# Learning in Ubiquitous Computing Environments

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## ABSTRACT

*The application of ubiquitous technologies in the improvement of education strategies is called Ubiquitous Learning. GlobalEdu is a model created to support ubiquitous learning. The model has the necessary support to implement learning-related functionalities in ubiquitous environments. The basic ubiquitous computing support must be supplied by a middleware where GlobalEdu lays atop. This article proposes the GlobalEdu model and its integration with two ubiquitous middlewares: ISAM and LOCAL. ISAM supports the creation of large-scale ubiquitous systems. As such, its integration with GlobalEdu results in large-scale ubiquitous learning environments. LOCAL is dedicated to create small-scale ubiquitous learning environments. The integration GlobalEdu/LOCAL results in a local ubiquitous learning environment. Based on this small-scale environment, the authors' created a system and applied it in a practical scenario involving the community of a Computer Engineering undergraduate course. The system was positively evaluated by 20 individuals and the initial results attest the system's usefulness.*

*Keywords:* *Context-Aware Computing, Location Systems, Mobile Computing, Ubiquitous Computing, Ubiquitous Learning*

## INTRODUCTION

In recent years, studies about mobility in distributed systems have been stimulated by the proliferation of portable electronic devices (for example, cell phones, handheld computers, tablet PCs and notebooks) and the use of interconnection technologies based on wireless communication (such as WiMAX, WiFi, and bluetooth). This mobile and distributed paradigm is called *Mobile Computing* (Diaz, Merino, & Rivas, 2009; Satyanarayanan et al., 2009).

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Moreover, the improvement and proliferation of *Location Systems* (Hightower & Borriello, 2001; Hightower & Smith, 2006) have motivated the adoption of solutions that consider the user's precise location for the provision of services, *Location-Based Services* (Dey et al., 2010; Vaughan-Nichols, 2009).

The adoption of these technologies combined with the diffusion of sensors enabled the availability of computational services in specific contexts – *Context-aware Computing* (Baldauf, Dustdar, & Rosenberg, 2007; Dey, 2001; Hoareau & Satoh, 2009). The idea consists in the perception of characteristics related to the users and their surroundings. These characteristics are normally referred to as context, i.e., any information that can be used to describe the circumstances concerning an entity. Based on perceived context, the application can modify its behavior. This process, in which software modifies itself according to sensed data, is named *Adaptation* (Satyanarayanan, 2001). In this scenario, the *Ubiquitous Computing* initially introduced by Abowd and Mynatt (2000), Satyanarayanan (2001), and Weiser (1991) is becoming reality.

The application of mobile and ubiquitous computing in the improvement of education strategies has created two research fronts called Mobile Learning and Ubiquitous Learning. Mobile learning (m-learning) (Tatar, 2003) is fundamentally about increasing learners' capability to carry their own learning environment along with them. M-learning is the natural evolution of e-learning, and has the potential to make learning even more widely accessible. However, considering the ubiquitous view, mobile computers are still not embedded in the learners' surrounding environment, and as such they cannot seamlessly obtain contextual information.

On the other hand, Ubiquitous Learning (Barbosa et al., 2007; Lewis et al., 2010; Ogata & Yano, 2009; Ogata et al., 2010; Rogers et al., 2005; Yin, Ogata, & Yano, 2004; Yin et al., 2010) refers to learning supported by the use of mobile and wireless communication technologies, sensors and location/tracking mechanisms, that work together to integrate learners with their environment. Ubiquitous learning environments connect virtual and real objects, people and events, in order to support a continuous, contextual and meaningful learning. A ubiquitous learning system can use embedded devices that communicate mutually to explore the context, and dynamically build models of their environments. It is considered that while the learner is moving with his/her mobile device, the system dynamically supports his/her learning by communicating with embedded computers in the environment. The opportunities made available by the context can be used to improve the learning experience.

This learning scenario is attractive, but is not easily implemented. We are investigating how to better match people's expectations for such a system. In our point of view, ubiquitous learning environments should support the execution of context-aware, distributed, mobile, pervasive and adaptive learning applications.

