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CONTRIBUTIONS FOR THE ARCHITECTURAL DESIGN OF MOBILE LEARNING ENVIRONMENTS

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ABSTRACT

Even providing several benefits and facilities with regard to teaching and learning, mobile learning environments present problems and challenges that must be investigated, especially with respect to the definition and standardization of architectural aspects. Most of these environments are still built in isolation, with particular structures and architectures, hindering aspects such as reuse and interoperability, for instance. On the other hand, several initiatives of using service orientation aspects to support and help the architectural definition of software systems have been investigated. In this paper we discuss the proposition of an architecture for service-oriented mobile learning environments. The architectural requirements that guided the establishment of the proposed architecture were defined by means of a systematic process, being prioritized and complemented with the help of domain specialists. In order to evaluate the proposed architecture, a prototype of a service-oriented mobile learning environment was implemented, showing the viability of practical application of such architecture, especially with regard to service consumption and service implementation, providing interoperability and reuse for educational services.

KEYWORDS

Architectural Requirements, Mobile Learning Environment, Service Orientation.

1. INTRODUCTION

Virtual learning environments, together with the advent of ubiquitous computing, have provided a new and innovative way of education – the mobile learning (*m-learning*) (Martin, 2010). In short, m-learning is characterized by the ability to promote a strong interaction among apprentices, teachers and tutors, enabling them not only to access the learning environment but also to contribute and actively participate of the knowledge construction process through mobile devices (e.g., mobile phones, tablets, laptops, radio, tv, among others).

Despite the benefits provided, mobile learning is still faced as a new and incipient concept, presenting some limitations that difficult its effective adoption, such as (Jong et al., 2008): (1) reduced processing power; (2) variable screen size; (3) limited energy (battery dependency); (4) transmission rates generally smaller than those of the cable network; (5) adequacy to usability aspects; and (6) lack of architectural patterns.

Considering the need of building quality and reusable mobile learning environments, efforts for developing architectural patterns have become increasingly relevant. Software architectures dealing with aspects of SOA (Service-Oriented Architecture) have gained particular importance within the context of mobile learning (Otón et al., 2010; Palanivel and Kuppuswami, 2011). However, in spite of such efforts, there is still a lack of a standardized set of architectural requirements, specifically defined to the mobile learning domain and in accordance with service-oriented issues.

In general terms, an architectural requirement can be defined as any requirement that is architecturally significant (e.g., performance, usability, reuse, security, interoperability, adaptation, among others), with particular responsibilities in relation to a given software domain (Schepman et al., 2012). The right definition of these requirements provides a better abstraction of the system to be developed, helping and supporting its architectural representation.

Motivated by this scenario, in this paper we propose an architecture for service-oriented mobile learning environments. The architecture was developed from a set of architectural requirements, defined through a systematic process. The general view of the proposed architecture comprises six layers, enabling a better reuse and interoperability. In order to evaluate the proposed architecture, a prototype for a mobile learning environment was implemented, showing the viability of practical application of the architecture, especially with regard to service consumption and service implementation. In the very end, the main idea is to promote interoperability and reuse for educational services.

This paper is organized as follows. In Section 2, the background for our work is summarized. In Section 3, the systematic process adopted in the establishment of the architectural requirements is presented. In Section 4, we briefly describe a set of architectural requirements for m-learning environments. In Section 5, we discuss the general view of the proposed architecture, focusing on its layers and main modules. The prototype of a mobile learning environment, implemented with basis on the proposed architecture, is presented in Section 6. Finally, in Section 7, we summarize our conclusions and perspectives for future work.

2. BACKGROUND

M-learning has appeared as a new type of electronic learning, taking place when the interaction among the actors of the learning process is performed through mobile devices. As a new and emerging paradigm, there are several attempts for defining m-learning. According to Schepman et al. (2012), m-learning refers to any kind of learning that occurs when the apprentice is not in a fixed place, or when he/she takes advantage of learning opportunities provided by mobile devices, thereby relating technological and mobility concepts. Ozdamli and Cavus (2011), in turn, address m-learning as an activity that allows individuals to be more productive when they consume, create or interact with information, supported by mobile devices.

No matter the definition adopted, the use of learning environments through mobile devices provides benefits that go beyond accessibility, convenience and communication (Schepman et al., 2012). However, despite the advantages offered and even with the increasing research related to the development of mobile learning environments, there are few works dealing with a well-established set of architectural requirements in this new learning setting (Efstratiou et al., 2000).

Due to the complexity and lack of architectural standardization regarding m-learning environments, difficulties concerning the use, integration, maintenance and reuse of these environments are still common during their development. In this sense, the adoption of a SOA can make the construction and adoption of m-learning environments easier and more flexible, promoting interoperability and reuse of best practices in the educational setting (Erl, 2009).

