
Automatic, Global and Dynamic Student Modeling in a Ubiquitous Learning Environment

Sabine Graf*

Graduate Institute of Learning and Instruction, National Central University, No. 300, Jhongda Rd., Jhongli City, Taoyuan 32001, Taiwan

Fax: +886-3-4273371 E-mail: sabine.graf@ieee.org

*Corresponding author

Guangbing Yang

School of Computing and Information Systems, Athabasca University, 1 University Drive, Athabasca, Alberta T9S 3A3, Canada

Fax: +1 (780) 675-6973 E-mail: guangbing@athabascau.ca

Tzu-Chien Liu

Graduate Institute of Learning and Instruction, National Central University, No. 300, Jhongda Rd., Jhongli City, Taoyuan 32001, Taiwan

Fax: +886-3-4273371 E-mail: ltc@cc.ncu.edu.tw

Kinshuk

School of Computing and Information Systems, Athabasca University, 1 University Drive, Athabasca, Alberta T9S 3A3, Canada

Fax: +1 (780) 675-6973 E-mail: kinshuk@athabascau.ca

Abstract: Ubiquitous learning allows students to learn at any time and any place. Adaptivity plays an important role in ubiquitous learning, aiming at providing students with adaptive and personalized learning material, activities, and information at the right place and the right time. However, for providing rich adaptivity, the student model needs to be able to gather a variety of information about the students. In this paper, an automatic, global, and dynamic student modeling approach is introduced, which aims at identifying and frequently updating information about students' progress, learning styles, interests and knowledge level, problem solving abilities, preferences for using the system, social connectivity, and current location. This information is gathered in an automatic way, using students' behavior and actions in different learning situations provided by different components/services of the ubiquitous learning environment. By providing a comprehensive student model, students can be supported by rich adaptivity in every component/service of the learning environment. Furthermore, the information in the student model can help in giving teachers a better understanding about the students' learning process.

Keywords: Student modeling, ubiquitous learning, adaptivity.

Biographical notes: Sabine Graf is Postdoctoral Researcher at National Central University, Graduate Institute of Learning and Instruction, in Taiwan. Her research interests include adaptivity in learning systems, student modeling, ubiquitous learning, artificial intelligence, and collaborative learning. Dr. Graf has published more than 40 journal papers, book chapters, and conference papers. She is involved in research projects dealing with mobile and ubiquitous learning, student modeling, and the application of e-learning at universities.

Guangbing Yang is a systems analyst and programmer at Athabasca University, School of Computing and Information Systems, in Canada. With over decade of industry experience, he has been involved in the development of large-scale software in the finance, education and wireless industry. He received his MSc in computer science from Athabasca University, and he currently works as a programmer for the iCORE/Xerox research project.

Tzu-Chien Liu is now an Associate Professor in the Graduate Institute of Learning & Instruction, National Central University (NCU), Taiwan. His researches mainly focus on mobile learning and ubiquitous learning, educational robots, and cognitive processes of technology application. He has (co-)authored more than 100 book chapters, journal and international conference papers.

Kinshuk is Professor and Director of School of Computing and Information Systems at Athabasca University, Canada. He also holds iCORE/Xerox/Markin Industrial Research Chair in Adaptivity and Personalization in Informatics. He has been involved in large-scale research projects for exploration based adaptive educational environments and has published over 200 research papers in international refereed journals, conferences and book chapters. He is Founding Chair of IEEE Technical Committee on Learning Technology and editor of the SSCI indexed Journal of Educational Technology and Society (ISSN 1436-4522).

1. Introduction

Ubiquitous learning extends e-learning by bringing the concepts of anytime and anywhere to reality, aiming at providing students with opportunities to learn and take in educational content in their daily living environments. In ubiquitous learning, students can move with their mobile device, which can act, on one hand, as a learning environment by itself, connecting the student to courses, online resources, learning activities, and communication features, and on the other hand, the mobile device can interact with surrounding devices, either used by other students or embedded in everyday objects. Considering the context of a location, the surrounding objects can enable students to have a more authentic learning experience and hands-on or minds-on learning. By knowing the location of other peers/experts, the learning system can help students to build face-to-face learning groups or ask an expert in the vicinity of students who might be able to help them in learning.

Ubiquitous learning in a narrow sense focuses on the awareness of surrounding devices, meaning that students move around with their mobile devices, which support learning by communicating with embedded objects and devices in the surrounding environment (Hwang et al., 2008; Ogata & Yano, 2004). However, a broad definition of ubiquitous learning emphasizes on the aspect of enabling students to learn at any place

and at any time, incorporating mobile and/or pervasive aspects (Hwang et al., 2008; Ogata & Yano, 2004). The ubiquitous learning environment introduced in this paper focuses on enabling students to learn anytime and anywhere by providing them with different components/services in order to facilitate learning in different situations and contexts. One of these services focuses on the narrow definition of ubiquitous learning, considering the learning objects at a specific location and recommends students activities based on the surrounded learning objects as well as the student's interests.

Besides focusing on anywhere and anytime learning, a main objective of the environment is to provide students with adaptive learning opportunities, considering the students' characteristics, needs, and current situation. For enabling rich adaptivity, the student model is a crucial part of the ubiquitous learning environment. A student model includes information about the student, based on the system's beliefs about him/her. The process of building and updating a student model is called student modelling. While Self (1994) provided a comprehensive description of student modelling from a point of view of the formal techniques, Brusilovsky (1994; 1996) classified student models and techniques for student modelling based on existing systems.

In this paper, we propose a student modeling approach for a ubiquitous learning environment, which builds and updates information in an automatic, global, and dynamic way, allowing the environment and all its components/services to access the gathered data and use them for providing rich and accurate adaptivity. Automatic student modelling means that the process of building and updating the student model is done automatically based on the behavior and action of students when they are using the system for learning. However, in order to build a reliable and robust student model, enough data need to be available. The global aspect of the student modelling approach aims at addressing this issue by letting various services in the system collaborate and contribute together in gathering and updating the data in the student model. Furthermore, the student modelling approach is dynamic which means that it is frequently updated according to the students' behaviour and actions.

