenario interests me.
5) I think the system will be valuable in my future work.
6) I believe the system will influence my work-based learning process in the future.

The learning system acceptance questionnaire includes three scales; that is, three items about "the ease of use of learning system", two items about "the attitude of the context-aware adaptation approach", and four items about "the usefulness of the learning system". They are:

1) It is easy to operate the interfaces of the learning system.
2) The response speed of the learning system is well-matched with learning progress on the site.
3) I think that device operation of the learning system is easy.
4) The adapted learning contents help me complete learning activities according to my contextual information.

5) Combining the mobile learning system and the real-world context is helpful to learning.
6) The progress provided by the learning system can benefit my learning achievement.
7) The guidance of the learning system is quite clear and effectively assists me in understanding the learning content and steps.
8) According to my experience, I would use this system if relevant to my work-based learning needs.
9) I would recommend the system to others.

The learning influence questionnaire consists of four questions. They are:

1) I could recall my learning and doing experience easily.
2) I could redo the task easily.
3) I find this system can facilitate my learning process.
4) I expect to learn from this approach in my future learning.

For the cognitive load questionnaire and the acceptance questionnaire, which have more than 5 questions, their Cronbach's alpha values were 0.795 and 0.897, respectively. These values provided us with evidence about the reliability of these two questionnaires, since according to (Nunnally et al., 1967) 0.7 is an acceptable minimum reliability coefficient. The analyzed statistics data of the question results include mean and standard deviation.

7.3.3 Experiment Procedure

We designed the procedure of the experiment. Its flow chart is shown in Figure 7.5.

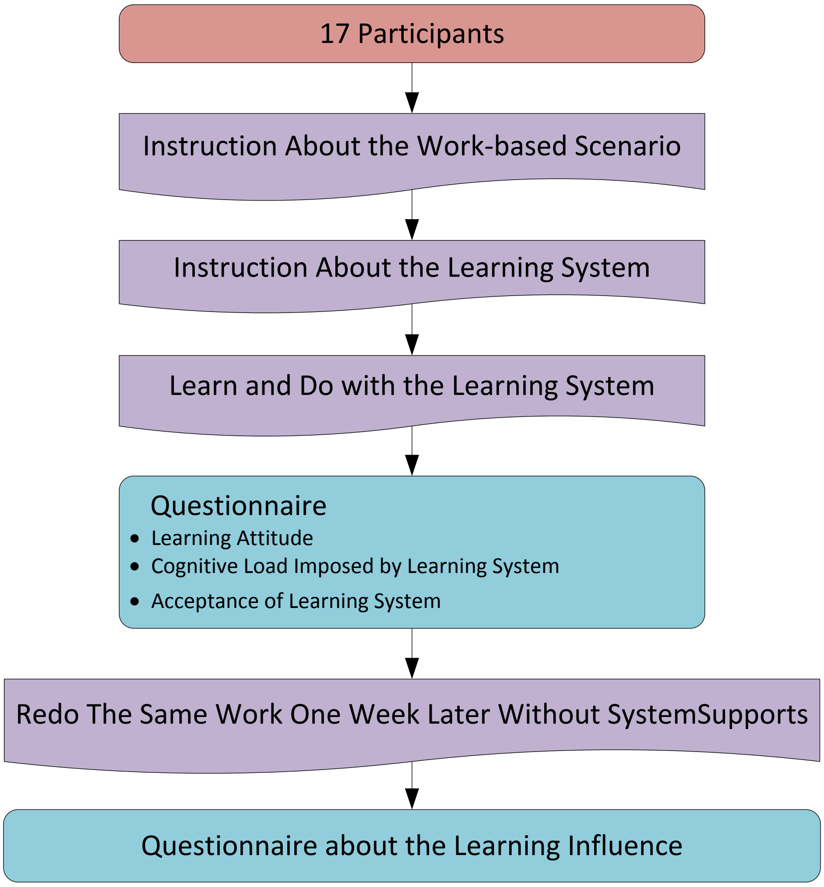


Figure 7.5 Flow Chart of the Experiment Procedure

At the start of the experiment, the 17 participants received a 5-minute instruction concerning the mission in the designed work-based learning scenario. Then, these participants received another 10-minute instruction concerning the operations of the learning system. Afterward, the participants carried out the mission with the support of the learning system. The system collected the related learning context and recommended the appropriate learning supports to them. During their learning and doing processes, these participants' learning performances were recorded on video. After finishing the assigned task, the participants received and filled out the questionnaires containing the questionnaires for learning attitude, cognitive load imposed by the learning system, and acceptance of the learning system.

