Adapting Learning Content to User Competences, Context and Mobile Device using a Multi-Agent System: Case Studies*

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E-learning has revolutionized the education field. This fact, and the rise of mobile technology has led to the emergence of m-learning. There have also been new challenges such as adapting the learning content to the students' context and mobile devices, as a student could be anywhere with a mobile device and in a specific context. This paper presents a new multi-agent system for solving these challenges which has been used in two case studies in a Master of Software Engineering course. The first case study presents the results of the experiments carried out with two simulated students with different profiles, contexts and characteristics. The second case shows the usage results of the system using different real mobile devices. The results showed that the learning content is selected based on the context specified by the student and the characteristics of the mobile device used. It was also observed that some of the learning content was not supported by the mobile devices due to its format.

Keywords: adaptation; multi-agent system; mobile device; context; competences; m-learning

1. Introduction

E-learning has revolutionized the field of education. It is based on using ICT (Information and Communications Technology), and its most important feature is the possibility of offering distance learning. This feature is usually highlighted as the main advantage of e-learning; however, the minimum hardware requirement is to have a personal computer, which can be a weakness of these systems because of the restriction in the learner's location. The independence of the location is not fulfilled even with a laptop, because real independence in time and location means being able to learn where and when a learner wants, with access to the content at all times [1].

For these reasons mobile learning (m-learning) has appeared. It is an evolution of e-learning based on the use of mobile devices. One advantage of this kind of systems is the availability of these devices, because at present the majority of the population has a mobile device most of the day [2]. Nowadays there is a technological revolution with the emergence of these devices, as people have incorporated them as one more tool in their daily lives, not only as a tool for social communication, but for leisure and work tasks, and even in the learning process. From this point of view, the learner may now have different devices when learning, with different features and limitations. These devices can be used any time and any where, so the context of the learner also varies depending on his or her location. There-fore, the problem presented in this paper is the need to provide context and mobile device awareness to learning systems, so that learning content is adapted to the learner based on these parameters.

As indicated above, the m-learning emerges as a mobile learning technology, so it could be a very powerful and important tool for learning, but it can also present some challenges and/or difficulties. Some of these challenges are listed below, which have also been a motivation for writing this paper.

- There are many types and models of mobile devices with different operating systems and features, so that not all devices support and reproduce the same files and formats. Consequently, not all devices could show the same learning content because it would depend on the device features. For example, if the learning content is a video and the learner's device does not support the video format, then the learning content cannot be shown. On the other hand, one of the most important disadvantages of mobile devices is their small size [3], which may pose some limitations for some learning content, e.g., large images may be uncomfortable for a small device.
- The nature of mobile devices (and the possibility to use them anywhere) implies that a learner can learn in different conditions and situations. This is usually called context [4]. For this reason, each learner has different contexts and situations where he/she can use his/her mobile device for learning. On the other hand, there may be some

learning content that is not suitable for certain contexts (e.g., playing audio when the learner is around people or in a noisy environment).

- Learners have different competences that have been previously acquired and it would be interesting to adapt the learning content to these competences and preferences [5, 6], because in this way the learning process could be customized and optimized for the learner [7].

This paper presents a multi-agent system able to (1) adapt learning content to different kinds of mobile devices and (2) to the learner's context, and also (3) to adapt subjects or courses to the competences of each learner. A prototype of this system has been developed and it has been tested in two case studies with the aim of checking how the system adapts the learning content based on different parameters. The paper also presents the results obtained in these case studies carried out with simulated students and with real mobile devices.

Section 2 of this paper shows the prior research related to the research topics (i.e., m-learning in the training process, context-based adaptation and adaptation of content for mobile devices). Section 3 describes the proposed system in order to solve the problem indicated in the introduction. Section 4 explains the results obtained after the completion of two experiments with the developed system, Section 5 shows a discussion with other studies and, finally, in Section 6 conclusions and future work are presented.

2. Prior research

The related work is subdivided into three groups: (1) use of mobile devices in the training process, (2) context-based adaptation and (3) content adaptation for mobile devices.

2.1 Use of mobile devices in the training process

Nowadays, e-learning is usually performed through the LMS (Learning Management System), but these systems usually do not support an appropriate access with a mobile device, e.g. the content is huge for a small screen, so it is difficult to access using the web browser of the mobile device to view the learning content [8].

Trifonova and Ronchetti [9] propose an architecture for supporting mobile devices in LMS systems. For this purpose, they say that a learning environment should have at least these three new functionalities: (1) Context Discovery, (2) Mobile Content Management and Presentation Adaptation and (3) Packaging and Synchronization.

The first functionality provides context information about the learner and his/her environment:

mobile device features, location of the learner/device, temporary information, etc. The second functionality uses this information and adapts the content to the learner's and the device's needs, and it can include adaptation of the structure, of the media format, quality or even type, etc. The third functionality allows keeping the content uploaded when the learner is offline.

These authors have tested this architecture on a real project [10], called ELDIT (Elektronisches Lernerwörterbuch Deutsch-Italienisch). This is a real e-learning system for training in languages that has been adapted to support access through mobile devices.

The most important issue found by these authors is the difference in the level of connectivity of the learner with an e-learning system and with an m-learning system. In an e-learning system, the learner is usually connected to the system; but in an m-learning system, the learner may not always be connected to the system because he/she may have disconnection periods (connection cost, infrastructure problems, etc.).

