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A conceptual model of personalized virtual learning environments

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Abstract

The Virtual Learning Environment (VLE) is one of the fastest growing areas in educational technology research and development. In order to achieve learning effectiveness, ideal VLEs should be able to identify learning needs and customize solutions, with or without an instructor to supplement instruction. They are called Personalized VLEs (PVLEs). In order to achieve PVLEs success, comprehensive conceptual models corresponding to PVLEs are essential. Such conceptual modeling development is important because it facilitates early detection and correction of system development errors. Therefore, in order to capture the PVLEs knowledge explicitly, this paper focuses on the development of conceptual models for PVLEs, including models of knowledge primitives in terms of learner, curriculum, and situational models, models of VLEs in general pedagogical bases, and particularly, the definition of the ontology of PVLEs on the constructivist pedagogical principle. Based on those comprehensive conceptual models, a prototyped multiagent-based PVLE has been implemented. A field experiment was conducted to investigate the learning achievements by comparing personalized and non-personalized systems. The result indicates that the PVLE we developed under our comprehensive ontology successfully provides significant learning achievements. These comprehensive models also provide a solid knowledge representation framework for PVLEs development practice, guiding the analysis, design, and development of PVLEs.

Keywords: Personalized learning; Agent oriented modeling; Conceptual model; Virtual learning environment

1. Introduction

At the dawn of the 21st Century, the education landscape is changing, in large part due to the Internet. Many of the traditional institutions of higher education, universities and colleges, are now beginning to develop and deliver Web-based courses via Virtual Learning Environments (VLEs) (McCormick, 2000). Therefore, in this technology-mediated learning area, the research and development of VLEs have been growing quickly. So-called VLEs can be defined as ‘computer-based environments that are relatively open systems, allowing interactions and encounters with other participants’ (Wilson, 1996). A Virtual Learning Environment is an environment in which students and educators can perform education-related tasks asynchronously, which is one of the most significant recent developments in the Information Systems (IS) field.

VLEs are best at achieving learning effectiveness when they adapt to the needs of individual learners (Park & Hannafin, 1993). VLEs should be able to identify learning needs and customize solutions that foster successful learning and performance, with or without an instructor to supplement instruction. These are called Adaptive Computer Assisted Instructions (ACAIs) (Davidovic, Warren, & Trichina, 2003) or Personalized VLEs (PVLEs) (Lassey, 1998; Martinez & Bunderson, 2000). The key issue of such approaches is the customization of learning environments for diverse student communities, which has been attracting more and more attention by educational professionals and researchers (Alavi, 2004; Castro, Kolp, & Mylopoulos, 2002; Roach, Blackmore, & Dempster, 2001). PVLEs tend to engage high-level personalized eLearning and to provide opportunities for innovation. Those opportunities develop online learners’ higher cognitive abilities and foster creativity. Such personalized eLearning requires higher-level thinking in more open situations and is inherently a creative, generative and reflective process (Alavi & Leidner, 2001). Individual online learners can be uniquely identified, with content specifically presented and progress individually monitored, supported and assessed (Akhras & Self, 2000). The learning process is

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a reflection of inherently active, generative and reflective high-level thinking in more open situations (Pea, 1985). Therefore, PVLEs are becoming more promising towards learning effectiveness (Lassey, 1998). PVLEs provide opportunities for online learners to amplify and extend cognitive capabilities as well as to organize the learning process by altering the tasks available to them. PVLEs emphasize the importance of scaffolding learner self-regulation and strategic process to help online learners managing the complexity of the learning situation (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989).

In order for the PVLEs to be succeeded, the comprehensive conceptual models corresponding to PVLEs are essential. A conceptual model is an explicit specification of a conceptualization, which defines the terminology of a domain in terms of the concepts that constitute the domain and the relationships between them (Gruber, 1993). Conceptual models are these diagrams used by systems analysts to represent specific requirements for new applications. These diagrams are designed to support communication between developers and users, to help analysts understand a domain, and to provide an input to systems design. Within the IS field, the task of conceptual modeling typically involves building a representation of selected phenomena in some domain consisting of a hierarchical description of the important concepts in a domain, as well as the properties of each concept (Wand & Weber, 2002). High-quality conceptual modeling work is important because it facilitates early detection and correction of system development errors. The development of conceptual modeling has drawn on results from knowledge representation and conceptual modeling (Mylopoulos, 1990; Wand, Monarchi, Parsons, & Woo, 1995).

The basic problem of conceptual modeling involves the development of an expressive presentation notation with which to represent knowledge (Wand & Weber, 2002). Therefore, the conceptual models of PVLEs are based on the knowledge of instructional design that must be rooted in strong pedagogical principles.

Most existing VLEs are based on the objectivist learning model. The objectivist learning model is based on stimulus-response theory. Learning is a change in the behavioral disposition of an organism that can be shaped by selective reinforcement. There is an objective reality and the goal of learning is to understand this reality and modify behavior accordingly. The goal of teaching is to facilitate the transfer of knowledge from the instructor to the learner. The instructor should be in control of the material and pace of learning. Via exercises, the instructor assesses whether knowledge transfer has occurred. To the objectivist learning model, the presentation of information is critical of the successful knowledge transferring (Leidner & Jarvenpaa, 1995).