One week after the work-based learning, the participants were asked to carry out the same mission again but, this time, without the learning supports. Similarly, their learning performances were recorded on video. Then, a questionnaire about learning influence had to be filled out after their mission.

7.3.4 Results and Discussion

In this section, the experimental results are discussed in terms of the dimensions of just-in-time learning achievement, learning attitude, cognitive load imposed by the learning system, acceptance of the work-based context-aware mobile learning system, and long-term learning achievement.

1) Analysis of Just-In-Time Learning Achievement

To evaluate just-in-time learning achievement, we recorded and analyzed these 17 participants' work-based learning performances. 14 participants completed the mission successfully with 26-minute operating time on average, while the other three participants failed the mission. The mission completion rate is 82%. Based on the performance recordings, we identify the reasons for failure as follows:

- Reason 1: One participant out of three is unfamiliar with operating the touch-screen mobile device. During the experiment, she always typed on the screen by mistake and was led to the interfaces she did not want to go to, which interrupted and disturbed her learning. Several minutes later, she decided to give up the experiment. In the interview after the experiment, she said that she rarely used the touch-screen mobile device. Also, she said she preferred to learn new knowledge with paper materials.

- Reason 2: Another participant operated the learning system correctly and got the exact contents for solving the problem set in the scenario. But he failed when he configured the TCP / IP parameter by following content on image. The image content indicates configuring the parameters by pressing the button bar on the control panel, which means pressing the right part of the button bar by considering the operator is right-handed. However, this participant is a left-handed operator. In the experiment, he pressed the left part of the button bar with his left hand, which meant that his settings returned to the original values. Several minutes later, he decided to give up the experiment.

- Reason 3: The third participant is the only one who cannot read the contents in English. We made a French version of the system prototype for this participant, and also we translated the learning contents from English to French. However, these translated learning contents caused confusion, thus forcing this participant to interrupt the experiment.

Apart from the individual differences and the statements of contents, none of the reasons above point to the design defect of the system and the irrationality of the work-based context-aware mobile learning approach. So, we can say that the result of the analysis of just-in-time learning achievement shows positively that such a learning approach and learning system could contribute to professionals' work-based learning achievement.

For the rest of the analyses, we focus on analyzing the results from the 14 participants who have completed the mission in the experiment.

2) Analysis of Learning Attitude

The learning attitude questionnaire analyzes participants' attitudes about obtaining new work-based knowledge and skills with the context-aware mobile learning approach. The result is illustrated in Table 7.1.

Table 7.1 Analysis of Learning Attitude

Questionnaire Item	Mean	S.D.
1. I am comfortable with this learning approach.	4	0.78
2. I think this learning approach is effective.	4.3	0.61
3. I prefer to use this approach in my future learning.	4.2	0.80

As illustrated in Table 7.1, the means of all these three items exceed 4, which shows that these participants can accept the learning approach with a context-aware mobile learning system, and agree that this approach could facilitate their learning in the actual work-based learning situation. Meanwhile, based on the standard deviations of these three items (which are less than 1), we observe that the participants' answers to these questions do not differ greatly, which proves that all participants have a positive learning attitude.

3) Analysis of Cognitive Load Imposed by the Learning System

The cognitive load imposed by the learning system questionnaire aims to identify the participants' cognitive load by using the context-aware mobile learning system in their work-based learning. Cognitive load is the amount of mental energy imposed on working memory at an instance in time (Cooper, 1990). This questionnaire concerns participants' mental effort exerted to use the system and to learn with the system. The analysis of cognitive load imposed by learning system is illustrated in Table 7.2.