At this point it is worth mentioning the difference between the terms "Adaptable" and "Adaptive". "Adaptable" means that the content adaptation is done manually and in advance, while "adaptive" means that the content adaptation can be automatically done at the moment by the system. ELDIT is only adaptable, but not adaptive.

Capuano et al. [11] propose an architecture called IWT (Intelligent Web Teacher). This architecture is flexible and easily expandable with new functions. It allows training with simple courses and intelligent courses, the latter having the possibility of being personalized for learners. The engine of the platform adapts the content to the mobile devices using the tool Microsoft Mobile Internet Toolkit, which allows building web content using adapted controls for mobile devices. The content is managed as "pills" or packages based on SMS (Short Message Service). An SMS can contain questionnaires and the learner can respond to these questions by sending an SMS to the platform.

Sharma [8] proposes a web services-based architecture for integrating mobile devices in the training process and introduces mobile devices as a tool that teachers can use for distributing tasks to learners. According to Sharma, there are two approaches for m-learning: the first is a simple access with a mobile device to a traditional LMS system and therefore e-learning becomes m-learning without any additional change. The second approach is taking into account the environment and the location of the learner when he/she connects to the LMS with a mobile device.

On the other hand, the literature discusses the use

of agents in the learning process [33] and authors have proposed frameworks, architectures and systems for mobile learning using techniques of artificial intelligence or multi-agent systems. The multi-agent system proposed by Andronico et al. [29] includes a module for giving recommendations to a learner based on similar learners and his/her profile. Kawamura and Sugahara [28] and Buraga [30] propose different ways for communicating mobile agents, the first one proposes using P2P (Peer to Peer) protocols, while the second proposes using SOAP protocol for exchanging information between the mobile agents (e.g. RDF profiles). Finally, Al-Sakran [31] proposes an architecture composed of mobile agents whose aim is to provide communication between students and allow individual and collaborative use. The main advantage of this system is supporting the process of composing personalized content for an individual user.

2.2 Context-based adaptation

The general definition of the term "context", as found in *Cambridge Dictionaries Online* is "the situation within which something exists or happens, and that can help explain it." More specifically, in computing, the term "context" can be defined as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" [12]. In computing, another term related to context is also used, "context-aware computing", which was first defined in 1994 by Schilit et al. as "One challenge of mobile distributed computing is to exploit the changing environment with a new class of applications that are aware of the context in which they are run. Such context-aware software adapts according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time." [13]. Other authors indicate that a system or an application is "context-aware" if "it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" [12].

An empirical study was done by Kim et al. [14], whose main aim was to detect the relevant context used in mobile Internet. The context information was categorized into two types: (1) personal contexts and (2) environmental contexts. The first refers to information about people who are using the mobile device, e.g. the emotional (joyful or depressed) and physical (moving or standing) states of the users are considered personal contexts. On the other hand, the second type describes the outer circumstances of mobile Internet users, e.g. the user's location as well as the number of people

who are physically close to the user, are considered environmental contexts.

Personal context is subcategorized into Internal and External context. The first refers to intrinsic aspects on the user's minds, i.e., why the user uses a mobile device and how he/she is feeling while using it. Therefore, the subcategories of Internal context are the purpose of use (Goal) and the state of feeling (Emotion). External context is related to the physical body of the user, and it is subcategorized into two components: Hand and Leg. Hand indicates the number of hands used to manipulate the mobile device, and Leg indicates if the user is moving or is not moving while he/she is using the mobile device.

Environmental context is divided into two categories: Physical and Social context. Physical context describes the distractions surrounding the user, considering distraction as visual and auditory distractions. Visual distraction indicates how much visual information is around the user, e.g., using the mobile device while the user is watching TV, and auditory distraction refers to the noise in the user's environment, e.g., listening to music or traffic noise. On the other hand, the second component of the environmental context is the social context, which is subdivided into two components: Co-location and Interaction. Co-location refers to how many people are around the user and interaction indicates how much interaction he/she has with them.

The empirical study by Kim et al. [14] was completed with 1552 effective sessions of participants and these sessions were classified in 256 different contexts (eight potential contexts: Goal, Emotion, Hand, . . . , with two possible values each, $2^8 = 256$ potential contexts). The results showed that the users used the mobile device most frequently in two specific contexts: the most frequent context was when participants had a hedonic goal, their emotional state was joyful, only one hand was used, their legs were not moving, visual and auditory distractions were low, few people were around them, and their interaction was low. The second most frequently experienced context was the same as the first, except that their goal was utilitarian rather than hedonic. The results also showed that there are many potential contexts, 99 of 256, in which the users never used the mobile device.

Having contexts defined and categorized, some works about context-based adaptation have been reviewed for establishing a solid base for this work.

Martin et al. [15] propose a new system of context-based adaptation for m-learning. Here the contexts considered are the idle time of the user (e.g. time in which the user is waiting for a bus), the information related to the location of the user and the type of his/her mobile device. The adaptation is implemented in three steps:

- Structure-based adaptation: the aim of this type of adaptation is supporting the selection of activities which are proposed to the learners. These activities can be different according to the learner and his/her requirements.
- Context-based general adaptation: this adaptation supports the inclusion/exclusion of activities from the activities list of a learner according to his/her particular context.
- Individual adaptation: this adaptation takes into account the specific conditions that must be met for an activity to take place.

Lemlouma et al. [4] indicate that an adaptation in a system is needed because the users' preferences change while they are using a system, but this would be impossible with previous adaptation and it is necessary to use a dynamic adaptation mechanism. This mechanism is based on the use of HTTP headers for identifying the type of mobile devices and the use of scripts files and XSLT sheets for adapting the content to the requirements of the users and their mobile device.