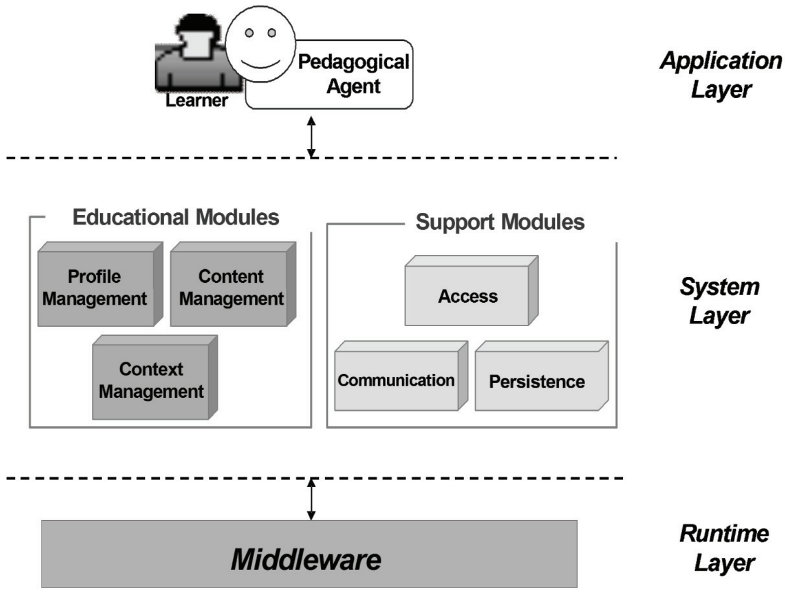
GlobalEdu is a model created to support ubiquitous learning. The model is structured into layers and can also be coupled with a ubiquitous computing middleware. This article proposes the GlobalEdu Model and its integration with two ubiquitous middleware projects: ISAM (Augustin et al., 2004) and LOCAL (Barbosa et al., 2007).

The ISAM project focuses on the building and management of large-scale ubiquitous computing environments (Augustin et al., 2004), and is being developed at UFRGS (Federal University of Rio Grande do Sul, Brazil). The integration GlobalEdu/ISAM results in a large-scale ubiquitous learning environment.

On the other hand, LOCAL aims to support small-scale, location-and-context-aware computing environments. It is being developed at University of Vale do Rio dos Sinos (UNISINOS, Brazil). Integrating GlobalEdu and LOCAL we have a small-scale ubiquitous learning environment. This integration was fully implemented and it was applied in a practical experiment to evaluate the system´s usability. In this evaluation we involved the community of a specific Computer Engineering undergraduate course at UNISINOS.

This article is organized in six sections. The next section details the model GlobalEdu. The following section proposes the integration between GlobalEdu and the middlewares. The fourth section approaches a full implementation of the GlobalEdu/LOCAL integration and describes the experiment used to evaluate our proposal. The fifth section presents previous work in the area of ubiquitous technology used to create pedagogical applications, and how it relates to our work. Finally, in the last

*Figure 1. GlobalEdu architecture*




section, we draw some conclusions and plans for future work.

## THE GlobalEdu MODEL

GlobalEdu aims to support ubiquitous educational applications. Its architecture is based on a layered organization, as shown in Figure 1. The Application Layer is represented by a Pedagogical Agent (PA), which follows the learner throughout the environment and helps in her/his interactions with the system.

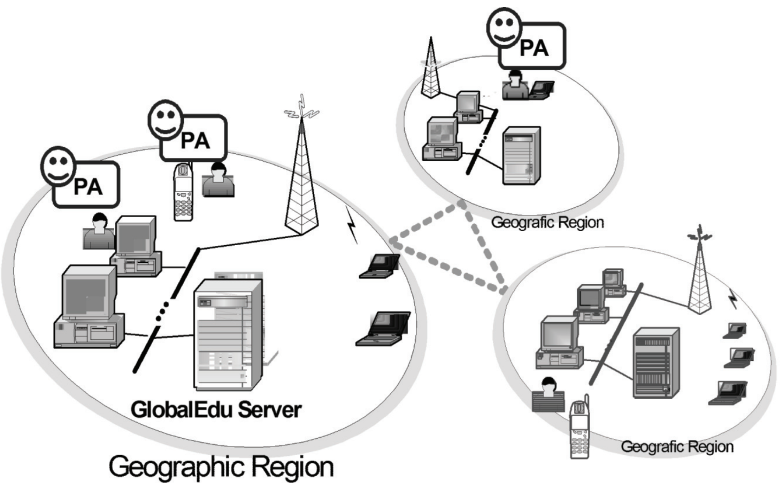
The System Layer is a set of Educational Modules (EM) and Support Modules (SM). The Educational Modules are responsible for performing content management tasks as well as manipulation of the learner model. The system has three Educational Modules: Profile, Content and Context Management. The Profile module is responsible for managing learner profiles. The Content module deals with the Learning Objects (Lewis et al., 2010) which are manipulated by the learner. The Context Management controls information in the context of interest of the learner and is in charge of adapting the resources that he/she is manipulating. The Support Modules are intended to help in the execution of the Educational Modules and the Pedagogical Agent, by managing the aspects of communication, adaptation of interfaces to devices, user access and persistence.