Some initiatives regarding the definition of service-oriented architectural requirements for m-learning environments can be found in the literature (Section 3.1). Such initiatives, however, are spread out, with no kind of standardization with respect to educational practices and issues of mobility and service-orientation (Erl, 2009; Otón et al., 2010; Basaeed et al., 2007; Thanh and Jorstad, 2005). Besides that, the establishment of architectural requirements for software systems in general, and for mobile learning environments in particular, is not a trivial task (Efstratiou et al., 2000). Guidelines to support the architectural design process and, at the same time, ensure the correct understanding of the specificities of the target domain, are required (Duarte Filho and Barbosa, 2013).

In a different but related perspective, Nakagawa and Maldonado (2007) worked on a process to support the development of reference architectures, referred to as ProSA-RA (Process based on Software Architecture - Reference Architecture). ProSA-RA focuses on how to deal with architectural aspects as well as on how to represent and evaluate reference architectures. The process comprises four basic steps: (1) Information Sources Investigation; (2) Architectural Requirements Establishment; (3) Reference Architecture Design; and (4) Reference Architecture Evaluation. In our work, we are particularly interested in Step 2 of ProSA-RA, since it establishes some general guidelines to identify and describe the common functionalities and architecture requirements presented in software systems.

Based on ProSA-RA (Step 2), we established a smaller but systematic process for the determination of architectural requirements. The process was applied in the context of mobile learning environments in order to define the architectural requirements for this domain. The process and its application are described next.

3. A PROCESS FOR THE DEFINITION OF ARCHITECTURAL REQUIREMENTS

The establishment of a set of architectural requirements for mobile learning environments was performed through a systematic process, which comprises four main steps: (1) Application Context Definition; (2) Identification and Analysis of Information Sources; (3) Design of Architectural Requirements; and (4) Prioritization and Complementation of the Architectural Requirements.

3.1 Step 1: Application Context Definition

Due to variety of the applications for mobile learning environments (e.g., distance, simulations, games, among others), in the first step, it is necessary to set the context for which these environments will be directed, thus being able to define the most appropriate architectural requirements for the environment. In this work, the application context was defined for mobile learning environments that can support traditional courses at undergraduate level and that can support learners in relation to basic education activities (e.g., activities submission, messaging, access to educational materials, among others). Teachers and tutors, which can also benefit from the environment, can monitor and track the activities of the apprentices. This context was defined based on the authors' experience and on the daily use of such environments in the learning setting. The idea is to facilitate the identification of main strengths and weaknesses in an educational environment.

3.2 Step 2: Identification and Analysis of the Information Sources

In this step, the goal is to get considerable knowledge about the target domain. This knowledge acts as the basis for the establishment of the architectural requirements. In our case, three groups of information sources were defined, based on their relevance in the context of mobile learning environments and SOA: (1) Concrete Architectures for Mobile Learning Environments; (2) Reference Models/Architectures for the Educational Domain; and (3) Service-Oriented Architectures.

3.2.1 Concrete Architectures for Mobile Learning Environments

In general, the research works analyzed in this group address issues related to communication, security, modularity, adaptation to the context and interoperability through service-orientation.

Otón et al. (2010) highlight two relevant aspects regarding the development and implementation of a learning system – reuse and interoperability among repositories of learning objects. Similarly, these aspects remain significant for investigation in mobile learning environments as well. In this sense, the authors presented a service-oriented architecture, implemented through web services, as a mean to provide the recovery of learning objects.

In the same perspective, Palanivel and Kuppuswami (2011) define a reference architecture for service-oriented learning environments. The service-oriented aspects provided higher interoperability, reuse, modularity and scalability to the educational practices.

Jong et al. (2008) discuss a reference model for social mobile systems such as social networking and learning systems. These systems are used by multiple users, allowing intercommunication among other participants. The reference model particularly focuses on issues of communication, adaptation to the user’s context and security when exchanging information (to ensure confidentiality and integrity).

The MOBIlearn project (Lonsdale et al., 2004) defines several educational services focusing on the user’s adaptation. Thus, adaptation is a relevant issue to virtual learning environments, since the student’s behavior is modified according to: (i) the inherent characteristics of the environment; and (ii) the content with which the student interacts.

Basaeed et al. (2007) propose an architecture for contributing to the learning process by means of web standards and web services. The authors apply a systematic approach to identify components based on the contextualization of learning, establishing their functionalities and features through web services.

Thanh and Jorstad (2005) propose a service-oriented architecture for mobile services. The requirements considered in the architecture are identified from a generic model of mobile services, which specifies: services for content delivery, services of user's management, scalability, addition of new services and security, among others.

Trifonova and Ronchetti (2004) also propose a generic architecture for supporting mobile learning. In such architecture, the functionalities of learning environments are presented as web services aiming at providing scalability, interoperability and reusability of educational content. Furthermore, characteristics such as communication and adaptation should also be addressed in the context of mobile learning environments. Actually, these characteristics, together with the characteristics of web services (discussed in Trifonova and Ronchetti, 2004 and Basaeed et al., 2011), are important in order to promote portability, reuse and scalability.