Table 7.2 Analysis of Cognitive Load Imposed by Learning System

Questionnaire Item	Disagree a lot %	Disagree %	Neutral %	Agree %	Agree a lot %	Mean	S.D.
1. I feel comfortable with my abilities to grasp how to use the system.	0%	7%	22%	57%	14%	3.8	0.80
2. I feel comfortable learning with the new system.	0%	14%	22%	57%	7%	3.6	0.85
3. I found that the learning procedure offered by the system is easy.	0%	0%	28%	43%	29%	4	0.78
4. The use of system in scenario interests me.	0%	0%	7%	57%	36%	4.3	0.61
5. I think the system will be valuable in my future work.	0%	7%	0%	57%	36%	4.2	0.80
6. I believe the system will influence how my work-based learning progresses in the future.	0%	7%	36%	50%	7%	3.6	0.76

As illustrated in Table 7.2, the standard deviations of all the items are less than 1, which indicate that the mean value of each item can reflect the participants' common evaluation. Based on the mean values of items 3, 4 and 5, which exceed 4, we can identify that the majority of the participants felt the need to employ the new system in their work-based learning, and felt that their learning process could be facilitated by the system. However, from the mean values of items 1 and 2, which are 3.8 and 3.6, respectively, we can see that a certain number of participants had not enough confidence in learning how to use the new system. Also, from the mean value of item 6, which is 3.6, we know that a part of the participants doubted that the learning system has the power to change their learning behaviors in the future.

4) Analysis of Learning System Acceptance

This questionnaire aims at querying the participants' acceptability of the work-based context-aware mobile learning system. Three scales are surveyed in this questionnaire, including easiness of the system, participants' attitude to the context-aware adaptation approach, and their opinions on the usefulness of the system. Table 7.3 presents the mean and the standard deviation of each question in this questionnaire.

Table 7.3 Analysis of Learning System Acceptance

Scale	Questionnaire Item	Mean	S.D.
Easiness of Learning System	1. It is easy to operate the interfaces of the learning system.	4.2	1.21
	2. The response speed of the learning system is well-matched with the learning progress on the site.	4.1	1.21
	3. I think that device operation of the learning system is easy.	4.1	1.14
Attitude of context-aware adaptation approach	4. The adapted learning contents help me complete learning activities according to my contextual information.	4.1	0.62
	5. Combining the mobile learning system and the real-world context is helpful to learning.	4.1	0.83
Usefulness of Learning System	6. The progress provided by the learning system can benefit my learning achievement.	4.1	0.62
	7. The guidance of the learning system is quite clear and effectively helps me understand the learning content and steps.	3.9	1.03
	8. According to my experience, I would use this system, if relevant, for my work-based learning needs.	4.2	0.65
	9. I would recommend the system to others.	4.1	0.83

As illustrated in Table 7.3, the mean values of overwhelming majority items exceed 4. Therefore, overall, there was a positive attitude and a positive momentum towards applying the context-aware mobile learning system in work-based learning.

More specifically, the first three items have the mean values 4.2, 4.1 and 4.1, respectively, which show that the participants evaluated ease of use of the system positively. It was also observed that, during the 10-minute instruction concerning system operation, after being taught once or twice, the participants were well familiar with system operations. However, based on the standard deviations of these three items, which exceed 1, it was found that not all of the participants completely accepted the easiness of the system. This observation implies that interfaces and operations need to be more carefully designed if they are to encourage more professionals to use this system, and in particular those who have little experience in using mobile devices. Also, more effort should be devoted to improving system response speed to match professionals' learning progress.

Questions "4" and "5" focus on evaluating participant's acceptance of the context-aware adaptation approach. The mean values of these two items exceed 4 with standard deviations of less than 1. These responses provided us with the evidence that the majority of the participants strongly agreed with the valid adaptation of learning contents based on their contextual information. The participants also agreed that adaptation of the learning contents helped them to complete successfully the assigned task in the experiment.

To evaluate the usefulness of the learning system, questions with a mean exceeding 4 include "6", "8" and "9". This means that the participants found the system was useful in supporting their appointed work-based learning, and they were eager to use this kind of system in their future actual work and also to share it with others. However, two out of fourteen participants gave two points to question 7, which meant its mean value was 3.9. In the after-test interview, these two participants pointed out the system guidance which confused them. These suggestions will be taken into account in our future work.

5) Analysis of Long-Term Learning Achievement

To evaluate the long-term learning achievement, we asked the 14 participants, who had completed the mission, to repeat the same work one week later, but without the support of the learning system. We recorded and analyzed their performance during the experiment on video, and asked them to fill out the learning influence questionnaire after the experiment.

