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Using mobile devices to support online collaborative learning

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Abstract. Mobile collaborative learning is considered the next step of on-line collaborative learning by incorporating mobility as a key and breakthrough requirement. Indeed, the current wide spread of mobile devices and wireless technologies brings an enormous potential to e-learning, in terms of ubiquity, pervasiveness, personalization, flexibility, and so on. For this reason, Mobile Computer-Supported Collaborative Learning has recently grown from a minor research field to significant research projects covering a fairly variety of formal and specially informal learning settings, from schools and universities to workplaces, museums, cities and rural areas. Much of this research has shown how mobile technology can offer new opportunities for groups of learners to collaborate inside and beyond the traditional instructor-oriented educational paradigm. However, mobile technologies, when specifically applied to collaborative learning activities, are still in its infancy and many challenges arise. In addition, current research in this domain points to highly specialized study cases, uses, and experiences in specific educational settings and thus the issues addressed in the literature are found dispersed and disconnected from each other. To this end, this paper attempts to bridge relevant aspects of mobile technologies in support for collaborative learning and provides a tighter view by means of a multidimensional approach.

Keywords: Mobile collaborative learning, mobile technologies, ubiquity, pervasiveness, constructivism, behaviorism, situated learning, social learning

1. Introduction

Over the last decade, we have witnessed an explosion of mobile devices and wireless technologies for communication and for sharing many types of informational resources. While this has dramatically transformed our society in the way we communicate, create, retrieve and share information, collaborate and socialize each other, the application of these technologies to certain sectors of society is still in its infancy [42]. Education, in the form of electronic learning and teaching, is still far from making the most of mobile technologies to support the day-to-day classrooms and enhance learning experiences and processes, however, great research efforts are increasingly being made to incorporate mobility in this domain.

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One of the most relevant implications of mobile learning is the inherent collaborative processes arisen during the learning activity. Computer-Supported Collaborative Learning (CSCL) has become a mature research field in educational technology that focuses on the use of information and communications technology (ICT) as a mediation tool within collaborative methods of learning [23]. In developing online environments that support collaborative learning, several issues must be taken into account in order to ensure full support to the online learning group. One key issue is mobility in correspondence with the current mobility of groups of learners and the widespread of mobile devices and wireless technologies [44]. Indeed, the proliferation of mobile phones and other handheld devices has transformed mobile collaborative learning from a researcher-led endeavor to an everyday activity, whereby mobile personal tools help people learn everywhere through either formal training or informal support, collaboration and conversation [25]. As a result, by the addition of mobility and the support of mobile technologies, the Mobile Computer-Supported Collaborative Learning (MCSCL) paradigm has appeared [62].

MCSCL bases the success of current and future collaborative learning applications on the capability of such applications to incorporate mobility to support the collaborative learning processes [44]. For this reason, this issue has already attracted the attention of researchers, pedagogues and developers of applications from e-learning and collaborative learning domains [5–8]. Current literature in collaborative learning is however rather short though intensively increasing over the last years. As a result, mobile collaborative learning is still in its infancy and many challenges are to be addressed before being fully benefited from incorporating mobility to day-to-day collaborative learning.

Mobility is seen by researchers and pedagogues as a new opportunity for education since it provides more chances for learners to personalize their collaborative learning process, enhance the social interactions, learn more effectively and more autonomously, and collaborate with other peers and teachers at anytime and from anywhere, inside and outside the formal collaborative learning context. Indeed, both the capabilities of mobile devices and their wide context of use contribute to their propensity to foster collaboration. Mobile devices can easily communicate with other devices of the same or similar type, enabling learners to share data, files and messages. They can also be connected from anywhere at anytime to a shared data network, further enhancing possibilities for communication. These devices are also typically used in a group setting, and so interactions and collaboration will tend to take place not just through the devices but also at and around them as well.

A great variety of challenges arise though when using mobile devices for MCSCL, ranging from technical – such as how to manage devices with very small screens and keywords, which do not facilitate easy access to text and impede input or annotation [25] – to educational – such as how to coordinate small learning groups in the classroom [9]. And yet mobile collaborative learning is about supporting groups of people for both formal and informal collaborative learning activities in which they are willing to participate, seamlessly, with a greatest success paradoxically occurring at the point where they do not recognize it as learning at all. [33].

This view is especially relevant in the context of MCSCL from a multiple dimensional perspective, with mobility centered and intersecting into each of these dimensions:

1. **Pedagogical perspective:** We are experiencing a current shifting from a traditional educational paradigm in formal settings (centered on the figure of a masterful instructor) to an emergent educational paradigm which considers students as active and central actors in their learning process and promotes, facilitates and enhances social interactions and collaborations between students [47]. In addition, learning happens anywhere. Students not only learn and collaborate in formal classrooms, but learning happens informally in the everyday life at any moment, from playing with friends in parks to visiting a rural area. Students learn by experience and involvement, by talking

with other peers and experts, by sharing and delving into a practical problem. Virtually any experience can be a learning opportunity [34]. Studies of informal learning [52] show that most of adults' learning activities happens outside formal education. While informal learning is a reality in people's lives, they may not recognize it as learning. Mobile technologies, with their reduced size and ease of use, provide the potential to support such activities.

Socialization has also important pedagogical implications in mobile collaborative learning by seeing mobile devices as mediated tools for collaboration that support the learners' personal relationships and social interactions with classmates, friends, family, group peers, tutors, etc.. By identify the social context [14] where the learning process took place and also the time, distributed learning network becomes a reality [16]. Mobile devices and other social software tools are the pivotal technology to get permanently connected wirelessly in any situation and for any reason. This has altered the rhythms of social time and has changed uses of social space [2].