Differently from the works presented so far, Martin (2010) analyzes the need for a secure and interoperable architecture. The architecture proposed in his work establishes some basic features with respect to a generic learning environment, such as: privacy, scalability, synchronization, extensibility and reusability, distributed resources and learning resources.

From the analysis of the works summarized in this section, a preliminary set of architectural aspects with respect to architectures for mobile learning environments has been identified, highlighting the need for studying and adopting service-oriented aspects, such as: (1) service orientation: to allow more flexibility and interoperability; (2) adaptation to context: to provide the users a context-based learning according to their location and the type of application; (3) communication: to guarantee a standardization among the data communication models; (4) security: to provide a private and reliable environment and, at the same time, synchronized with other system users; and (5) modularization: to be structured in modules and components in order to promote a better reuse, modification and quality through the lifecycle.

3.2.2 Reference Models/Architectures for the Educational Domain

The analysis of reference architectures is particularly relevant to the identification of architectural requirements, since from their representations and descriptions is possible to identify general concepts related to educational practices.

The MoLE Project (2013) specifies a reference architecture structured in components and layers to specifically suit the main practices and activities of m-learning. The proposed architecture is based on a set of mobile educational services (e.g., user authentication, data synchronization and reporting) whose goal is to enable a better integration among educational environments.

Additionally to the basic services related to integration of the mobile services, the architecture has a module, the "mobile authoring tool", that allows the creation and sharing of educational content in a mobile way. Some of the main functionalities provided by this module are: (1) creation of tasks; (2) creation of automatic evaluations; (3) creation of quizzes and questionnaires; (4) creation of didactic materials; (5) creation of exercises and tests; and (6) creation of online evaluations.

In another project, the IMS Global Learning Consortium (2013) proposes an educational reference architecture focused on service orientation. The initiative establishes guidelines with respect to the integration and representation of educational practices, without addressing however mobility and ubiquitous issues. The architecture is structured in four layers: (1)

application layer; (2) application services layer; (3) common services layer; and (4) infrastructure layer. A set of educational services for supporting educational practices is also proposed: (i) course administration services; (ii) authoring services; (iii) evaluation and communication; (iv) delivery of educational content; (v) customization; and (vi) course documentation.

Finally, based on a detailed analysis of features and functionalities of several different learning environments, Barbosa et al. (2013) propose a reference architecture for learning environments, referred to as EducAR. Particularly, EducAR has an authoring module, responsible for supporting the development of educational content. Basically, this module addresses issues such as: (1) content structuring and modeling; (2) content edition; (3) automatic generation of content; (4) sharing, reuse and integration of content; and (5) content capture. Since EducAR has been developed for "traditional" learning environments, mobile issues have not been addressed on its definition.

Based on the results discussed in this section, key concepts representing the basic functionalities of mobile learning environments could be determined. Thus, the set of architectural requirements should take in consideration concepts (and their relation with educational practices) such as: (1) adaptation to context; (2) adaptation to learning standards; (3) user management; (4) course administration; (5) content authoring; (6) content delivery; (7) user evaluation; (8) course and system documentation; (9) communication; and (10) customization.

3.2.3 Service-Oriented Architectures

In order to identify characteristics for providing a better reuse and interoperability of services among mobile learning environments, aspects of service orientation should also be considered. Particularly, we have investigated models and reference architectures for service orientation, as discussed next.

Alzaabi et al. (2010) propose a reference architecture for the architectural description of SOA. As a complement, Zimmermann et al. (2009) define a reference architecture to ease and support the development of service-based systems.

The OASIS project (2006) establishes a common vocabulary and a reference model for the service-oriented architectural style. The model defines relationships and main concepts regarding the SOA domain, such as: visibility, description of services, policies and contracts, ways of interaction, and execution context.

Finally, based on different implementations of service-oriented systems, Dillon et al. (2007) deal with a reference architecture based on reverse engineering. This architecture takes into consideration the analysis and addition of requirements (functional and nonfunctional) already implemented, being supported by the best practices of implementation of service-oriented systems.

From the analyzed works, we point out as the main concepts and functionalities required for the development of a service-oriented system: (1) service description; (2) service publication; (3) service interaction; (4) governance; (5) quality of service; (6) service composition; and (7) policies.

3.3 Step 3: Design of the Architectural Requirements

In this step, all the characteristics previously identified (Step 1) must be analyzed and mapped into architectural requirements. In our case, the mapping was performed with the help of researchers and domain experts in order to facilitate the determination of the relevant architectural requirements to the context of mobile learning. Additionally, the architectural requirements defined were also analyzed with respect to a set of mobile learning environments, aiming at verifying the relevance of these requirements in real learning environments. The environments considered for this analysis/comparison were: *Blackboard Mobile*[1]; *Desire2Learn*[2]; *Mobl21*[3]; *Amadeus Mobile*[4]; *MLE Moodle*[5]; e *Mobile Sakai*[6]. Such environments were chosen based on their good rates of usage by learners, teachers and tutors.