All participants completed the assigned mission successfully one week after their work-based learning. This proves the positive effect of the learning approach with the work-based context-aware mobile learning system on the learning achievements of the participants in the experiment. What's more, analysis of the learning influence is illustrated in Table 7.4.

Table 7.4 Analysis of Learning Influence

Questionnaire Item	Mean	S.D.
1. I could recall my learning and doing experience easily.	4.0	0.39
2. I could redo the task easily.	4.5	0.52
3. I find this system can facilitate my learning process.	4.3	0.74
4. I expect to learn from this approach in my future learning.	4.1	0.88

As illustrated in Table 7.4, the mean values of these four items exceed 4, which indicates that the participants could recall and redo their task depending on their learning experience of one week before. What's more, the standard deviations of these four items are 0.39, 0.52, 0.74 and 0.88, respectively, which indicate that the individual participants' responses are close to the participants' mean responses. This proves the validity of each question of this questionnaire.

Apart from the analyses stated above, from the records of participants' learning performances, we notice that: for the majority of the participants, the time used for the experiment was wasted mostly in finding the exact words in the list to express their maintenance action and the action object. According to this evaluation feedback, in the future work, a function, which allows professionals to type the keywords and which applies the keyword similarity algorithm to find the relative learning units, should be developed.

7.4 Conclusion

In this chapter, we presented the evaluation of the learning effect with the WoBaLearn system. First, we introduced the case study for carrying out the evaluation by describing the designed work-based learning scenario and the implemented system prototype for providing learning supports to the mission in the scenario. Then, we introduced the participants involved in the experiment, the instruments used for the evaluation, and the experiment procedure. Finally, we illustrated the results obtained from the experiment, before analyzing these results and discussing their implications.

From analyses of these results, we can conclude that the proposed WoBaLearn system could help professionals to achieve a good learning effect in their work-based learning. This system generates less cognitive load, allowing professionals to operate easily on this system. Based on participants' evaluation, we can expect that the WoBaLearn system would be recognized widely by professionals, and enjoy a good practical application prospect.

8 Conclusion and Future Work

8.1 Contributions

Related references and data indicate that work-based learning, which is just-in-time, work-related, informal and spontaneous, is a crucial approach to promoting personnel's and enterprises' competitiveness. To improve personnel's capacities and thus promote enterprises' development, our research work focused on applying a context-aware mobile learning approach to facilitate work-based learning by providing professionals with just-in-time learning experiences delivered by their mobile devices and tailored to their learning needs, personal characteristics and also particular circumstances.

Our work designed and implemented a work-based context-aware mobile learning system, named WoBaLearn. With the benefits of this work, professionals can use their mobile devices to access personalized and adaptive learning supports whenever and wherever they run into problems. More specifically, the advancements of the WoBaLearn system can be identified as individuality, seamlessness, immediacy, interactivity, situating of instructional activities, and permanency. The details of these advancements are listed as follows.

- **Individuality:** The system can recommend proper learning units according to professionals' personal ability, interests, requirements, objective, schedule, etc.

- **Seamlessness:** The system is beneficial in integrating learning activities with working activities. What's more, the learning process provided by this system cannot be interrupted when the professional's location changes.

- **Immediacy:** Wherever professionals are, they can get information immediately to support them in solving their problems. Otherwise, they can ask for suggestions from experience-related colleagues or initiate a discussion with nearby people.

- **Interactivity:** Professionals can interact with experts, experienced colleagues or peers synchronously or asynchronously. Mobile devices allow the usage of instant messaging, phone, online chat, email, etc. Hence, learning partners are more contactable, and exchanging of knowledge and skills is more available.

- **Situating of instructional activities:** The problems encountered and the corresponding knowledge and skills can all be presented in their nature and authentic forms. This aspect helps professionals to notice the features of problem situations that make particular actions relevant.

- **Permanency:** Along with professionals' work, their learning processes can be recorded continuously and stored in a centralized server. These recordings can be reviewed and shared permanently.

The main research contributions of this thesis can be illustrated in four categories: the architecture of WoBaLearn (a work-based context-aware mobile learning system), the WbML context model (an ontology-based hierarchical context model for work-based learning), a set of adaptation strategies for work-based learning and an adaptation engine to execute these strategies, and an implementation of the WoBaLearn system.

