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FACE TO FACE COLLABORATIVE LEARNING SUPPORTED BY MOBILE PHONES

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To my parents, family and friends who supported me during this work and throughout my whole career.

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RESUMEN

El uso de handhelds en ambientes educativos ha ido en aumento en los últimos años y han existido muchas experiencias exitosas que avalan el uso de este tipo de herramientas, en particular en sistemas de aprendizaje colaborativo cara a cara. Sin embargo, el costo que presentan estos dispositivos hace difícil su masificación a nivel escolar. Los teléfonos celulares representan una alternativa a estos dispositivos. Con el objetivo de probar estos dispositivos como plataforma para actividades educativas colaborativas, adaptamos una aplicación existente para PDA a ser usada en celulares con capacidad WiFi. Este trabajo estudia los problemas de desarrollar este tipo de aplicaciones para teléfonos celulares y analiza un estudio de usabilidad realizado en la aplicación de la actividad para la enseñanza de la Física. Los resultados obtenidos muestran la viabilidad de usar este tipo de plataforma considerando las limitaciones de procesamiento, red e interfaz de los dispositivos. Un diseño adecuado permite una rápida apropiación de la tecnología por parte del usuario. Sin embargo se observa una menor eficiencia.

Palabras Claves: Colaboración, celulares, CSCL, educación, usabilidad

ABSTRACT

The use of handheld computers in educational contexts has increased considerably in recent years and their value as a teaching tool has been confirmed by many positive experiences, particular within collaborative learning systems (MCSCL). The cost of the devices has hindered widespread use in schools, however, and cell phones have emerged as an attractive alternative. To test the functionality of cell phones as a platform for collaborative educational activities, the authors adapted an existing PDA application for use on cell phones equipped with Wi-Fi. This article examines the problems of developing applications for this alternative technology and reports on a usability analysis of a collaborative classroom activity for teaching physics. The results confirm the viability of the cell phone platform, with due account taken of the device's processing, network and interface limitations. With an appropriate design, users quickly master the technology, though a certain decline in efficiency relative to PDAs was observed.

1. INTRODUCTION

1.1 Motivation

The increasingly low costs of mobile phones combined with the constant need of communication demanded by our society, are transforming these devices in the most used and widespread platform around the world. The innate connectivity provided by these mobile devices and the continuous improvement in their processing power and storage capabilities present a tremendous opportunity for the development of new software, targeted to a mobile, connected and massive user-base. This reality is particularly relevant in an educational context, where this lower cost platform represents an ideal medium for the massive deployment of educational activities in the classroom. However, like any other technology used in the classroom, a careful analysis must be made of the inherent limitations of the devices, and of the software design aspects that must be considered when creating this activities.

1.1.1 Mobile Phones and Learning

The use of mobile phones in the classroom has increased in recent years. Most of the existing educational activities implemented in these devices allow the students to give immediate feedback to questions given by the teacher, using either short text answers (Markett et al, 2006) or multimedia answers (Lindquist et al, 2007). The communication between the student phones and the teacher is usually based on SMS or MMS, the messaging services provided by the phone company. This represents a problem considering that each message travels through the phone company's network and therefore must be paid. In order to expand the use of these devices in more schools including public ones and expand the diversity of the activities, there is a need to find and alternative communication mechanism that bypasses the phone company and allows free and reliable communication.

Another problem that must be considered when developing educational activities in mobile phones is that the restrictive nature of the hardware and software used in these devices produces inherent learning limitations. These limitations can be synthesized as follows (Shudong and Higgins, 2005):

1. Narrow Output: Small screens and low resolution has to be considered in the amount and type of information that can be delivered to user.

2. Restricted input delivers a slow and inconvenient delivery of information from the user to the device: Specially designed keyboards have shown fast input but require a lot of training.

Mobile phones, however, provide a series of advantages in comparison with other existing devices like laptops, desktops and PDAs. The first and most important advantage is in the number and cost of devices. By 2003 there were 1.4 billion mobile phones, compared to 607 million computers including laptops and desktops (Keshav, 2005). Today the gap has increased even more and mobile phones are the dominant platform around the world. In terms of cost, mobile phones are considerably cheaper than any other device. Another main advantage of mobile phones is the power management of these devices, which is critical to battery-based devices. Laptops and PDAs usually sacrifice battery power for backlit and processing speed, having autonomy that ranges from 2 to 8 hours. Mobile phones, in contrast, have always been designed with power management as one of the main aspects, allowing them to have talk-time of 6 to 8 hours and autonomy of days in stand-by mode (Keshav, 2005). This stand-by mode present in every phone is another important advantage, because it allows the device to power off most of its services and still receive incoming data, something that laptops and PDAs cannot.

1.1.2 Collaborative Learning

Social interactions are fundamental to educational development: they allow the sharing of ideas and the construction and shaping of understanding (Cole & Stanton, 2003). Individuals working together on a common problem communicate and mobilize knowledge, sharing different ideas and views that allows them to build together a better solution (Zurita & Nussbaum, 2004a). There is a necessity to develop this social and communication abilities through the educational process, allowing the students to learn these essential skills.

There are different pedagogical models that consider social interaction as one of their key elements, using different approaches to provide the required environment that allow students to communicate and interact achieving a better and enriched understanding. One of these models is Collaborative Learning (CL) which promotes group interaction in a coordinated effort to achieve an educational goal (Dillenbourg, 1999). In CL, the collaboration of each member of the group is required to complete a given task, and through this collaboration, each member achieves a better understanding of the given problem. The creation of an effective CL environment depends on the following key factors (Zurita & Nussbaum, 2004a–b):

Individual responsibility: Each member must be responsible for his or her own work, role and effort to learn.

Mutual support: Each member must help in the teaching of the other members of the group.

Positive interdependence: The main goal of collaborative activities is the group goal. Therefore, collaboration is considered a success when every member of the group has interacted and accomplishes their individual goals.

Social face-to-face interactions: The decision making process must include discussions between all collaborators. Productivity is therefore influenced by the ability of the group to efficiently exchange opinions, negotiate and construct an answer together.

Formation of small groups: Communication, discussion and achievement of consensus can be only carried out in small groups, and each member of the group must be physically close to the other members.

Technology may be incorporated in a Collaborative Learning context, with the objective of controlling the interactions of participants (Kumar, 1996). This Computer Supported Collaborative Learning (CSCL) provides information, regulates tasks, administrates rules and roles and mediates in the acquisition of new knowledge. In this context, the computer is seen more as a partner than as a tutor (Zurita & Nussbaum, 2007) providing a support environment for the social network between students, which ideally must be transparent to the interaction. The problem of most existing CSCL applications is that they are implemented for personal computers and require that the participants be physically located behind the computer screen. For this reason, these applications do not allow the development of face-to-face interactions (Inken et al, 1999), which is one of the key factors described previously, making it difficult for this support environment to become transparent. An alternative solution to this problem is the use of hand-held mobile devices (PDAs and mobile phones). The use of these devices allows the creation of an environment where collaboration is formed in a natural manner. Using wireless network technology existing in these devices, a transparent support network is created that facilitates face-to-face interactions because of the physical characteristics of the small devices and the mobility that permits the creation of these wireless networks (Macker & Corson, 1999).

1.1.3 Activity Framework

Face to face collaborative learning activities need the support of software capable of adapting to different content and class dynamics. This necessity has encouraged the development of a series of generic software frameworks for mobile devices, which provide a number of basic functionalities needed by this kind of activities. These frameworks must be extensible, allowing the creation of different activities supported by the same services, and modular, allowing the modification of the service components. For the purpose of this work, a software platform called Activity Framework (Echeverría et al, 2006) was used. The Activity Framework (AF) was originally designed for Windows Mobile PDAs (a.k.a. Pocket PC) and was built over the .NET Compact Framework using C# language. The framework was chosen based in two main reasons. Firstly, AF had already been tested with success in different face to face collaborative learning activities and it provided the necessary services to create new activities. The second reason was the software platform used

to develop AF: the .NET Compact Framework which allowed us to port seamlessly AF from PocketPC devices to Windows Mobile Phones (a.k.a. Smartphones).