In the next section, the ubiquitous learning environment is introduced, explaining its aims and giving a brief description of the environment's components/services. Subsequently, the student modeling approach is described in detail, pointing out which characteristics and needs of students are stored in the student model, how the respective information is gathered and updated, which components/services contribute in this process, and how this information can then be used by other components/services. In order to verify the proposed student modeling approach and help teachers to get a better understanding about the students' learning processes, a tool has been implemented, which makes the data in the student model visible. This tool is presented in Section 4. Section 5 concludes the paper by discussing the benefits of the student modeling approach as well as future work.

2. The Environment

This research is part of a larger project that aims at providing students with an adaptive ubiquitous learning environment which facilitates learning at any time and any place. The architecture of this environment can be seen in Figure 1. The learning environment uses the multi-agent system paradigm, consists of different servers and databases, and provides several services for the students. The services cover different areas of the educational process and support students in different situations. In the following subsections, the services of the environment are introduced.

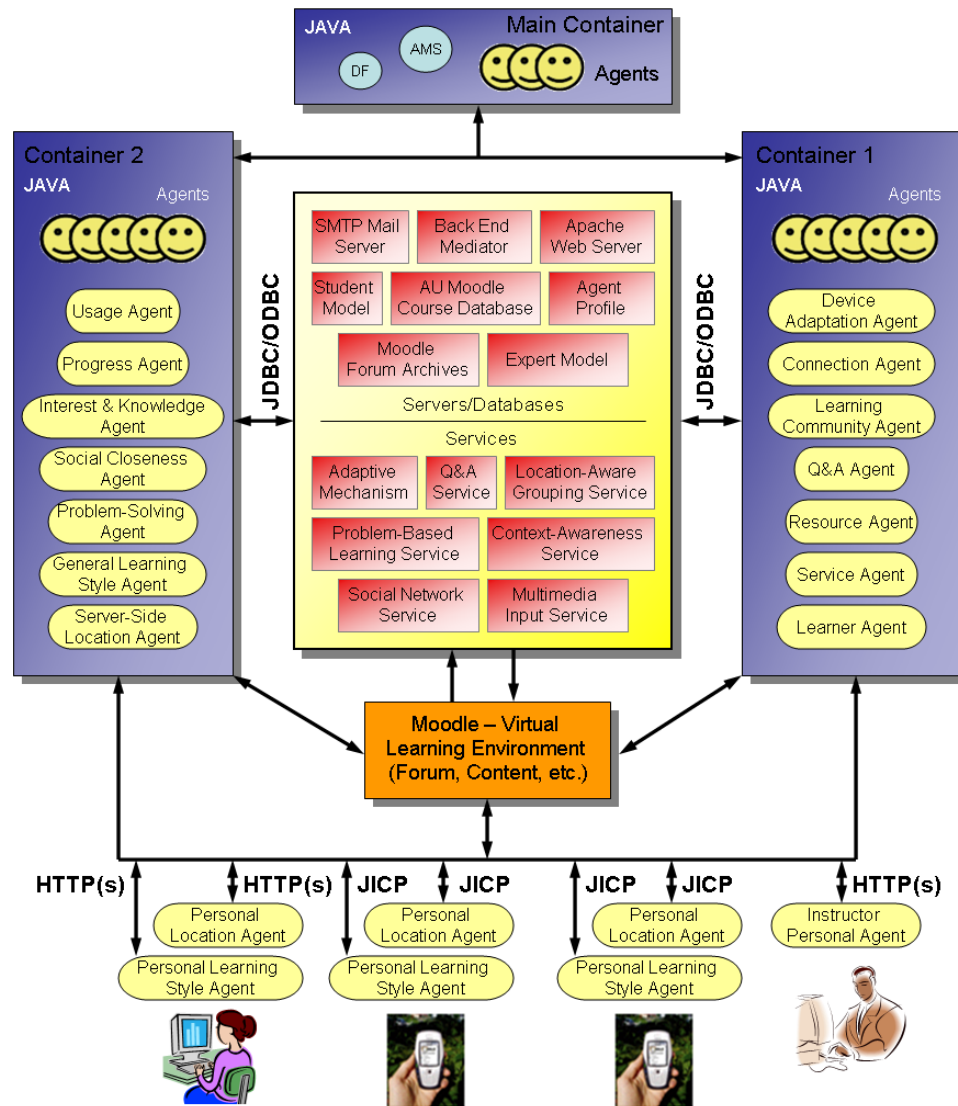


Figure 1: Architecture of the Adaptive Ubiquitous Learning Environment

2.1 Adaptive mechanism and content presentation

In order to provide students with learning material and activities for learning the basic elements of the course, the ubiquitous learning environment is combined with the learning management system Moodle (2008). Moodle is one of the most well known learning management systems with more than 45,000 registered sites world wide (Moodle Sites, 2008) and an evaluation showed that it is one of the most appropriate environments for being extended with respect to adaptivity (Graf & List, 2005).

The adaptive mechanism focuses on providing students with adaptive courses within Moodle, considering the students' learning styles. The incorporation of learning styles has high potential to make learning easier for students. Felder, for example, pointed out that students with a strong preference for a specific learning style might have difficulties in learning if their learning style is not supported by the teaching environment (Felder & Silverman, 1988; Felder & Soloman, 1997). On the other hand, incorporating learning styles can make learning easier, less complex, and less time-consuming (Graf & Kinshuk, 2007) and possibly lead to better achievement (Bajraktarevic et al., 2003).