2.3 Content adaptation for mobile devices

Mobile learning (m-learning) is an e-learning extension, in which mobile devices and wireless technologies are used to perform the learning process. M-learning lets one further extend the e-learning paradigm, i.e., the ubiquity of learning, to being able to learn any time and anywhere [35]. Due to the wide variety of existing mobile devices and their different technical characteristics, the application of m-learning is complicated and limited. Most e-learning systems developed to date have rarely taken into account these differences [36], and e-learning systems should be modified when new devices with different characteristics appear, so that one can continue to use them with the new devices.

The mobile content adaptation, according to [17], commonly consists of content filtering, application filtering, polymorphic presentation and content classification.

- Content filtering: content is selected and presented by taking into account the learning situation of the learner, e.g., a student sitting in a cafe may want to perform some learning task using their mobile device.
- Application filtering: depending on a learning method, the same content is to be provided by different applications.
- Polymorphic presentation: learning content could be presented with different levels of detail (this could be considered as a synonym of content transformation by some authors [18]), e.g., showing a complete content or a slides presentation.
- Content classification: this method is based on

content and application filtering, since a list of learning content is presented, from which the learner can decide what learning object they want to learn.

As part of this classification, different mobile adaptation approaches have been categorized by W3C (World Wide Web Consortium) [16]. This categorization is focused on where the adaptation is performed: client-side, server-side or proxy-based.

Chen et al. [34] presented a comparison between the students' preferences on a desktop PC and on a mobile phone. They proposed a framework that provides adaptivity when students change devices to access computer-based learning content. Furthermore, the framework includes contextual factors, such as localization, although it is based on location names so that environments with the same name of locations may also change. This could be a limitation of this research. It would be better to connect location characteristics rather than location names with students' preference changes.

Based on the limited capabilities of an adaptation in a client-side and the opportunities that distributed systems offer for content adaptation in the server-side, Gómez et al. [18, 19] propose an adaptation process. This process is subdivided into two processes: (1) adaptation process at design-time and (2) adaptation process at run-time. The first sub-process uses IMS-LD (IMS-Learning Design) [20], a standard that provides a generic and flexible language to model and implement the learning design and expresses different pedagogies in XML language. This standard is used for making decisions on which learning objects may be shown or hidden. So, this sub-process proposes a content transformation task with the main aim of changing the properties of some multimedia resources to others, e.g., WAV format files can be converted to MP3 formats or changing text to speech or vice-versa.

The adaptation at run-time is done when the learner is interacting with the LMS system. If the user uses a mobile device that does not meet the requirements for showing the learning content, a new transcoding process must be carried out. In order to detect the learner's mobile device capabilities, the specification WURFL (Wireless Universal Resource FiLe) [21] is used.

WURFL is a based-XML repository of capabilities for mobile devices. It contains information about more than 7000 different mobile devices. For a particular mobile device, some interesting capabilities are showed, such as screen resolution (width and height), reproducible multimedia formats, etc. There are some alternatives for describing the capabilities of mobile devices, e.g., UAProf (User-Agent Profile) [22]. UAProf is based on CC/
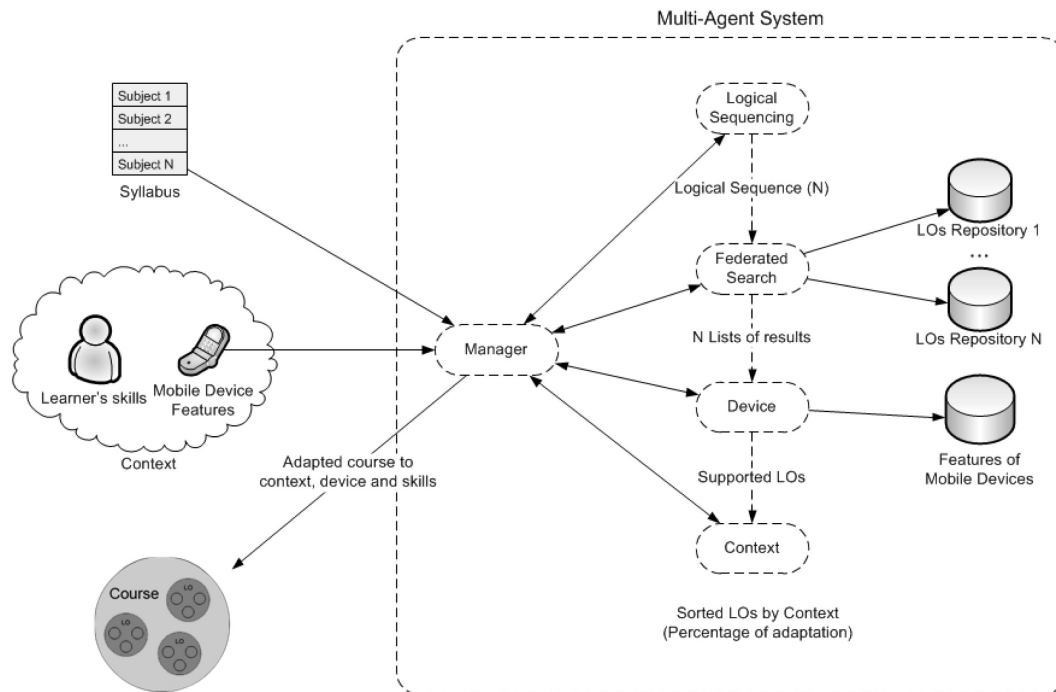
Fig. 1. Designed multi-agent system.