The software architecture of Activity Framework (Figure 1-1) is based on the concept of Modules and Plugins. Modules are extensible software components of the framework that provide different useful services for the different activities developed. Example of this modules are the Communication Module (Comm Mod) that provides network messaging services and the User Module (User Mod) that provides group and user management. The other important components are Plugins which are the specific collaborative activity developed and must include the graphic user interface (GUI) of the application. The creator of the activity has the responsibility to implement the plugin using the services given by the framework. Additionally, a default plugin is provided with the framework to manage the initialization of the basic modules and to choose the desired activity plugin.

The communication between modules and plugins is managed by the Module Manager, the central component of the framework. The Module Manager is responsible for activating the subscribed modules when the application starts, and to load the chosen plugin for the session. When all the modules and the specific plugin are loaded, the Module Manager acts as a hub between the components. If a plugin needs to communicate with a module, it first notifies the Module Manager indicating which module is the recipient of the message. With this information, the Manager passes the notification to the corresponding module which is responsible to execute the command asked by the plugin. To abstract the interaction between the manager and the different modules and plugins these components were implemented using the IModule and IPlugin interfaces, allowing a generic access to all components providing extensibility in both modules and plugins.

Figure 1-1: Architecture of the Activity Framework
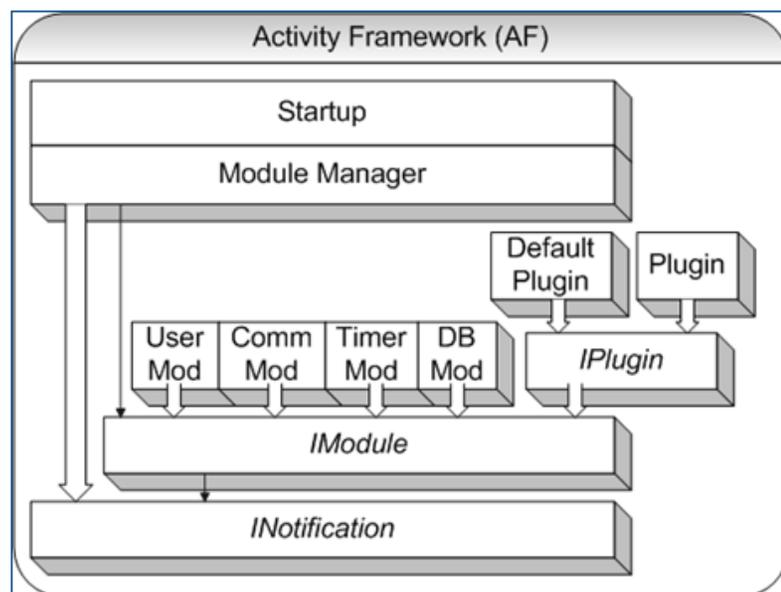
One of the first face to face collaborative learning activities implemented using AF with PDA devices was LCC (Figure 1-2), Learning to Collaborate Collaborating (Cortez et al, 2005). This activity was designed to teach different skills necessary for collaboration, including leadership and teamwork. In the context of this activity I started working with the framework specifically improving the performance of the communication module. The original network module of the framework (Figure 1-3) used a message protocol based on UDP, implemented in the UDPMessenger class. This original protocol added an extra layer of control to the raw UDP datagram to allow the acknowledgement of received messages. This original protocol presented latency and package loss issues that generated some problems when the LCC activity was used with many users. Several empirical tests showed that the use of a connection oriented protocol like TCP provided better results than the current UDP based message service, speeding up communication and lowering the error rate of the system. A new class, TCPMessenger, was added to the module replacing the UDP based protocol with a TCP based one, that although was more expensive in computational resources, provided better general results. With these modifications the LCC activity was tested successfully.

Figure 1-2: LCC activity screenshots

Figure 1-3: Network module of AF
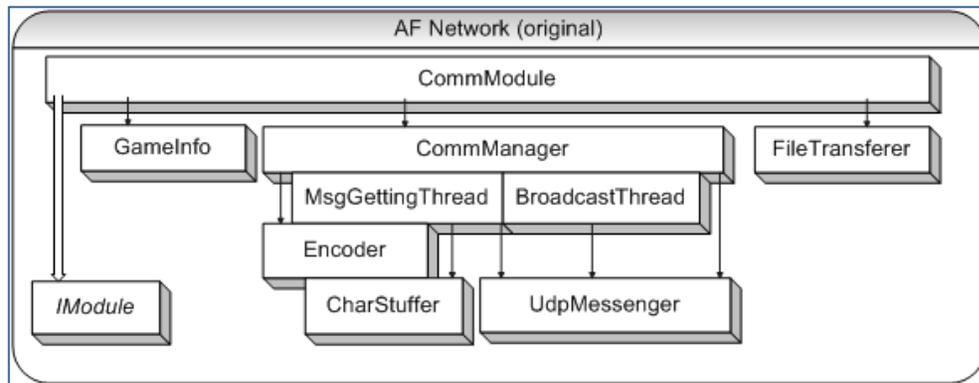
The problems presented by LCC, caused by the original network module of the framework, showed the relevance of wireless communication in the context of these activities. The modifications made to the framework for this purpose resulted in the basis for the additional changes required to port AF to be used in mobile phones, which are described in section 2.3.3.

1.2 Hypothesis

The hypothesis of this work is that it is possible to develop face to face collaborative learning activities using mobile phones, provided that careful consideration is taken in the device limitations.

1.3 Objectives

The main objective of this work is to analyze how mobile phones can be used to develop educational activities. A more concrete objective is to develop a face to face collaborative learning activity to be used with mobile phones and test it in a classroom. The activity will be based in a previous one, developed for PDAs, but with extensive modification considering the mobile phone limitations. To support the activity, a wireless network architecture will be developed to allow communication between devices. This network will be tested in real environments to understand the main limitations and problems that appear in the context of these devices.

A usability study will be developed based on the usage of the application and devices by ninth grade students. The objective of the study will be to analyze how the use of mobile phones affects the development of collaborative activities, in comparison with the usage of the same activity in PDAs.

1.4 Methodology

To achieve the objectives stated for this work, there were three aspects that had to be initially determined: the mobile phones to be used, the collaborative activity to be implemented, and the framework to support the development of the activity. The mobile phone used for this work was the Imate SP5 (Figure 1-4), a Windows Mobile 5 based device manufactured by HTC. The main characteristics of the device are:

Built-in Wifi: The devices have the ability to communicate using the 802.11b wireless local network protocol.

Small resolution screen (QQVGA) with no touchscreen capabilities.

Numeric keyboard, action buttons and four-directional joystick as input mechanisms.

Support for .NET Compact Framework software.

Although these devices do not represent the average low cost phone, its input and output limitations are similar, allowing a valid comparison in these aspects. Additionally, the Wifi capabilities allow the implementation of a local network independent of the phone company and there is evidence that this technology will be common in mobile phones in the next years (Keshav, 2005).

Figure 1-4: Imate SP5 mobile phone

The activity chosen to be used in this work was COL (abbreviation for Collaborative Activity), a face to face collaborative learning application based on multiple choice

questions (Cortez el al, 2005). In this activity students are gathered in randomly chosen groups of three, where each student has a mobile device. The teacher sends to the whole a class a set of multiple choice questions and the students of each group must provide answers to each one of them, first individually and then as a group. The system only allows the students to proceed to the next question when the three of them have agreed on the answer and when this answer is correct, forcing them to discuss and collaborate to achieve the desired outcome. To support the activity, the framework AF (Echeverría et al, 2006), described in section 1.1.3, was selected to provide the necessary services to implement COL in mobile phones. Major modifications were made to the framework's network to obtain a good performance. Once the development of the activity and its integration with the framework was completed, it was tested in a real classroom, where several usability tests were performed.