2. **Technological perspective:** Technology is getting smaller, more personal, ubiquitous, pervasive, and powerful. Mobile devices range from the use of Personal Digital Assistants and tablet computers to context-aware devices for field trips, museums, and tourist visits [42]. This way, mobile technologies provide flexibility and ubiquity by accessing learning materials anytime, anywhere and adapt them to learners' personal features, preferences and interests, as well as pervasiveness by means of the latest wearable devices for learning across contexts [26].
3. **Evaluation perspective:** Many projects and experiences have been carried out so far involving MCSCL [14,62]. However, due to the novelty of this approach and the lack of a comprehensive framework for broader formative evaluation, most of these projects have been scenario-based [9] designed for a specific educational activity that illustrate innovative practice by using mobile technologies [9]. The general aim of these projects and experiences is both to evaluate technical and pedagogic effectiveness and to assess the impact of the introduction of mobile devices and services in the day-to-day collaborative learning [51].

In this paper, we take these different dimensions of MCSCL one step further and first we analyze the pedagogical perspective in more depth, then study how mobile technologies intersect with the different pedagogical approaches considered. Finally, we propose an evaluation based on well-fundamented real experiences [50], which considered the different aspects and perspectives presented here. To this end, next section presents and describes in detail the most popular pedagogical models currently used in education, and specifically in collaborative learning. Section 3 proposes how mobile devices can connect with the different pedagogical models, delineate them, and eventually enhance and improve the collaborative learning experience. Section 4 evaluates the application of mobile devices to collaborative learning [12]. The paper ends with summarizing the main ideas presented and outlining future directions of mobile collaborative learning.

2. A multidimensional approach for mobile collaborative learning

In this section, we consider many of the current pedagogical paradigms that support learning and in particular collaborative learning, and give some clues to help understand the potential of using mobile devices in this context.

Current educational paradigms foster students to learn, with the help of instructors, technology and other students, what they will potentially need in order to develop their future academic or professional activities [47]. These new educational views are strongly related to well-fundamented pedagogical theories [33,53], such as constructivism [22], behaviourism [37], situated learning [27], problem-based learning [23], context-aware learning [24], social learning [14], and collaborative learning [15], with collaboration as the basis to accomplishing them. However, critical argument is about the lack of pedagogic and didactic concepts on the usage of mobile devices in education since most of these theories fail to capture the distinctiveness of mobile learning [42]. This is because they are theories of teaching, predicated on the assumption that learning occurs in a classroom environment, mediated by a trained teacher. Any theory of mobile learning should embrace the considerable learning that occurs outside the classroom and is personally initiated and structured [51].

Next, current pedagogical models and educational paradigms are further described and analyzed from the possibilities offered by incorporating mobility and mobile technologies to support these models.

2.1. Constructivist learning

Constructivist's central idea is that human learning is constructed rather than received, that learners build new knowledge upon the foundation of previous learning. This view of learning sharply contrasts with the traditional one in which learning is a passive and individual transmission of information from the instructor to learner [6].

Within a constructivist learning framework, instructors should encourage students to discover principles for themselves. In order to transform learners from passive recipients of information to active constructors of knowledge instructors must give learners an environment in which to participate in the learning process, and the appropriate tools to work with that knowledge.

Mobile devices provide a unique opportunity to have learners embedded in a realistic environment at the same time as having access to supporting tools. Each learner carries a networked device which allows them to become part of the dynamic system they are learning about. Therefore, learners are able to experiment and learn from the environment by themselves.

2.2. Behaviorist learning

Within the behaviorism paradigm [37], learning is thought to be best facilitated through the reinforcement of an association between a particular stimulus and a response. This theory is relatively simple because it relies only on observable behavior and describes several universal laws of behavior. Behaviorism often is used by teachers, who reward or punish student behaviors.

Eventually, however, educators feel that although stimulus-response does explain many human behaviors and has a legitimate place in instruction, behaviorism alone is not sufficient to explain all the phenomena observed in learning situations. The cognitive approach gain attention, while the behaviorist theorists go on to explore the possibilities of programmed learning for the computer age. Today, all computer-assisted instruction is solidly planted on the foundation laid by behaviorist researchers.

The use of mobile devices can enhance the behaviorist learning process by stimulating students with the presentation of engaging teaching materials and tasks, obtaining responses from learners, and providing appropriate feedback (reinforcement). In addition, video games, which are replacing some curricula's teaching methods, are implemented using advanced portable video game consoles. They are used to compete in matches' against computer-generated opponents offering faster increasing process of stimuli-response-feedback [33].

2.3. Situated learning

The situated learning paradigm [27] holds that learning is not merely the acquisition of knowledge by individuals, but instead a process of social participation. It also emphasizes the idea of cognitive apprenticeship where teachers (the experts) work alongside students (the apprentices) to create situations where the students can begin to work on problems even before they fully understand them [33].

Situated learning requires knowledge to be presented in authentic contexts (settings and applications that would normally involve that knowledge) and learners to participate within a community of practice. The following models are part of the situated learning approach:

– **Problem-based learning:** Problem-based learning (PBL) [23] is a student-centered instructional strategy of situated learning, where students collaboratively solve problems and reflect on their experiences. PBL is typically organized with small groups of learners, accompanied by an instructor, faculty person, or facilitator. Throughout the process of exploring a problem, learners are encouraged to identify the areas of knowledge they will require to understand the problem [31]. The group then collects these learning issues, along with data, hypotheses and plans for future inquiry in a structured manner and uses the collected information to develop a plan for the next iteration of problem formulation, solution, reflection and abstraction.
  Mobile devices, such as PDA and smart phones can support PBL for students in different learning contexts. For instance, a mobile-led system allows students to efficiently run, monitor and control their scientific experiments in remote laboratories at anytime, from anywhere [56]. PBL can also be facilitated by mobile technologies to share information resources among the group members (e.g. portable electronic whiteboards).
– **Context-aware learning:** The importance of usage of contextual information in collaborative learning rises with the complexity of information systems [1,24]. Any information that can be used to characterize the situation of entities (whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves is called contextual information [1]. Software systems should adapt to the users by anticipating their actions, communicating with other peers and entities which are in some way connected with the users and by taking into account the state of user's surroundings. This way of adaptation to the state and user's needs and preferences is called context-awareness and has been of a special interest to many researchers [1,24,41].
  Therefore, context consisting of contextual information that describe a learner's profile is to enable personalised and adapted learning provision based on the learner's current location [41]. Context awareness is then being explored not just as a way to deliver appropriate content but to enable appropriate actions and activities, including interactions with other learners in the same or similar contexts [33].
  Mobile devices reinforce the learning personalization and adaptation by the natural alliance between learning as a contextual activity and personal mobile technologies [1] as well as leverage the context where the learners are located and find the right collaborator, right information and right learning services in the right place at the right time [61].