By way of contrast, the constructivist learning model denies the existence of knowledge transfer. From a constructivist point of view, knowledge is created or constructed by each individual learner (Jonassen & Wilson, 1993). Learners are assumed to learn better when they are required to discover things by themselves rather than simply through the process of being instructed. Learners must control the learning plans. The instructors serve as the creative mediators of the process. They provide tools for helping learners construct their own views of reality. Very recently, a few constructivist learning model-based VLEs have been developed (Akhras & Self, 2000). Such VLEs need to be attuned to special features of the learner, the learning environment, and the interaction between learner and learning environment.

The research and development of PVLEs are still at an early stage. Currently, the most existing research only provides the conceptual models of PVLEs without implementation and validation. For instance, the Personalized Hypermedia Systems aim mainly to bridge the gap between traditional hypermedia systems and personalized systems (Raad & Causse, 2002). In this research, Raad and Causse (2002) classify and model personalized methods into two categories: personalized presentation (including additional explanation, prerequisite explanation, comparative explanation, and sorting explanation); and personalized navigation (including direct guidance, sorting links, hidden links and annotation links).

In this paper, a conceptual model of PVLEs, which can be regarded as an application of the constructivist learning model, is described. In order to represent such models, a number of knowledge primitives of VLEs is modeled in Section 2, such as curriculum, learners, instructors, etc. Section 3 describes the conceptual models of VLEs in general based on two pedagogical principles: objectivist learning and constructivist learning model. Based on the discussion in the above sections, the ontology of PVLE is developed in Section 4, while the experimental evolution of PVLE is presented in Section 5. Section 6 is the conclusions.

2. Conceptual models of knowledge primitives

In order to ensure that a VLE can work, it should have a large knowledge base. Such knowledge can be modeled into two levels: the domain level that is related to the real world domain, and the meta level that is about the knowledge of the domain level knowledge.

2.1. Domain level model

The domain level knowledge in VLEs contains the curriculum of domain knowledge, learners, instructors and the relationship among them. The curriculum model is the structure of the curriculum. A portion of the Curriculum class diagram of such a model is shown in Fig. 1. The Curriculum class in Fig. 1 has a number of important attributes, such as keywords, difficulty level, description, etc. Content is a sub-class of Curriculum. There are

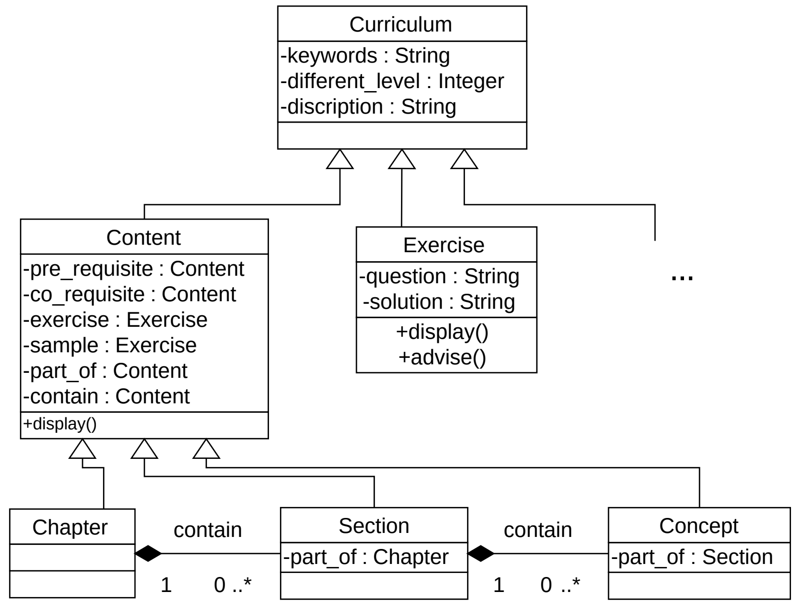

Fig. 1. Partial class diagram for course curriculum.

a number of attributes in the class Content, e.g. pre_ requisite, co_requisite, exercise, example, etc.

Similar to Fig. 1, Fig. 2 shows a portion of learners and instructors models. In VLEs, learners are engaged in goal-orientated learning processes. Based on pedagogical principles, learning goal is either defined by instructors under the objectivist learning model or learners under the constructivist learning model. Dweck identified two major classes of goal orientations: learning goal orientation, that is to develop competence through expanding one's abilities by mastering challenging situations; and a performance goal orientation that involves demonstrating and validating one's competence by seeking favorable judgments and avoiding negative judgments (Dweck, 1986). Learning and performance goal orientations are associated with different personal beliefs about ability and effort (VandeWalle, Cron, & Slocum, 2001).