The Runtime Layer is a middleware which supports the execution of educational applications, providing the system with necessary features, such as perception of contextual elements, code migration and communication mechanisms.

The Context Management module manages learner context in each location the learner interacts. This module detects changes of contextual elements in the different locations where the learner is. The Social Context and Physical Context compose the learner context.

The Social Context has contextualized information about Location Context and the presence of other PAs in the current context. Location Context contains information about People (name, e-mail, commitments and roles), Events (type, description and location) and Resources (name, type, description and commitments) related to a specific location. The

*Figure 2. GlobalEdu environment*




presence of other PAs presupposes the existence of other learners with the same goals, competencies and preferences, whose information the learner may access for contact or not. This information can also be used for the creation of learner groups within the same context.

The Physical Context represents the resources accessed by the learner, such as network, locations and devices. We consider that the ubiquitous computing environment monitors Physical Context elements. Also, any element state changes are informed to the Context Management.

The Context Management module has the capability to know how to locate the learner in his/her current environment, to identify a learner in the corresponding context and to provide information adapted to the device the learner is using. In the same way, each location is modeled as a Geographic Region and has information about Location Context. So, for GlobalEdu, the ubiquitous environment is composed by cells and these have different contexts (Figure 2). For example, a University can be considered a cell and its buildings, different contexts.

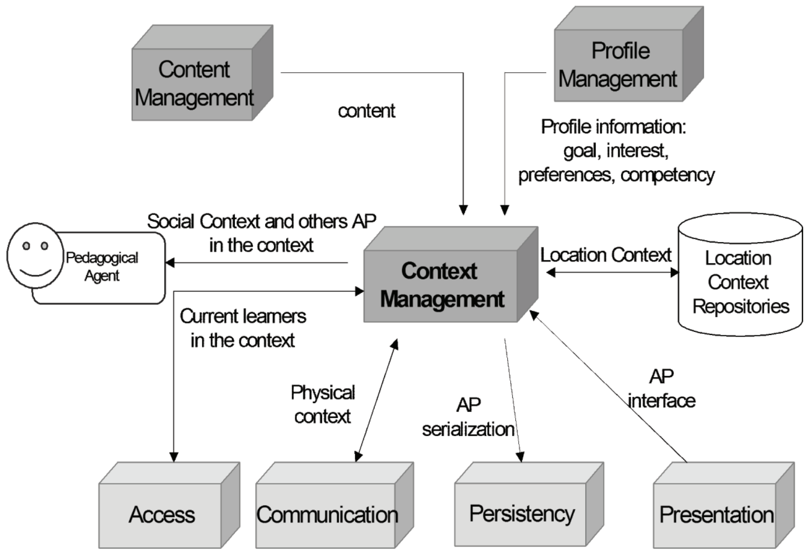
Learners need to authenticate themselves in order to interact with the environment. This event is handled by the Context Management module. When a new learner enters into the environment, the Social Context changes. In this case, the service takes two actions: (1) notifies other learners in the corresponding context (Location Context), and (2) sends to the new learner adapted information about the current context he/she is in. User profiles are compared in order to define learners with the same goals, competencies and preferences, whose information the learner may access for contact or not.

For the adaptation process, there is a relationship between the Context Management module and the other elements of the architecture (Figure 3). With this, learners can ask explicit information about the Social Context they are part of. They can also extend the search for information to other contexts. This can be useful in the case of finding learning objects related to the learner's goals, for instance.

## GlobalEdu, ISAM, AND LOCAL

GlobalEdu supports the basic features needed to implement learning-related functionalities in ubiquitous environments. The basic ubiquitous computing support must be supplied by a middleware (Figure 1). GlobalEdu has been integrated with two ubiquitous environments: ISAM (Augustin et al., 2004) and LOCAL

*Figure 3. Context management*




(Barbosa et al., 2007). ISAM supports the creation of large-scale ubiquitous systems. As such, its integration with GlobalEdu results in a large-scale ubiquitous learning system. On other hand, LOCAL is dedicated to create small-scale location and context-aware ubiquitous systems. GlobalEdu integrated with LOCAL results in a local ubiquitous learning system.