1) **The architecture of WoBaLearn - a work-based context-aware mobile learning system**

   From analysis of the results of an online survey, our work identified professionals' learning processes and needs during their work-based learning. Based on this analysis, we proposed the architecture of a work-based context-aware mobile learning system, named WoBaLearn. This architecture was designed to arrange the proposed learning activities complying with the practical working process. Also, this architecture was designed to possess abundant functions to facilitate professionals' essential learning needs.

   During the design of this architecture, three essential elements were taken into consideration, namely:

- The context model, which is in charge of describing explicitly the learning context taken as the system input.

- Learning units, which are the source of knowledge and skills provided by the system.

- The adaptation engine, which acquires the learning context values and produces the adapted learning units, learning partners and learning activities based on a set of adaptation strategies.

We proposed the architecture of WoBaLearn with three layers:

- The context sensing layer, which contains various physical and visual sensors to sense the learning context values defined in the WbML context model.

- The learning adaptation layer, which manages the direct context aspects sensed from the context sensing layer and infers the indirect context aspects, as well as providing appropriate learning supports depending on just-in-time learning context and a set of learning adaptation strategies.

- The learning application layer, which is in charge of interacting with professionals, for example, collecting their information and requirements, displaying adaptive learning units, providing appropriate communication approaches, etc.

This architecture can support the WoBaLearn system in adapting learning supports according to professionals' learning needs, personal characteristics and particular circumstances. This architecture ensures that professionals acquire personalized, just-in-time and problem-based knowledge, skills, and also partner supports in real working situations.

2) WbML context model - an ontology-based hierarchical context model for work-based learning

Based on the specificities of work-based learning, our work proposed an ontology-based hierarchical context model, named the WbML context model.

This WbML context model adopted the hierarchical design approach. It consists of two layers:

- The common layer, which generalizes the common context aspects in ubiquitous computing and their inherent properties.

- The domain layer, which captures the context to characterize the particular work-based learning domain.

The common layer of this model is generic enough to provide the possibility for sharing information and services among different application domains. Also, the domain layer of this model is extendible, so that the model is able to cover all the work-based learning situations.

This WbML context model was described by ontology written in OWL-DL. The ontology-based approach has the ability to describe context semantically in a way which is independent from programming language, underlying operating systems or middleware. In our research, Protégé was used to build the ontology of the WbML context model, and Jena was applied to manipulate the model context in the Java program.

3) A set of adaptation strategies for work-based learning and an adaptation engine to execute these strategies

To implement adaptivity and personalization in WoBaLearn, our work proposed five learning adaptation strategies and an adaptation engine for carrying out these strategies to implement the adaptation process. These five learning adaptation strategies include:

- Adaptation of learning units selection
  This adaptation is used to select the adaptive learning units from the learning unit database of the system. The selected learning units should be those most relative to the professional's current work as well as being in a display format adapted to the professional's preference, mobile device capacity and workplace situation.

- Adaptation of learning units sequence
  This adaptation is used to reorder the selected learning units by taking into account the professional's personalized settings, such as his / her learning style, task proficiency and mother language.

- Adaptation of learning units navigation
  This adaptation is used to produce adaptive pedagogical units based on the recommended learning unit and its prior / extended / intensive knowledge. This adaptation can organize an individual learning unit into a knowledge system, which can satisfy people's cognitive needs.

- Adaptation of learning partners communication
  This adaptation is used to help professionals find their appropriate learning partners, and also to provide a proper communication approach by considering these partners' locations and availabilities.

- Adaptation of learning activities generation.
  This adaptation is used to generate automatically adaptive learning activities, including just-in-time activity, review activity and progress activity. These activities can not only provide professionals with a solution to overcome the work problem at hand, but also help them to enlarge their knowledge and skills within an adaptive and personalized learning cycle.

4) An implementation of the WoBaLearn system

Based on the design basis, we implemented the WoBaLearn system with the PHP, WordPress, Java, Jena, OWL, XML and MySQL technologies, using the development and running tools Eclipse, JDK, Protégé and WampServer. This implemented system can:

- Handle a set of learning adaptation rules and match them with the learning context values automatically, so as to enable the designed adaptation strategies.

- Provide the professionals with the learning units which are personalized, work-related, environment adaptive and just-in-time.