3.4 Step 4: Prioritization and Complementation of the Requirements

In order to validate the requirements identified in Step 3, the next step of the systematic process consists of conducting a prioritization and complementation of such requirements with the support and knowledge of specialists. Priorities were defined throughout of research with the help of 50 domain experts, which participated in online interviews conducted through checklists. Of the 50 specialists, 33 answered the checklist, providing feedback regarding the requirements defined. The checklist was created as a template in order to facilitate its application by the evaluator.

The prioritization was denoted by the symbols: *(NA)* Not Applicable; *(+)* Unsatisfying; *(++)* Regular; and *(+++) S*atisfactory. The idea is to denote the relevance and impact that these requirements have on service-oriented mobile learning environments. It is worth to notice that the architectural requirements prioritized as (NA) were discarded from the set of architectural requirements, since their applicability was not verified in the prioritization.

4. ARCHITECTURAL REQUIREMENTS FOR MOBILE LEARNING ENVIRONMENTS

After the prioritization and complementation, the requirements were mapped into a set of architectural requirements for service-oriented mobile learning environments. In short, the set of requirements was defined by four specific areas, being divided into four distinct groups: Architectural Requirements for Learning Environments in General (AR-LEG); Architectural Requirements for Mobile Learning Environments (AR-ML); and Architectural Requirements specific to SOA (AR-S).

[1] http://www.blackboard.com/platforms/mobile/overview.aspx
[2] http://www.desire2learn.com/
[3] https://www.mobl21.com/
[4] http://amadeus.cin.ufpe.br/index.html/
[5] http://mle.sourceforge.net/
[6] https://confluence.sakaiproject.org/display/MOBILE/Home

4.1 Architectural Requirements for Learning Environments in General

1-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **provide information about the course**;
2-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **provide information about the system/environment;**
3-AR- LEG (+++) - The architecture should support/enable the development of learning environments that **allow the customization** of the educational content;
4-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **automate the evaluation process**;
5-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **support the authoring of didactic material**;
6-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **provide security** to their users in relation to aspects of mobility;
7-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **enable the management of content** by the instructors and administrators;
8-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **enable learners' evaluations**, in a formal or informal way;
9-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **support the delivery of didactic material**, being possible to explore different media interactions;
10-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **provide feedback mechanisms for evaluation**, which can be conducted by means of scores, reports or even messages;
11-AR-LEG (+++) - The architecture should support/enable the development of learning environments that **manage the users and courses**, with different profiles and visions.

4.2 Architectural Requirements Specific for Mobile Learning Environments

1-AR-ML (+++) - The architecture should allow the development of m-learning environments that **manage the use of resources**, allowing the environment to use appropriate types of resources in relation to mobile devices, especially the bandwidth and memory consumption;
2-AR-ML (++) - The architecture should enable the development of m-learning environments that provides **mechanisms for the efficient energy consumption**. The idea is to ensure energy conservation techniques for mobile devices, saving power when no activity is being performed, guaranteeing greater energy autonomy over learning;
3-AR-ML (++) - The architecture should support/enable the development of m-learning environments that **allow synchronous and asynchronous communication** (among learners/tutors/system);
4-AR-ML (++) - The architecture should enable the development of m-learning environments that provide the **knowledge just-in-time**, allowing the knowledge of the learning object

can be led and represented in anywhere, ensuring authenticity in their activities regardless of their location;

5-AR-ML (++) - The architecture should support/ensure **accessibility adapted for mobile devices**, supporting different languages of the communication and cognition (e.g., screen magnification/zoom, screen rotation, customization of colors and brightness);

6-AR-ML (+++) - The architecture should allow that the **upgrade and configuration** of a mobile learning environment can be performed a simple and automatic way, avoiding errors by users;

7-AR-ML (++) - The architecture should allow the m-learning environment can **synchronize and coordinate** its information with other mobile devices, allowing to the users the independence on these devices;

8-AR-ML (+++) - The architecture should support/enable the development of m-learning environments that provides **portability in relation to mobile devices** without the need to apply other actions (settings);

9-AR-ML (+++) - The architecture should support/enable the development of m-learning environments that provides features to **improve the social interaction** among users;

10-AR-ML (+++) - The architecture should support/enable the development of m-learning environments that provides **adaptation to the context**, ensuring adaptation to the user´s context in relation to physical, social and timing issues, among others.

11-AR-ML (+++) - The architecture should support/enable the development of m-learning environments that **allow collaboration among users** through wikis, forums, microblogging, social networks, among other tools.

