Teachers’ support with ad-hoc collaborative networks

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Abstract
Efforts to improve the educational process must focus on those most responsible for implementing it: the teachers. It is with them in mind that we propose a face-to-face computer-supported collaborative learning system that uses wirelessly networked hand-held computers to create an environment for helping students assimilate and transfer educational content. Two applications of this system are presented in this paper. The first involves the use of the system by students, transforming classroom dynamics and enabling collaboration and interaction between the students and the teacher. In the second application, the system is used to help teachers update their knowledge of subject content and exchange methodological strategies.

Keywords
collaborative learning, hand-held computers, teacher training, wireless networks

Introduction
At the Third International Math and Science Study held in 1999, it was revealed that two of every five Chilean teachers suffered from a low level of confidence in their own ability to teach science (Ministry of Education (TIMSS-R) 1999). Five years later, a study by the OECD (2004) showed that this finding had not changed. The study also concluded that ‘Chilean teachers enter teaching with levels of subject knowledge that are very low compared with teachers in developed countries and many developing countries’. These results suggest that if the quality of education is to improve, teachers must receive better support and training.

The present article proposes that teachers be supported and trained using a collaborative learning system backed by wirelessly connected hand-held computers. The system may be considered as a face-to-face computer-supported collaborative learning system (Zurita & Nussbaum 2004b), whose functioning is based on theories of collaborative learning (CL) and computer-supported collaborative learning (CSCL). Dillenbourg (1999) defines a collaborative activity as the commitment of three to five participants in a coordinated effort to reach a specific educational objective. Studies suggest that when students work in groups in a collaborative context, i.e. CL, better academic results are obtained (Johnson & Johnson, 1999) because the students learn more, retain longer what they have learned, develop abilities of superior reasoning and critical thought and feel more valued and confident (Gómez & Alamán 2001).

The creation of an effective CL environment depends on the following five key factors, as summarized in Zurita & Nussbaum (2004a–c):

● 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.

The incorporation of technology into the teaching process within the CSCL framework leads to educational environments in which the technology is used to control interactions between the participants (Kumar 1996). The technology provides information, regulates tasks, administers rules and roles and mediates in the acquisition of new knowledge.

Most CSCL applications are implemented for personal computers and require that the participants be physically located behind the computer screen (Inken et al. 1999). Thus, when a CSCL activity is performed within a single space such as a school classroom, these applications do not allow for the development of face-to-face interactions, described by (Johnson & Johnson 1999) as one of the key factors for obtaining good results in a collaborative work group. By contrast, wirelessly interconnected hand-helds (Palms and Pocket PCs) enable a mobile environment of collaboration to form in a natural manner. Such an environment facilitates face-to-face interactions because of the physical characteristics of the small devices and the mobility that permits the creation of wireless networks (MANET, Macker & Corson 1999). Figure 1 illustrates how the use of these kinds of tools incorporates the functionalities of CSCL systems while maintaining the face-to-face interactions inherent in CL.

In this article, we begin by describing a face-to-face CSCL system, and then analyse two applications that support the teacher. The first application transforms the classroom into a collaborative environment for teaching science. The second involves the same model, using it in this case for training teachers to update their knowledge and interchange methodological strategies.

**System description and design**

The aim of the face-to-face CSCL system is to help the teacher transform classroom dynamics. The idea is to move from a teacher-centred arrangement, where the teacher radiates knowledge in front of a passive class of children, to one where children are active and the teacher acts as a mediator. To achieve this, the students are organized into groups, and each child is given a wirelessly (WiFi) interconnected hand-held device (Pocket PC).
Figure 2 illustrates the system’s philosophy. Before the start of a session, the teacher downloads the collaborative job to be worked on from the project’s Internet website to his/her Pocket PC. Once in the classroom, s/he sends the activity from his/her Pocket PC to the children’s machines over the wireless network. The distributed system divides the children into groups of three (Dillenbourg 1999), in which they work face-to-face with the support of the technology. Because the groups are allocated randomly and a new set of groups are created for each session, each child has the opportunity to work with every other, thus promoting new social interactions. This gives them a sense of closeness and facilitates the learning and collaboration processes (Zurita & Nussbaum 2004a–c).

The teacher controls and monitors the activity from his/her Pocket PC. The technology supports his/her mediator’s role. S/he knows from his/her machine which groups need assistance and which activities are proving to be difficult for the entire class. Although the students immediately find out where they have made mistakes, the teacher is just as quickly made aware of which are the weakest subject areas and thus can instantly reinforce and refocus the contents of the class. Once the activity is completed, the teacher returns to the website and the results of the activity are uploaded. This allows the different actors in the educational process to follow the children’s outcomes over the Internet.