The following pages describe how the activity was implemented and integrated with the framework, explaining the necessary modifications that were made, and how the usability analysis was designed and executed:

On the second semester of 2006 we developed the initial version of COL for mobile phones. The application was designed as a plugin for the AF framework, implementing the necessary requirements to accomplish this. The COL plugin was developed as a single program, but with two different user modes: master (for the device used by the teacher) and slave (for the devices used by the students). In master mode, the application provided the teacher the necessary functionalities to select a specific activity (sequence of questions and answers of a subject) for a class. These activities were previously loaded in the teacher device from a central database. After selecting the activity, the teacher sent it to the students along with the information of the groups. During the development of the activity, the application showed a summary table of the results of every group while the students were answering. In slave mode, the program allowed the students to view the questions and answers, giving the adequate feedback according to the students and group responses.

The general class diagram of the COL plugin is presented in Figure 1-5. The details of the software components of the plugin are shown in Table 1-1.

Figure 1-5: Class diagram of COL application
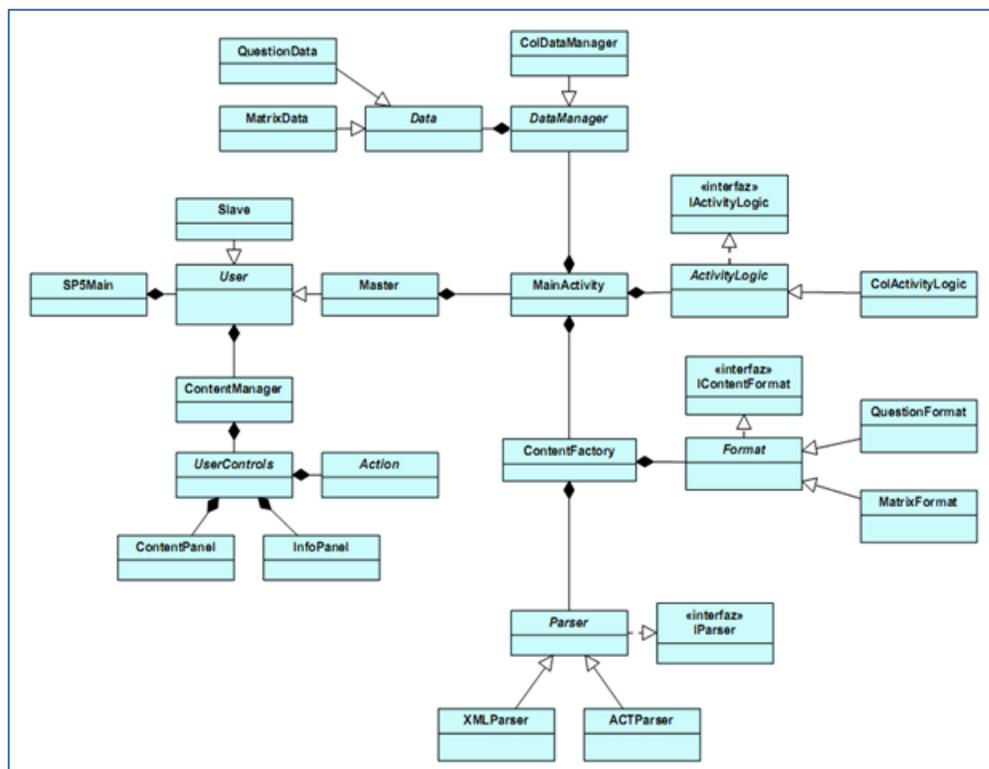
Table 1-1: Main components of COL application

Component	Function
SP5Main	- Connection point with AF framework (implements IModule interface)
User	- Abstract class representing the possible user modes of the application. - Master and Slave subclasses represent the main component of each of the defined user modes.
ColContentManager	- Manager of the content displayed in each device. - In the Slave mode, the manager controls the sequence of questions and answers displayed in the students devices. - In the Master mode, the manager controls the summary results of each group displayed in the teacher device.
MainActivity	- Represents the activity that is used in a specific session. - Includes a logic controller, data creation and storage components.
DataManager	- Contains the data of the current activity including question, answers and student results.
ContentFactory	- Generate the activity contents to be used in the application from the files were the data is packed.
ActivityLogic	- Logic controller of the activity. Manages the interaction between the data and the information displayed.

Some major modifications were made over the original activity to accommodate to the limitations of the devices. The most important change was how the question and answers were shown in the phone, and how the answer was selected by the students. In the original activity, the question and the multiple answers were all displayed in one screen, taking advantage of the size of the PDA display. When a student wanted to answer, he or she simply had to use the stylus of the device to select by pointing and clicking the chosen alternative. In the mobile phones, however, showing all the content in one screen forced the use of scrollbars making

it slow to review the choices. Additionally, mobile phone screens are not touch sensitive, making it impossible to replicate the answering method used in PDA devices.

Figure 1-6: Screenshots of the activity implemented in the mobile phones
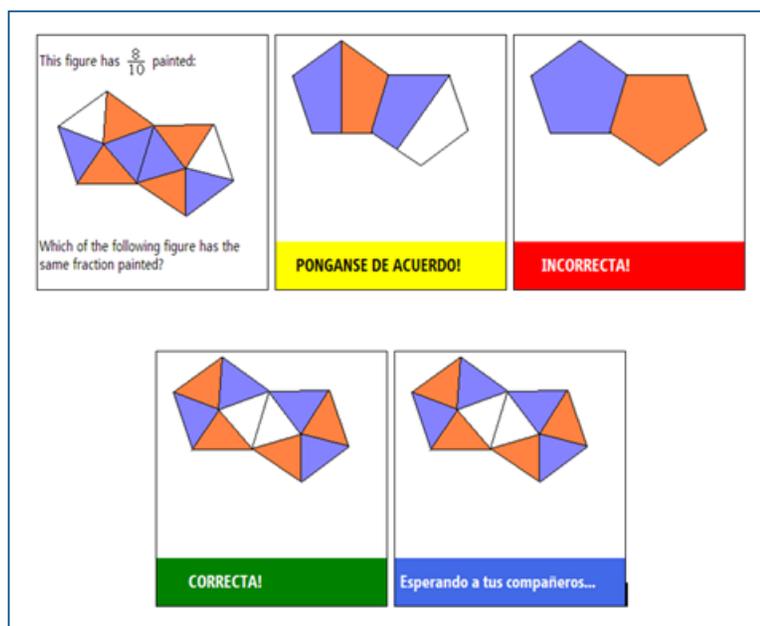
To overcome the display problem, a circular information container was developed to show question and answers. In this container, only the question or one of the answers is shown at a time in the screen. To access the others, the user must use the phone's joystick to move to the next screen. The circularity of the container allows going back to the original question once the user has moved through all the screens of the answers. Changing the way the information was displayed also helped to solve the input problem. In the new application model, the student chose an answer simply by moving to the screen associated with it and pressing an action button defined on the phone.

In parallel with the development of COL, the Activity Framework was ported to the mobile phones. The devices used where compatible with the .NET Compact Framework platform which allowed an easy transition of the framework from PDAs to the phones. After some minor modifications, AF was fully ported and working in this new platform. The COL activity was built as an AF plugin, designed using the framework services and structure, easing the integration between the parts.

On the first semester of 2007 both AF and COL activity were completed for the initial lab tests. During these tests several difficulties were discovered. Although the basic functionalities of the framework and activity worked, when more than 20 devices were used simultaneously, the number of message lost made impossible to complete a full activity. Additionally, when activities with more than 20 questions were tried, the devices became unresponsive. These initial tests showed that more

work was needed in the activity and the framework to take the next step and test the application in a classroom.

To overcome some of these problems, the device used by the teacher was changed from a mobile phone to a PDA. The device used was an Imate Jamin, manufactured by HTC and with Windows Mobile 5 operating system. Considering that most of the network load was received by the teacher's device which had to process all the answers from the students, changing it to a more capable one should decrease the network errors. Empirical validation confirmed this hypothesis. In addition to these modifications, the memory used by the activity was reduced, solving the problem of unresponsiveness seen in the tests when activities with multiple questions where tried.

With these modifications, the application was tested successfully in the lab and on the spring of 2007 the first classroom experiences where tried. For these experiences, an initial usability analysis was designed to measure the efficiency of the system and the user satisfaction achieved by the students. The tests were made in two sessions with ninth and tenth graders in a public school of Santiago (Figure 1-6). During the tests, a group observers gathered information for the usability analysis.