2.4. Social learning

The socio-cultural theory of learning views that learning takes place in a social context [14], and the forming and re-forming of concepts need not necessarily take place only at the level of the individual, but that collaborative group work and sharing with peers (and others) can be a powerful way of confronting one's own conceptions, contributing to the need to restructure one's cognitive schemas.

This theory follows many theoreticians, since [54], who also established the importance of social interactions among individuals. In learning, high level cognitive functions are originated through the interactions among learners. Thus, learning is perceived as being as much about communication as it is about content. Communication is not confined to peer-to-peer. It can involve teachers, experts, workmates, friends and family [33]. Social constructivist is a view of learning based on social interactions, where creating a student-centered, self-directed learning environment is seen as necessary for deep learning to occur.

Communities of practice also refers to the process of social learning that occurs and emerge and evolve when learners who have common goals interact as they strive towards those goals [57]. Communities of practice form part of the current pedagogical discourse and research that emphasize different learning practices, distinguishing between formal, non-formal, and informal learning [52].

Collaborative learning can happen formally in traditional and virtual classrooms at schools and universities, fully institutionalized, bureaucratic, curriculum driven, and formally recognized with grades, diplomas, or certificates [30]. Non-formal describe collaborative learning organized outside the formal education system, which tends to be short-term, voluntary, and have few if any prerequisites. They typically have a curriculum and often a facilitator [30]. Informal collaborative learning happens anywhere and includes all experiences that occurs outside the curriculum of formal and non-formal educational institutions and programs. Informal collaborative learning can mainly be either self-directed, referring that learning tasks are undertaken by individuals (as part of a group) without the assistance of an facilitator, or accidental, when the group of learners did not have any previous intention of learning something out of that experience [29].

Even though computers traditionally have been used as individual tools in collaborative applications, mobile devices, thanks to its mobile property, can provide the necessary support so that those collaborators can socially interact with freedom [41]. Indeed, mobile technology can offer very important aspects to achieve a natural social interaction among collaborators.

2.5. Collaborative learning

Collaborative learning, supported by computing technology, originated the area of CSCL, which is currently a mature research field [15,23,36]. An important issue raised in collaborative learning is the change from divergence to shared understanding and to possible construction of knowledge. The point is to understand how collaborative interactions develop over time: whether students raise new issues (ideas) more frequently as they become more familiar with the discussion and discussants, and whether shared knowledge building becomes richer over time, and subsequent evidence that students were able to construct their own understanding based on their interactions with others. [38,45] investigated whether collaborative learning in asynchronous discussion groups results in enhancing academic discourse and knowledge construction. Their research work showed that students in the discussion groups were very task-oriented and that higher proportions of high phases of knowledge construction were observed.

However, current interaction among students by using home computers as mediating collaboration means, demands the implicated actors to be rather statically behind a desk. This situation leads to a loss of mobility of the collaborators, which restricts their social interactions and impedes the awareness with the learning context and location [41].

3. Technological advances in support for mobile collaborative learning

This section shows the latest mobile and wireless technologies in conjunction with modern infrastructure and software paradigms, such as grid computing, Web 2.0, and ontology-based and context-aware systems, to realize the next mobile communities of learning practice and pedagogical models presented in the previous section.

After a short introduction of the impact of mobile technology in the education domain, three technological perspectives, namely devices, software and infrastructure, are gazed at in more depth to provide a rather complete view of the existing technological solutions for MCSCL.

3.1. A gaze at current mobility needs in education

Current college students' culture is indistinctively wireless and mobile connected. By means of a great variety of mobile and wearable devices, such as PDA, smart phones, and laptops, tablets, handheld or palmtop computers, portable media players (e.g., iPods), and so on, they are not isolate from classmates, friends and family, but incredibility flexible, fluid, communicative, and collaborative, more than ever when it comes to their social connections in their virtual life. In addition to the extremely popular social networking applications and other social tools, such as blogs, wikies, discussion boards, and so on, they are permanently connected wirelessly in any situation and for any reason. More broadly, mobile and wireless computing has altered the rhythms of social time and has changed uses of social space [2].

Within higher education, instructors are beginning to realize the impact of creating communities of learning practice and incorporating social learning into their courses by means of mobile technologies. Students bring to the course an extensive network of information input, peer connections, and the potential of a wider scope of application than what has been the case until now. The negative side is the overwhelming technological intrusion at anytime and anywhere, even though technology is sometimes not necessary at all while participating in certain face-to-face learning activities. Some instructors have seen this as something to be controlled though and they are trying to integrate this reality into the learning environments. Mobile devices are especially well suited to different environments simply because they are available in different contexts, and so can draw on those contexts to enhance the learning activity. Context-aware mobile devices can support students by allowing a learner to maintain their attention on the world and by offering appropriate assistance when required [33].

This technological revolution is however followed by strict accessibility, availability, security, performance that existing infrastructures can address only in small-scale and quite often not sufficiently or resulting in high costs [7]. High performance computing, such as Grid [18], as the enabling technology for next generation m-learning applications aiming at making affordable to meet demanding non-functional requirements appearing in this context.