The adaptive mechanism aims at extending Moodle in order to enable it to provide courses that fit the different students' learning styles. Moodle provides teachers with many different types of learning objects or activities, ranging from simply presenting learning material or examples to more advanced features such as quizzes, glossaries, surveys, wikis, chat, and many more. The adaptive mechanism is developed in a generic way, giving teachers and administrators the possibility to add whatever kind of learning object they want to use in their adaptive courses. As a result, teachers can continue using the learning management system, while taking full advantages of its enhanced features. Additionally, the adaptive mechanism facilitates the provision of courses that more closely fit students' different learning styles and therefore promotes learning.

2.2 Location-aware grouping service

A main feature of the ubiquitous learning environment is that it considers the students' current location. As pointed out by Chen et al. (2008), a number of studies have shown that mobile devices can facilitate face-to-face collaborative learning, increasing social interaction among students. The location-aware grouping service aims at assisting students in building face-to-face learning groups and therefore enables them to take advantage of collaborative learning. The location-aware grouping service includes three tasks: the detection of the students' location, the optimal grouping of students, and the provision and monitoring of collaborative learning activities for learning groups.

The mobile device of each student runs a personal location agent which identifies the students' location. Based on the location as well as other personal information such as the students' preferred time of learning, learning styles, problem-solving abilities, current state in the course, knowledge level, and how well students know each other, the grouping algorithm recommends possible group members for the group. If students accept to build a group, they are navigationally guided by the system to come near to each other and the learning group is provided with a learning activity, where students have to work on different tasks to complete that activity collaboratively. The learning activity aims at encouraging students to help each other in solving tasks and to discuss their results and findings with each other in order to come up with an overall solution.

2.3 Context-awareness service

Another main feature of the ubiquitous learning environment is not only to consider the students' current location but also the environmental context of the students' current location, in terms of what the student can learn at this location by using real-life objects available at that location. By being aware of the surrounding learning objects and possible location-specific learning activities, students can be provided with hands-on or minds-on learning as well as a more authentic learning experience.

In order to help a student to plan his/her learning activities when learning in the real world, an ubiquitous learning system needs to know what the student is looking for

and/or really interested in (Chang & Chang, 2006; Ogata & Yano, 2004). The context-awareness service aims at identifying a specific context-aware knowledge structure for each student, based on their interests as well as the available knowledge structures in different domains in the ubiquitous learning environment. This personalized context-aware knowledge structure gives information about which learning objects and activities students are looking for and interested in. Once the personalized context-aware knowledge structure has been found, the service can identify the learning objective(s) that the student is interested in, propose learning objects and activities to the students based on their interests, and lead them to the places where they can learn through experience.

2.4 Problem-based learning service

This service focuses on allowing students to learn through problem-based learning. Problem-based learning is a learner-centered approach, which is grounded in cognitive theories and focuses on putting students in real-world problem situations that can enhance the students' motivation (Haith-Cooper, 2000). In addition, problem-based learning also promotes the skills and knowledge required in problem solving by working collaboratively/cooperatively in small groups (Duch et al., 2001; Savery & Duffy, 1995).

This service encourages students to learn through problem-based learning by solving problems individually or in groups. While in the location-aware grouping service the focus is on building face-to-face learning groups in order to join students with peers with whom they can discuss and solve tasks together, the focus of this service is on problem-based learning, where students work in groups, communicate online or face-to-face, consider different contents and learning material, and go to different locations in order to cooperate in solving the problems. By using problem-based learning, students are encouraged to construct knowledge for application in the real world, develop problem-solving skills such as critical thinking and scientific reasoning, develop skills of self-directed learning or lifelong learning, and be more motivated in learning (Barrows, 1986; Bernstein et al., 1995; Charlin et al., 1998; Neufeld et al., 1989).

2.5 Question and answer service

Facilitating communication with other students and with teachers as well as supporting exchange and sharing of knowledge are other important features of a learning system. In order to make communication and knowledge sharing/exchange more convenient and efficient, the discussion forum in Moodle is extended with a question and answer service, which aims at assisting students in finding suitable answers to their questions. The service is intended to work in a multi-modal setting in order to provide students access and interaction to both questions and answers through mobile devices as well as from the Web, and enable multiple media formats of questions/answers such as text, graphics, and voice.

If a student asks a question in the discussion forum, this question is passed on to the question and answer service, which searches for a suitable answer in different sources, including a search in the past question/answer pairs, followed by a search in the Moodle site, and after that continues with a search in the whole web. If still no suitable answer is found, the question will be passed on to the teacher in order to be answered.

When searching for suitable answers, the student's context and characteristics are considered, including information such as the current course, the current state in the course, previously asked questions, currently viewed learning objects and performed learning activities, the current location of the student, his/her interests and knowledge level, and his/her learning styles. By considering this information, the service is able to identify answers which other students with similar context and characteristics found

useful and can recommend them as suitable answer. Furthermore, additional information about answers can be gained from tagging, where students can provide meta-information about the answer, describing the topic as well as qualitative aspects such as the pedagogical value of an answer.

Another feature of this service is to provide students with a list of possible question/answer pairs which might be of interest for them, based on the information about their context and characteristics.

2.6 Multimedia input service

Mobile devices offer a rich source of interaction. On a mobile device, students have access to various forms of input that allow them to create text (via keyboard and digital ink), images (via the camera), and sound (via the microphone) on a relatively small, portable device. By combining these input media types constructivist learning can be promoted.

Use of multimedia enables rich environment for learning. This service aims at encouraging students to use the rich input facilities, such as text, images, voice and digital ink, offered by mobile devices to enhance interaction. In order to draw conclusions about students' preferred usage of multimedia inputs, the service analyses the students' usage of different multimedia inputs, using the discussion forum in Moodle as source of information and providing students with learning activities which encourage the usage of different input modes. The service looks into which input modes individual students prefer in general and which input modes they prefer in different contexts and situations.