4.3 Architectural Requirements Specific to SOA

1-AR-S (+++) - The architecture must **provide mechanisms for capturing, monitoring, registering and notifying** the non-compliance of quality requirements established among service providers and service customers;

2-AR-S (+++) - The architecture should enable the development of **scalable** educational environments, **capable of evolving incrementally** through the addition of new services;

3-AR-S (+++) - The architecture should allow the educational services that can be **treated uniformly**, i.e., can be published, located and used in the same way;

4-AR-S (+++) - The architecture should support the development of learning environments that **provide information about their characteristics and normative directions of use** through standardized descriptions;

5-AR-S (+++) - The architecture should allow that educational tools implemented in different programming languages and under different platforms **can be easily integrated**;

6-AR-S (+++) - The architecture must provide mechanisms for that didactic materials, as services, **can be published and discovered** by client applications;

7-AR-S (+++) - The architecture should allow that the educational services **can interact directly or through the use of an enterprise service bus**;

8-AR-S (+++) - The architecture should support the development of learning environments that **provide semantic descriptions**, allowing their classification in the service repositories;

9-AR-S (+++) - The architecture should support the development of learning environments that **provide information and documents related to their quality characteristics**;

10-AR-S (+++) - The architecture should enable that the mobile learning environments **communicate with other educational tools**;

11-AR-S (+++) - The architecture should allow **a partial instantiation**, that is, learning environments developed according to this architecture can be built without the need of implementing all the modules specified.

5. A SERVICE-ORIENTED ARCHITECTURE FOR MOBILE LEARNING ENVIRONMENTS

Based on the architectural requirements identified in the previous section and in Duarte Filho and Barbosa's work (Duarte Filho and Barbosa, 2014a), we have instantiated a service-oriented architecture for mobile learning environments, enabling the development of a service-oriented educational environment together with the incorporation of mobile aspects.

Figure 1 shows the general view of the proposed architecture, which has been defined in accordance with the architectural requirements previously discussed. The application layer illustrates specific modules of the educational domain. Furthermore, it incorporates elements related to SOA, fostering a better reuse and interoperability. The elements described in this view can be built using the most appropriate technologies and languages to their implementation.

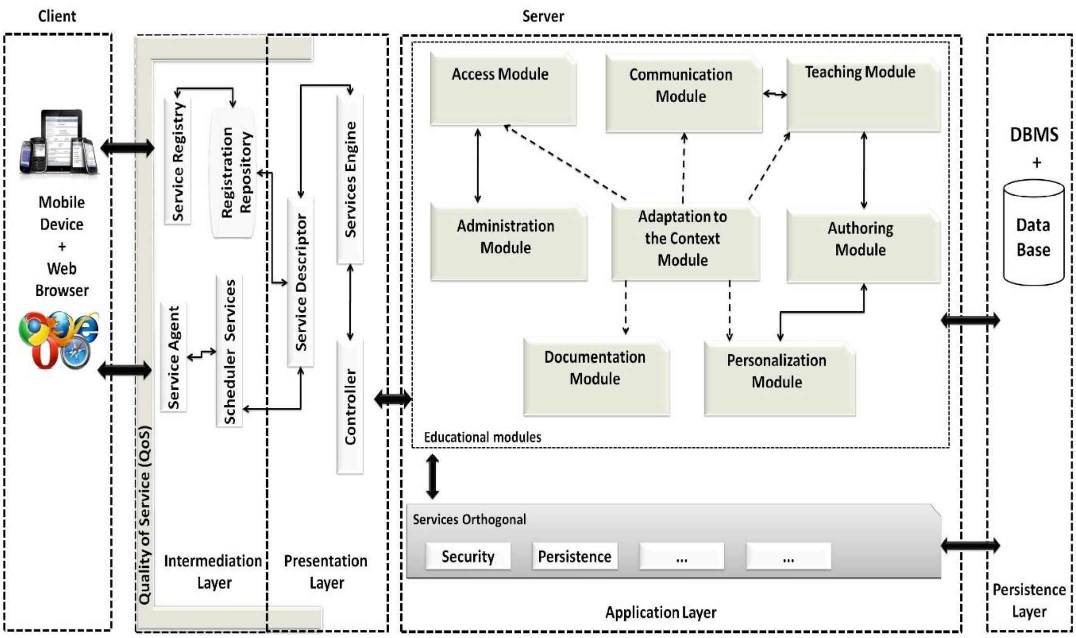


Figure 1. Service-oriented architecture for m-learning environments: General view.

View Layer: client-side layer, whose primary task is to support different types of browsers and mobile devices, allowing communication with the server. The web server should return the information (request) in order to be interpreted and rendered to the client. Based on service orientation issues, the View Layer should exchange information via XML and SOAP protocols, ensuring interoperability in communication.

- Plug-in Module: this module is complementary to the View Layer. It is responsible for allowing tutors and learners to communicate through different mobile learning environments and traditional learning environments. To do so, each environment may have specific plugins for communication, easing the exchange of messages.