PP (Composite Capabilities/Preference Profiles) specification of W3C and its goal is to include, in the HTTP (Hypertext Transfer Protocol) header, a file reference where the capabilities are described. But this alternative presents some drawbacks: (1) the use of UAProf in the HTTP header depends on the manufacturer (not all mobile devices actually use UAProf in their HTTP headers) and (2) about 20% of the links are broken, according to the statistics of UAProf webpage.

On the other hand, De-Meo [32] proposes the X-Learn system, which is a multi-agent system mainly composed of three agents: (1) User-Device Agent, (2) Skill Manager Agent and (3) Learning Program Agent. X-Learn and the system proposed in this paper share various similarities: both have an agent for adapting the content according to the mobile device of the user, and other agents for adapting to the skills and the syllabus. The main differences between them are the following: (1) context-based adaptation is not covered in X-Learn, and (2) X-Learn works with only its own repository, whereas the system we propose can work with different learning objects repositories.

3. Multi-agent system proposed

In this research the premises are as follows: (1) students do not have the same skills or knowledge (competences) when they start a course or subject; (2) if a student uses a mobile device for learning, he/she may have some difficulties viewing some content due to the characteristics of their device; and (3) the learning contexts could be different when using mobile devices because they can be used everywhere. Therefore, the pedagogical objectives are (1) to offer a personalization of the learning course or subject based on the competences of the students, (2) to ensure that students are able to view all content on their mobile devices, and (3) to take into account the student's context for selecting the correct learning content.

The main aim of this work is to propose a new design of a multi-agent system (MAS) (Fig. 1) that is able to adapt learning content to learners' contexts, to their mobile device and to their competences. Five different agents have been designed to carry out this task; they work collaboratively and make up a multi-agent system. The system has been designed as a MAS for enhancing modularity, reusability, flexibility and reliability [31]. Using this strategy we are able to assign one adaptation process to each agent so that the system could be extended in the future with new agents and new adaptations methods or techniques.

The designed system has three elements as inputs: the learner's competences, the features of their mobile device, their current context and the learner's syllabus. The output will be a course (a set of learning objects) adapted to these parameters. Each of the agents is explained below with their inputs and outputs.

Table 1. Example of syllabus of a web developing program

Subject name	Prerequisites	Competences obtained
1.Introduction to Web Developing	–	Basic knowledge of web developing
2. HTML	Basic knowledge of web developing	HTML knowledge
3. CSS	HTML knowledge	CSS
4. JavaScript	HTML knowledge	JavaScript
5. HTML 5	HTML knowledge, JavaScript knowledge	HTML 5
6. Java EE	HTML knowledge	Java EE

3.1 Logical sequencing agent

The logical sequencing agent establishes a sequence of the topics or subjects that the learner has in their syllabus. This problem is represented as a Permut-CSP (Constraint Satisfaction Problem) [23] where the topics/subjects are the elements to be permuted, and their prerequisites and the competences obtained are the restrictions.

The inputs of this agent are the learner's competences and his/her syllabus. The output is a sequence (or some of them) with the plan adapted to the learner, e.g., a syllabus of a web developing course (Table 1).

A learner could have acquired the competence of basic knowledge of web developing, so in this case this subject is not taken into account to make the sequence of the syllabus (Table 2).

This might seem an easy problem but with a significant number of subjects in a syllabus this problem could became hard to solve. Some techniques of Artificial Intelligence have been studied in order to solve this type of problems, such as Genetic Algorithms and PSO (Particle Swarm Optimization) [5], heuristic and local search [24], although a study demonstrated that PSO is the optimal technique for solving this problem [25].

3.2 Federated search agent

This agent performs a federated search in different learning object repositories with each element of the sequence calculated by the previous agent. The specification SQI (Simple Query Interface) [26] is used to search in different learning repositories, and the titles of the subjects/topics of the syllabus are used as keywords for the search. After searching in learning repositories, a list of learning objects is created with the results for each subject/topic, removing the duplicated LOs (Learning Objects).

Table 2. Some examples of valid sequences for the web developing program

Sequence 1	Sequence 2	Sequence 3
2. HTML	2. HTML	2. HTML
3. CSS	4. JavaScript	6. Java EE
4. JavaScript	5. HTML 5	3. CSS
5. HTML 5	3. CSS	4. JavaScript
6. Java EE	6. Java EE	5. HTML 5

For example, for a sequence of N elements (topics or subjects), this agent would return N lists of learning objects (one for each topic or subject).

Only the LOs packaged following the specification of IEEE LOM (Learning Object Metadata) [27] are kept in the lists (the remaining LOs are discarded) because the next agents use this file to obtain information about the LO.

3.3 Device agent

The main aim of this agent is to filter the learning objects that the learner's mobile device does not support, e.g., if a mobile device does not support the Flash format, all learning objects in Flash format are removed from the list.

The inputs of this agent are the results obtained by the previous agent and the features of the learner's mobile device. These features are searched in WURFL using the User-Agent[1] when the learner connects to the system. Once the mobile device model is located in WURFL, some features of this mobile device are obtained, e.g., the screen resolution can be found in the "resolution_width" and "resolution_height" fields; or the fields "bmp", "jpg", "png", "gif", etc. with true/false values represent whether the mobile device shows or does not show these image formats.