Allowing students to select how they interact with each other supports the students' preferred learning styles and enables students to communicate more easily. Students may also feel more connected with each other as voice and images can support the student's social presence and help students feel more of a community of learners (Garrison et al., 2000).

2.7 Social network service

The social network service aims at integrating social network features into the ubiquitous learning environment. As discussed before, communication is a crucial issue in a learning environment and social networks have the potential to increase communication among students and help in building a learning community.

It is anticipated that a significant number of students already participate in online social networks outside the educational institutions. A recent study suggests that up to 96% of young online users engage in social sites such as MySpace, Facebook, YouTube and Flickr (Grunwald Associates LLC, 2007)

Using social networks in the ubiquitous learning environment has two advantages: first, students can benefit from the social network features in terms of communicating with their peers in different ways, using different kinds of Web 2.0 features, and build a learning community. Second, information from already available social network accounts can be used in order to get additional data for the student model and, in turn, enhance the possibilities of adaptivity in the learning environment. However, an important issue in this context is control and trust. Therefore, an interesting research challenge is to provide a controllable, safe interaction between the formal educational world and the informal world of social networks and Web 2.0 features.

3. Student Modeling

One of the main objectives of the ubiquitous learning environment is to provide students with rich adaptive support in each service. Therefore, the student model plays a crucial role, storing and updating the relevant information about students which is needed in order to provide adaptivity.

The student model aims at identifying students' characteristics, needs, and situation in an automatic way, using students' behavior and actions in order to automatically infer the relevant information. All services contribute data in order to build and update the student model frequently. Furthermore, all services have access to the information stored in the student model. Since the ubiquitous learning environment is developed using the concept of agents, agents are responsible for gathering data from different services, calculating the respective information, storing it in the student model, updating the information if necessary, and providing services with access to this information.

The student model includes the following categories of information about students: profile, usage of the system, progress, interests and knowledge level, learning styles, problem-solving abilities, social closeness, and location. Each of these categories includes several kinds of information. In the following subsections, the student modeling process for each category is explained in more detail, giving a description of the relevant information of each category, showing which services require the respective information as well as deliver data to obtain the information, and introducing the tasks of the agents for gathering and providing the respective information.

3.1 Profile

Different from all other categories of the student model, the profile of the student includes only static information, which is mainly used for administrative issues rather than for providing adaptivity in the services. The profile includes information such as the student's name, gender, student ID, begin of study, grade, study program, and contact address. Once students register in the ubiquitous learning environment, they have to provide the respective information and can later update the information if required.

3.2 Usage of the system

This category of the student model aims at gathering information about how students use the system, which services they use, and when they use the system/services for learning. It includes three kinds of information about the students, referred to as variables: The *current course* specifies which course the student is currently logged in and learning in. Regarding this variable, also a history of used courses is stored. In addition, the student model stores information about the *preferred services* of each student, including how much time a student spent in each service and which services he/she used most for learning. Furthermore, the *preferred learning time* is stored, using categories such as morning, afternoon, evening, night as well as weekend and weekdays.

The information about the current course can be gathered from the login interface of the ubiquitous learning environment, where students need to specify in which course they want to enter. In order to populate the student model with information about the preferred services and learning time, all services need to contribute by storing data about the usage of the respective service in a central database table.

The *usage agent* is responsible for assisting the services in updating the central database table. Therefore, the services send a request to the usage agent whenever a

student starts or finishes using the service, and the usage agent fills then the central table with the respective information. Furthermore, the usage agent is responsible for providing access to the abovementioned kinds of information. Once a request from a service comes in, the agent calculates the required information, such as what the preferred learning time of the student is or which service he/she prefers, and passes the information to the requesting service.

The information about the current course is used by the adaptive mechanism for providing material and activities for the respective course, the location-aware grouping service for grouping students from the same course, the context-awareness service for suggesting suitable learning objects and activities, the problem-based learning service for assigning suitable problems, and the question and answer service for getting the context of the question. The information about the preferred service can give information about the preferred learning style of a student and is therefore used as a pattern in the detection process of learning styles. The preferred learning time is used by the location-aware grouping service in order to group students who prefer to learn at the same time.

3.3 Progress

The progress of students includes information about three variables. First, information about *viewed learning objects (LO)* and *learning activities (LA)* are stored, allowing seeing which LOs and LAs were visited or conducted last. Second, the students' *state* in the course is stored, indicating how many percentage of LOs and LAs a student has already conducted in each service and overall. Third, the *questions asked* in the discussion forum (including the extension of the question and answer service) are stored, indicating how many questions a student has posted and what he/she has posted so far. All three variables include not only information about the current progress of students but store also the past data.

Information about the viewed LOs and LAs as well as the students' state in the course is gathered from the adaptive mechanism, the location-aware grouping service, the context-awareness service, and the problem-based learning service. All these services contribute to filling a table including the last viewed LOs and LAs, from which the students' state can also be calculated. Information about previously asked questions can be collected from the question and answer service, which is connected to the discussion forum in Moodle.

The *progress agent* is responsible for updating the information in the student model with respect to the students' progress. Therefore, whenever a student is visiting an LO, conducting an LA, or asking a question in the discussion forum, the respective service sends a request for updating to the progress agent, who then updates the information in the student model. Furthermore, the progress agent is responsible for answering requests about viewed LOs and LAs, the current or past state of a student, as well as currently or previously asked questions.

All three kinds of information are used by the question and answer service, in order to find answers which were recommended by students who looked at similar LOs and LAs and had a similar state in the course when annotating the answer as useful. Furthermore, the previously asked questions of the students are considered in the search process. The currently viewed LOs and LAs are additionally used by the problem-based learning service in order to assign students a suitable problem. The current state of the students is used by the location-aware grouping service in order to build suitable learning groups and by the context-awareness service in order to plan an appropriate learning path for the student.