- Break down the selected learning units into adaptive pedagogical units, which can provide beginners with prior knowledge and skills to help them to compensate for their lack of experience, or provide the experienced and experts with the necessary extended and / or intensive knowledge and skills to help them to progress.

- Offer professionals with the opportunity to modify their learning context as well as the learning units sequence rules, so as to enable the learning units to be reselected and reordered, so that the learning process can be consolidated.

- Provide professionals with knowledge and skills which are not limited to those stored in the system learning unit database. Professionals have the possibility of searching on the Internet to find the most appropriate learning contents themselves. The system organizes these new contents into a learning unit by labeling them with AM-LOM metadata. Then, this newly created learning unit can be added to the system learning unit database, thus expanding the system source of knowledge and skills.

- Provide professionals with appropriate learning partners who are experienced and available, or nearby and able to give immediate suggestions.

- Propose proper collaborative approaches with learning partners by taking into account partners' locations and availabilities.

8.2 Future Work

We plan our future research work on the basis of the work already completed. In general, future work will focus on three aspects: carry out more evaluations, consider more cases, and improve the current system.

1) Evaluation

We will continue the present evaluation with more and real professionals. This work enables us to obtain abundant data and get more reliable analysis results. Also, we will design and carry out a comparative evaluation to examine whether the work-based context-aware mobile learning approach is better than other approaches. The comparative evaluation is schedule to contain two experiments:

a. The first experiment focuses on comparing the learning and performance results with the proposed work-based context-aware mobile learning system and with the traditional learning approaches, for example professional training.

b. The second experiment focuses on comparing the learning and performance results with the proposed work-based context-aware mobile learning system and with the traditional learning systems used in enterprises, for example the LMS.

2) The case study

We will construct the experimental environment together with comprehensive sensors, for example, physical sensors for collecting illumination level and noise level. This work will enable our system to collect more context defined in the WbML context model, and help to examine the conflicts and consistency of context relationships in this context model. This work can also help to examine system efficiency in a more complex situation, including massive context collected and administrated, and a large number of adaptation strategies executed. What's more, we will extend the system application field to more work-based learning scenarios, which can help examine the coverage and scalability of our system.

3) System improvement

We plan to enrich system functionalities according to the opinions collected from the evaluation. For example, according to participants' feedback about how to find the exact words in the list that expresses their maintenance action and the action object, a function, which allows professionals to type the keywords and applies a keyword similarity algorithm to find the relative learning units, will be developed.

We also plan to add the functionality in our system for modifying the adaptation strategies. In the current work, the proposed adaptation strategies can adapt the learning supports according to just-in-time learning context. However, these adaptation strategies are fixed once they have been defined. That is to say, they execute the same logic for all professionals. Our future work will focus on providing professionals with interfaces for modifying the logic of these adaptation strategies.

For example, for adaptation of learning units sequence, the sequencing criteria will not be limited to learning style, task proficiency and mother language. Instead, professionals can add or delete the criterion according to their actual situations.

What's more, we will consider in the WoBaLearn system the new process for creating the learning units.

Appendix1 Work-based learning questionnaire

Questionnaire

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Instruction:

According to your experience in work-based learning (learning activity that occurs on day-to-day work activities as you acquire new knowledge and skills to develop new approaches to solve problems), select one choice to indicate your answer. Choose only one answer for each question.

Thanks.

Basic information:

Gender: □ Male □ Female

Company type: ____

Professional Function: ______________________________________

Questions：

1. **How often do you get into the listed difficulties?**

I don't even know what's wrong, it's difficult to locate the problem precisely.	□Very often □Often □Occasionally □Rarely □Never
I know the problem, but it's difficult to find appropriate learning contents.	□Very often □Often □Occasionally □Rarely □Never
I don't know who can give me instructions or suggestions.	□Very often □Often □Occasionally □Rarely □Never
I don't know how to contact them.	□Very often □Often □Occasionally □Rarely □Never
Did you encounter any other difficulties?	________________________________ ________________________________

2. **If you have difficulties in locating problem precisely, measure the frequency of listed reasons. If not, go to 3.**

I lack learning experience or relative information about my work.	□Very often □Often □Occasionally □Rarely □Never
I have learning experience and possess relative information, but lack practical experience and cannot recognize the problem in my work.	□Very often □Often □Occasionally □Rarely □Never
Are there any other reasons?	_____________________________