VLEs emphasize the nature of knowledge, learning and teaching, which have led to architecture that focuses on representing the knowledge to be learned (curriculum model), inferring the learner's knowledge (learner model), and planning instructional steps to the learner (instruction model) (Akhras & Self, 2000). The construction of dynamic learner profiles is based on the learners' behavioral patterns and their learning activities. The profiles can be utilized to support collaborative learning and to enable personalized instruction to different learners. Interaction among learners in VLEs plays an important role in fostering effective learning process (Piccoli, Ahmad, & Ives, 2001). Knowledge sharing or building is the process by which an instructor and learners achieve, through discussions, a shared understanding of a particular concept. Hooper also indicates that persisting interactions are correlated positively with learners' achievement (Hooper, 2003).

The Learner's model is related to Learning_Goal, Learning_Plan and Learner_Profile. It has an associated action, 'self_assessment'. A number of instructional strategies are stored in the class Instruction, including teaching_attitude, motor_skill, intellectual_skill, and problem_solving_skill.

2.2. Meta level model

From the discussion in Section 1, VLEs achieve greater learning effectiveness when they need to be attuned to features of the learner (i.e. the situation), the interaction between learner and learning environment, and the learning process. The meta level entities do not focus on basic knowledge structure, but on the nature of the learners' learning contexts through which learners can construct their own knowledge about a domain by experiencing the domain and interpreting their own experiences (Akhras & Self, 2002). A portion of these meta level entities is presented in Fig. 3.

As shown in Fig. 3, the Situation model characterizes an open context in which learners' interactions make explicit in the VLEs the information about the context in which the interactions occur and the nature of these interactions. A number of important attributes are defined in the Situation entity (Akhras & Self, 2000). The event represents the current situation; the pre-condition represents an event that must occur before the current situation, and the post-condition represents an event that will occur after the current situation.

The Interaction model is related to the occurrence of events or the entities that hold situations and to the cognitive states, activities, and contexts. An interaction object is

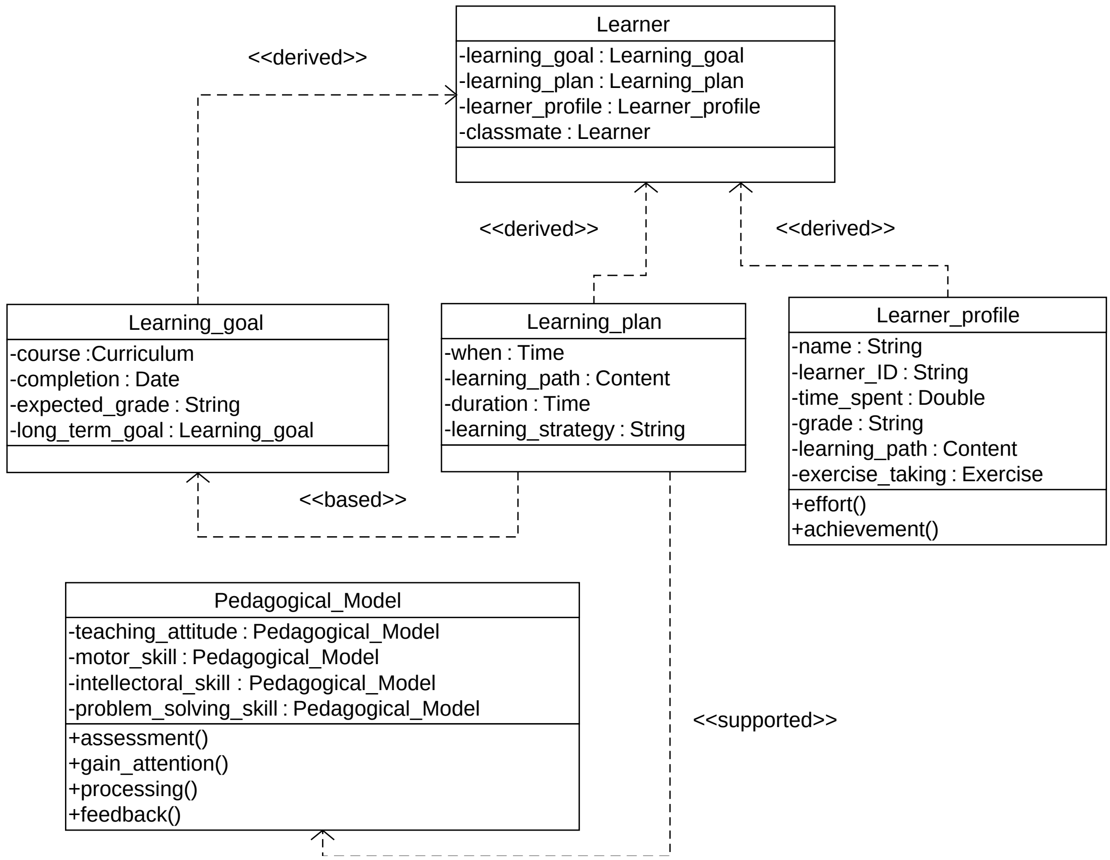

Fig. 2. Partial class diagram for the learner and the pedagogical model.

usually in a particular situation and shares some situation(s). The learner's actions are to capture the various ways, such as utilizing, generating, or accessing objects. The learner's cognitive states are intended to capture the various ways in which entities of a situation are related to learner's previously formed cognitive structure (Akhras & Self, 2002).