3.2. Technological devices

Many collaborative learning activities have been around for learners in our lives. From our infancy, we have been many times outside the classrooms to be taught at the same place where the knowledge can be empirically acquired. Field trips, museums exhibitions, tourism, visits to cities, rural areas, etc. With the current technological support, this outdoors activities have been extremely enhanced giving more opportunities for context-aware, behaviorist, and problem-based learning. Indeed, a traditional field trip is now a source of new knowledge more than ever before. Learners can use their PDA individually or in small groups to record the sound of the water, take pictures of vegetation, check the name of certain

Fig. 1. Multiple choice questionnaire for learning purposes delivered in a mobile phone (source: [10]).

plant and mineral, and measure the flow of a river, as part of the learning tasks required by the teacher in the form of questions and activities sent to learners' PDA. The teacher, in turn, receive the responses and results directly in her handheld computer, which has the means to correct and give back immediate feedback to learners (right and wrong questions) and also provide explicit scaffold on the same scenario the learners are studying.

From the literature, certain classification is made in order to organize the great variety of existing technology for education into personal, shared, portable and static [33] In this paper, we just consider personal and portable devices, such as mobile phones and PDA, since those shared, portable technology forces the student to move, not the device (e.g., interactive museum displays).

The following is a list of the existing portable and personal devices most used for educational purposes [58]:

- **Mobile phone** (also called cellphone and handphone, see Fig. 1): This is a long-range, electronic device used for mobile voice or data communication over a network of specialized base stations known as cell sites. In addition to the standard voice function of a mobile phone, telephone, current mobile phones may support many additional services, and accessories, such as SMS for text messaging, email, gaming, Bluetooth, infrared, camera with video recorder and MMS for sending and receiving photos and video, MP3 player, radio and GPS.
  Mobile phones are probably the most common device used for educational purposes. Even though its functionalities are more limited than more advanced mobile devices, such as laptops and handheld computers, the proliferation of mobile phones (reaching 4 billion worldwide mobile subscriptions at the beginning of 2009)[1] make this type of mobile technology widely and broadly available for education. The downside is its small screen and keyword size that restrict the annotation capability and the content presentation as well as short battery life that impedes long periods of teaching and learning.

[1]Source: International Telecommunication Union (ITU).

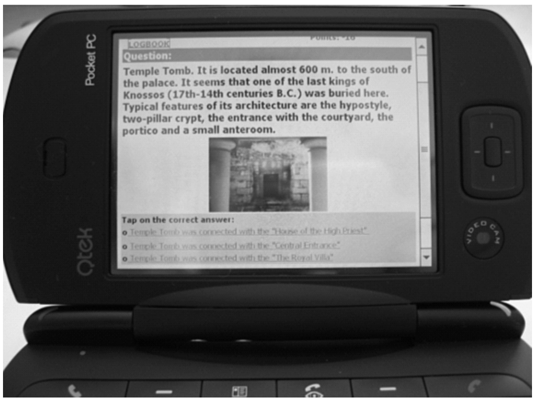

Fig. 2. By using smart phones, learners can investigate on the ground and provide answers in the same scenario where the questions are about (source: [10]).

Text messaging, voice communication and pictures are the most used resources to basically support each of MCSCL pedagogical models presented in the previous section. For instance, mobile phones are commonly used for behaviourist learning, where students send frequent vocabulary messages and revision material via SMS text messages. Mobile phones also allow students to access multiple choice questions and answers, and practical exercises (see Fig. 1).

- **Smartphone** (Fig. 2): This is a mobile phone offering advanced capabilities, often with PC-like functionality. Usually, a smartphone is a phone that runs a complete operating system software providing a standardized interface and platform for application developers. It also provide advanced features like e-mail, Internet and e-book reader capabilities, and/or a built-in full keyboard or external USB keyboard and VGA connector. In other words, it is a miniature computer that has phone capability.

  Growth in demand for advanced mobile devices boasting powerful processors, abundant memory, large screens and open operating systems has outpaced the rest of the mobile phone market for several years. The inconvenience of this technology is not being generally affordable and the lack of standards across the different devices (i.e., learning material is usually device-dependent when generated in a specific device and thus it is not presented in the same way on every device).

  Smartphones help fulfill certain phases of certain complex pedagogical models in MCSCL, such as the behaviorist, social and context-aware (see Fig. 2) learning paradigms [33], by making the most of advanced features offered by these devices (e.g., retrieve and share with peers any type of data from the Internet, identify the own's surrounding location by the geographical information available [41], review, listen and practice speaking, and provide services such as phrase translation, quizzes and live coaching, etc.).

- **Laptop Personal Computer** and **Tablet Personal Computer** (Fig. 3): They are also referred as Notebook PC and are personal computers designed for mobile use and small enough to sit on one's lap. Both integrates most of the typical components of a desktop computer, including a display, a keyboard, pointing device, speakers, and often including a rechargeable battery, into a single small and light unit. A Tablet PC is equipped further with a touchscreen or graphics tablet/screen hybrid to operate the computer with a stylus or digital pen, or a fingertip, instead of a keyboard or mouse.

  Because of its size, capabilities, and portability, laptops are probably the most popular personal desktop-computer-based device supporting technology for MCSCL. The downside is the relatively short battery life and portability. Since laptops and tablets offer similar computer power and

Fig. 3. A Tablet PC to support problem-based learning by discussing the data collected in the field (source: [5]).

Fig. 4. A student taking notes with a handheld PDA-like device.

computing capability than traditional desktop computers, they can be used to fully support the problem-based learning pedagogical model eliminated by offering the necessary mobility and full power, allowing learning groups to meet and fully work in a library, bar, classroom, field (see Fig. 3), etc. On the other hand, these devices are not suitable for supporting context-aware and social learning, since its size restricts the portability and usability in certain outdoors locations and for specific learning activities (e.g., field activities, tourist visits, etc.).