Figure 1-7: Students using the system in the initial tests
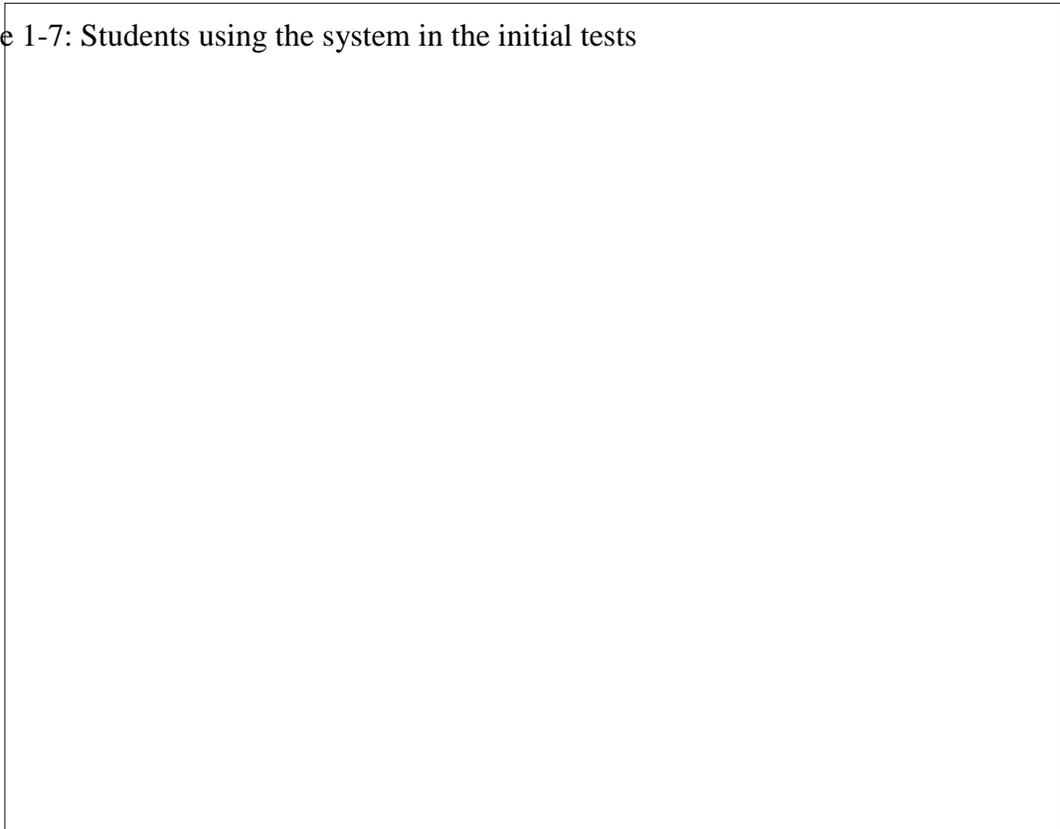
The results of the experiences were encouraging: most of the groups in both sessions were able to complete the activity. Additionally the usability analysis showed that most of the students were very satisfied with the use of the devices in an educational context. However, some problems occurred. The network message loss, although reduced, was still a critical problem that had to be addressed. Also a new problem appeared: when the students pressed some of the multiple hardware buttons of the mobile phone, external actions were executed losing the focus of the application, making it difficult to return to the activity. The worst cases occurred when the students turned off the devices, making it impossible to recover.

Two main conclusions were achieved at this point. First, the network module must be completely redesigned to consider the limitations of the devices from the start. Second, all of the device buttons must be handled by the application or, if possible, externally blocked. Controlling the action triggered by each button was the only way to avoid the problems found. With these two tasks in mind, a third iteration of the system was developed. The network module was redesigned, creating a new communication protocol, based on TCP initially, and UDP in case of message loss. The message size was optimized to reduce network traffic and several measures were taken to manage errors. To control all the hardware buttons several tricks were necessary, but finally it was possible to block the default actions of every button in the device.

On the second semester of 2008, the third iteration was ready and the application was again tested in a classroom. This time, the application was used for six sessions with ninth graders of the same school as the first test. For these sessions a new usability analysis was designed to fully study the impact of the device. Four elements were measured: Learnability, Memorability, Efficiency and Satisfaction. A specific observation guideline was designed for each of these objectives. To gather more precise information on the difference between the use of mobile phones and other devices, during the six sessions the class was divided in two groups: one group used mobile phones to resolve the activity, the other group used PDAs to resolve the same activity. This situation allowed us to have a control group to compare the results obtained by the students with the mobile phones. The details of the usability analysis and its experimental design are described in detail in section 2.4.

1.5 Results

The concrete result of this thesis was the development of a collaborative activity for mobile phones supported by a wireless network module. Additionally, an existing framework was successfully ported to be used in this new platform allowing future collaborative activities to be developed.

On a conceptual ground, this work validates the use of mobile phones as a support platform for educational activities based in collaboration. The usability analysis provides evidence for this, and shows what considerations should be taken when devices are used. Details of these results can be found in section 2.4.2.

Finally, based on the experience gathered in the implementation and testing of the application, a series of mobile phone software design guidelines were obtained, which are described in the following section.

1.6 Mobile Phone Software Design Guidelines

The process of implementing the COL activity in mobile phones and the testing made in the classroom provided us considerable information for the future development of software in mobile phones. Based on this data gathered, we developed a list of recommendations and guidelines that our experience shows should be considered when developing software for these platforms:

User centered design: The first recommendation obtained from this work is that when new software is developed for mobile phones, the user must take a central role in the process. In our work, the iterative process of creating the COL activity was continuously validated in the classroom, with our target users, the students. Through this constant validation we received invaluable feedback that allowed us to correct many aspects of the application. The considerable limitations and constrains of mobile phones make it essential to analyze how the user interacts in a real

environment with the software, to determine if the tasks presented can be achieved in a efficient and satisfactory manner.

Device oriented design: Considering that each mobile phone has its own and different hardware, an analysis and testing of the selected target platform's resources is recommended before designing software. In the initial iteration of our application the main problems were caused by the lack of consideration of the device limited resources. The design of the activity completely neglected the limited amount of memory, allocating space simultaneously for every information screen (all the questions and answers), making it impossible to scale the activity to more than 15 questions. Also, the network module, ported unchanged from the PDA version of AF, didn't consider the phone's reduced processing capabilities and the lesser quality of the wireless network hardware. It was essential to rethink completely the initial design of both the activity and the network module considering these limitations to achieve a working application. If a previous assessment of the device resources had been made, this initial iteration would have presented far less issues to solve.

Hardware buttons handling: Another relevant guideline obtained from our work is the importance of considering how every button in the device will be managed. Mobile phones are devices with multiple and diverse hardware buttons including the numeric keyboard, the joystick, the start and the end call buttons. Additionally, depending on extra functionality that may be included (cameras, music reproduction, etc.), the device may contain many more buttons. In our case, for instance, the phones had eleven additional buttons, each one associated to a specific action. The problem that arises with this situation in the context of software development is based on three reasons: first, many of these buttons cause unwanted actions for the given program (take a picture, open the device menu, etc.); second, the standard software development APIs for the devices do not provide an easy handling of every button; and third, the users will very likely press some of these buttons when interacting with the application. In our initial tests, when we didn't control through our application every button, many students had problems caused by this issue. To manage every button in the system, in our case, at least three different techniques were necessary. Our experience shows that it is essential to answer at least two questions related to button handling before developing software for mobile phones: Can the application manage every button in the device? If it can't manage every button, can the application recover fast and in a reliable way when an intended action associated to a button occurs?

User interface rethinking: The final recommendation that our experience provides is to rethink the design of user interfaces considering the device main limitations (small screens and limited input delivery systems) but also in a way that the best user experience is achieved. For example, the most common way of solving the small screen problem is using scroll bars, but when there is too much data displayed this solution can cause an unpleasant user experience. In our case, to manage this situation we used a virtual screen container that allowed the user to move between multiple sections (in our application, questions and answers) with the device joystick. This approach can be generalized to display any large sized screen by splitting them into discrete navigatable sections. With this alternative solution, we

are taking advantage of the device resources to achieve and overall better user experience in accessing the required content.