The Process model presents how patterns of interaction in one situation are connected to patterns of interaction in another situation. The cumulativeness represents how the knowledge learned in one situation can be used in another situation later. The constructiveness represents the integration of a learner's previously constructed knowledge with aspects of new learning experiences. The self-regulatedness represents the meta-cognitive processes in which aspects of previous learning experience are revised in a later situation (Akhras & Self, 2002).

3. Conceptual models of virtual learning environments

In Section 1, we noted that most existing VLEs are based on the objectivist learning model. Such VLEs are teacher-centered learning environments that are able to provide online learners with pre-defined course content according to learning plan, which specifies the sequence of these content units. Therefore, online learners are passive in learning activities and lack the opportunities to interact with the environments appropriately. An ideal VLE should be built

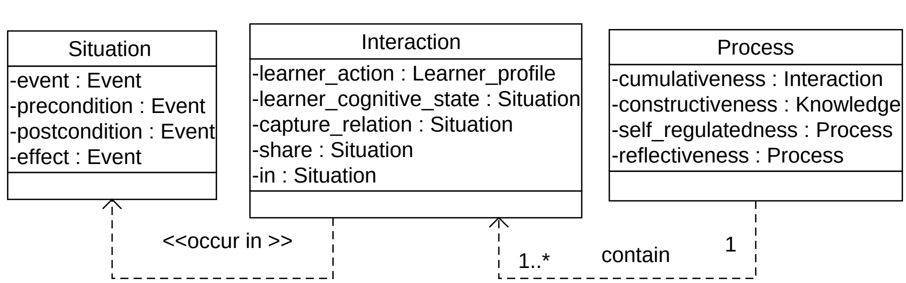

Fig. 3. Partial class diagram for situation, interaction and process.

with reference to the constructivist learning model where online learners are able to control their learning process, receive adaptive instruction, experience personal relevant subject matters, and communicate with VLEs.

3.1. VLEs under the objectivist learning model

According to the objectivist learning model viewpoint, the pedagogical role of the system is to present to the learner the content of instructional units according to a plan generated by an instructional planner. These units of curriculum can be lessons, problems, explanations, examples, exercises, tests, etc. related to the knowledge of the domain, and the plan describes how these units are to be sequenced. It is usually divided into two phases, carried out by the instructional planner: content planning, which defines, according to the instructional goals and characteristics of the learner, the concepts to be learned and sequenced; and delivery planning, in which, for each concept to be learned the planner generates a sequence of instructional actions adapted to the individual learner. The objectivist-based model presented in Fig. 4 is based on a number of existing eLearning systems (Wang, 1997a,b; Xu & Wang, 2002). The model demonstrates the relationships between teaching model, domain model and learner model. The domain is modeled in terms of the knowledge to be learned into the Curriculum model that stores all the curriculum information, such as contents, exercises, examples, and the relations among them. It also specifies the relationships between these components, such as logical dependencies and hierarchies (Akhras & Self, 2002).

A learner's knowledge is modeled in terms of the learner's correct or incorrect knowledge concerning the domain. When a learner is studying, his/her learning activities (such as his/her learning path, learning time, learning pace, and learning achievements) are monitored and analyzed and the profiling data and stored in the learner model. Learners receive the content of instructional units according to a learning plan generated by the instructor. These units can be lessons, explanations, examples, exercises, tests, etc. related to the knowledge of the domain and the plan describes how these units are to be sequenced (Akhras & Self, 2002). A teaching model represents the knowledge to select teaching strategies for instructional activities, present them to learner, and handle the learner's response. Under the objectivist pedagogical principle, VLEs emphasize the structure of domain knowledge, the way learners learn, and the way learning can be promoted.

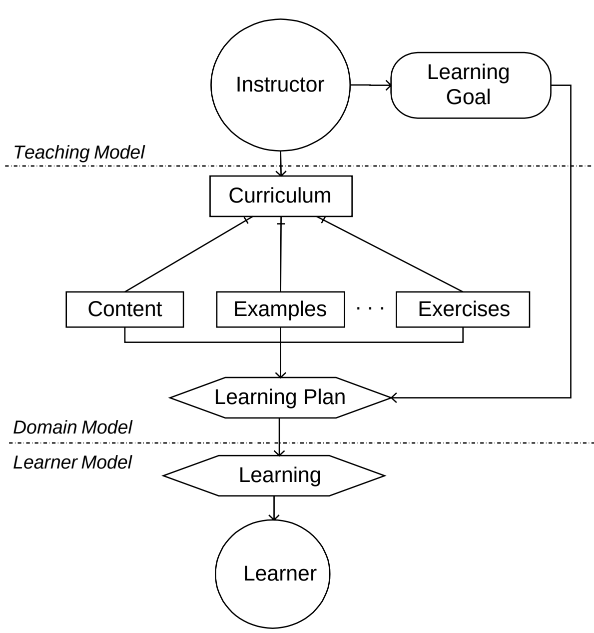

Fig. 4. Conceptual model of objectivist VLEs.