– **Handheld Personal Computer** (Fig. 4): They are also referred as Palmtop PC or Pocket PC, which is a term for a computer built around a form factor which is smaller than any standard laptop computer. A personal digital assistant (PDA) is considered a handheld computer. Newer PDA commonly have color screens and audio capabilities, enabling them to be used as mobile phones (smartphones), web browsers, or portable media players. Many PDAs can access the Internet, intranets or extranets. Many PDAs employ touch screen technology.
  Handheld devices are commonly used in the classroom for digital note taking (see Fig. 4). Students can spell-check, modify, and amend their class notes or e-notes. Some educators distribute course material through the use of the internet connectivity or infrared file sharing functions of the PDA. Textbook publishers have begun to release e-books, or electronic textbooks, which can be uploaded

Fig. 5. A group of children using iPods media players to listen to podcasts in an outside class activity.

directly to a PDA. Software companies have developed programs to meet the instructional needs of educational institutions such as dictionaries, thesauri, word processing software, encyclopedias and digital planning lessons.

PDA, more commonly than smartphones, are used by learners to support visits to museums, field studies, etc. by having an interactive audio-visual tour, taking observational notes, taking photo, querying networked database and comparing data, etc. Also, teachers use this device to collect learners' responses and results to tests and field activities and provide feedback to them [33]. This supports most of the pedagogical models of MCSCL, such as the constructivist approach, by allowing learners to discover principles for themselves and acquire new knowledge upon the foundation of the existing knowledge.

– **Portable media players** (Fig. 5): This is a consumer electronics device that is capable of storing and playing digital media. Digital audio players that can also display images and play videos are portable media players. The data is typically stored on a hard drive, microdrive, or flash memory. Other types of mobile devices, like mobile phones, are sometimes referred as portable media players because of their playback capabilities.

  Podcasting (Fig. 5) is currently one of the most populars portable media formats used in education. Podcasting is a term used to describe a collection of technologies for automatically distributing audio and video programs over the internet. Podcasting enables independent producers to create self-published, syndicated "radio shows", and gives broadcast radio or television programs a new distribution method. Any digital audio player or computer with audio-playing software can play podcasts. The term "podcast", however, still refers largely to audio content distribution.

  They are usually audio and video programs on desktop computers, laptops, iPods (Fig. 5), smartphones, handhelds, and other mobile devices. Hundreds of free educational programs are available online. Podcasting can support several pedagogical models, such as context-aware learning, by offering news/issues related to the subject, books/journals/films reviews, explanation of key concepts/terminologies, background information about the subject, links to make wider connections, questions students should be thinking about before the class, etc. [33].

3.3. Technology as software

Following this social approach, the so-called "web 2.0 social software" [3,35], such as blogs, wikis, and podcasting) provide new opportunities for creating social constructivist learning environments focusing upon student-centered learning and end-user content creation and sharing. Building on this foundation, mobile web 2.0 has emerged as a viable teaching and learning environment. Today's wi-fi enabled smartphones provide a ubiquitous connection to mobile web 2.0 social software and the ability to view, create, edit and upload user generated web 2.0 content for the creation of social constructivist learning environments that bridge multiple learning contexts [7]. Next, an extract of some of the most popular Web 2.0 social tools for education are described [58]:

– **Blogs:** A blog is a type of website, usually maintained by an individual with regular entries of commentary, descriptions of events, or other material such as graphics or video. Many blogs provide commentary or news on a particular subject; others function as more personal online diaries. A typical blog combines text, images, and links to other blogs, Web pages, and other media related to its topic.
  The ability for learners to leave comments in an interactive format is an important part of social and collaborative learning pedagogical approaches since it allows for developing critical and reflective thinking [11].
– **Wikies:** A wiki is a website that allows for the easy creation and editing of any number of interlinked Web pages. Wikis are often used to create collaborative websites, to power community websites, and for note taking. The collaborative encyclopedia Wikipedia is one of the best-known wikis.
  Wikis are the most obvious form of collaborative learning and also greatly support the social and constructivist approaches by both supporting social interaction [48] and allowing learners to build knowledge upon the foundation of previous learning [46].
– **Discussion boards** (see Fig. 6): Internet forums could be described as a web version of a newsgroup or electronic mailing list allowing people to post messages and comment on other messages. People participating in an Internet forum may cultivate social bonds and interest groups for a topic may form from the discussions.
  Many online courses' curricula includes the participation of students in on-line web-based discussions with the aim of sharing and discussing their ideas. Indeed, the discussion process plays an important social task where participants can think about the activity being performed, collaborate with each other through the exchange of ideas that may arise, propose new resolution mechanisms, as well as justify and refine their own contributions and thus acquire new knowledge [49].

In addition to these social tools, Semantic Web [59] and ontologies [13], are also considered in the context of Web 2.0 for the provision of customized and dynamic learning (e.g., adapting the learning content in different formats and with different technologies). They are eventually integrated into advanced Learning Management Systems for mobile education, such Moodle [32].