The process we are proposing here integrates two technologies. The first of these is the Internet as a communications media for downloading activities and uploading results, enabling an easy and transparent delivery of activities to teachers and of students’ outcomes to persons in authority and others who may be involved. The second technology is the wireless network, which permits working in groups independent of any other hardware. This affords portability, meaning that collaborative activities can be performed anywhere even when no electrical outlets are available.

**Software architecture**

The software for this experiment was implemented in a three-layered system (Fig. 3):

- **Network layer**: allows information to be sent and received among the hand-holds in an efficient and controlled manner.
- **Activity player**: responsible for providing tools and services for the integration of multimedia elements and software in the third layer (**collaborative activity**). The activity player provides a structure and a collection of services for developing applications.
- **Collaborative activity**: the final application.

The system’s design differentiates between two roles: the teacher, who uses the master version of the software, and the students, who use the slave version.

The network layer uses the TCP/IP and UDP protocols working over a wireless WiFi network (IEEE 802.11b). The network is configured in peer-to-peer (P2P) mode (**ad hoc network**) and has no access either to the Internet or a local network. This allows the system to be used independently of any other hard-
ware infrastructure. The network is constructed using these standard protocols and allows the activities to send text messages and data. It supports asynchronous message sending and allows synchronous conversation to be held between machines in the form of successive messages. The network also permits the transmission of files. A file can be sent from any hand-held to any other through a guaranteed path (TCP), or from one hand-held to many others simultaneously (multicast), through a non-guaranteed path (UDP), which is then verified through TCP, machine by machine, resending any data that may have been lost.

The nucleus of the system, which is the activity player, communicates with the Network Layer and provides a series of tools and services for the integration of network services and multimedia elements into the activities. The activity player offers a set of services that include:

- **Student and activity administrator**: This searches for and lists the machines present in a network and selects the activity to be executed from a list. This activity is then sent from the master to the slaves before the application starts.
- **Activity definition**: A collection of packed files containing an XML file that specifies the screens and objects to be used, and includes the images, sounds and other binary files required for its execution. Among these files are the expansion modules, or plugins, that contain the specific pieces of software required for the activity’s full functionality.
- **Message services**: These allow the internal objects and plugins to communicate with one another, both in local form within a machine and in remote form through the network.
- **Storage of data and execution of statistics**.
- **Flow control** between the various screens making up an application.

The activity player architecture supports expandability of the basic set of included objects. As such, an application may be constructed both from included objects and from objects specifically developed for the given activity, as may be required in any particular case.

In a collaborative activity, groups of three students must solve a problem by consensus. The activity is composed of an XML specification and a set of three plugins that complement the activity player by adding the activity’s specific functionality. These plugins are:

- **Group creator plugin (GCP)**: Responsible for both creating the collaborative groups in the master (the teacher’s machine) and notifying the slaves (the students’ machines) as to which collaborative group they belong to.
- **Group holder plugin (GHP)**: Communicates with the GCP and is responsible for storing, within each slave, the collaborative group number and the IP number of each other member of the group.
- **Question controller plugin (QCP)**: Runs for each exercise on each slave, and is responsible for the activity’s logic flow, answer evaluation, collaboration and answer storage.

Description and design of the collaborative activity

The face-to-face CSCL system is designed to implement collaboration, and can be used to create and execute various different activities. In the experiments discussed in this article, we created an activity in which the participants, arranged in groups of three (Dillenbourg 1999), were required to answer a set of multiple-choice questions collaboratively on their Pocket PCs. The hand-helds used with a wireless network adapted effectively to the teacher’s requirements and allowed the students the necessary mobility to work collaboratively.

The logic of the collaborative activity for any given group is shown in Fig. 4. The members of a group must reach a unanimous agreement before answering the question. This is arrived at through discussion among the members. On any given occasion, a particular group member may tend to dominate the discussion, but as noted earlier, the random nature of group formation will provide opportunities for every student to develop different discussion strategies with many others. If the students do not agree on an answer, the system will keep asking the same question again until everyone in the group concurs. Only then will it validate the answer. If the answer is incorrect, the

1IPAQ H3760: 64 MB RAM, colour display, Pocket PC 2002 operating system. The devices were used with the PC Card Expansion Pack and a WiFi card for wireless communication (IEEE 802.11b).
system informs the group of their error and requires them to reconsider the same question, with the previously selected erroneous alternative now excluded, until the correct response is arrived at. Once all the members of the group select the correct answer, the group can then proceed to the next test question.