## Large-Scale: GlobalEdu and ISAM

The ISAM Project (Augustin et al., 2004) provides a common system platform, allowing the execution of applications across a wide range of equipment as well as automatic distribution and installation. ISAM is based on the vision that ubiquitous applications are distributed, mobile and context-aware by nature, and assumes that "the computer" is the whole network, large-scale pervasiveness (Augustin et al., 2004). The ISAM Pervasive Environment (ISAM*pe*) is composed of elements that correspond to the physical infrastructure of the mobile network. The physical organization adopted in ISAM is the cellular hierarchy (Figure 4). Each cell has a base and the cells are connected to support the ubiquitous environment. A cell manages nodes such as desktops and mobile devices which can be connected either by wired or wireless networks.

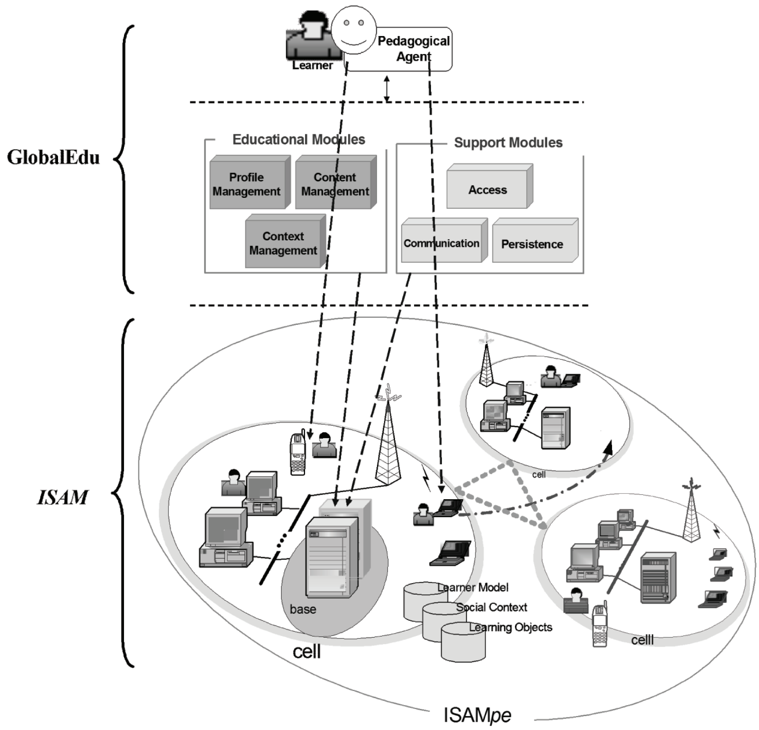
As can be seen in the Figure 2, GlobalEdu also uses a cellular hierarchy. It is possible to map the GlobalEdu architecture to ISAM (Figure 4). The Pedagogical Agent (PA) is mapped to mobile nodes and the Educational and Support Modules are mapped to the bases (servers in a cell). The Modules are heavyweight execution units, and are executed in network servers. On the other hand, PA is a lightweight execution unit, so it can be executed in mobile devices.

Each ISAM cell has one instance of GlobalEdu. Users can change their context (cell), carrying their PA. ISAM supports the basic ubiquitous computing-related aspects and GlobalEdu supports the specific learning aspects.

## Small-Scale: GlobalEdu and LOCAL

The LOCAL project (Barbosa et al., 2007) aims to provide a location-and-context-aware ubiquitous architecture geared to create small-scale learning environments. LOCAL is composed by seven subsystems (Figure 5): (1) *User Profiles*,

*Figure 4. GlobalEdu and ISAM*




which store information related to the users using the PAPI standard (Institute of Electrical and Electronics Engineers, 2011b); (2) *Personal Assistant*, which acts as the system's interface, residing in the user's mobile device; (3) *Location System*, used to determine the physical position of the mobile devices; (4) *Learning Objects Repository*, which stores and indexes content related to the teaching process; (5) *Tutor*, an analysis engine capable of making inferences by using the data supplied by the profiles and the location system; (6) *Communication System*, used to establish communication between the different parts of LOCAL, and between the system and its users; (7) *Event System*, used to schedule tasks.