3.4. Technological infrastructure

Modern mobile collaborative learning environments must provide advanced enablement for the distribution of learning activities and the necessary functionalities and learning resources to all participants,

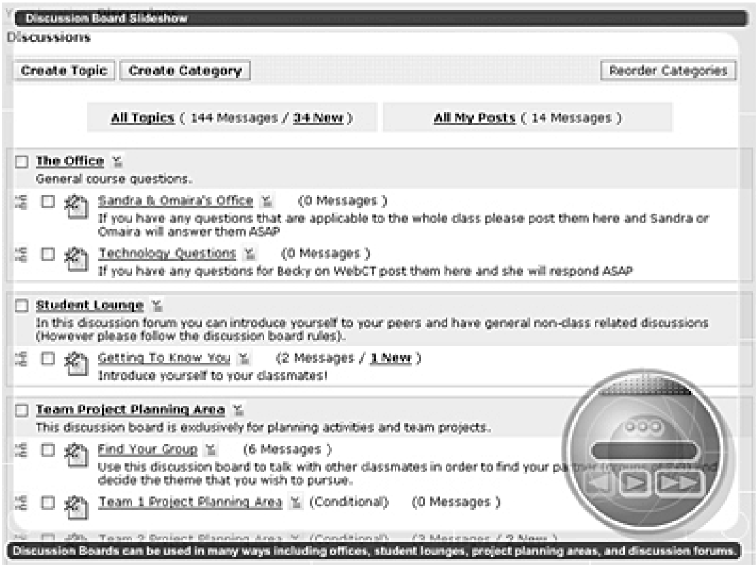

Fig. 6. A on-line discussion board to support in-class discussions.

regardless of where these participants and resources are located, and whether this location is static or dynamic. The aim of newest learning environments is to enable the learning experience in open, dynamic, large-scale and heterogeneous environments. As a result, ubiquity and pervasiveness are essential requirements to support formal and informal learning and to allow all learning community members, from a variety of locations, to cooperate with each other by means of a large variety of technology-enhanced equipment. Therefore, non-functional requirements, such as scalability, flexibility, availability, security, interoperability are to considered for the development and adoption of the next generation of mobile learning systems [7].

To address these complex issues, next we present powerful and pervasive technologies, namely Grid, distributed and wireless infrastructure. Ubiquity and pervasiveness are especially relevant in this context in order to provide not only anywhere anytime learning but also unconscious learning.

- **Mobile Grids:** MCSCL, as the next generation of CSCL, comprises an exciting new trend in learning techniques allowing for the learner to have an active role in the learning process and enabling continuous education through anytime-anywhere access to and construction of knowledge and expertise as well as collaboration among learners. Following the latest advances in mobile computing and communications and coming to meet the need for advanced knowledge management and undisruptive but still affordable access to learning content, this enhanced learning process brings a new educational era in the academic and business sectors. This revolution in the learning domain, however, is followed by strict accessibility, availability, security, performance non-functional technical requirements that existing infrastructures can address only in small-scale and quite often not sufficiently or resulting in high costs.
  These advanced infrastructural needs in combination with the innate business goal for lower cost and higher profit are driving key business sectors such as multimedia, engineering, e-health, gaming, m-learning, among others towards adopting new efficient and scalable solutions into their business. Grid technology [19] of nowadays aims at providing such an infrastructure that can also serve the rising needs of the business and educational domain. As a full inheritor of Grid, Mobile Grid [28]

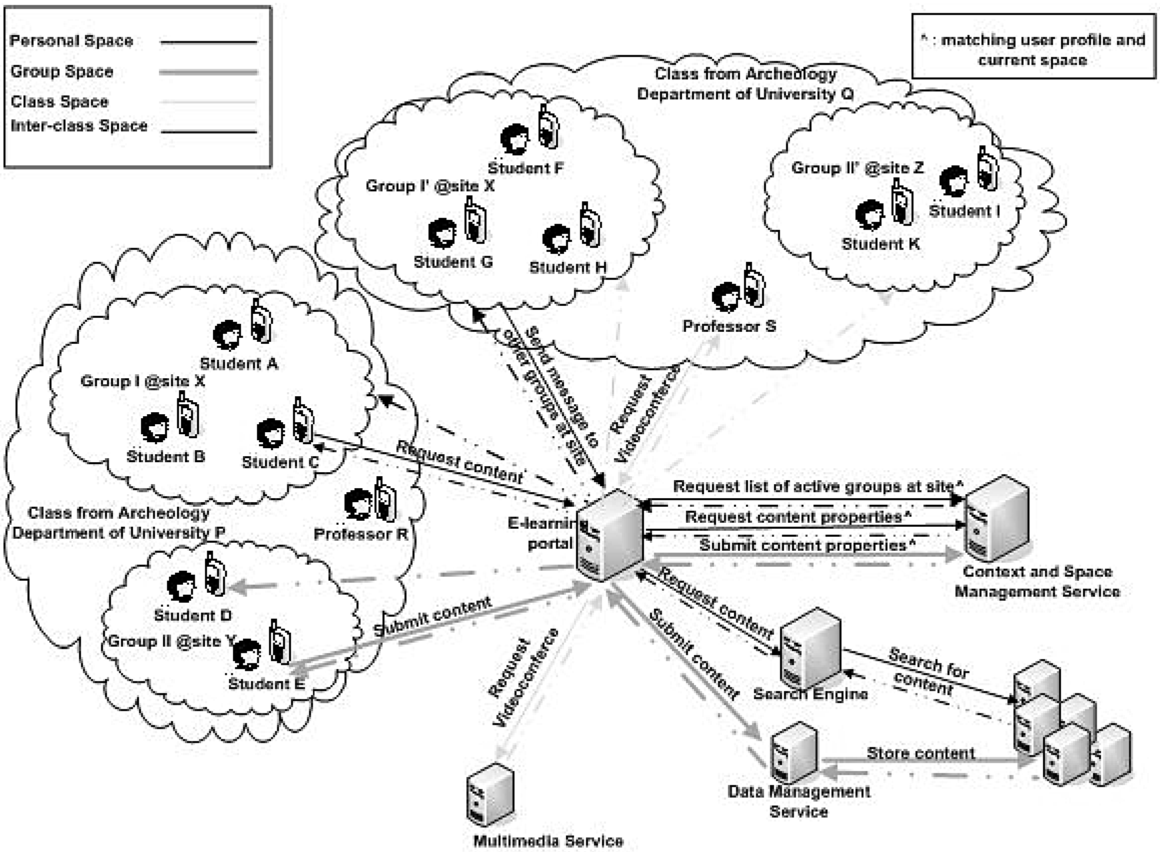

Fig. 7. Grid infrastructure supporting an m-learning environment (source: [4]).

with its additional trait being its ability to support mobile resources (serving either as a service provider or a service consumer) in a seamless, transparent, secure and efficient way comes to serve the additional infrastructural needs posed by mobile applications, such as m-learning.