Based on the above perspective, the philosophy of most existing Intelligent Tutoring Systems (ITSs), a kind of VLEs, is based on a more objectivist learning model of the nature of knowledge and of what it means to acquire knowledge. In such ITSs, the instructors, i.e. the instructional agents in the VLEs, play the major role for the learning plans, based on the determination of the cognitive state of the learner in terms of their knowledge and misconceptions.

3.2. VLEs under the constructivist learning model

The proponents of the constructivist model believe that adaptiveness is mainly based on features of the learner, learning situation and the learning process. However, constructivist-based VLEs are very new. The constructivist learning model presented in Fig. 5 is based on the INCENSE system, developed by Akhras and Self (2000).

Under the constructivist pedagogical principle, VLEs are attuned to features of the learner, the environment, and the interaction between learner and environment. The main implications for the design of constructivist VLEs emphasize that the domain is modeled in terms of situations rather than in terms of knowledge structure, that learning evaluation focuses on the learning process rather than on the achievement itself, and that the opportunities for learning arise from afforded situations rather than being provided on the basis of teaching strategies (Akhras & Self, 2002).

In the constructivist learning model, the knowledge is individually constructed from what learners do in their experiential worlds and cannot be objectively defined (von Glasersfeld, 1989). Knowledge cannot be pre-specified before learning. Rather than concentrating on logical analysis of domain structure and dependency relationships between the contents, the concern of the constructivist learning model focuses on the learning processes through which the perspectives and interpretations that are relevant to learning can be constructed. Therefore, the domain is modeled in terms of the learning situation rather than its structured knowledge.

Learning is an interactive process between learning and environment, i.e. 'learning by doing'. This process is a time-extended process of interacting in situations that involves aspects of learner's actions, learner's cognitive structures,

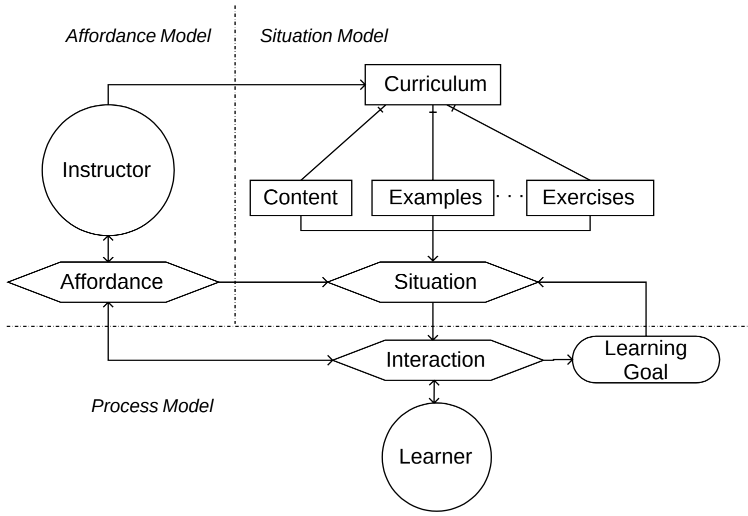

Fig. 5. Conceptual model of constructivist VLEs.

and contexts of interaction between learner and environment that span time (Akhras & Self, 2002). It focuses not only on the knowledge to be acquired, but also on the knowledge to be constructed. Therefore, the process model is broader than the learner model in objectivist VLEs with the cognitive states and properties of interactions and of sequences of interactions that can denote how learners care constructing knowledge.

The learning sequence, in constructivist VLEs, emerges in the interaction between the learner and the environment from a combination of factors that depend on the opportunities available for the learner in the interaction contexts and on the learner's previously constructed knowledge (Akhras & Self, 2002). These opportunities characterize affordability of learning situations to learners whose learning process is at a certain state. The utility of a situation for a learner at a certain time is determined by affording that situation with respect to features of single interactions and with respect to features of time-extended processes of interaction (Gibson, 1977). Therefore, a model of affordances indicate the possibilities in situations for the development of relevant learning activity, for a learner whose learning process is in a certain state, and is the basis for creating spaces of interaction for the learners.

From the discussion above, it is summarized that the constructivist model of VLEs is broader in perspective than the objectivist model of VLEs. In constructivist VLEs, the learning process at a certain time is modeled by the set of patterns of interaction developed up to that time (the interaction model) and by the set of properties of the courses of interaction that hold as a consequence of these patterns (the process model). Modeling affordance of learning situations allows constructivist VLEs to adapt the interaction that occurred in the VLEs and the process of such interactions of learning.

In short, the learner's learning process in a constructivist VLE plays the major role for the adaptiveness of the learning situation. The role of the pedagogical strategy is not to determine instructional events but to provide profitable spaces of interaction to the learners, which are determined on the basis of the interaction model and the process model. PVLEs can be viewed a kind of constructivist VLE in terms of learner's learning process.