Data Layer: located at the database server, this layer corresponds to the set of data to be stored and retrieved for use in the mobile learning environment. Its main role is to receive information requests from the web server, and then perform query functions, change and deletion of data in the database. To ensure integrity, a persistence module has also been incorporated into this layer.

- Persistence Module: this module is responsible for managing the application database, performing queries and storing relevant information, ensuring integrity for user information. To enable the data to be persisted in the database, a Systems Management Database (DBMS) can be used, being complemented with the use of frameworks. Such frameworks ease the mapping of attributes between traditional relational databases and object models of the applications, being used to facilitate manipulation and data recovery.

Presentation Layer: server-side layer, whose primary task is to receive information requests from the client application, and then perform the visual presentation of information on the learning activities. This layer should analyze the original data and request the appropriate style information (e.g., XML). Additionally, it should send the information in the appropriate style to the application server, transferring it again for the requesting client. To provide compatibility with aspects of SOA and to increase interoperability and reuse of resultant applications, three modules were defined:

- Service Descriptor: it defines the types of data used in the request of the features and also the types of data returned to customers after processing.
- Requests Controller: it is responsible for orchestrating the execution of other modules in order to provide the functionality offered, ensuring synchronization of services, which can be used simultaneously by several apprentices (in a collaborative mode) or even by tutors (in a supervised mode).
- Services Engine: it processes the service requests, making messages written in languages and protocol standards into data types used by implementations located in the Application Layer.

Application Layer: this layer contains elements that add features related to the core functionality of a mobile learning environment. Located at the application server, the Application Layer is responsible for accepting the service request according to the documents sent. For instance, we can consider services of login, reporting, performance, customization, among others. All services defined in the Application Layer should be developed focusing on modularity and cohesion in order to be used in different environments, therefore increasing the reuse. To ensure efficiency to educational practices, eight modules were defined:

- Access Module: this module is responsible for consulting the database of the learning environment in order to get information, verifying whether it may or may not have access to the services. Depending on the context, some services may be free or paid.
- Teaching Module: this module is responsible for the delivery and presentation of educational content, and for the learner's evaluation through the availability and application of exercises, quizzes and tests, among others. Adaptability of content is also addressed in this module.
- Authoring Module: this module is responsible for supporting the development of educational content (materials and evaluations). In short, it addresses issues such as: *(1)* structuring and modeling content, performing the identification and representation of the concepts and their relationships; *(2)* editing content, aiming at the creation of media (videos, images, among others) and educational documents; *(3)* automatic generation of content, facilitating its construction in a specific format, especially with respect to the dimensions of a mobile device screen; *(4)* sharing and content integration, associated with the use of ontologies, terms of dictionaries, glossaries, among others; and *(5)* content capture, regarding the capture and storage of discussions and experiences of tutors and apprentices, obtained along the courses and classes.
- Personalization Module: this module is classified as a crosscutting concern, being related to the other modules of the Application Layer. Its main goal is to establish mechanisms for creating and using templates, multilanguage support and adequacy to patterns (such as IMS, SCORM, LOM, and others). The functionality implemented in this module affects all the others (represented by stereotyped lines <<crosscuts>>), changing the behavior in order to insert features related with the customization.
- Documentation Module: this module is responsible for providing mechanisms of management and storage of information regarding the mobile learning environment (such as online help and FAQ of the environment), user information and course information (e.g., objectives, class plan, schedule, FAQ of the course, among others).
- Administration Module: this module addresses the administrative issues present in general Web systems, with emphasis in the management of users and courses. Regarding the users' administration, the main issues considered refer to authentication and establishment of the access levels, as well as adding, deleting and updating users. Performance reports, participation and frequency of users (i.e., apprentices) are also addressed. Furthermore, the module performs the management of the course, dealing with issues such as inclusion, exclusion and statistics of the course.
- Adaptation to the Context Module: mobile learning environments must be able to automatically detect all information related to the context of the users and tutors (e.g., place, time and, in some cases, physical conditions). This module is fundamental for

detecting and recording the learner's current situation in the learning environment. The idea is to provide the tutors a better understanding and knowledge about the apprentices.

- Collaboration/Communication Module: this module defines the type of communication used by the learning environment through the mobile device. Such communication can be asynchronous or synchronous. In general, it allows users to determine the way of communication, e.g., SMS, MMS, speech interface or only the keyboard. This is possible due to the interoperability among mobile devices. When the device has incompatibilities in some type of communication, exceptions must be launched and treated. This module also gathers synchronous and asynchronous tools to assist the communication between apprentices and tutors, such as chat, web conferences, e-mail and messages, among others. Collaborative tools like wikis, forums and groups can also be considered.