Figure 5 shows the interfaces that comprise the collaborative activity. The activity begins with a text and three options shown to each group member. Each of them must then choose one of the options on their hand-held. The possible sequences of actions are illustrated in the figure. The left sequence represents the case where everyone answers correctly. In the middle sequence, everyone answers incorrectly. In such a case, the participants must answer the same question again, and as the figure shows, the incorrect alternative is deactivated so the participants cannot choose it again. This helps them see what went wrong and leads to a collaborative discussion that should also help them to clarify their ideas. If they again choose a wrong answer, it will also be deactivated, leaving only the final, correct alternative activated. Thus, there can be no more than three unanimous attempts per question. In this manner, the students are guided by the software in their collaborative discussion.

Since in Chile school classrooms typically have up to 45 students, it is particularly important that the teacher be supported in his/her mediation efforts. Once a question is unanimously selected by the group, the teacher’s machine wirelessly retrieves it. This allows the teacher to monitor on his/her Pocket PC the 15 groups’ outcomes on each question. As a monitoring tool, the device provides a fast and reliable analysis of the students’ knowledge level with respect to the subject content presented in class and enables the teacher to take the necessary measures to reinforce the students’ weakest subject areas.

Applications of the system

In what follows, we examine two specific experimental applications of the face-to-face CSCL system in the educational process. The first illustrates how it can be used as a medium for collaborative discussion between students in groups in order to change the classroom dynamic. The second is a teacher training situation in which teachers, guided by a teacher trainer, can discuss and share their knowledge and practice.

Collaboration inside the classroom

Design of the experiment

A face-to-face CSCL system experiment was implemented at a public high school located in Santiago, Chile. The experiment took place over a 5-week period and involved the participation of two tenth year (secondary school) classes of 45 students each.
Whereas one of the classes used the actual face-to-face CSCL system, students in the other class, who also received Pocket PCs and the same set of questions, had to give their answers as individuals. In other words, no groups were formed in the second class and collaboration was not permitted. In this way, the effects of collaboration using the CSCL system could be observed. For both groups, the teacher participated in

**Fig. 5** Students' interfaces of the collaborative activity.
the system after teaching the material on which the activity questions were based.

The chosen subject area from which the questions were selected was Physics, which, according to the Ministry of Education, Chile, TIMSS-R study (1999), is the subject in which Chilean students have the greatest problems. Tenth Year students at the school where our experiment was conducted took three 45-min physics classes each week. The teacher used the first two classes to teach the material involved, whereas the third was turned over to the collaborative activity. Over the 5-week period of the experiment, the teacher covered an entire physics unit on the topic of heat.

The questions used in the activity were developed based on the course programmes and plans set by the Chilean government’s Ministry of Education. A group of teacher trainers, assisted by a team of psychologists, began by designing conceptual maps that outlined the interrelationships between the various concepts included in the curriculum. With these maps as a reference, the questions were designed to evaluate each student’s knowledge of the required concepts. For each question, the number of attempts required to answer it correctly was recorded (from 1 to 3 attempts; see ‘Description and design of the collaborative activity’).

The 143 questions that we used were arranged in four tests, and were given to 14 groups in the case of the collaborative activity ($N = 56$) and to 44 students in the individual activity ($N = 175^2$). The results are presented below.

**Results**

The results demonstrate that the differences between the outcomes of the collaborative and the individual activities are statistically significant (see Table 1). The average percentage of correct answers to the questions on the first try was 71.1% for the collaborative activity, higher than the 64.9% for the individual one ($t = 3.694$, $P < 0.05$, independent sample test). This allows us to conclude that the system induced the students to discuss the questions in a collaborative fashion, and that these discussions led them to obtain better results on the first try. The students in the collaborative activity reasoned and learned together, sharing their knowledge and thereby reducing the percentage of error on the first try compared with the percentage scored by the group answering as individuals.

On comparing the average number of attempts at each question in the individual and the collaborative modes, we also obtained statistically significant differences between the two groups ($t = -5.927$, $P < 0.05$, paired samples $t$-test). It was discovered that the students who worked collaboratively obtained, on average, a better result (Table 2).

**Reinforcement of teachers’ knowledge**

**Design of the experiment**

The second experimental application of the face-to-face CSCL system is its use in teacher training sessions involving refresher courses for updating the subject knowledge of science teachers. A total of 272 teachers who underwent such training in 2004 were divided into 14 sections, each of which contained an average of 19 teachers in one subject area, either mathematics, physics or biology.