On the other hand, in the LOM file there is a field that shows the format of the LO. This field is called "format" and it is within the "technical" category. According to the specification,"this data element shall be used to identify the software needed to access the learning object." The possible values are defined by the MIME (Multipurpose Internet Mail Extensions) standard, e.g., "image/gif", "text/html", "video/mpeg", etc.

Each LO format is compared to the supported formats by the learner's mobile device, discarding those incompatible learning objects.

3.4 Context agent

Once all learning objects are supported by the learner's mobile device, these learning objects are sorted by context. Each learning object is designed

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[1] User-agent is used for detecting what application is connecting with the World Wide Web. http://www.w3.org/Protocols/rfc2616/rfc2616-sec14.html

for a specific context, represented by using LOM, more specifically the field number 5.6 "Context" of the specification. The possible values for this field are each of the specific contexts categorized by Kim et al. [14], e.g., "hand: one, emotion: low", etc., in CSV (Comma Separated Values) format.

On the other hand, the learner's context is obtained from the learner through a questionnaire. Taking into account the learner's context and the contexts specified for the LOs, the number of matches can be obtained, e.g., a learner could have a low level of visual distraction and a specific learning object could be designed for a low level of visual distraction, so this is a match. Once the number of matches is established for each learning object, the percentage of adaptation to the context can be obtained as follows:

$$Adaptation\ Context\ Percent$$
$$= \frac{\#\ matches\ with\ the\ learner's\ context}{\#\ total\ of\ specific\ contexts\ of\ the\ LO} * 100$$

This percentage is calculated for each learning object and later the LOs are sorted by this percentage in descending order. The first LO in the list will be the most adapted to the learner. The sorted list is shown to the learner with the coefficient of adaptation of each LO, so they can choose one from the most adapted.

3.5 Manager agent

Its main aim is to manage the other agents, since these are not aware of each other's presence. It ensures that agents' inputs and outputs are running correctly. All agents are called by this manager agent and when they finish their execution the manager agent receives the results and invokes the next agent, if necessary.

This agent also aims to interact with the learner and it is also responsible of invoking the execution

Table 3. Syllabus of the subject "Usability" with the prerequisites for each lesson

Lesson	Title	Prerequisites
L1	Human–Computer Interaction	–
L2	User interfaces design	L1
L3	Usability for homepages	L1
L4	Content design	L1
L5	Evaluation techniques and methods	L2
L6	Evaluation by inspection	L5
L7	Evaluation by inquiry	L5
L8	Usability testing	L5
L9	Accessibility	L3, L4
OL10	Human characteristics	L1
OL11	Hardware and software characteristics	L1
OL12	Elements of social context	L1
OL3	Metaphors	OL10
OL14	Methods of evaluation beyond usability testing	L6, L7, L8

of an specific agent if any parameter of the learner is changed, e.g., if the learner changes his/her mobile device, a new execution of the "Device Agent" is necessary for filtering again the learning objects; or if the learner's context changes, the "Context Agent" should sort again the list of LOs.

The execution sequence of the four main agents (sequencing, federated search, device and context) has been established based on the probability of changing, e.g., the learner's context will probably change more than their mobile device because the learner can move from one place to another or they can change some component of their context while the mobile device will be the same in all situations.

4. Case studies and results

In order to test the system in different contexts and with different levels of adaptation, a prototype is developed based on the functionality and design described in the previous section. It uses the object-oriented language Java.

This section shows the case studies performed to validate the proposed system, as well as the results obtained.

The purpose of Case study 1 is to execute the system using a real syllabus and to test its operation. To do this, some simulated learners with different contexts are used, this way the responses of the system (in general) and the context adaptation (in particular) are checked.

Case study 2 aims to check the operation of the adaptation to mobile devices. For this purpose, some real devices are selected and the system is tested with them to check that different learning objects are shown depending on the features of each device.

4.1 Case study 1: Using the system with a real syllabus

The developed prototype has been deployed with a real syllabus, specifically with the course "Usability" of the Master in Software Engineering for Web of our institution. This course is made up of 14 topics (Table 1), 9 of which are mandatory (labeled as LX) for all learners and five of which are optional (labeled as OLX).

First, for this syllabus it is necessary to establish the prerequisites for each lesson in the subject (Table 3). This is done with the collaboration of the two professors of the University of Alcalá that teach the subject. They have been teaching it for several years and are experts in the subject.

Each lesson in the course is represented by its prerequisites, thus establishing restrictions that must be met before the learner can learn each of the lessons. As can be seen in Table 3, there are some

Table 4. Simulated context of student 1

Context	Value
Goal	Utilitarian
Emotion	High
Hand	Two
Leg	Stopped
Visual Distraction	Low
Auditory Distraction	Low
Co-location	Low
Interaction	Low

lessons that require that the learner has the competencies corresponding to other lessons.

When the priority between lessons about the subject have been established, the system is ready to be used by learners. Two different simulated profiles of hypothetical learners have been designed for testing the system. For carrying out this case study, the syllabus of "Usability" subject and the learning content of this course are used. The subject has different learning content in different versions (text documents, audio, video and interactive presentations) for the learning process.

The objectives of this experiment are to simulate different hypothetic contexts and to try to access the system with them, in order to observe the behavior of the system.

4.1.1 Simulated student 1

The first profile designed for this scenario was a person located at home who wants to learn about the subject "Usability" to improve their training. This person has no previous competencies on this topic.