4. Ontology of personalized virtual learning environments

In order to demonstrate the usefulness of the conceptual models developed in the previous sections, an application using such models to develop the formal representation of PVLEs is described in this section. PVLEs are based on the constructivist learning pedagogical where they are attuned to features of the learner, the environment, and the interaction between learner and environment. To develop a prototype PVLE, intelligent agents supported personalized eLearning system, for introductory Information Systems, ontology for representing the conceptual model is described in Fig. 7 based on the modeling method, *Tropos* (Bresciani, Anna perini, Giorgini, Giunchiglia, & Mylopoulos, 2004; Castro et al., 2002).

Tropos proposes a software development methodology and a development framework, which is founded on concepts used to model early requirements by utilizing the notions of actor, goal and (actor) dependency (Bresciani et al., 2004; Castro et al., 2002; Mylopoulos, Kolp, & Castro, 2001). The *Tropos* approach is a requirement- and goal-oriented software-modeling method, which is particularly appropriate for generic, component software systems (Jonassen & Wilson, 1993). Comparing with UML, a popular modeling tool, *Tropos* could be used to present agents, their goals, and the dependencies among them. Using the *Tropos* methodology, we are able to model the world from the following very important perspectives: (1) Social entities, such as relevant

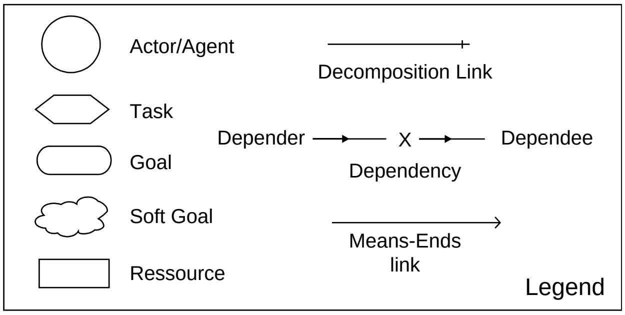

Fig. 6. The stereotypes.

agents/actors (e.g. learners, instructors, planers, etc.), their obligations and capabilities; (2) Agent intentions; (3) Communications and dialogs among agents; (4) Learning processes and their relationships.

Using such methods, each category of knowledge in a PVLE is treated as a class (with its instances being its instantiation). All classes of information can be organized within a hierarchy. Such a knowledge hierarchy can be divided into two levels: the domain level and the meta level (Wang, 1997a,b). The domain level knowledge is the representation of domain entities, while the meta level knowledge is the knowledge about domain level knowledge. In our conceptual model, all the knowledge about the curriculum, about the learners, about the instructors, is domain level knowledge; while the knowledge about situation, interaction, and the processes is meta level knowledge. The stereotypes of the *Tropos* figures are shown in Fig. 6 (Mylopoulos et al., 2001).

In the ontology of the PVLEs (shown in Fig. 7), the Curriculum stores the curriculum information, such as contents, exercises, examples, and the relations among them; the Learner Profile stores the learning history of each individual learner. When a learner is studying, his/her learning activities (such as his/her learning path, learning time, learning pace, and learning achievements) are monitored and analyzed by the Activity agent and the profiling data will be stored in the Learner_Profile.

Based on the situation and the Learner Profile, the Interaction agent models such interaction and builds the Interaction model. The Process agent will evaluate the interaction model and build the new process model. By the emergence of learning situations, the interaction model and the process model, the Interface agent will provide personalized interaction, personalized contents, and personalized exercises to the learner.

Based on this approach, a prototype Personalized eLearning System Architecture was designed and the corresponding Intelligent eLearning System (IeLS) was implemented (Xu & Wang, 2002). The IeLS architecture is shown in Fig. 8.

There are three layers in the IeLS. The Repository layer contains a number of resources, such as the Content Model (Curriculum), the Student Profile, the Student Model and the Learning Plan. Similar to Fig. 1, all the contents, i.e. the chapters, the sections, the concepts, and the exercises, are represented by the Curriculum model and stored in the system repository. The structured information, e.g. the relations among these entities, is also stored in the repository. Other than these static models, the dynamic models shown in Fig. 4, such as the student model, the student profile, and the learning plan, are also implemented and stored in the repository initially.

Based on the constructivist learning model in PVLEs described in Fig. 8, a number of software agents have been developed in the IeLS: the Activity Agent, the Modeling Agent, the Planning Agent and the User Interface Agent. Combining the meta level model of the constructivist learning model, the learning process can be described as follows: the activity agent records the student interaction activities in the learning process and generates the student profile. Based on such student profile, the modeling agent