From the non-functional requirements perspective, Grid infrastructures support the priority scale of m-learning environments, which lie on availability, security, performance and mobility (see Fig. 7). The infrastructure supporting an m-learning environment must guarantee 24/7 availability of information, complex informational flows, real or 'near' real-time data integration and delivery across heterogeneous data sources, unrestrained, seamless access to learning objects and courseware as well as real-time analysis of data and fast end-user access and interaction [4].

– **Distributed computing and P2P**: Distributed and P2P systems [21] have become popular for file sharing among Internet users. Due to improvement on network communications and the processing power of desktop machines, there is an increasing interest in exploring P2P technologies for developing groupware tools that could support eLearning.

  Most of nowadays online learning systems are web-based, which as centralized systems, show several limitations such as maintenance cost, scalability and having a single point of failure. P2P technologies are an important alternative to develop decentralized online learning systems in which students can be more than mere clients and can use their own computational resources for task accomplishment during online learning process [60].

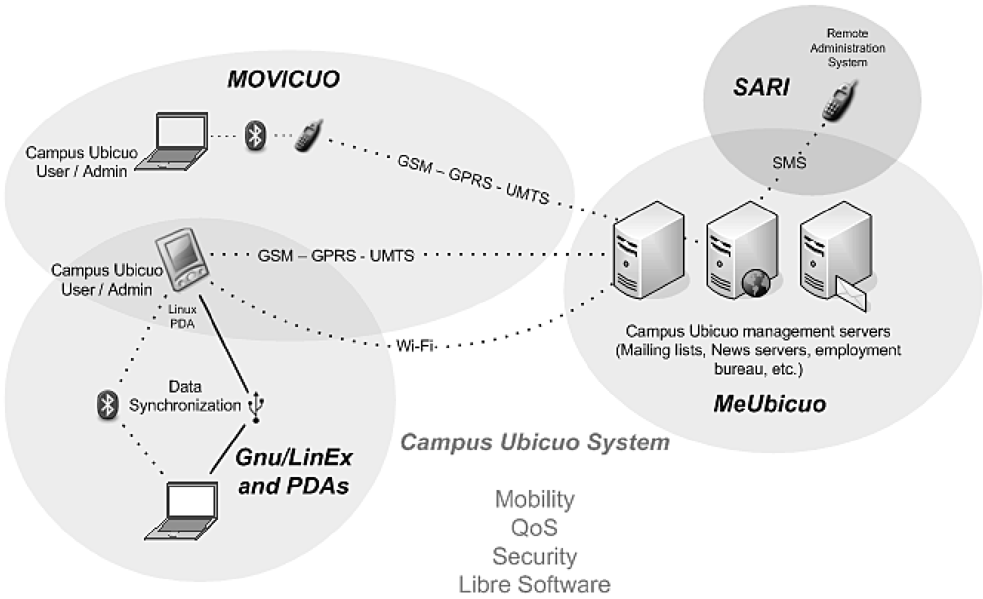

Fig. 8. Architecture of Campus Ubicuo System (source: [8]).

– **Wireless infrastructure:** Mobile communications are the basis that makes possible MCSCL. The scene of any educational institution supporting mobile collaborative learning is composed by several wireless technologies [17], such as WLAN (Wireless Local Area Network) or Wi-Fi networks are the most common wireless technologies in a local institution; GPRS and UMTS allows mobility in wide areas and are used to be always connected when local Wi-Fi networks are not available (see Fig. 8).

These days, it is common to find all the aforementioned technologies available in learning centres, so it is necessary to manage these technologies to obtain the greatest benefits that can help in the MCSCL process [8].

4. Towards an evaluation model of mobile collaborative learning

There is still not enough accumulated experience nor standard evaluation framework on MCSCL formative models, and most of the examples refer to informal education and/or specific-pedagogic tertiary education projects. Evaluating various pedagogies on different scenarios within the same project, not only provide an appraisal of the technical and pedagogical value of these MCSCL scenarios, but also inform the research community about appropriate evaluation models and evaluation procedures, which are lacking in the MCSCL area [7].

In addition, sound pedagogical principles for designing MCSCL scenarios have been explored for the enabling technologies and learning platforms. The complexity of the design increases because the learning strategies include a great variety of mobile devices as an added motivating aspect, and outdoors location-based complex scenarios are usually part of the learning context. Furthermore, the novelty of the approach and the complexity of the technologies involved add an extra difficulty to put into practice these rich scenarios in real learning situations. The complex panorama is completed by the fact that the users, teachers and students are included in the evaluation process from the very beginning [50].

Table 1
Overview of the use of mobile technologies for each pedagogical model

	Mobile phone (SMS, etc.)	Smartphone and PDA	Laptop and handheld PC	Desktop PC	iPod	Software (wikies, forums)	Wireless and P2P networks
Behaviourism	X	X					
Constructivism		X	X			X	
Situated learning		X	X		X		
Socialcultural learning			X	X			X

For the purpose of evaluation of the MCSCL pedagogies presented in Section 2 and considering the technological approach described in Section 3, in this section we provide procedural guidelines and technological suggestions while designing, implementing and evaluating case studies for MCSCL pedagogies [7,33,41]. To this end, well-fundamented experiences and projects have been analyzed from the literature in order to make this review (see Table 1 for an overall review). Due to the novelty of MCSCL, successful and mature case studies from mobile learning have been also considered in this section, such as the COLLAGE project [5,10,50] and all related study cases described in [33].