Each of the experiments using the system, which were carried out in eight different cities around Chile, lasted 20 h. Two of the 20 h were taken up by an initial diagnostic evaluation and $6\frac{1}{2}$ h were devoted to methodological work guided by a teacher trainer; $8\frac{1}{2}$ h were spent on collaborative work using the face-to-face

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**Table 1.** Group statistics. The average of the percentage of right answers in the first try is higher in the students who used the system

<table>
<thead>
<tr>
<th></th>
<th>Collaborative ($N = 56$)</th>
<th>Individual ($N = 175$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of correct answers</td>
<td>71.12 10.1</td>
<td>64.87 13.4</td>
</tr>
</tbody>
</table>

**Table 2.** Paired samples statistics. The average number of attempts for each question is statistically higher in the students who used the collaborative system

<table>
<thead>
<tr>
<th></th>
<th>Collaborative ($N = 143$)</th>
<th>Individual ($N = 143$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of correct answers</td>
<td>1.369 0.40</td>
<td>1.489 0.34</td>
</tr>
</tbody>
</table>

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$^2$In some of the tests not all the students were present.
CSCL system with the teachers divided into groups of three, and 3 h were reserved for the final evaluation and discussion of the results.

The initial diagnostic evaluation was compared with the final evaluation in order to establish the level of achievement of each participant. Both assessments used the same questions so as to observe quantitatively the progress of each participant in percentage terms. The initial evaluation was used not only as a pre-test but also to help orient the methodological and collaborative work in those areas where participants were weaker.

Results
Upon comparing the results of the pre- and post-evaluations obtained by each section, we found statistically significant progress averaging 15.5%, an average increase from 76.2% of questions answered correctly on the pre-test to 86.8% on the post-test (Table 3). Each mathematical teacher improved his/her performance in 18%, biology teachers improved in 4% each and each physics teachers in 21%. It is interesting to observe that biology teachers improved less. It is known that in Chile, these are the best-prepared teachers, therefore their pre-test results were always higher than the ones of the other subjects’ teachers.

The teachers worked collaboratively in discussing their answers and exchanging classroom experiences, and the teacher trainer resolved their doubts and differences.

Discussion
During the entire process of the first experiment, we observed a high level of motivation among the students. This was due both to the expectations created by the experiment itself and the change in classroom dynamics produced by the introduction of the Pocket PCs. All students participated and gave their opinions in face-to-face interactions that were focused and mediated by the technology.

A key factor that should be emphasized is the ability of both students and teachers to understand and take advantage of the system, integrating it into the classroom so completely as to make it their own. In a report on the experiment that appeared on Chilean television, one of the students said: ‘This project is really different. It is a new way to learn physics, a subject that many of us are scared of because it is complicated. But this method of learning using computers is more entertaining, more effective, and easier because you have to explore the questions’. (Meganoticias Television, Channel 9, broadcast 6 November 2002). Another student added: ‘It’s a tool that allows us to learn new things, and at the same time exercise our minds, allowing us to share knowledge with our classmates. If there’s something you don’t understand, you can ask the teacher’. (China Television, Channel 11, broadcast 5 November 2002). Comments such as these show how the collaborative application can both mo-

<table>
<thead>
<tr>
<th>Class</th>
<th>City</th>
<th>Participants</th>
<th>Pre-test (%)</th>
<th>Post-test (%)</th>
<th>Increment (%)</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>Rancagua</td>
<td>17</td>
<td>90.3</td>
<td>93.9</td>
<td>4.0</td>
<td>-3.371*</td>
</tr>
<tr>
<td></td>
<td>Santiago</td>
<td>18</td>
<td>91.2</td>
<td>94.8</td>
<td>4.0</td>
<td>-4.968*</td>
</tr>
<tr>
<td></td>
<td>Santiago</td>
<td>33</td>
<td>89.8</td>
<td>93.0</td>
<td>3.5</td>
<td>-4.991*</td>
</tr>
<tr>
<td>Physics</td>
<td>Santiago</td>
<td>10</td>
<td>65.9</td>
<td>77.6</td>
<td>17.8</td>
<td>-3.629*</td>
</tr>
<tr>
<td></td>
<td>Valparaiso</td>
<td>10</td>
<td>68.2</td>
<td>84.6</td>
<td>24.0</td>
<td>-6.004*</td>
</tr>
</tbody>
</table>

*P<0.05
tivate and mediate communication and knowledge transfer between the students.