3.4 Interests and knowledge level

This category of the student model includes students' *interests* and *knowledge level* as well as past data about both. Both kinds of information are based on a global concept map, which is built by the context-awareness service and extended by the concepts of the problem-based learning service and the social network service. This concept map provides a hierarchy of the concepts, giving information about sub-concepts and upper concepts. Interests are measured in terms of strong interest (if a student showed interest more than once in a specific concept), weak interest (if a student showed only once interest in the concept), and disinterest (if a student rejected to learn about the concept at the majority of requests). For the knowledge level, three degrees are used, namely above-average, average, and below-average.

While being interested in a concept does not necessarily imply that the student has knowledge about this concept, for the knowledge level, some kind of assessment is required. Interests in concepts can be gathered from the context-awareness service according to which LOs/LAs students chose to visit/conduct and which LOs/LAs students rejected to visit. Additionally, information about interests can be gathered by the problem-based learning service from the visited LOs, conducted LAs, and solved problems. Furthermore, the social network service can provide data about students' interests, for example, from classifying students' bookmarked entries. For the knowledge level, information can be gathered from the problem-based learning service, where the students' performance in solving a particular problem is measured.

The *interest and knowledge agent* is responsible for assisting services in adding new concepts to the concept map as well as add/update students' interests and knowledge level in the student model. Furthermore, the agent provides information about interests and knowledge level to requesting services.

The students' interests play an important role for the context-awareness service, which plans students' navigation paths based on their interests. Furthermore, the problem-based learning service uses interests in order to assign problems, and the question and answer service uses the information about students' interests in order to find suitable answers which were annotated as useful from students with similar interests. In addition, the knowledge level is considered when searching for suitable answers in the question and answer service. Furthermore, the knowledge level is important for the location-aware grouping service in order to build suitable learning groups.

3.5 Social closeness

This category includes information about the *level of familiarity* between students, indicating whether they know each other, have already learnt together, and are willing to learn together. Furthermore, information about the students' *general preference for collaboration*, in terms of whether they like to work and learn together with other peers, is stored.

Data for gathering the students' general preference for collaboration is gathered from the location-aware grouping service, where students are asked whether they want to build a group with other peers. Furthermore, the decision about entering a group provides information for the level of familiarity, showing that the students are willing to learn together and, after completing the learning activity, that they have learnt together and of course know each other. Moreover, the problem-based learning service can contribute in identifying which students know each other and learnt together based on the built groups. The social network service can provide additional information about who knows each other based on the contact lists in the social networks.

The task of the *social closeness agent* is to assist the services to build and update the database tables regarding social closeness. Therefore, when a grouping request is answered, a group is built, or the contact list in a social network is updated, the agent needs to update the information in the student model. On the request from services, the agent calculates the level of familiarity as well as the students' general preference for collaboration from the data stored in the student model and provides the requesting service with the respective information.

The level of familiarity is used by the location-aware grouping service and the problem-based learning service in order to build suitable groups. Furthermore, it is used by the social network service in order to highlight peers the student knows or is more familiar with. The general preference for collaboration is used on one hand by the problem-based learning service in order to get a better understanding about the learning processes in a group, and on the other hand, the preference for collaboration can contribute and provide additional information for identifying learning styles.

3.6 Problem-solving abilities

This category deals with problem-solving abilities, including *critical thinking*, *scientific reasoning*, *motivation in problem-solving* as well as the *overall problem-solving ability*. Each of these abilities can be seen as a variable in the student model. For all variables, the currently identified ability as well as previously identified abilities are stored.

The problem-solving abilities can be identified by the problem-based learning service by looking at how students solve problems and which performance they achieve on solving problems, assuming that each problem requires certain abilities. The *problem-solving agent* is responsible for building and updating the information about students' problem-solving abilities in the student model and provides this information to other services.

The problem-solving abilities are used by the problem-solving learning service in order to assign suitable problems to students. Furthermore, the location-aware grouping service includes the information about problem-solving abilities for recommending suitable group members. In addition, problem-solving abilities can provide information for identifying learning styles and are therefore used as patterns in the identification process of learning styles.

3.7 Learning styles

For considering learning styles, the Felder-Silverman learning style model (FSLSM) (Felder & Silverman, 1988) was used. Many learning style models exist in literature (e.g., Honey & Mumford, 1982; Kolb, 1984; Pask, 1976). However, most of them classify students into few groups, whereas Felder and Silverman describe the learning styles of a student in more detail, distinguishing between preferences on four dimensions: *active/reflective*, *sensing/intuitive*, *visual/verbal*, and *sequential/global*. By using scales, the degree of preference can be expressed, allowing also to describe a balanced learning style. Another main difference is that FSLSM is based on tendencies, indicating that students with a high preference for certain behaviour can also act sometimes differently. In addition, FSLSM is suggested and used very often for technology enhanced systems (e.g., Carver et al., 1999; Kuljis & Liu, 2005).

The student model uses the students' behavior, actions, and preferences in several services for automatically inferring students' learning styles. Graf, Kinshuk, and Liu (2008) introduced an approach for identifying learning styles from the behavior and actions of students in a course in Moodle. The student modeling approach introduced in

this paper is based on this approach but extended by the use of data from other services. Patterns about students' behavior and actions are also extracted from the problem-based learning service. Furthermore, the question and answer service can provide information about students' communication behavior, including the time students spent on reading question/answer pairs, the number of posted questions, and students' preference for specific media types and particularly tagging answers. Furthermore, the multimedia input service provides more detailed information about students' preferred media type. Patterns regarding communication are especially relevant for identifying learning style preferences for the active/reflective and visual/verbal dimension. In addition, some of the variables can act as patterns for providing information for identifying learning styles. The usage of services and the students' preferred services can give information about their learning styles. Furthermore, the willingness for collaboration gives an indication with respect to the active/reflective dimension. In addition, some of the problem-solving abilities, such as critical thinking, give indications of preferences for specific learning styles. Furthermore, additional information might come from the Index of Learning Styles questionnaire (Felder & Soloman, 1997), which was developed for identifying learning styles based on the FLSM and can be filled out by students optionally. Data from this questionnaire can be used for initializing the student model, while data about students' behavior and actions can then be used for revising and improving the information in the student model.