The purpose of learning is hedonic because the learner wants to voluntarily improve their training and therefore they have a high level of motivation. As the learner is at home, a quiet and relaxed situation can be assumed, so they can use their mobile device with two hands and there are few visual or auditory distractions. The learner is also around people but has little interaction with them. Table 4 shows the hypothetical context detailed for this profile.

Once the access to the adaptive system of this hypothetical student 1 has been simulated, the result of the implementation is shown in Fig. 2.

As shown in Fig. 2 (left), the system recommends starting with Lesson 1 because the learner had no initial competencies in the subject.

In Fig. 2 (right), it can also be observed that the learning object that best fits the context has 87% of adaptation, followed by two learning objects with 75% of adaptation and finally two learning objects with 62% of adaptation.

Section 4.1.3 will discuss these results compared to those obtained for student 2.

4.1.2 Simulated student 2

On the other hand, the hypothetical student 2 has an opposite context to that of student 1 (Table 5). We suppose that this new student learns the usability subject with a hedonic goal and a low level of emotion. They use their mobile device while they are moving, using one hand. They have a low visual distraction but a high auditory distraction, and finally they have a high level of co-location and a low level of interaction with other people. We also
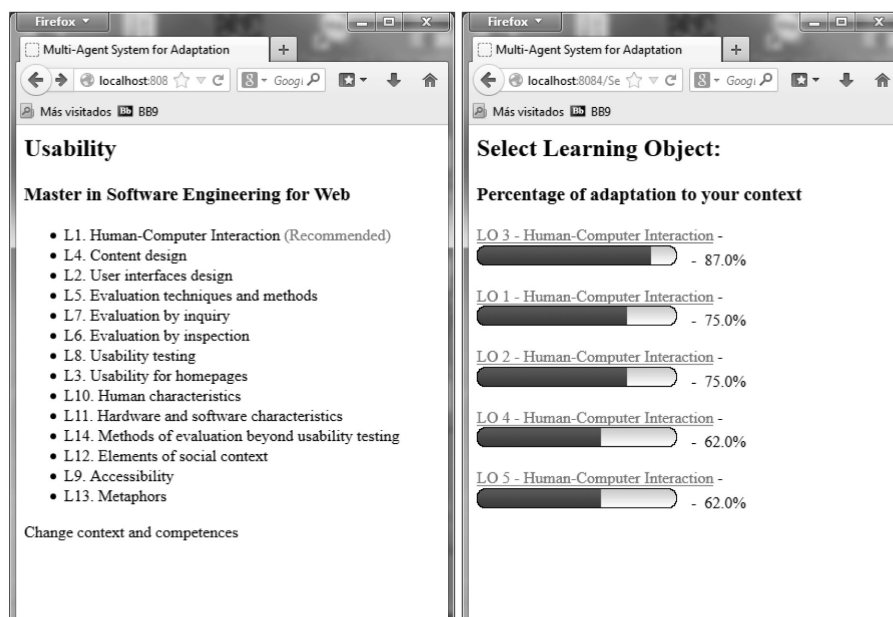

Fig. 2. Simulated sequencing (left) and adaptation to the context (right) for student 1.

Table 5. Simulated context of student 2

Context	Value
Goal	Hedonic
Emotion	Low
Hand	One
Leg	Moving
Visual Distraction	Low
Auditory Distraction	High
Co-location	High
Interaction	Low

suppose that they have some competences in usability, e.g., they already know lessons 1 and 2.

The execution of the system for this hypothetical subject is shown in Fig. 3. This student has more lessons recommended (lessons marked as "Recommended" in Fig. 3, left) because they have competencies in lessons 1 and 2. This student would have the possibility of learning six different lessons.

We suppose this student chooses Lesson 12, "Elements of social context", one of the recommended lessons. Figure 3 (right) shows the context adaptation for this student: three learning objects have 50% adaptation, followed by another two with 37% adaptation. The next section shows a comparison between the results obtained for student 1 and those obtained for student 2.

4.1.3 Results of Case study 1

Comparing both executions of the system, it can be seen that student 1 has only one lesson available (marked as "Recommended") and student 2 has the possibility of choosing one of six different topics. This is because the first student does not have competencies on the usability subject and the

second learner has some competencies. If we check these recommendations with the prerequisites of the subject, we note the recommendations of the system are right for both hypothetical students.

Secondly, if we compare the percentage of adaptation for both students, the first one has higher values (the highest value for student 1 is 87% adaptation) than the second one (the highest value is 50%). This may be due to the context selected for the hypothetical student 2, who had some distractions and a co-location with people. So in this case we observe the learning content is sorted out, based on the learner's context.

4.2 Case study 2: Using the system with different mobile devices

In this case studying different real mobile devices are used in order to test the adaptation of the device agent. To check the operation of the adaptive system it is necessary to simulate the learner context and competencies, so we use hypothetical student 1's context and competencies (details in previous section) with all mobile devices. These parameters, therefore, will not affect the results.

Table 6 shows the mobile devices used for this case study. It is important to note that the mobile devices have been selected with different screen sizes and operating systems to observe different results.