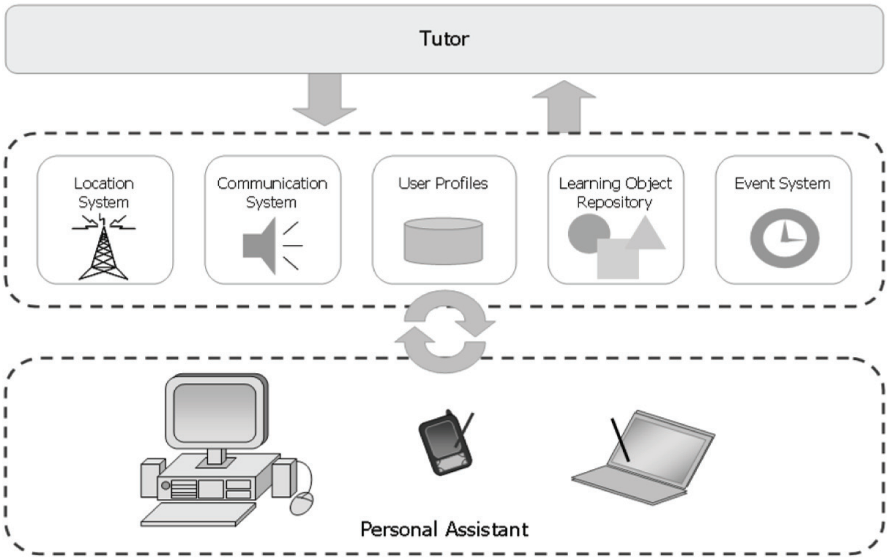
The personal assistant (PA) is the module which accompanies the learner in its mobile device. It allows users to stay connected to the system, while providing a certain degree of independence. The location system ties users' physical location data to symbolic names (contexts). This allows real time mapping of mobile device positions. As the learner authorizes the location system in its PA, it begins to determine the device's position and physical context changes, along with the time and date of such changes. With this data, it is possible to completely track the learner's movements. User profile data, alongside context information, is used in the learning process.

GlobalEdu uses the services offered by LOCAL to monitor and control the environment (Figure 6). GlobalEdu's PAs are executed in the learner's devices, mapped to the LOCAL's Personal Assistant.

The Location System and the Event System are used to treat the location and event information used by the Context Management Module. Moreover, the central role of pedagogical inferences to explore the Social Context (Figure 3) is mapped to the tutor subsystem.

Content Management Module is supported by the Learning Object Repository and the Pro-

*Figure 5. LOCAL architecture*




file Management by the User Profiles System. Communication Support Module is mapped to the LOCAL Communication System. Other Support Modules are not used.

LOCAL is oriented to small-scale ubiquitous environments and its architecture was projected to a centralized execution (only one server). As such, there is only one GlobalEdu instance (Figure 1). Modules are executed in the network server and the PA executes in the users' mobile devices.

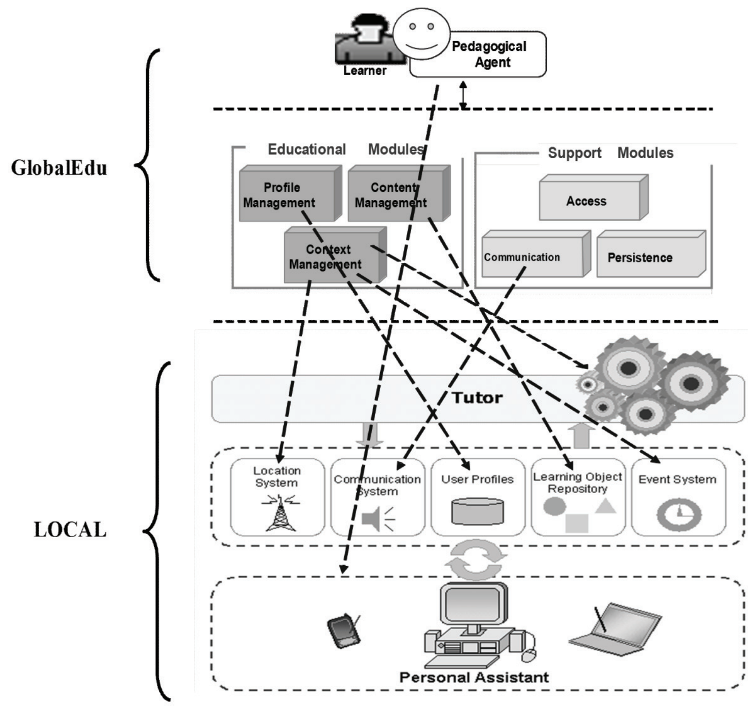
## PRACTICAL SCENARIO: GlobalEdu AND LOCAL