3. **As the sources of your learning contents, measure the importance of the listed items.**

Books.	□Very Important □Important □Somewhat Important □Not Important
Articles in professional magazines.	□Very Important □Important □Somewhat Important □Not Important
Employee manuals.	□Very Important □Important □Somewhat Important □Not Important

Presentations and materials at professional meetings.	□Very Important □Important □Somewhat Important □Not Important
Class materials used in professional training.	□Very Important □Important □Somewhat Important □Not Important
Information recordings of your organization. (e.g., the supplier and custom lists for a retail company.)	□Very Important □Important □Somewhat Important □Not Important
Professional articles, instructions or reference materials on blogs and websites.	□Very Important □Important □Somewhat Important □Not Important
News, policies or procedures published on line.	□Very Important □Important □Somewhat Important □Not Important
Discussions or opinions published on line.	□Very Important □Important □Somewhat Important □Not Important
Are there any other sources?	________________________________

4. Based on the impact of your finding learning contents, measure the importance of the listed factors.

Matching my current working activity.	□Very Important □Important □Somewhat Important □Not Important
Based on my previous knowledge.	□Very Important □Important □Somewhat Important □Not Important
Content is displayed in my preferred format, e.g. text, video or audio, etc.	□Very Important □Important □Somewhat Important □Not Important
Are there any other factors?	________________________________

5. Based on the impact of your finding learning partners, measure the importance of the listed factors.

He/she should be someone who has relative experience.	□Very Important □Important □Somewhat Important □Not Important
He/she should be someone I am familiar with.	□Very Important □Important □Somewhat Important □Not Important

He/she should be someone who can give me immediate responses.	□Very Important □Important □Somewhat Important □Not Important
Are there any other factors?	___________________________________

6. **Measure the frequency of using the followed approaches as a learning communication method.**

Face to face	□Very often □Often □Occasionally □Rarely □Never
On-line Chat	□Very often □Often □Occasionally □Rarely □Never
Discussion boards on websites	□Very often □Often □Occasionally □Rarely □Never
Email	□Very often □Often □Occasionally □Rarely □Never
Social Network	□Very often □Often □Occasionally □Rarely □Never
Video Conference	□Very often □Often □Occasionally □Rarely □Never
Phone	□Very often □Often □Occasionally □Rarely □Never
SMS (short message)	□Very often □Often □Occasionally □Rarely □Never
Are there any other communication methods?	________________________________ ________________________________

7. **After solving problems with new knowledge or skills, is it necessary to review them later for consolidation?**	□Very necessary □Necessary □Somewhat necessary □Not necessary
8. **After solving problems with new knowledge or skills, is it necessary to learn other related contents to extend your learning?**	□Very necessary □Necessary □Somewhat necessary □Not necessary

9. **If the answer to 8 is positive, measure the necessity of the listed further learning.**

The topics related to the knowledge and skills which I have just learned.	□Very necessary □Necessary □Somewhat necessary □Not necessary
The knowledge and skilled learned of my learning partners.	□Very necessary □Necessary □Somewhat necessary □Not necessary

10. **Are there any other supplementary activities that could facilitate your learning?** ___________________________________

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Abstract

Increased interest has been shown in context-aware mobile learning systems. These systems aim to provide learning supports via mobile devices and adapt them to specific educational needs, personal characteristics and particular circumstances of an individual learner or a group of interconnected learners. Work-based learning is a crucial approach to promote professionals' working and learning efficiency, which is need-targeted, personalized, just-in-time and location-based. These characteristics predict that context-aware mobile learning systems can play a role in promoting the effect of work-based learning. However, relatively few context-aware mobile learning systems are proposed for learning and competence development in work contexts. This dissertation proposes the design, implementation and evaluation of a context-aware mobile system for work-based learning, named WoBaLearn. More specifically, in the dissertation, we worked on: (1) the learning theories related to work-based context-aware mobile learning; (2) the approaches for designing a work-based context-aware mobile learning system; and (3) the technologies and methodologies for implementing and testing the designed system.

The main contributions of this thesis are:

1) Proposal of an ontology-based hierarchical context model for work-based learning
We defined an initial context model for describing contextual information in work-based mobile learning, named WbML. This model adopts a hierarchical designing approach which classifies context into a common layer and a domain layer. This approach improves the reusability of this context model. Also, the WbML context model is built based on ontology for describing context semantically.