1.7 Future Work

There are several improvements that can be made to the application. As the usability test showed, the transition between questions and answers was slow, making it less efficient to complete the activity using the phones than with PDAs. Improving the speed of these transitions should shorten this efficiency gap between devices, although the inherent differences in the way the question an answers are displayed will make it very difficult to completely eliminate the difference.

Additional work is also needed in the framework. In the current state of the application, when a problem occurs and a student has to restart the device, he won't be able to continue his participation in the activity. Moreover, the rest of his group won't also be able to continue. It is necessary to develop a recovery mechanism that allows a device to restart the activity and reconnect to the teacher's device after a problem.

To further validate the results of this work, other tests should be made with different collaborative activities implemented over the phones analyzing what design aspects should be considered. Additionally, the application should also be tested with students of different ages, especially younger ones, to analyze their specific interaction with the devices.

1.8 Conclusions

Several conclusions were obtained from the implementation and testing of the collaborative application in the phones. The main conclusion is that it is possible to develop face to face collaborative learning activities using mobile phones if the device limitations are considered when developing these activities.

In a general sense, this work allowed us to determine the main issues that must be considered when developing rich educational activities for mobile phones. In terms of the user interface, although the input and output limitations are an important factor, they can be overcome by considering these factors when designing the applications. The use of a container that allows navigation between multiple screens using the device's joystick (like the one implemented in our application) is an example of a user interface designed thinking in both the limitations of the device and in the user. Is essential to validate this new user interface designs with usability studies, which will provide feedback of how the user really experiences the interaction with the application.

Another user interface issue that appeared during the field tests of this work was related to the existence of multiple hardware buttons in the device. Our experience in the classroom showed that there is an almost certainty that some of the students

will press, both unintentionally and intentionally, many buttons that are not used in the applications. This should be expected, considering that most of the surface of the device is covered with buttons, and that the students have a natural curiosity when first handling a new platform. The main problem that occurred was that many of the buttons were programmed for different tasks that took the user out of the application or even worse, turned off completely the device. Unlike computers, where most of them have only keyboard and mouse buttons which can be easily handled and controlled in the application, different mobile phones have different hardware buttons and only some of them are easily controlled by the application. In our case, we used at least three different techniques to control the different buttons of our phones. The conclusion obtained from this issue is that when mobile phone application are designed, every button must be completely handled by the application or in cases when this is not possible, the application must be able to quickly restart after an unintended action is executed on the device.

The use of a local protocol like Wifi shows that it is possible to create educational activities using mobile phones with a free network, which is an important advantage to SMS or GPRS based communication. Regarding the network communication, another important conclusion that can be extracted from this work is the necessity of using wireless network protocols developed considering the device limitations. Mobile phones have less processing power and worse wireless network cards than PDAs and laptops, and these factors affect directly in the performance of the network communication between devices. A network protocol that works well in some devices (like the original AF network in PDAs) will not necessarily work correctly in a more restricted device like a mobile phone, proving that it is necessary to adapt and fine-tune the network module for the specific device where it will be used. Special consideration must be taken in the message loss, which with these lower performance device increases. When working with these devices this problem must be considered as part of the regular conditions, forcing the development alternatives ways of handling this issue in the application.

Based on the usability test and the comparison between phones and PDAs, there are many conclusions that can be mentioned. Firstly, the system showed to be easy to learn and remember validating the modifications made in order to accommodate the collaborative application in these new devices. The easy learning of the application is also explained by the fact that most students had already used mobile phones (validated in a survey made to the students before trying the activities), and they handled the devices without any problem, sometimes even finding features that we didn't know existed. This result shows another important advantage of mobile phones in comparison with other devices: because of its high penetration in society there is an almost flat learning curve for the students when using the devices. This allows the students to concentrate on learning only in how the application is used and not in how the device works.

The results of the satisfaction survey taken on the students after the development of the activities, showed a general positive attitude when using the devices. The opinion of the majority that a class with mobile phones is better than one without them, proves that the use of this kind of devices give an additional motivation to the students to develop their activities. Although this motivation usually associated with

technology fades away with time, it is still important that at the initial stages the students show interest in the application. However, the survey also showed some negative considerations from the students. An important group showed frustration and loss of interest when the system didn't work correctly. This shows that in this context the problems in the applications must be minimal, or in the contrary the students will not maintain this motivation during much time.

Some of the most interesting conclusions of this work were obtained from the comparison between mobile phones and PDAs. First of all, it was proven that there are no differences in the learning outcome of the students when using mobile phones, at least in the context of the collaborative activity implemented. This shows that the modifications made to the activity didn't affect in the pedagogical model underlying it, and validates mobile phones as adequate substitutes for PDAs in this context. The second important conclusion involves the efficiency of the students when using the different devices. It is clear that students are considerably more efficient when using the PDAs than when using mobile phones. There are many possible reasons that affect this result including the difference in the way question and answers are displayed and the longer time that the PDAs application has been tested and improved compared to the mobile phone one. However the most important reason is clearly the performance limitations that are inherent to these lower cost devices. There is a clear trade-off between lower costs and system efficiency in mobile devices, which must be considered when developing applications for mobile phones. These applications must be optimized to achieve the best performance possible given the devices limitations, implying that more time should be taken developing for mobile phones than other more capable platform.

This work must be seen only as a first step in the development of face to face collaborative activities in mobile phones. Considering this, the results have provided considerable information for future research, validating the use of these devices and delivering a series of design considerations that must be taken when developing application for mobile phones.

2. Face to face collaborative learning supported by mobile phones

2.1 Introduction

The rapid proliferation of mobile phones among students is generating a novel platform for the development of classroom interaction systems. Applied in the context of task-based learning, these devices have the potential to support distributed practice and encourage classroom interactivity *(Meurant, 2006).* Mobile phone learning relies on email and SMS as the main methods of communication between learners and learners and between learners and instructors. Social presence through synchronous instant messaging provides learners with continuous awareness of available support and encourages sharing of learning experiences (Kekwaletswe and Ngambi, 2006). In some cases the teacher can project messages and develop an interactive loop with students during class (Markett *et al.*, 2006), even extending the communication with visual media and reducing the students' cognitive load (Lindquist *et al*., 2007). However, this type of communication is inadequate for learning situations where oral communication between students is encouraged (Schwabe and Goth, 2005). Additionally, when learning applications are SMS-based and thus use the telephone company as the network hub, communication between devices may be restricted due to the cost implied.

To develop social and communication abilities while also teaching a set curricula, a constructive approach can be used in which the computer is seen more as a partner than a tutor (Zurita & Nussbaum, 2007). Such systems can be considered as a training method that allows the exchange, control and building of knowledge among peers (Aïmeur *et al*., 2001). The social network, where group members interact in person, is supported by the technological network that coordinates and synchronizes activity states, mediating the activities and the peers' social interaction (Zurita & Nussbaum, 2004a)

To achieve a face-to-face computer-supported collaborative learning environment, the network must be comprised of wirelessly interconnected devices (Zurita & Nussbaum, 2004b). Such a network can be created using mobile phones that incorporate either Bluetooth or Wi-Fi. Bluetooth is a technology found on many cell phones, but has certain limitations regarding range and number of simultaneously connected devices (Ferro & Potorti, 2005) that hinders its use in the classroom. Wi-Fi, on the other hand, does have reasonable range capabilities and can support various work groups in a classroom environment (Zurita & Nussbaum, 2004a). Its disadvantage is that it is enabled only on the most advanced models. This drawback

will presumably disappear in the medium term as growing demand for cell phones with broadband Internet connections leads to widespread ownership of Wi-Fi enabled units (Keshav, 2005). The devices will then provide a platform that qualifies as an economic replacement for those currently used in classroom educational activities.

Due to their size, however, mobile phones have other inherent limitations in learning contexts. Their small, low-resolution screens restrict the amount and type of information that can be returned to the user, and constraints on their input mechanisms result in a slow and inconvenient transfer of information from user to device (Shudong and Higgins, 2005).