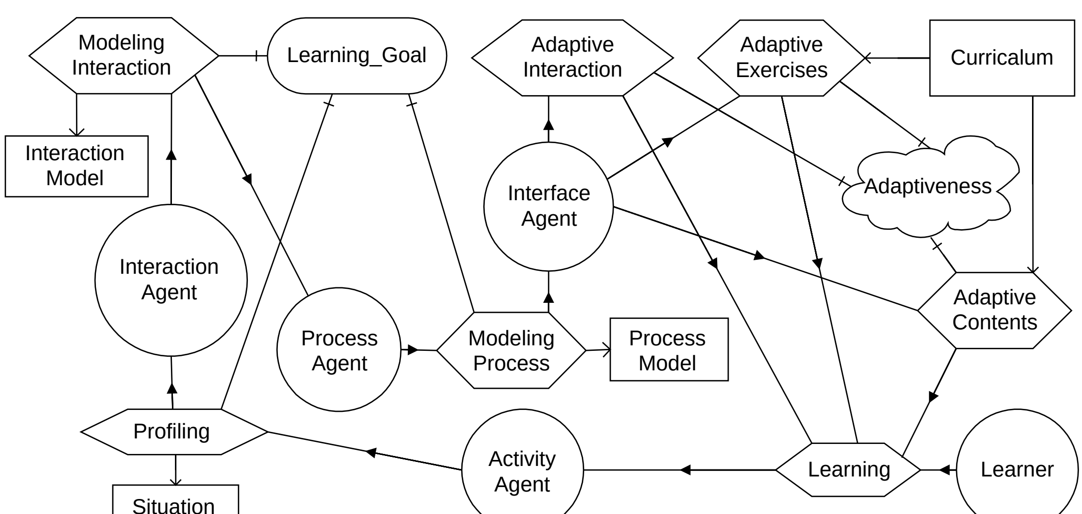

Fig. 7. Ontology of PVLEs.

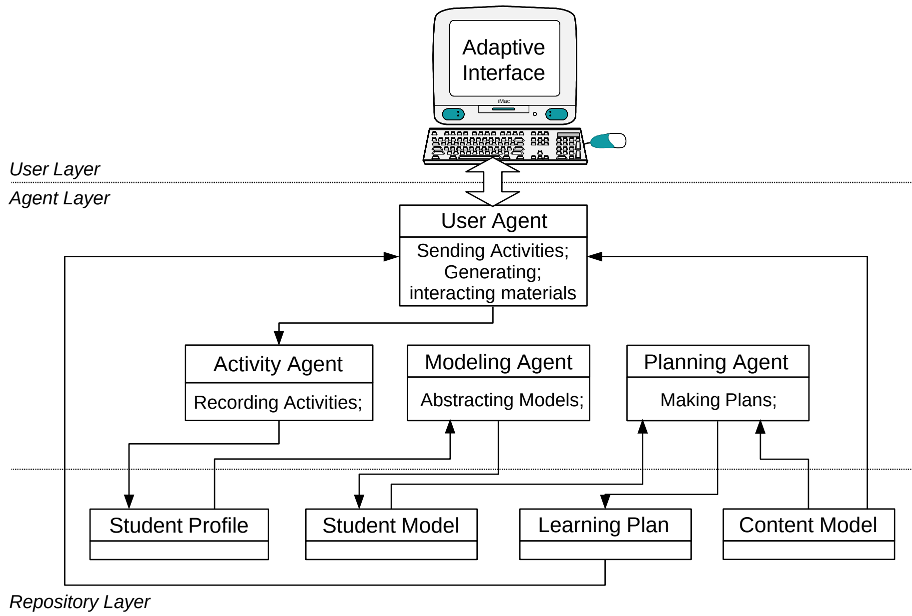

Fig. 8. Personalized eLearning system architecture.

revises the student model at a certain time sequence within the process model. Such modification of the student model invokes the planning agent to revise the learning plan, which indicates the possibilities in situations for the development of relevant learning activity. The personalization features of the IeLS can be described as follows:

(1) *Learning*. Different types and levels of learning materials are provided to the learner by the IeLS, based on the learner's model, the learning plan, and the instruction model. Therefore, individual learners are able to construct the domain knowledge based on their own learning pace and interaction with the learning environment.
(2) *Self-evaluation*. After learning a section, the learner is advised to take exercises. The questions are generated dynamically based on the content model, the current learner's model as well as the instruction model. The self-evaluation is not only that the examination of the domain knowledge will be successful, but also the cognitive learning process. It indicates the affordance of the relevant interaction of sequenced learning by individual learner.
(3) *System adjustment*. Based on these analyses, the IeLS will perform the following tasks: (a) modify the learner's profile; (b) modify the current learning plan based on the instruction model; and (c) start a new that takes new modifications in to account.

5. Experimental evaluation of the PVLEs

In order to evaluate our prototype system in the areas of personalized learning facilities and learning effectiveness, the prototype system, IeLS, was developed and a field experiment was conducted with a 4-day online course to undergraduate students with free registration in April 2002 in our university. In this experiment, participating students' performance and perception were collected.

The field experiment was designed to adopt two parallel learning groups repeated measure to vary the learning environments, which are non-personalized regular eLearning System (eLS) and personalized Intelligent eLearning System (IeLS). The personalization facilities were developed in the IeLS, and retain the eLS as a control eLearning environment. Both systems deliver the instruction of the same course, *Introduction to the Oracle Database*, which is a four-chapter online course. In total, 228 students participated. They were assigned randomly to two systems, and completed the course work during the experiment, which lasted 4 days. Hundred and seventeen of them were using IeLS and 111 students used eLS. In the beginning of the experiment, students were required to take a pre-test, and then move on to the learning procedure. They received the instruction directly from the systems, took quizzes after each chapter, and then took the final exam. The main objective of our experiment was to evaluate the students' learning achievements when using our prototype IeLS. Through an Independent Samples Test, we derived the learning performance comparison of the two groups of students. Details are presented in Tables 1 and 2 and illustrated in Fig. 9.