The *general learning style agent* is responsible for providing services with information about the learning styles of students, which are stored in a central database table. Furthermore, one *personal learning style agent* exists for each student, who monitors the students' behavior and actions in the services, or more specifically, monitors the changes in the database tables. If data regarding the relevant patterns for identifying learning styles change (e.g., a student posts a message or the critical thinking ability of a student is identified or updated), the personal agent calculates whether a change of the currently stored learning styles of the student is required and updates it if necessary. Through the usage of personal agents, the student modeling approach is able to improve and revise the information in the student model frequently, leading to a higher accuracy for adaptivity.

The learning styles are used as basis for the adaptive mechanism in order to provide students with courses in Moodle which fit to their learning styles. Furthermore, the problem-based learning service uses the information about learning styles in order to assign suitable problems to students and the location-aware grouping service considers learning styles for building groups. Furthermore, the question and answer service incorporates learning styles in order to provide answers which fit the preferred way of perceiving and acquiring information, such as considering the preferred media type.

3.8 Location

This category includes the current and past *location* of students. Location information is, on one hand, identified and stored as GPS coordinates and, on the other hand, a textual description is assigned, in the form of a postcode or address as well as a name of the place such as "home" or "Athabasca University".

The identification of the current location of a student is performed by a tool provided by the location-aware grouping service. For identifying the current location of a student, the mobile device of each student runs a *personal location agent*, which periodically acquires available location information from GPS satellites, base stations of cellular networks, or access points for Wi-Fi broadband wireless networks, considering the differences of various mobile devices in the market. In order to make the

identification of the current location of the student faster, the identification is based on an initial location. This initial location is the location of a place, where the student usually uses the system, such as at home or at the work place. The information about this initial location is requested from the student. As an alternative, information about the country, city and maybe even students' postal address can be extracted from the social networks service.

While the personal location agents are responsible for updating the location information of each student, a *server-side location agent* answers requests from services to get information about the current and past location of students.

The location information is used by the location-aware grouping service in order to assist students in building face-to-face learning groups. Furthermore, the information about the location is important for the context-awareness service in order to use information about the students' current context for learning, such as which learning objects are close to the student and which activities can be conducted at the current place. Moreover, the location is used by the problem-based learning service in order to assign suitable problems, learning activities, and learning objects to the students. Furthermore, in the question and answer service, the students' current location is used to search for question/answer pairs which were asked by students who were at the same place when they asked their question.

4. Visualization of the Student Model

On one hand, a detailed and frequently updated student model is a crucial requirement for providing rich adaptivity to students. On the other hand, the information in the student model can also be of help for teachers to get a better understanding about how and to what extent students use the system, which learning objects and learning activities they visited and conducted, and what their progress, state in the course, knowledge level and other characteristics are.

The screenshot shows a web browser window titled "Athabasca University - Learning Communities Project - Mozilla Firefox". The address bar shows a local file path. The page has a header with the text "LEARNING COMMUNITIES PROJECT" and a navigation bar with tabs: "Student Model", "Profile", "Progress", "Learning Style", "Interests & Knowledge", "Problem Solving", "Usage", "Social Connectivity", and "Locations". The "Student Model" tab is active, showing a "Student List" on the left with names like John Smith, Mary MacGregor, Paula Shaw, Jay MacCown, Kirk Young, and Joe Dow. The main area displays the "Current Profile" for "JAY MACCOWN". Below this, there are two sections: "SELECTED PROFILE:" and "New Profile:". The "SELECTED PROFILE:" section contains a form with fields for First Name (Jay), Last Name (MacCown), Gender (Male), Student ID (12345), Begin of Study (2005-09-01), Grade (Undergraduate), Study Program (History), Address (Some street4), City (Some city4), Province (Some province4), Country (Some country4), Home Phone (123-456789), Work Phone (123-987654), Cell Phone (987-654321), and Email (jmaccown@athabasca). An "Update Profile" button is at the bottom of this section. The "New Profile:" section has a prompt: "Enter a Name, Gender, Student ID, and other information to be added as a new student profile to the system." Below this are input fields for First Name, Last Name, Gender, Student ID, School Year, Grade, Subjects, and Address, each with a "Some Test Property" placeholder. The footer includes "©Copyright 2009" and a language selector for English, Français, and Español.

Figure 2: Interface for students' profile

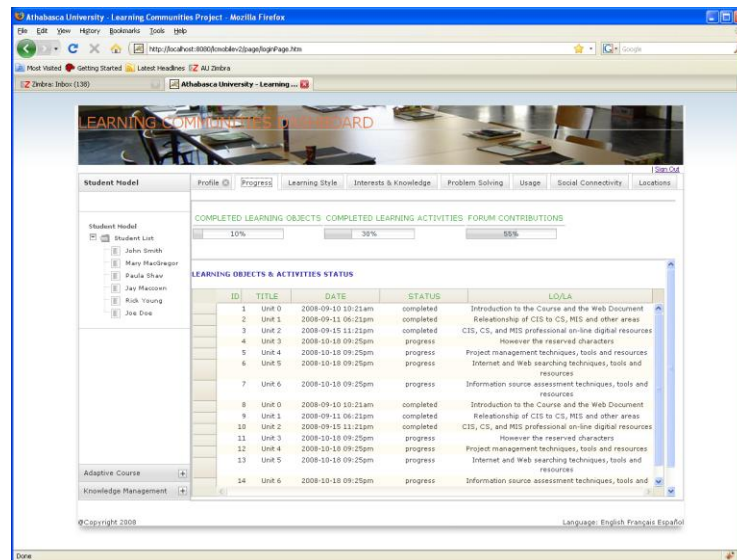


Figure 3: Interface for students' progress

In order to give teachers the opportunity to see such information, we provide them with a tool that makes the data in the student model visible. Examples of screen shots can be seen in Figure 2 and Figure 3. Figure 2 shows the information in the students' profile and Figure 3 presents information about students' progress, showing the students' state in the course, in terms of how many learning objects, learning activities and forum entries a student has already completed. Furthermore, a teacher gets information about when a student visited a particular learning object (LO) or learning activity (LA) and his/her status in the corresponding learning unit.