In this article we study the use of cell phones in the classroom as a support for collaborative work. A network was created for the purpose using i-mate SP5 Smartphone devices which, in addition to having a small screen without touchscreen capability, a number pad and action buttons, were enabled for Wi-Fi. An existing collaborative classroom activity application designed for use with PDAs (Cortez *et al*., 2005) was ported to the phones and an established framework was adapted to provide network and group management services (Echeverría *et al.*, 2006).

The remainder of this work is organized as follows. Section 2 introduces the activity implemented on the cell phone network, with emphasis on its derivation from the existing PDA activity that was modified to be usable with the SP5's. Section 3 describes the framework used for developing educational activity applications on the devices, and also details the changes that were necessary to adapt it from the original version. Section 4 discusses a usability analysis of the new application, and finally, Section 5 presents our conclusions.

2.2 The Collaborative Activity

In the original collaborative activity, which was developed for use with PDAs, students equipped with individual devices are randomly organized into groups of three and required to answer a series of multiple-choice questions (Figure 2-1a) sent by the teacher's unit at the start of the activity session. The activity is designed so that all group members participate in discussing the questions as they search for agreement on the answers. If the members originally submit different individual responses, the system will inform them that they must come to a consensus (Figure 2-1b) before sending in a single final response. If they answer incorrectly the system instructs them to try again, but with the wrong choice now eliminated (Figure 2-1c). Once the group settles on the right answer and submits it (Figure 2-1d), the system will allow them to proceed to the next question. In the meantime, the teacher continually receives information on the state of progress of the different groups and can observe which ones are having difficulties and which questions the students are struggling with (Figure 2-1e).

Figure 2-1: Different activity states

(a)   (b)   (c)

(d)   (e)
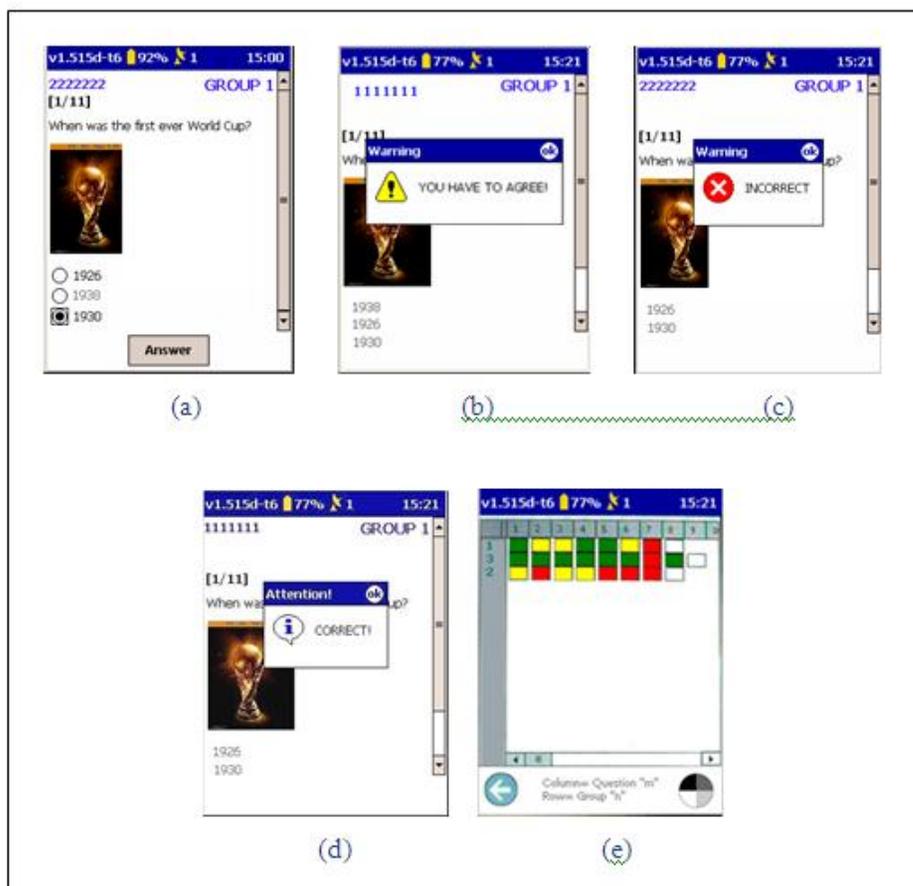
In porting this PDA-based activity to cell phones, consideration had to be given to the devices' input and output limitations. Whereas PDAs have a touchscreen that supports point-and-click interaction at any location on the screen using a stylus, interaction with cell phones takes place through a keyboard, action buttons and a four-way joystick. Thus, a response in this collaborative activity cannot be chosen simply by pointing to it, meaning that some alternative mechanism must be designed. As for output, the PDAs use QVGA (320x240 pixels), which is big enough to show both a question and the various response options on a single screen, with a scrollbar where required (Figure 2-2a). This is not possible on the cell phones, which use the significantly smaller QQVGA (160x120 pixels), so the display model shown in Figure 2-2b had to be adopted. In this system, the first screen displays only the question and the response options must then be accessed using the left and right joystick buttons. Pressing these buttons cycles the display one by one through the individual response screens, and when the last option is arrived at, continuing in the same direction returns the display to the original question. Once a student has decided on an answer, he/she must access that screen and press the predetermined action button. This arrangement effectively solves the two problems described earlier. By separating the question and the response options into different screens, the display space for any single item is enlarged, and by displaying only one answer per screen, a response can be chosen simply by pressing a button.

Figure 2-2: QVGA and QQVGA screenshots

(a)   (b)
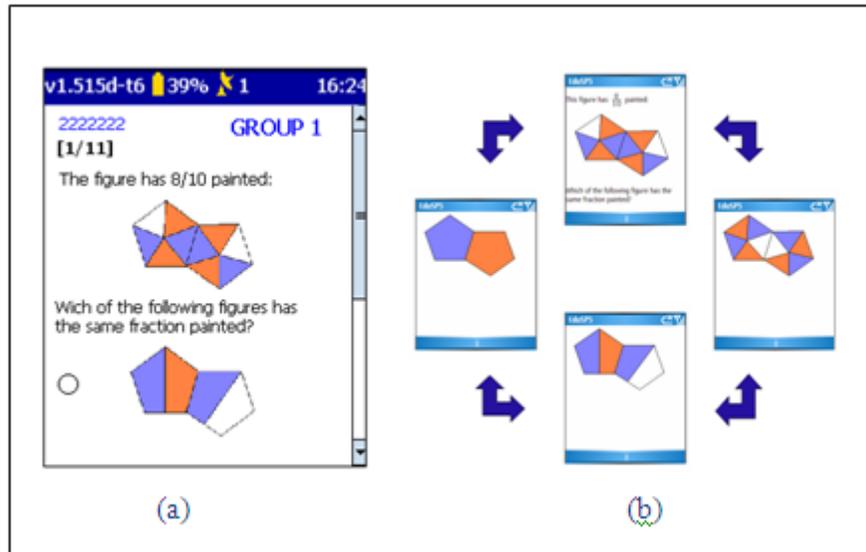
2.3 Framework

2.3.1 General Description

The framework we employed for developing a cell phone activity is a pre-existing program known as Activity Framework (AF) (Echeverría *et al*., 2006) that was itself developed in C# on the .NET Compact Framework for use with Pocket PCs. The advantage of AF was that it had already been used to build mobile device activities similar to the one proposed here. Its architecture was thus known to suit the needs of the present application and provide the required network services. Furthermore, since it was developed on the .NET platform, porting it for use with Smartphones involved only minor modifications, unlike the changes that would have been necessary with frameworks highly coupled to a specific platform.

AF framework is based on a module architecture that lends extensibility both to the services it provides and the activities developed in it. The interface of the activities must be developed as well as their internal logic, and the framework's various functions can be utilized to carry out generic operations. The main service provided by the framework is wireless network communication, which permits the activities to send and receive information among the various devices.

Initial testing of AF with the Smartphones revealed a series of communication problems stemming from the hardware limitations of the SP5's. For the most part the difficulties were related to the high latency and elevated loss rate for messages sent between the devices that prevented the proper functioning of the application. Furthermore, since for each class the activity must be able to send new content, it

was found necessary to add new capabilities to the network component, in particular the ability to send files simultaneously to multiple devices.