4.1. Behaviorism

Considering a project on an English language course using mobile phones [33], the following are the procedure and technology used to evaluate the impact of mobile devices when applying the behaviorism pedagogical approach to this course:

- SMS text messages to send frequent vocabulary messages and revision material via mobile phones.
- Mobile phones with online services enable content delivery and access multiple choice questions and answers, and practical exercises.
- Smartphones to review, listen and practice speaking, and provide services such as phrase translation, quizzes and live coaching.
- PDAs within a Grid Mobile infrastructure to present content specific questions, gather student responses rapidly (real time) and anonymously, and assemble a public, aggregate display, to show variation in the group’s ideas (distributed learning).

4.2. Constructivism

Scenarios in the COLLAGE project [50] were developed combining several pedagogical approaches within the constructivism pedagogical theory where the individual learner constructs knowledge based on his/her pre-existing and current experiences. The learning environment build throughout the project resembled computer games for children, facilitating pupils’ interaction and acquisition of new knowledge. On the other hand, the situated learning approach suggests the acquisition of knowledge through social participation and collaboration. In COLLAGE scenarios students and teachers confronted problems together in authentic learning situations. Procedure and technology to consider:

- PDA to run participatory simulations where learners play an active role in the simulation of a dynamic system or process.
- Handheld PC where context-sensitive data (raw data) and social interactions (interviews with ‘virtual’ experts) are used to supplement real world interactions.
- Discussion boards and wikies to elaborate the activity being performed, collaborate with each other through the exchange of ideas that may arise, propose new resolution mechanisms, as well as justify and refine their own contributions and thus acquire new knowledge [49].

Fig. 9. Students taking biological samples in the Fodele scenario and discussing the data with the teacher (source: [5]).

4.3. Situated learning

Considering both the Fodele scenario within the COLLAGE project [50] and the Ambient Wood project described in [33], which both are based on context-aware and problem-based learning: A series of activities were designed around the topic of habitats, focusing on the plants and animals in the different habitats of woodland and the relationships between them (see Fig. 9). In addition, a visit to a museum was part of these projects.

Procedure and technology involved:

- PDA to take observational notes, take photo, query networked database and compare data about animals and plants, etc.
- iPods to support field-based activities, e.g. listen to pre-loaded instructions, taking photos and observational notes, record students own reflections, etc Also, podcasts with news/issues related to the subject, books/journals/films reviews, explanation of key concepts/terminologies, background information about the subject, links to make wider connections, questions students should be thinking about before the class, etc.
- Handheld PC to support field studies and share and discuss on the data collected (see Fig. 9-b), provide an interactive audio-visual tour, allowing visitors to view video and still images, listen to expert commentary and reflect on their experience by answering questions or mixing a collection of sound clips to create their own soundtrack for an artwork.
- Smartphones contained background information in a variety of media about works on display, in addition to games, opinion polls and the possibility of communication with other museum visitors via standard text messages.

4.4. Social-cultural learning

As part of the social-cultural learning approach, quite a few projects have been developed over the last five years specifically in MCSCL [14,62]. In these MCSCL experiences, the procedure found is very similar. The teacher first downloads the activity from the project website and then transmits the activity to the students. After the teacher launches the activity, the students are automatically assigned to collaborative groups (typically three to five students per group). Upon completion of the activity, the teacher collects the students work. During the MCSCL activities, students are not allowed to progress to the next question until they answer the current question correctly.

Students have various resources available during the activity, including textbooks, their own notes and the guidance of their teacher. It should be noted that rather than seeking to replace the teacher, the MCSCL system attempts to support teachers by providing additional tools to support them in performing their duties.

An interesting feature of these projects in that the general architecture used for MCSCL uses a mobile ad hoc network that works over a wireless network. The devices are set up to communicate only between each other (peer-to-peer or P2P) and have no access to either the internet or local networks. The system can thus be used independent of any other hardware infrastructure. Procedure and technology involved:

– Teacher's handheld PC is used to distribute activities to a mobile network, students work in collaborative groups (students have to come to agreement before the answer can be submitted), teacher collects students works through Pocket PC.
– Students work can be downloaded to the school's PC for analysis.
– Students' laptops are connected directly using distributed infrastructure in the form of P2P.
– Wireless network to provide full mobility within the school environment.

5. Conclusions and future directions

In this paper a three-dimensional approach has been provided to help understand and unify the rather dispersion currently existing in advanced learning practices and pedagogical goals from the era of MCSCL. Even though quite a few projects have been carried out so far, it is still in its infancy and only certain pedagogical models have been applied in conjunction with the inherent collaborative learning. After an overview of both pedagogical and technological perspectives on MCSCL, suggested procedures point out ways to tightly evaluate the combination of these two perspectives.

We hope the survey and suggestions made in this paper are found useful by MCSCL designers and developers involved in the generation of the latest on-line learning systems and applications as well as educational institutions, which incorporate MCSCL into the very rationale of their pedagogical models.

Having a look at near future, mobile technologies will become more ubiquitous, pervasive and networked, with enhanced capabilities for rich social interactions, context awareness and internet connectivity, such technologies can have a great impact on collaborative learning. Learning will move more and more outside the formal classroom and into the own learner's environments, both physical and virtual, thus becoming more situated, personal, collaborative and informal. Thus, the challenge for the future will be to discover how to use mobile technologies to transform learning into a seamless part of daily life to the point where it is not recognized as learning at all.

Future work will consider other important dimensions not addressed in this first approach, such as technology affordability as well as support for disenfranchised learning and engagement of learner identities [55] in order to provide a more complete view of current MCSCL. From this new perspective, the aim is to analyze a range of learning programs that have utilized m-learning to understand how people learn and develop strong identities as well as discuss on the potential to engagement in learning and learner identities in regional areas.

Furthermore, we plan to make an in-depth analysis of interaction analysis and knowledge discovery through data mining techniques for mobile collaborative learning to provide tutors and learners with ongoing progress of mobile learning during the collaboration activity.

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