5. Discussion and Conclusions

In this paper, an automatic, global, and dynamic student modeling approach for a ubiquitous learning environment was introduced. This approach uses the behavior and actions of students in order to identify the students' progress, learning styles, interests and knowledge level, problem solving abilities, preferences for using the system and/or services within the system, social connectivity, and the current location of the students. Most ubiquitous learning systems provide adaptivity based on few characteristics of students (Graf & Kinshuk, 2008), considering for example only their current location and maybe their knowledge level. In contrast, the student modeling approach presented in this paper aims at including many characteristics in order to provide rich and accurate adaptivity in each service and allow teachers to get a better understanding of the students' learning process.

By using an automatic approach to identify all these characteristics, students do not need to provide explicit information to the system but just need to use the system for learning, while the system is logging the data about students' behavior and actions and using that data for automatically inferring their characteristics. Furthermore, the approach

is dynamic in terms of frequently updating the information in the student model in order to keep the student model accurate and therefore being able to respond immediately to students' needs and provide them with suitable and adaptive support and/or learning opportunities.

Gathering all this information in an automatic and dynamic way is possible due to the several services included in the ubiquitous learning environment, which aim at supporting students in different learning situations. All services of the environment contribute in the student modeling process, providing data from different learning situations and contexts. This global aspect of student modeling has several benefits. First, information which is used by more than one service needs to be gathered only once and can then be used by all other services. Second, data for identifying one characteristic can be gathered from different services, which leads not only to more information but also to a more accurate student model, especially when aiming at frequently updating the student model. Third, information which is needed by a certain service, might be easily gathered by other service and can therefore be provided in the global student model.

However, the services themselves should not be dependent on each other. Therefore, the learning environment is designed in such a way that if services require certain information in order to provide adaptivity, they are able to detect this information by themselves. Furthermore, several kinds of information are optionally included in the adaptation process, meaning that they enrich adaptivity if available but a service can also provide students with learning experience without this information.

In systems for non-mobile learning, researchers have also focused on combining different components or services for providing adaptivity and personalization. Brusilovsky (2004), for example, proposed a similar but more generic architecture for adaptive e-learning. In this architecture, distributed reusable intelligent learning activities can be combined. Furthermore, a student model gathers event-specific data from the learning activities and provides information in order to support adaptivity. Our approach is different in several issues: while Brusilovsky's architecture is generic and therefore does not predefine the intelligent learning activities included in the system, in our system the services are known, which allows gathering more detailed information for student modeling. Furthermore, since our system focuses on ubiquitous learning, additional characteristics are relevant such as the current location of students and their social connectivity. Furthermore, our system integrates in a learning management system (LMS), while Brusilovsky's architecture is proposed as an alternative to LMSs. By extending LMS, teachers can continue using their existing courses and can extend them by using the available services rather than being forced to develop a new course from scratch. Another example of related work is MUPPLE (Mödrtscher & Wild, 2008), which focuses on web application mashups, displaying various web-based tools in one aggregated view. However, MUPPLE focuses on personalization aspects regarding how students can design their learning environment, in terms of exchanging web applications, deleting applications, and so on, while our approach aims at providing adaptivity and personalization within these applications/services.

Our future work will deal with evaluating the adaptive functionality of the services of the environment. Furthermore, students' behavior and actions gathered in the student model will be analyzed in order to draw conclusions about the functionality of the services and about possible improvements. In addition, we plan to analyze whether and how students' characteristics change during their learning process in the learning environment.

6. Acknowledgements

The authors wish to acknowledge the work of this research would not be possible without gift funding provided to the Learning Communities Project by Mr. Allan Markin. The authors would like to thank the National Science Council of the Republic of China, Taiwan, for financially supporting this research under Contract No. NSC 96-2520-S-008-007-MY2 and NSC 097-2811-S-008-001-.