2.3.2 Development of network module

A new network module was developed for providing communication services adapted to the SP5's hardware limitations and the requirements of the activity. The module was implemented in a way that ensured the least amount of coupling with the rest of the framework so that it could be re-used in future projects not employing AF. The resulting network architecture is shown in Figure 2-3, with the functionalities of each component detailed in Table 2-1.

Figure 2-3: Network architecture
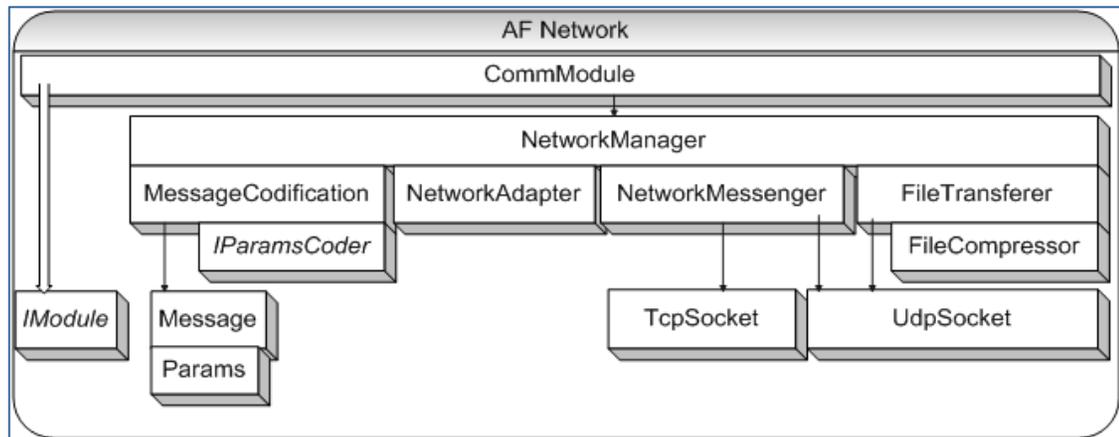
Table 2-1: Main components of new AF Network

Component	Function
CommModule	- Connection point with AF framework (implements IModule interface) - Uses the services provided by NetworkManager, the only input point for the new module.
NetworkManager	- Centralizes and unifies the network services provided by the other components. - Implements high-level services.
NetworkAdapter	- Manages the relevant information from the Wi-Fi network adapter (IP, subnetwork mask). - Permits connection to a given access point.
NetworkMessenger	- Implements unicast send protocols, both reliable (using TCPSocket) and unreliable (using UDPSocket). - Implements unreliable broadcast send protocols (using UDPSocket). - Manages message reception threads.
FileTransferer	- Implements protocol for sending files simultaneously to multiple devices (using UDPSocket). - Permits sending of multiple files with prior compression (using FileCompressor).
MessageCodification	- Responsible for coding and decoding network messages (represented by Message class). - Enables differentiated coding by type of sent parameter data (represented by Params class).

To sidestep the latency and message loss problems a network protocol was developed containing two subprotocols. The first one is an implementation that uses TCP as a transport protocol. The advantage of TCP is that it provides certainty as to whether a message has arrived at its destination complete or with a certain degree of loss (partial or total). The subprotocol makes three retries, and if all three fail the system switches to a second subprotocol, an implementation of UDP in which the originating device repeatedly sends the message until delivery confirmation is received from the destination device. Each time the recipient receives a message, it must send a delivery confirmation. If the recipient receives the same message more than once it discards the repeats, notifying the higher layers only of the first arrival.

If, after a certain preset time, the sender receives no delivery confirmation, it stops sending and notifies the application that the message could not be delivered.

The TCP-based subprotocol provides reliability of message delivery at a reasonable send speed but imposes a high processing cost on the devices using it, which in the present case means a greater chance of information loss. To ameliorate this the retry technique and the secondary (UDP) subprotocol were incorporated. Although the latter's message send time is longer than with TCP, it imposes lower processing costs. If the cell phones are not able to process the TCP messages, they can therefore resort to the UDP alternative. Our experiments demonstrated that using the second protocol reduced message loss.

A protocol for sending files simultaneously to multiple devices was also developed. This protocol partitions the original file into UDP packets and sends them via network broadcast. If any of the packets do not arrive at an intended recipient, a message is sent requesting that they be resent. If the sender has already completed the sending process, it resends the requested packets plus all the following ones. The protocol also offers the option of compressing multiple files before sending them.

The various network messages were designed to keep their size to a minimum and function well with the protocols and services implemented. To facilitate the optimal provision of the network module's various services, each message contains certain meta-information. This includes the identification of the message type (see Table 2-2), which the recipient must know for deciding what action to take; the type of parameter sent, which allows the recipient to decode messages using the appropriate system; and, in the case of UDP messages, a parity bit to check their integrity upon reception. If a parity error is found, the message is not processed.

Table 2-2: Type of network messages

Type of Message	Description
MsgTCP	Standard message sent using reliable TCP protocol.
MsgUDP	Standard message sent using reliable UDP protocol.
AckUDP	Delivery confirmation for UDP message.
FileAck	Delivery confirmation for complete file. Enables sender to ascertain whether file was delivered to each network member.
FileToBeSent	Message indicating that a file will be sent so that recipients can initiate the necessary reception functionalities.

Since the network developed for the cell phones is designed to operate in infrastructure mode, various services were added to provide information on the network adapter and the available access points in the environment.

Functionalities and notifications were included in the activity to manage network communication problems that occur more frequently with cell phones than Pocket PCs given the former's hardware limitations. For example, if the network module is not able to send a certain message, it notifies the activity so that the latter will permit the user to retry. Also, the teacher's application incorporates functionality allowing it to "free" a group that is blocked from advancing because a message from the teacher did not arrive. This ensures students can continue with the activity even if a message is lost.

2.4 Usability Analysis

2.4.1 Experimental Design

A usability analysis was conducted to determine the effects of the cell phones' hardware limitations on the collaborative activity. The analysis was carried out over six activity sessions with ninth-grade students (approximately 14 years old) at a public secondary school serving children from the lower socio-economic strata in Santiago, Chile (see photo, Figure 2-4). The activity chosen for these test sessions was designed for teaching physics.

Figure 2-4: Students taking part in the collaborative activity

The analysis is based on measurements of four attributes typically associated with system usability: learnability, efficiency, memorability and satisfaction (Nielsen,

1993). Different observation forms were defined incorporating relevant metrics for establishing how well the system performed on each attribute.

Before the test sessions began, a survey was taken of the students to determine their familiarity with the technology. The results indicated that 73.53% of them used a cell phone at least a few times a week and none had never used one. As for computers, 81.82% used them at least a few times a week and only a single student had never used one.

To measure learnability the corresponding observation form was used to record, for each activity question, the time taken by the group to answer it, the score they obtained and the number of queries group members addressed to each other or the teacher on the use of the system. The data on these metrics were collected during the first test session. For memorability, the second attribute, the same observation form was used but the measurements were taken during the second session, held a week after the first one. This meant that if the time taken to answer and the number of system queries was lower than the first session results, the students could be considered to have remembered satisfactorily how the system functioned.

Efficiency, the third analysis attribute, was measured by comparing the students' performance with cell phones to that achieved when using PDAs for the same activity. For this purpose the class was divided into groups that used either cell phones or PDAs, switching the technologies every two sessions to avoid bias in the experimental and control groups. The first of two metrics employed was the percentage of all the questions in an activity each group managed to answer, whether correctly or not. The idea was to determine whether the cell phones slowed the pace of the activity. The second metric was the percentage of all the questions answered for which a correct response was given, the point in this case being to establish whether the use of cell phones affected performance.

Finally, to evaluate the satisfaction attribute the researchers conducting the test sessions made various observations based on qualitative criteria to gauge how comfortable the students were with the activity and the use of cell phones for performing it. Video recordings were also made of a specific group and the entire class for later analysis. A survey was taken at the end of the final session to ascertain the students' opinions of the functioning of the activity.