2) Design of a set of adaptation strategies for work-based learning and an adaptation engine to execute these strategies
We proposed a set of adaptation strategies concerning learning units selection, learning units sequence, learning units navigation, learning partners communication, and learning activities generation. These strategies adapt learning supports depending on professionals' just-in-time learning context. We proposed also an adaptation engine which executes these proposed strategies to implement learning adaptations.

3) Construction of the WoBaLearn architecture
Combined with the conceptual design bases about the context model, learning contents, adaptation strategies and adaptation engine, we proposed the system architecture of WoBaLearn which enables the WoBaLearn system to achieve the adaptive learning services.

4) Implementation of WoBaLearn
We implemented the proposed system with modern technologies, and set a user study to evaluate it. Evaluation results provided us with the evidence that this system can offer professionals a satisfactory learning experience and facilitate their work activities.

Keywords: Work-based learning; context-aware mobile learning; system design; context model; adaptation strategy; adaptation engine.

Résumé

Un intérêt accru a été élevé sur les systèmes d'apprentissage mobiles contextualisé. Ces systèmes visent à fournir les supports d'apprentissage via des appareils mobiles et de les adapter aux besoins spécifiques de l'éducation, les caractéristiques personnelles et les circonstances particulières d'un apprenant ou un groupe d'apprenants interconnectés. L'apprentissage en milieu de travail est une approche essentielle pour promouvoir l'efficacité de travail et d'apprentissage des professionnels. Il est besoin ciblé, personnalisé, juste-à-temps et basé sur la localisation. Ces caractéristiques prédisent que le système d'apprentissage mobile contextualisé peut jouer un rôle dans la promotion de l'efficacité de l'apprentissage en milieu de travail. Cependant, il y a relativement peu de systèmes d'apprentissage mobiles contextualisé proposées pour le développement de l'apprentissage et de la compétence en situation de travail. Cet article propose la conception, la mise en œuvre et l'évaluation d'un système d'apprentissage mobile contextualisé pour le milieu professionnel, nommé WoBaLearn. Plus précisément, dans la thèse, nous avons travaillé sur: (1) les théories de l'apprentissage mobile contextualisé et l'apprentissage en milieu de travail; (2) les approches pour la conception d'un système d'apprentissage mobile contextualisé pour le milieu professionnel; et (3) les technologies et les méthodologies de mettre en œuvre et de tester le système d'apprentissage conçu.

Les principales contributions de cette thèse sont:

1) Construction d'un modèle de contexte hiérarchique et basé sur une ontologie pour l'apprentissage en milieu de travail

   Nous avons défini un modèle de contexte initial pour décrire l'information contextuelle de l'apprentissage mobile en milieu de travail, nommé WbML. Ce modèle adopte l'approche hiérarchique, et est construit par l'ontologie.

2) Proposition d'un ensemble de stratégies d'adaptation pour l'apprentissage en milieu de travail et un moteur d'apprentissage pour exécuter ces stratégies

   Nous avons proposé un ensemble de stratégies d'adaptation. Ces stratégies adapter les supports d'apprentissage en fonction du contexte d'apprentissage actuel. Nous avons proposé également un moteur d'adaptation qui exécute ces stratégies pour mettre en œuvre les adaptations d'apprentissage.

3) Conception de l'architecture d'un système d'apprentissage mobile contextualisé pour le milieu professionnel

   Combinant avec les bases conceptuelles sur le modèle de contexte, des contenus d'apprentissage, les stratégies d'adaptation et le moteur d'adaptation, nous avons proposé l'architecture de WoBaLearn système qui permet à WoBaLearn de réaliser des services d'apprentissage adaptatif.

4) Mise en œuvre du système et son évaluation avec une étude de cas

   Nous avons implémenté le système avec les technologies modernes, et mis une étude de cas pour évaluer ce système. Les résultats d'évaluation nous ont fourni la preuve que ce système peut offrir aux professionnels une expérience d'apprentissage satisfaisant et faciliter leurs activités de travail.

Mots-clés: l'apprentissage pour le milieu professionnel; l'apprentissage mobile contextualisé; la conception du système; le modèle de contexte; la stratégie d'adaptation; le moteur d'adaptation.