Lesson 1 of the Usability topic is selected with each mobile device (Table 3). This lesson is available in five different learning objects with different formats (provided by the professors of the subject): A video with Flash format, an interactive learning object in HTML, an audio in mp3 format and two
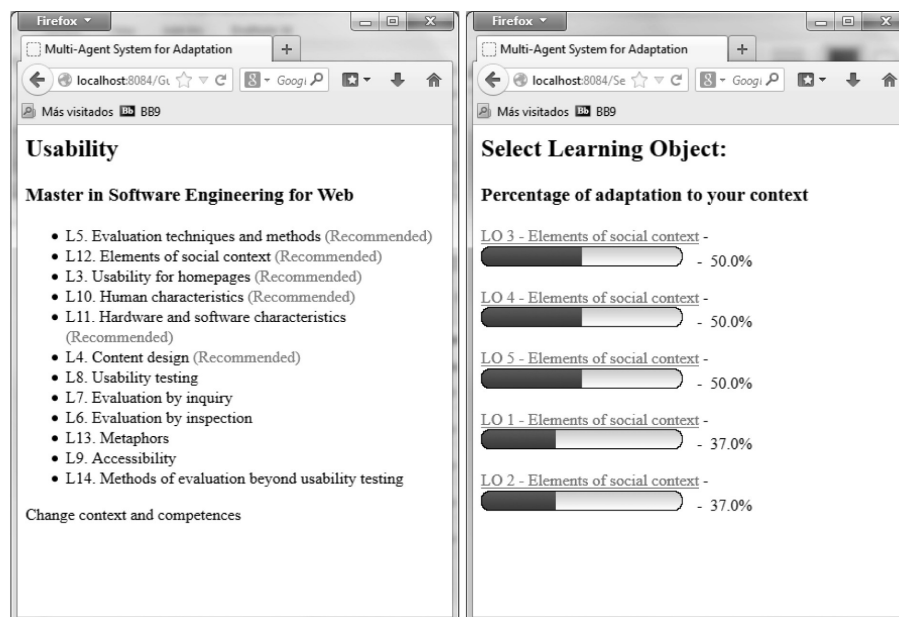
Fig. 3. Simulated sequencing (left) and adaptation to the context (right) for student 2.
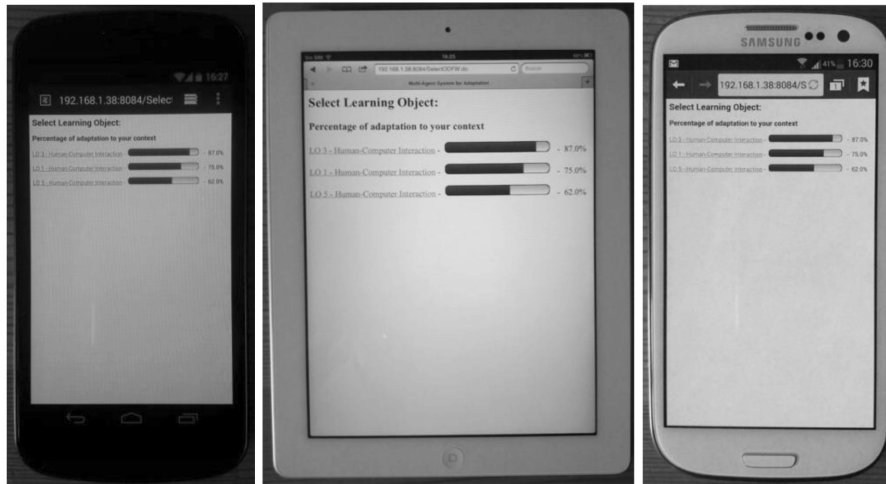
Fig. 4. Samsung Galaxy Nexus (left), iPad 2 (center) and Samsung Galaxy SIII (right).

documents in PDF and Word formats. Depending on the mobile device used, some learning objects are shown or hidden, based on the device characteristics. Table 6 shows the learning objects that are visible for each mobile device and Fig. 4 shows some examples of the execution of this experiment.

The results show that most of the mobile devices support learning contents in HTML (100%), MP3 (82.35%) and PDF (88.24%) formats, but Flash and Word (both 35.29% of the cases) learning contents are supported only by a reduced number of mobile devices (Fig. 5).

Observing the results, we could determine that the system is able to select the correct formats of the learning objects based on the mobile device characteristics. However, we saw a small issue: the mobile device limitations were provided by the WURFL [21] repository and some devices were marked as "not possible to reproduce Flash" or "not ready for Word document," but we observed that these devices were able to reproduce some

versions of flash and Word documents. In some cases it was necessary to install additional software on the devices for showing these kinds of format. Taking this into account, we could determine that it is not enough to use only one mechanism for detecting the characteristics of mobile devices.

5. Discussion

There are numerous proposals about adaptive systems in e-learning [14, 31], although the main difference in our system is that none, except ours, allows the adaptation to these three ways (competencies, mobile devices and context) at the same time. More specifically, the differences existing between the proposed system and the system proposed by De-Meo are the following: (1) context-based adaptation is not covered in X-Learn, and (2) X-Learn works with only its repository, so the system's proposed could work with different learning objects repositories. In other cases, the context