Quality of Service Layer (QoS): a mobile learning environment consists of a dynamic combination of different types of resources that must be adapted to the apprentice's needs according to his/her current context. The adoption of a service-oriented approach can help on this adaptation. Every service, being consumed or produced, must be in agreement with quality requirements. In the educational setting, services can not adversely affect the performance of learning activities to the users of environments. In this sense, this layer aims at analyzing and verifying the compliance with the quality requirements established in the other layers of services. The QoS layer is directly integrated with: (1) the Intermediation layer; and (2) part of the Presentation layer (description of services). The layer must capture, monitor and record nonconformities that perhaps may occur over consumption of the educational services, hindering the use of the educational environment.

Intermediation Services Layer: this layer plays an important role in the control and organization of the educational services. It enables that other services can be discovered, associated and made available in an efficient way to the learning environment. The layer consists of three main elements: (1) service registry; (2) service agent; and (3) scheduler.

- Service Registry: one of the important aspects of the oriented-services systems are the resources to manage the lifecycle of the services, which provide management of different levels of operation and the definition of attributes along with the service records. This allows the mapping of available services, facilitating the monitoring of services, and the centralized management of its exceptions. One way of performing the service registry is the use of brokers or matchmakers (Dillon et al., 2007).
- Service Agent: it is a mediator of service that intercepts and modifies the messages transmitted between existing services (providers) and clients (requesters). Generally, this mediator represents a framework of routing and transport requests between service providers and their customers. Services of mediation are implemented using mediation modules that contain mediation flows, being materialized, for instance, by implementing an ESB (Enterprise Service Bus). One of the main aspects of ESBs is the standardization of the interfaces of consumption through a single access point.

- Scheduler: this element has the objective to manage requests for services performed by the customers, verifying the existence of the dependency described by a descriptive language, such as XML. To perform simple services requests, simple policies can be implemented and applied in practice. However, when the service requested is a composite service with multiple dependencies, interoperability requirements between the parties and their usage policies should be analyzed and assigned to the scheduler.

6. A PROTOTYPE FOR A SERVICE-ORIENTED MOBILE LEARNING ENVIRONMENT

The proposed architecture was evaluated through a case study, which consisted of implementing a prototype for a mobile learning environment. A part of the evaluation was also based on Duarte Filho and Barbosa's work (Duarte Filho and Barbosa, 2014b). The prototype implementation is important since it illustrates the viability of practical application of our architecture, particularly with respect to service consumption and service implementations, thereby providing better interoperability and reuse for educational services. Another benefit from this implementation was to check consumption and integration of different services, whether they are educational or not.

Table 1 shows the functionalities of the prototype implemented up to now. The table also shows the services that have been implemented together with the services (of third party) that were consumed and have been incorporated in the prototype. It is noteworthy that besides the prototype being implemented based on practices of SOA, knowledge provided by the architectural requirements along with the architecture proposed in this paper has also been used.

Table 1. Prototype functionalities and services (developed and consumed).

Functionalities Implemented (in the usual way)	**Third party services**	**Developed as a service**
Educational content and data repository	Password recovery	Score board
Message trading between tutors and students	Facebook sign in	Email notification
New user sign up	Address autocompletion by ZIP code	Wiki
Course managment	SMS/MMS services	
Microblog for collaboration	Quiz service	

The services implemented so far were built in a self-contained way, following the concepts of SOA[7] and aiming to increase the ability to reuse application. All services that have been implemented can be allocated and consumed by other educational applications. A business process responsible for coordinating the interaction between developed and consumed services was also defined. The concepts related to the context of services were mapped according to

[7] http://www.oracle.com/br/products/middleware/soa/overview/index.html

WSDL[8] technology. For a productive way to build services descriptions, the Axis2[9] Service Engine was used.

We highlight that the focus of this case study was to demonstrate the viability of the implementation and consumption of educational services, verifying its integration in a real mobile learning environment. It is also important to point out that the interactions among services were performed directly, i.e., the addresses of the services used were previously known, therefore not requiring the implementation of the Intermediation Layer. Furthermore, the implementation of the Quality of Service (QoS) layer was not considered, being the quality treatment performed in a simple manner, by means of exceptions and conditional treatments.

The prototype was developed according to the application context defined in Section 3.1. The authors aimed at defining and developing a prototype that would allow a mobile learning environment focused on communication and collaboration, facilitating the exchange of messages between tutors and learners, and increasing collaboration among users regarding pedagogical activities.

Figure 2-(a) illustrates the environment Welcome Page, which is the user Authentication Page as well. Figure 2-(b) refers to the User Account page, responsible for all information about the user. Figure 2-(c) exemplifies the Message feature, providing channels of communication in student-student and student-tutor ways. Figure 2-(d) represents a Microblog feature, which replaces a conventional forum. The idea is to provide a better communication and collaboration among students and tutors in the context of mobile learning, easing practices and educational activities. Each course has its own microblog.

Figure 2-(e) shows the Course page. From this page, the user can access features like Repository, Participants and Microblog. The tutor can also change settings or even delete the course. Each course has its own Repository, shown in Figure 2-(f). All course participants can access the repository and most of the educational content can be found there.