2.4.2 Results

The results garnered from the learning and memorability attribute measurements are displayed in Table 2-3. At the first session it was observed that only on the first two questions was there any confusion among the students regarding how to use the system, with relatively longer times taken to answer the questions and more system queries. Beginning with the third question, response times stabilized around an average of one minute per question and no further queries on system use were made. This tendency continued through the second session as the students demonstrated they had no difficulties remembering how the system worked.

Table 2-3: Average response time per question and number of system queries, first two sessions

	Questions 1 – 2		Questions 3 – Final	
	Average response time per question	Average number of system queries	Average response time per question	Average number of system queries
1st session	~ 3 minutes	2	~ 1 minute	0
2nd session	~ 1 minute	0	~ 1 minute	0

In the case of the efficiency attribute, the data are summarized in tables 4 and 5 for the six sessions of activity measurements with groups using both PDAs and cell phones. Table 2-4 shows the percentages of questions answered in each session. As can be seen, in all but the last session the students who utilized PDAs responded to at least as many questions as those with cell phones. Also, whereas the PDA group answered more than 70% of the activity questions in all six sessions, the cell phone group did so in only three, all of which involved shorter activities and thus allowed more time to complete them.

Table 2-4: Percentage of all questions answered, by session and type of device

	PDAs	Cell Phones
1st session	100.00%	100.00%
2nd session	74.79%	61.54%
3rd session	72.50%	40.00%
4th session	100.00%	69.64%
5th session	100.00%	100.00%
6th session	93.18%	100.00%
Average	90.08%	78.53%

Table 2-5 contains the data on the percentage of questions for which correct answers were given. They indicate that in every session except the first and third, the performance differences between PDAs and cell phones were less than 3 percentage points. The averages for the six sessions also did not differ significantly.

Table 2-5: Percentage of all questions answered for which a correct response was given, by session and type of device

	PDAs	Cell Phones
1st session	48.18%	40.82%
2nd session	43.54%	40.82%
3rd session	37.37%	67.99%
4th session	47.14%	46.78%
5th session	47.73%	47.73%
6th session	73.30%	72.73%
Average	49.54%	52.57%

As regards the satisfaction attribute, which was measured for cell phone use, the results of the survey taken after the final session are set out in Table 2-5. The students' responses were ranked on a five-level scale that ranged from Strongly Agree (++) to Strongly Disagree (--).

Table 2-6: Responses to satisfaction survey

	--	-	O	+	++
The system is confusing.	38.24%	29.41%	26.47%	5.88%	0.00%
The system is enjoyable to use.	6.06%	0.00%	12.12%	57.58%	24.24%
I lost interest when the system broke down.	20.00%	20.00%	37.14%	8.57%	14.29%
I would like to use the system again.	2.94%	5.88%	8.82%	32.35%	50.00%
A class using cell phones is more fun than a normal class.	0.00%	15.63%	12.50%	28.13%	43.75%
I felt frustrated when I was unable to execute the action I wanted.	21.21%	30.30%	21.21%	12.12%	15.15%
The cell phone always did what I wanted it to do.	9.38%	15.63%	46.88%	18.75%	9.38%
Interacting with the cell phone was frustrating.	23.53%	44.12%	17.65%	14.71%	0.00%
Interacting with the cell phone requires a lot of mental effort.	33.33%	36.36%	15.15%	6.06%	9.09%

These results show that 81.82% agreed with the statement that the system was enjoyable to use. Furthermore, 67.65% felt that interacting with the cell phone was not frustrating and 69.7% disagreed with the view that interacting with the cell phone required a lot of mental effort.

Finally, the main observation made by the researchers over the course of the testing was that in certain sessions, momentary problems arose when students pressed cell phones buttons that were not assigned for the activity, setting off actions in the devices that interfered with the process. This occurred only in a minority of groups, but their members were very frustrated by it and communicated this sentiment in their survey responses, agreeing with the statements that "I felt frustrated when I was unable to execute the action I wanted" and "interacting with the cell phone was frustrating." Some of these students felt the problem was their own fault, leaving them feeling very insecure.

2.5 Conclusions and Future Research

This study demonstrated that cell phones can be used for supporting collaborative work in the classroom. If enabled for Wi-Fi they form a classroom network that is free of cost, a genuine advantage when compared with the very real cost of maintaining a network based on SMS messages or the per-device subscription fees

for a GPRS or other similar network setup. It was also found that although Wi-Fi networks can be formed by a large number of cell phones, these devices have certain hardware restrictions that must be taken into account. In particular, their processing limitations must be considered in the design of collaborative activities, for if an activity application is not sufficiently responsive its users will quickly lose interest. The communication protocols must keep network load to a minimum, and functionalities that allow the activity to recover after message loss are needed. If the network modules address these issues, relatively little effort is required to extend them to other network infrastructures with limited resources. In cases where one of the users (a teacher, for example) has to handle greater message loads, his/her device must be a higher capacity unit. In the cell phone application described in this study, the teacher used a PDA.

A usability analysis of this application, developed for a collaborative classroom activity, led to a number of significant conclusions. The results obtained during the first test session showed that the system was easy to learn, as indicated by the fact that after only two activity questions, virtually all of the participating students understood how the application worked. The ability to remember how it functions was demonstrated by the results of the second session, which revealed no difference in response times between the first and last activity questions nor any remaining doubts among the students about the use of the system.

As regards satisfaction with the application, two observations in particular are worth noting. First, the use of the cell phones comes naturally to the students, as was evident in the way they found the devices both simple and enjoyable to use. Thanks to their familiarity with the technology, the cell phones' interface limitations compared to PDAs caused them no difficulties. Second, although the activity assigned only a few of the devices' many buttons, the unused ones were sometimes pressed by students in the early sessions, either by accident or out of curiosity. In a number of cases this set off actions in the units that interrupted the activity and frustrated the participants, and in the later sessions the unused buttons were blocked. This is an issue that must therefore be considered when implementing educational activities on cell phones.

In order to measure the cell phones' functionality against that of PDAs, the activity was conducted using both technologies and the results compared. The cell phones were clearly less efficient, for two principal reasons. The first reason was that the response options for the multiple-choice questions had to be viewed on these devices one by one, whereas on the PDAs they could be displayed on a single screen together with the original question. This meant that accessing the full range of information needed for answering on the cell phones was not as fast. The second reason was that the cell phones' processing limitations made transitions between questions slower than on the PDAs, adding to the time taken by the response process. Despite these disadvantages, however, no significant differences were found over the six test sessions between student performance levels on the two types of devices, with groups using either technology getting the same number of correct answers. This demonstrates that for the type of activity in question, cell phones do not have a negative impact on performance.

Finally, the work reported here represents only a first step in promoting the widespread use of cell phones as an educational platform. To validate their usefulness, more activities will have to be designed that test their behavior with other types of applications and users, such as children of different ages. The efficiency limitations of the technology must also be taken into account in these designs in order to reduce the observed usability differences between cell phones and PDAs.

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APPENDICES
APPENDIX A: ACCEPTANCE EMAIL

From: Alejandro Echeverría alejandro.echev@gmail.com
Sent: Tue, Dec 30, 2008 at 4:14 PM
To: psotka@msn.com
Cc: Miguel Nussbaum mn@ing.puc.cl

Dear Mister Psotka

Please find enclosed our paper "Face-to-Face Collaborative Learning
Supported by Mobile Phones" in PDF and DOC formats that we submmit to your
consideration to the Interactive Learning Environments Journal.

I kindly ask you to send me an acknowledgement of reception.

Thanking you in advance.
My best wishes for 2009

Alejandro Echeverría

From: Joseph Psotka psotka@msn.com
Sent: Tue, Dec 30, 2008 at 4:37 PM
Reply-To: psotka@msn.com
To: alejandro.echev@gmail.com
Cc: Miguel Nussbaum mn@ing.puc.cl, b.c.e.scott@cranfield.ac.uk,
p.j.maclean@cranfield.ac.uk

Dear Alejandro Echeverría,

Dr. Scott and I take tursn reviewing papers, and your paper falls to him to review.

You should hear from him shortly.

Best, Joe Psotka
Co-Editor, ILE