Since 2005, the Mobile Computing lab (MobiLab, http://unisinos.br/laboratorios/mobilab/index_eng.html) at University of Vale do Rio dos Sinos (UNISINOS, Brazil) has been working on research topics related to the area of ubiquitous computing. One of the main goals is to investigate how ubiquitous technologies could be used to improve learning in the undergraduate courses (Barbosa et al., 2007). Moreover, in 2002 the University has created a specific undergraduate course focuses in the integration of knowledge areas related to Engineering and Computer Science. The course is called Computer Engineering course (nicknamed ComEng). The ComEng forms a strongly-tied, interdisciplinary community where both the teachers and the learners are encouraged to use the mobile computing infrastructure in their daily activities. There is a permanent search for new ways to better explore this technological infrastructure in pedagogical activities in this course.

ComEng and MobiLab share the same physical space in a building at the UNISINOS. The first choice in order to evaluate our proposal was the creation of a ubiquitous learning scenario in this space. We used the integration GlobalEdu/LOCAL to implement a small-scale ubiquitous learning system, called LocalEdu system. The LocalEdu was implanted in the ComEng/MobiLab shared physical space and it was used to conduct a usability test.

The scenario encloses nine rooms covered by four wireless access points (Figure 7). This coverage is needed for our location technology, where we use the access points for WiFi signal triangulation. MobiLab is located specifically in the room 212. The other eight rooms sup-

*Figure 6. LOCAL adapted for GlobalEdu*




port most of educational activities of ComEng. Currently, MobiLab has 45 HP iPAQ hx4700 pocket PCs, 20 HP tc1100 tablet PCs, 14 docking stations for the tablets and several wireless antennas. These equipments were used in the experiments described in this article.

The location system has two parts: (1) a webservice created in C# and (2) a database which stores context information. The Personal Assistant was developed in C#, using the .NET Compact Framework. The assistant runs in iPAQs hx4700 and tablet PCs tc1100. It reads potency information from the four wireless access points and forwards it to the location system. The system uses this information to determine the position of users' mobile devices.

The profile system was implemented using MySQL. Users fill in their personal and contact information using an online tool made in PHP and AJAX technology. This tool can be accessed via desktops and via mobile devices. The Tutor and Communication System perform their tasks without user intervention. They were both implemented in C# as Windows Services.

A test was conducted with a sample consisting of 20 individuals, between learners and professors of a Computer Engineering undergraduate course at UNISINOS. This test was realized into five moments: each moment, a set of four individuals interacted with the system. The following steps were considered: 1) each participant was given an HP iPAQ hx4700 mobile device, which they used to authenticate into the system; 2) the participants then received suggestions to participate in one of two workshops (based into user profile data); 3) the participants were notified whenever a professor they wanted to chat with was available; 4) in the fourth step, the system searched for matches between participants' profiles, suggesting learning resources related to their interests; and 5) the users were instructed to go to the workshop rooms. The ubiquitous system

*Figure 7. Prototype test scenario*


then made available on the iPAQs the program of the chosen event (per user).

After following these steps, the users were asked to answer a survey, with questions relating to their experience. The questions had answers in a scale going from 1 (very weak) to 5 (excellent). An answer with the value 0 (zero) meant the user had no particular opinion about that feature. Table 1 shows the relation of questions used in the evaluation. The aspects of context-awareness were analyzed through questions 1 to 7. There was special interest into the adequate presentation of content related to pedagogical events, and the use of the system to track user location. Figure 8 presents the results of these questions, as answered by 20 test subjects. As can be seen, results indicate good acceptance in relation to contextual information.

The proposed daily use of the system as learning tool in the classroom, as well as interaction between users and contextual elements were analyzed through questions 8 to 10. These relate mostly to the usability of the system. The results in Figure 9 indicate a good acceptance by the test subjects. Over 60% of those subjects considered the system *good* or *excellent*. If we take into consideration the test was performed in a limited and controlled scenario, the 32% of people that considered the system *satisfactory* are also a good indication that this system is well fit for daily usage.