References

- 1 Bajraktarevic, N., Hall, W., & Fullick, P. (2003). Incorporating Learning Styles in Hypermedia Environment: Empirical Evaluation. In P. de Bra, H.C. Davis, J. Kay & M. Schraefel (Eds.) *Proceedings of the Workshop on Adaptive Hypermedia and Adaptive Web-Based Systems* (pp. 41-52). Nottingham, UK: Eindhoven University.
- 2 Barrows, H.S. (1986). A Taxonomy of Problem-Based Learning Methods. *Medical Education*, 20 (6), 481-486.
- 3 Bernstein, P., Tipping, J., Bercovitz, K., & Skinner, H.A. (1995). Shifting Students and Faculty to a Problem-Based Learning Curriculum: Attitudes Changed and Lessons Learned. *Academic Medicine*, 70 (3), 245-247.
- 4 Brusilovsky, P. (1994). The Construction and Application of Student Models in Intelligent Tutoring Systems. *Journal of Computer and Systems Sciences International*, 32 (1), 70-89.
- 5 Brusilovsky, P. (1996). Methods and Techniques of Adaptive Hypermedia. *User Modeling and User-Adapted Interaction*, 6 (2-3), 87-129.
- 6 Brusilovsky, P. (2004). Knowledge Tree: A Distributed Architecture for Adaptive E-Learning. In S.I. Feldman, M. Uretsky, M. Najork & C.E. Wills (Eds.) *Proceedings of the International Conference on World Wide Web* (pp. 104-113). New York, USA: ACM Press.
- 7 Carver, C.A., Howard, R.A., & Lane, W.D. (1999). Addressing Different Learning Styles through Course Hypermedia. *IEEE Transactions on Education*, 42 (1), 33-38.
- 8 Chang, A., & Chang, M. (2006). Creating an Adaptive Mobile Navigation Learning Path for Elementary School Students' Remedy Education. In *Proceedings of the International Conference on Interactive Computer Aided Learning*, Villach, Austria.
- 9 Charlin, B., Mann, K., & Hansen, P. (1998). The Many Faces of Problem-Based Learning: A Framework for Understanding and Comparison. *Medical Teacher*, 20 (4), 323-330.
- 10 Chen, N.-S., Kinshuk, Wei, C.-W., & Yang, S.J.H. (2008). Designing a Self-contained Group Area Network for Ubiquitous Learning. *Educational Technology & Society*, 11 (2), 16-26.
- 11 Duch, B., Gron, S., & Allen, D. (2001). *The Power of Problem-Based Learning*. Sterling, VA: Stylus Publishing.
- 12 Felder, R.M., & Silverman, L.K. (1988). Learning and Teaching Styles in Engineering Education. *Engineering Education*, 78 (7), 674-681.
- 13 Felder, R.M., & Soloman, B.A. (1997). *Index of Learning Styles Questionnaire*. Retrieved November 15, 2008, from <http://www.engr.ncsu.edu/learningstyles/ilsweb.html>.

- 14 Garrison, D.R., Anderson, T., & Archer, W. (2000). Critical Inquiry in a Text-Based Environment: Computer Conferencing in Higher Education. *The Internet and Higher Education*, 2 (2-3), 1-19.
- 15 Graf, S., & Kinshuk (2007). Providing Adaptive Courses in Learning Management Systems with Respect to Learning Styles. In G. Richards (Ed.) *Proceedings of the World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education (E-Learn)* (pp. 2576-2583). Chesapeake, VA: AACE Press.
- 16 Graf, S., & Kinshuk (2008). Adaptivity and Personalization in Ubiquitous Learning Systems. In *Proceedings of the Symposium on Usability and Human Computer Interaction for Education and Work (USAB 2008)* (pp. 331-338). Berlin: Springer.
- 17 Graf, S., & List, B. (2005). An Evaluation of Open Source E-Learning Platforms Stressing Adaptation Issues. In P. Goodyear, D.G. Sampson, D.J.-T. Yang, Kinshuk, T. Okamoto, R. Hartley & N.-S. Chen (Eds.) *Proceedings of the 5th International Conference on Advanced Learning Technologies* (pp. 163-165). Los Alamitos: IEEE Computer Science.
- 18 Graf, S., Kinshuk, & Liu, T.-C., (2008). Identifying Learning Styles in Learning Management Systems by Using Indications from Students' Behaviour. In *Proceedings of the International Conference on Advanced Learning Technologies* (pp. 482-486). Los Alamitos: IEEE Computer Science.
- 19 Grunwald Associates LLC (2007). *Creating & Connecting: Research and Guidelines on Online Social and Educational Networking*: National School Boards Association.
- 20 Haith-Cooper, M. (2000). Problem-Based Learning within Health Professional Education. What Is the Role of the Lecturer? A Review of the Literature. *Nurse Education Today*, 20 (4), 267-272.
- 21 Honey, P., & Mumford, A. (1982). *The Manual of Learning Styles*. Maidenhead: Peter Honey.
- 22 Hwang, G.-J., Tsai, C.-C., & Yang, S.J.H. (2008). Criteria, Strategies and Research Issues of Context-Aware Ubiquitous Learning. *Educational Technology & Society*, 11 (2), 81-91.
- 23 Kolb, D.A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Englewood Cliffs, New Jersey: Prentice-Hall.
- 24 Kuljis, J., & Liu, F. (2005). A Comparison of Learning Style Theories on the Suitability for Elearning. In M.H. Hamza (Ed.) *Proceedings of the Iasted Conference on Web Technologies, Applications, and Services* (pp. 191-197). ACTA Press.
- 25 Mödritscher, F., & Wild, F. (2008). Personalized E-Learning through Environment Design and Collaborative Activities. In *Proceedings of the Symposium on Usability and Human Computer Interaction for Education and Work (USAB 2008)*. Berlin: Springer.
- 26 Moodle (2008). Retrieved November 15, 2008, from <http://www.moodle.org>.
- 27 Moodle Sites (2008). Retrieved November 15, 2008, from <http://moodle.org/sites/>.
- 28 Neufield, V., Woodward, C., & Macleod, S. (1989). The McMaster M.D. Program: A Case Study of Renewal in Medical Education. *Academic Medicine*, 64 (8), 423-432.
- 29 Ogata, H., & Yano, Y. (2004). Context-Aware Support for Computer-Supported Ubiquitous Learning. In *Proceedings of the International Workshop on Wireless and Mobile Technologies in Education* (pp. 27- 34).

- 30 Pask, G. (1976). Styles and Strategies of Learning. *British Journal of Educational Psychology*, 46, 128-148.
- 31 Savery, J.R., & Duffy, T.M. (1995). Problem Based Learning: An Instructional Model and Its Constructivist Framework. *Educational Technology*, 35 (5), 31-38.
- 32 Self, J. (1994). Formal Approaches to Student Modelling. In G.I. McCalla & J. Greer (Eds.) *Student Modelling: The Key to Individualized Knowledge-Based Instruction* (pp. 295-352). Berlin: Springer.