The teacher’s role in the use of this technology should also be stressed. The technology is not intended to replace the teacher. The aim, rather, is to support the teacher and give him/her additional tools to better carry out his/her pedagogical role. ‘The teachers are very important because they’re the ones who guide us and clear up any doubts we have during the activity,’ said one of the students (Chilevisión Television, Channel 11, broadcast 5 November 2002). The physics teacher who participated in the experiment agreed: ‘I think that the search for new technologies to assist the teaching process is a good thing’ (Chilevisión Television, Channel 11, broadcast 5 November 2002). He added that with the experiment, ‘our work as teachers is made easier. We can detect what the students’ weaknesses are, which things are harder for them to learn and where they make mistakes, so we can then reinforce those areas.’ (El Mercurio newspaper, 2 November 2002). This comment reflects the fact that the teacher obtains the results of the test immediately. Furthermore, since the teacher is present during the entire activity to help the student, s/he can easily observe which concepts are causing the most difficulties and therefore need extra work.

As regards the second experiment, which involved upgrading teachers’ subject area knowledge, participants were surveyed regarding the evaluation questions, the use and assimilation of the technological tool and the collaborative software. It was discovered that they approved of the combination of collaborative and methodological activities. The technological tool was felt to be an extremely valuable component for facilitating the learning process, and the collaborative activities were especially valued as a teaching aid and an opportunity to learn. Also, the methodological activity was found to facilitate the interchange not only of knowledge but also of effective pedagogical strategies that teachers can apply in their teaching activities.

An aspect of the system that deserves to be emphasized here is the immediate detection of the student’s weaknesses. This makes it possible for the teacher to quickly discover which subject contents need to be given more emphasis, either in class or for specific groups. This is particularly important in teacher training, for pure knowledge as well as pedagogical abilities is a fundamental requirement for teachers. Indeed, the teachers’ level of mastery of a subject area sets the maximum level his or her students can aspire to, so any deepening of that subject knowledge is another way of increasing the students’ possibilities to learn.

Conclusion

We have presented two applications of a face-to-face CSCL system that support the work of school teachers. The first transforms the classroom dynamic from one in which students are sitting behind their desks listening to the teacher to one where they are active participants, and where collaborative work is combined effectively with traditional teaching. The second application uses the same technology for teacher training. In both applications, we obtained statistically significant results. This indicates that the collaborative discussions facilitated by this face-to-face CSCL system help students to better assimilate educational content, thus increasing their level of knowledge.

The immediate aim of our experiment was to improve knowledge of a particular subject area. The experiment showed that this learning environment stimulates social and communication skills as well. It provides a classroom space in which the students, by working ostensibly on academic issues, also learn to work in a collaborative face-to-face context, thereby developing abilities that are not normally addressed in school. It should be noted at this point that when we use collaborative activities to teach educational content, we are assuming that the students are working effectively in teams and that the process of collaboration itself is properly carried out. We observed instead that even when the groups use the proposed system for managing and guiding the collaborative process, thus ensuring that the discussions are carried out in an effective way, the academic results of the activity strongly depend on each participant’s aptitude for working as part of a team. We are working on a study that correlates the collaboration process with the learning process, to complement the results obtained in this paper. Collaboration in itself is an aim in today’s working needs; therefore, it should be an educational goal in and of itself.

In this paper, we have demonstrated one particular type of technologically based face-to-face collabora-
tive mediation in which members of a group must build an agreement on the answer to a given question. Other types are also possible. In Zurita and Nussbaum (2004a), each member of a collaborative group receives an element, which, when combined in some way with the other members’ components, forms an object that is the goal of the group. This form of mediation is suitable for constructing words, ordering numbers, etc. In Zurita and Nussbaum (2004b), the members of a collaborative group must interchange the objects they are initially provided with in order to arrive at a defined objective. This type of collaborative activity is particularly appropriate for basic mathematics, discussing questions and their possible answers, etc.

In all of these cases, technology supports the collaborative work by:

- Providing a space for organizing materials and information.
- Coordinating and synchronizing activity states.
- Mediating the activities and the social interaction of the participants.

Since this collaborative system is built with ad hoc networks whose only requirements are hand-held devices in wireless communication, and therefore are independent of any additional hardware, the participants’ mobility can be maintained anywhere and the collaborative environment can be created in any setting.

Although the system presented here uses new technology for improving learning, technology generally has not yet lived up to its expectations as a revolutionary educational tool. Mobile wireless learning is an important opportunity, but certain points must be kept in mind when applying it:

- Technology is the media, not the aim. We must understand the problems we are dealing with and make technology transparent for the users.
- The classroom should be an interactive environment. We must move from a teacher-centred class with passive students to one where the students are active and the teacher is a mediator in their learning process.
- The teacher must be supported as an integral element. We must provide tools for assisting him/her work in class and for preparing him/her with adequate subject area content and teaching techniques.

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References