Table 6. Results: supported learning objects for each mobile device

| Mobile device	Operating system	Flash	HTML	MP3	PDF	Word
Blackberry Curve 9360	Blackberry 7.1 OS		×			
Blackberry Torch 9860	Blackberry OS 7		×			
HTC Desire	Android 2.2		×	×	×	
HTC Magic	Android 2.2.1		×		×	
HTC Radar	Windows Phone 7.5	×	×	×	×	×
HTC Wildfire	Android 2.3.5		×	×	×	
iPad 2	iOS 4		×	×	×	
iPhone 4	iOS 4		×	×	×	
LG L3 E400	Android 2.3.6	×	×	×	×	×
Nokia Asha 302	Symbian S40 Asha	×	×	×	×	×
Nokia Lumia 610	Windows Phone 7.5	×	×	×	×	×
Nokia Lumia 710	Windows Phone 7.5	×	×	×	×	×
Samsung Galaxy Mini	Android 2.2		×	×	×	
Samsung Galaxy SIII	Android 4.0		×	×	×	
Samsung Google Galaxy Nexus	Android 4.0		×	×	×	
Samsung Omnia W	Windows Phone 7.5	×	×	×	×	×
Sony Xperia U	Android 2.3		×	×	×	
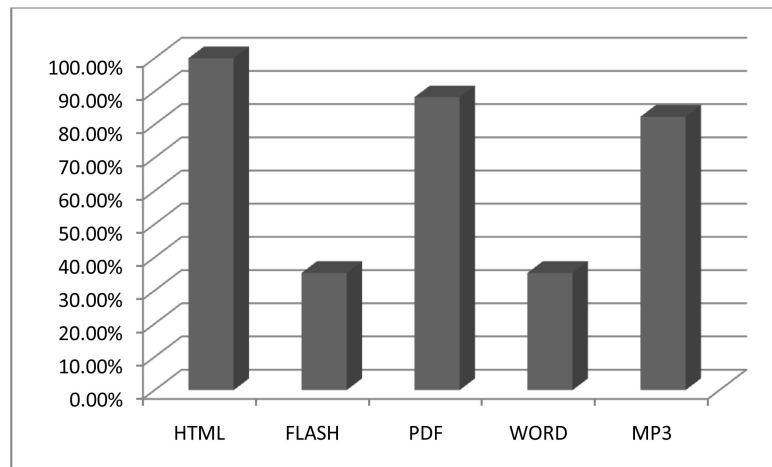
Fig. 5. Adaptation percentage for different formats.

used is the idle time [15], however the proposed system in this paper uses the contexts specified by Kim et al. [14], which allows one to specify with more details the user's context and to increase the customization level.

Not all are benefits, but also a disadvantage has been detected in this system: it may be necessary to adapt the learning content to the mobile devices, changing its graphical interface. For example, if a learning content is in HTML format but it is designed for a large screen, it would be interesting to adapt it to a small screen by transforming its appearance. However, this could be solved by incorporating in the proposed system a new agent for transforming the learning content using transformation languages, such as XSLT (Extensible Stylesheet Language Transformations) language for texts or other transformation mechanisms between different file formats, e.g., WAV to MP3, etc. This was what other similar researchers did, such as Gómez et al. [17, 18], who used transformation mechanisms in an adaptation process at run-time.

On the other hand, using a multi-gent system allows one to divide the problem into sub-problems and design a specific intelligent agent for solving each sub-problem. Moreover, the system is easily expandable with new intelligent agents for including new adaptation mechanisms or including new adaptation factors.

Finally, a limitation of this study is that the impact on teaching and learning has not been assessed yet, although we are preparing an experiment for assessing the adaptive system in a real course. There will be two groups of students: an experimental group and a control group. The experimental group will use an adaptive system and the control group will use a non-adaptive system. The learning performance will be compared and analyzed to assess the adaptive system.

Another limitation of this study is, as mentioned, that some devices were detected as "not possible to reproduce Flash" or "not ready for Word document," but we observed that these devices were able to reproduce some versions of flash and Word documents.

6. Conclusions and future work

A system for adapting learning content to learners' competencies, context and to their mobile device has been designed. This system presents some advantages compared with other similar systems: it has been designed as a multi-agent system, allowing the delimiting of the functionality of each agent and being easily expandable with new functionality, if necessary. On the other hand, the system considers a complex learner's context, according to the context categorization of Kim et al. [14], showing the learning content to the learners in an accurate way and showing the percentage of adaptation of each learning object. In addition, the system filters the learning objects based on the mobile device's features, removing those that cannot be shown.

For demonstrating the system viability, a prototype has been developed and two case studies have been performed. The first one demonstrated that the system is able to adapt learning objects taking into account different user's context and competencies. In this first case, two simulated profiles of students have been created and the system has been tested with these profiles. It has been observed how adaptation varies from one student to another. It has also been observed that certain contexts may not be suitable for learning, such as being on the move or having visual or auditory distractions, due to the adaptation percentage being very low.

In the second case, the proposed system was tested with different real mobile devices, showing

how the system is able to detect the characteristics of the mobile device and to show only the learning content, which is supported by the mobile device. In 100% of the cases the learning objects in the HTML format were displayed by all mobile devices, however only 35.9% of mobile devices were able to show the learning objects in Word and Flash format. Therefore it is important to take this into account when creating learning content. Although in some cases, installing specific software is needed for showing content in certain formats. We could conclude that the adaptive system is able to adapt different learning objects in different formats to mobile devices but it would be interesting to investigate some other techniques and methods for detecting the limitations of the mobile devices (and to improve the system).

Finally, three new research ways are proposed:

- Adaptation at run-time: the system proposed does not modify learning content, so a new interesting research line would be to transform these contents according to the mobile device characteristics using some techniques for modifying the learning content.
- Adaptation based on accessibility: a new intelligent agent could be added to the system for adapting the learning content based on the learner accessibility. The learning content would be shown to the learner by taking into account whether they have any accessibility disability.
- Automatic detection information: the information about the learner (competences, context, etc.) is provided to the system by questionnaires, so a future work would be to get this information automatically, e.g., using sensors of mobile devices.

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