It should be noted that, in this survey, adaptability aspects were not given a proper analysis. These aspects could be better analyzed if the test involved a heterogeneous sample of mobile devices (desktop PCs, tablet PCs and iPAQs).

## RELATED WORK

Some projects are investigating the use of ubiquitous computing to provide new learning perspectives. For instance, JAPELAS (Yin, Ogata, & Yano, 2004) is a system created with the goal of supporting learning of polite expressions in Japanese. The students, using handheld PCs, are assisted in the identification of the correct polite expressions to be used in a particular context. JAPELAS only allows the contact between two users. A new version called JAPELAS2 (Yin et al., 2010) is oriented towards supporting the interaction between many people, with a collaborative/social approach. Both systems use location technology

*Table 1. Relation of questions used in the evaluation*

| N. | Q: "What was your evaluation of…" |
|---|---|
| 1 | …notifications about the availability of professors? |
| 2 | …notifications about events, based on location and your profile data? |
| 3 | …notification about the availability of physical resources? |
| 4 | …information about users related to your interests, at your location? |
| 5 | …the presentation of content related to events at your location? |
| 6 | …the usefulness of this system for teaching? |
| 7 | …the use of this system to determine your physical location? |
| 8 | …the stimulus to interaction between users in the same location? |
| 9 | …the possibility of using this system in daily activities? |
| 10 | …the possibility of using this system in the classroom? |

and user profiles, but they represent a specific application, namely, the correct use of Japanese polite expressions. GlobalEdu uses location information and learner profiles in a generic approach, in order to explore pedagogical opportunities in a context-aware environment. With GlobalEdu's Content Management, it's possible to learn about any kind of content.

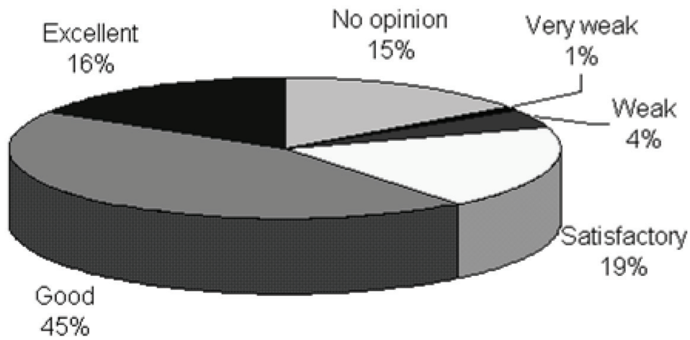
The Ambient Wood Project (Rogers et al., 2005) is dedicated to the design and building of pervasive environments. WiFi and sensor-based technologies are connected with a variety of mobile and standalone computational devices. The proposal is that digital augmentation offers a promising way for enhancing both indoors and outdoors learning processes. The GlobalEdu's Context Management uses the Social and Physical information to improve the learning process. The integration between GlobalEdu and LOCAL explores indoors learning applications through WiFi technology, and with ISAM integration, GlobalEdu intends to explore both indoor and outdoor applications.

Other approaches explore RFID (Radio Frequency Identification) technology to integrate the real world in the pedagogical experience. TANGO (Ogata et al., 2010) allows placement of RFID tags on real objects. The tags can be detected when a learner visits an environment. A mobile device can be used to interact with objects, in order to improve the learner's vocabulary through the questions and answers previously registered in each object. Moreover, Mobio Threat (Segatto et al., 2008) is a pervasive game that represents another pedagogical approach based on RFID technology. In Mobio Threat, RFID tags are implanted in game objects, such as trees and rooms, to allow learners to interact with these real objects using their mobile devices. Its main goal is to support learning about epidemics and disease control. During the game, the players have to work with pathological agents and chemical reactions. The pedagogical contributions are centered in the areas of Chemistry and Biology.

TANGO and Mobio Threat use the same strategy to improve the pedagogical experience, i.e., they integrated the real world in the educational process using RFID technology. Differently from GlobalEdu, both proposals focus on specific pedagogical areas. GlobalEdu is a generic ubiquitous learning model. Moreover, the integration between GlobalEdu and ISAM is general enough to support the interaction with real objects using RFIDs or any other kind of technology.