Because the students were assigned to two systems randomly, their pre-test scores are comparable, indicated in Table 1 and Fig. 9. There is no difference in terms of students' learning achievements in the Chapter 1 quiz, which might be due to the fact that students were not yet familiar with the system facilities, and the learning time was

Table 1
Learning performance comparison (mean of score)

	Pre-test	Chapter 1 quiz	Chapter 2 quiz	Chapter 3 quiz	Chapter 4 quiz	Final exam
IeLS (117)	55.7	66.1	83.0	76.8	74.4	83.3
ELS (111)	54.9	71.3	75.6	70.2	65.1	72.3
t (*p*-value)	0.246 (0.806)	−1.583 (0.115)	2.228 (0.027)	2.080 (0.039)	2.586 (0.011)	3.316 (0.001)

Table 2
Learning time spent comparison (mean of minute)

	Chapter 1	Chapter 2	Chapter 3	Chapter 4	Total
IeLS	33	59	38	44	180
ELS	42	83	54	57	255
t (*p*-value)	3.088 (0.02)	2.957 (0.03)	2.292 (0.024)	2.057 (0.34)	3.331 (0.001)

too short to achieve a learning difference. From Course Chapter 2 on, we found that the learning performances in the two groups differed significantly, with students who used IeLS achieving higher scores than the students who used eLS. This indicates that the IeLS, our prototype of PVLE, can provide a better VLE, which can help students to achieve greater learning effectiveness.

Table 2 depicts the time spent on learning the contents in each chapter and shows the significant efficiency of learning in the IeLS. Fig. 9 also demonstrates the differences between the two study groups in terms of the time spent to perform each quizzes and the final exam. It was predicted that students who study in the IeLS would (1) spend less time to (2) achieve better exam scores comparing with those studying in eLearning System (shown in Fig. 9). MANOVA analysis reports that students in IeLS achieved significantly higher learning performance compared with those in eLS and manifesting a F value of 3.745 ($p=0.002$).

6. Conclusions

This study focuses on the development of the conceptual models for the personalized VLEs, including the models of knowledge primitives in terms of learner, curriculum, pedagogical, and situational models, models of VLEs in general, and particularly, the definition of the ontology of PVLEs based on constructivist pedagogical principle. It concludes that the domain knowledge is modeled in terms of the learning process situation rather than the knowledge itself, and that learning is afforded as a result of the learning situation rather than particular teaching strategies.

Based on those comprehensive conceptual models, a prototyped multiagent-based educational system has been implemented. A field experiment was conducted to investigate the learning achievements of personalized VLEs by comparing personalized and non-personalized eLearning systems. The experimental results reveal that online learners using the personalized VLE achieved significant greater learning achievements as compared to their counterparts using the non-personalized eLearning System. Thus, it indicates that personalized VLEs provide opportunities for online learners to amplify and extend their cognitive capabilities as well as to organize the thinking processes by altering the tasks available to them through individualized instruction. It also indicates that the PVLE system was developed successfully under our comprehensive ontology. In summary, the contributions of this study include:

(a) a formal representation for VLEs in terms of knowledge primitives perspective and pedagogical principle perspective;
(b) a conceptual model of PVLE, which is based on the constructivist learning model represented by a powerful modeling method, *Tropos*;
(c) the agent-oriented ontology of PVLEs, where agents (or actors) in the model are able to carry out actions to achieve goals or perform tasks with intentions; and
(d) the separation of the domain level and the meta level that reveals the meta level model provides deep understanding of the learning.

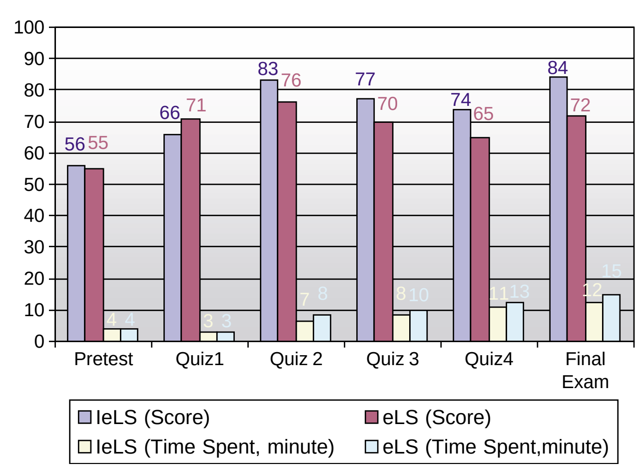

Fig. 9. Learning achievements.

The application of our models can lead to unambiguous understanding of the concepts and pinpoint the likely causes of learning failure. Furthermore, such conceptual models provide a uniform framework with which different approaches can be integrated together to provide more sophisticated functions and facilities. Therefore, by creating a rich conceptual model, the study provides a solid framework for PVLE development practice. The impacts of these comprehensive models provide a solid framework for PVLEs development practice, guiding the analysis, design, and development of PVLEs.

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