[8] http://www.w3schools.com/webservices/ws_wsdl_documents.asp

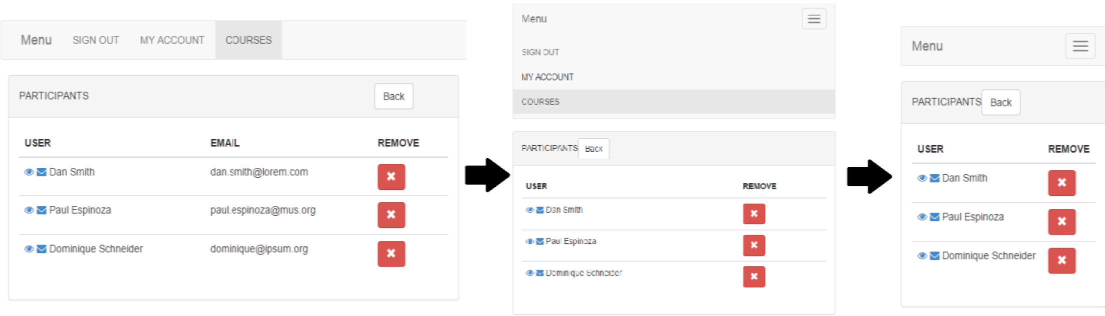
[9] http://axis.apache.org/axis2/java/core/

(a) Welcome Page (b) User Account (c) Message

(d) Microblog (e) Course (f) Repository

Figure 2. Prototype: General view.

For the front-end, we have adopted Bootstrap[10], one of the most popular HTML5[11], CSS3[12] and JavaScript[13] frameworks for developing responsive projects on the web. In short, the framework allows a good visualization and use in any screen size (Figure 3) with a single source code, facilitating the use both by tutors in big screens and by students in smartphones or tablets.



Desktop 14'' **Tablet 10''** **Smartphone 5''**

Figure 3. Prototype responsive design.

Besides CSS3, HTML5 and JavaScript, other technologies have been used as well. For the back-end, a PHP framework based on the MVC[14] (Model-View-Controller) architectural pattern, referred to as CodeIgniter[15], helps on the URL routing, database access and data manipulation, clear and complete documentation, good performance and safety for the learning environment.

Web Services also make use of CodeIgniter for implementation, but they have mostly been developed following the REST[16] (Representational State Transfer) architecture. The return types are XML[17] (eXtensible Markup Language) and JSON[18] (JavaScript Object Notation), a lightweight data-interchange format, easily readable and writable by humans, and machine parsable.

7. CONCLUSIONS AND FUTURE WORK

In this paper we described an architecture for mobile learning environments. The architecture was designed and modeled based on a set of architectural requirements for service-oriented mobile learning environments. The requirements were elicited through a systematic process, taking into consideration: (1) the application context definition; (2) the investigation of related work; (3) the analysis of existing mobile learning environments; and (4) the help/support of

[10] http://getbootstrap.com/
[11] http://www.w3schools.com/html/
[12] http://www.w3schools.com/css/
[13] http://www.w3schools.com/js/
[14] http://www.w3schools.com/aspnet/mvc_intro.asp
[15] https://ellislab.com/codeigniter
[16] http://rest.elkstein.org/
[17] http://www.w3schools.com/xml/
[18] http://www.json.org/

specialists to prioritize and complement the requirements. In the end, the proposed requirements were categorized in four groups of specific areas: (1) architectural requirements for learning environments in general; (2) architectural requirements specific for mobile learning environments; and (3) architectural requirements specific for SOA.

Based on the architectural requirements identified, a service-oriented architecture for mobile learning environments was instantiated, enabling the implementation of a service-oriented learning environment together with the incorporation of mobile aspects. The general view of the proposed architecture comprises the following layers: View Layer, Data Layer, Presentation Layer, Application Layer, Quality of Service (QoS) Layer and Intermediation Services Layer. The elements described in this view foster a better reuse and interoperability, and can be built considering the most appropriate technologies and languages to their implementation.

In order to evaluate the proposed architecture, a prototype for a mobile learning environment was implemented. The implementation results provided evidences on the viability of practical application of the architecture, especially with regard to service consumption and service implementation, promoting interoperability and reuse for educational services.

The main contribution of this work lies on providing guidance for architectural design of new mobile learning environments as well as for evolution and maintenance of the existing ones. Indeed, the right definition of architectural requirements can promote a better abstraction of the system to be developed/evolved, helping its architectural representation. As a consequence, the determination of this architecture can provide benefits with regard to overall quality, interoperability, reuse, domain comprehension, and reduction of the time spent in the development/maintenance of mobile learning environments.

As future work, we intend to define a complete reference architecture for mobile learning environments, also addressing other architectural views (i.e., module view, runtime view and deployment view). The architectural requirements and the architecture defined in this paper will play a fundamental role in this direction, acting as the basis for the establishment of such reference architecture. We are currently working on this perspective; details should be reported in short term.

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