Few projects in the area of ubiquitous learning use Learning Objects (Lewis et al., 2010) to represent pedagogical content. JAPELAS (Yin, Ogata, & Yano, 2004; Yin et al., 2010) was designed for a specific purpose, and does not use Learning Objects. The Ambient Wood

*Figure 8. Context data (questions 1 to 7)*



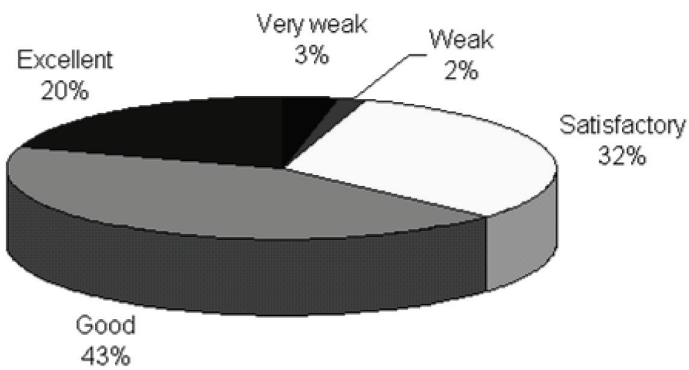

Project (Rogers et al., 2005) does not support Learning Objects. Its focus is specifically on pervasive environments based on digital augmentation. Yang (2006) proposes a peer-to-peer access to content in a ubiquitous learning environment. The proposal also does not specify how the content is going to be represented. Unlike these works, GlobalEdu employs the notion of Learning Objects and uses the Content Management Module to support a generic management of LOs.

Schmidt (2005) summarizes the characteristics of context-aware learning systems and presents a case study that uses Learning Objects based on the SCORM standard (Advanced Distributed Learning, 2011). However, GlobalEdu uses the LOM standard (Institute of Electrical and Electronics Engineers, 2011a). SeLeNe (Rigaux & Spyratos, 2011) and Elena (Simon et al., 2002) also use the LOM standard; however, they do not consider the adaptation of content according to the learners' current context, as GlobalEdu proposed through its Context Management Module.

## CONCLUSION

In this article we proposed GlobalEdu, an innovative proposal that allows the exploration of the benefits of ubiquitous learning environments. Different from other approaches, GlobalEdu does not depend on a specific ubiquitous environment. Also, it can be coupled with mostly any learner model or learning objects model. The model was integrated with two middlewares to create small-scale and large-scale ubiquitous learning environments. A prototype

*Figure 9. Daily usage (questions 8 to 10)*



of a small-scale system was implemented and used in an experiment involving the community of an undergraduate Computer Engineering course. The results of the experiment show that GlobalEdu can be used in generic learning situations. Moreover, the system usefulness was positively evaluated by a group of individuals of the course. Currently, we are improving the prototype. After that, another round of tests shall be conducted. So far, the following general conclusions can be underlined.

Firstly, location technology stimulates the use of mobile devices as learning tools. The location system, by providing precise location data, is a key component of the contextualization process. As such, improvements to the location system mean that the whole system (and thus, the learner experience as well) will benefit from it.

Secondly, GlobalEdu contains the basic modules to support ubiquitous learning and its integration with LOCAL creates a practical and viable system that can be applied in real learning situations. Some aspects of Educational Modules can be underlined. The *Content Management* allows a generic pedagogical approach through the use of Learning Objects. This approach is relevant because allows the learning about any kind of content. The *Profile Management* has a relevant role in the pedagogical process because it allows the personalization of the learning. Moreover, the *Context Management* explores the social and physical contexts of the learners, using in an integrated manner the other two educational modules. As can be seen in the Figure 3, the *Context Management* has a central role in the GlobalEdu model.

GlobalEdu and its integration with the middlewares constitute an initial proposal. The following activities will allow the future of the study:

- A future expansion of the learner profiles would support a more extensive handling of learner information, enabling a better match between the system features and each learners' personality and learning style (considering, for instance, the issue of competences development or cognitive styles);
- Currently, GlobalEdu stimulates the initial contact among students using their profiles and locations. A future model expansion will contemplate more sophisticated aspects of collaborative learning, for example, specific tools to support and to articulate collaborative activities such as projects development;
- New tests should be performed in order to evaluate globaledu as a learning tool in long-term courses. We intend to use an improved version of system based on the integration globaledu/local to support this future work;
- We intend to create and evaluate a large-scale ubiquitous learning system based on the integration GlobalEdu/ISAM.

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