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Computer supported collaborative learning using wirelessly interconnected handheld computers

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Abstract

Collaborative learning is widely used in elementary classrooms. However, when working without technological support, some problems can be detected. We describe how weaknesses in coordination, communication, organization of materials, negotiation, interactivity and lack of mobility can be solved with a mobile computer supported collaborative learning environment with Handhelds interconnected by a wireless network. The collaborative activities, analyzed with and without technological support, are math and language activities for 6- and 7-year old children. The results of our work identify an effective way of using handheld computers to support collaborative learning activities that address the above mentioned weaknesses.

Keywords: Collaborative learning; CSCL; Distributed learning environments; Interactive learning environments

1. Introduction

The goal of collaborative learning (CL) is to assist teaching in a specific educational objective through a coordinated and shared activity, by means of social interactions among the group members, Dillenbourg (1999). These social interactions are essential to achieve the desired learning, as a result of a continuous attempt to construct and sustain a shared and open point of view of the problem, Vygotsky (1978). As early as 1890, social psychology literature discusses the social facilitation effect on learning, concluding that under collaborative face-to-face interaction conditions, group members working on a common problem communicate to one another a sense

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of urgency that tends to heighten their mobilization of energy, and as an ultimate result their motivation (Newcomb, Turner, & Converse, 1965). The design elements of a face-to-face CL activity are formed by a set of group and individual tasks, and roles and rules, which need to be evaluated to assure the desired social interaction.

In our work, two face-to-face CL activities for children without technological support were evaluated to measure the group members' social interactions and collaborative efforts in order to identify the actual weaknesses.

With the support of a Personal Computer (PC) network, it is possible to address most of the weaknesses found in a Computer Supported Collaborative Learning (CSCL) activity. However, all of them can be addressed with Mobile Computer Supported Collaborative Learning (MCSCL) activities (Table 2), implemented with wirelessly intercommunicated Handhelds.

Handhelds allow a more natural mobile collaboration environment (Danesh, Inkpen, Lau, Shu, & Booth, 2001; Imielinsky & Bradinath, 1994). Mobility allows the members of the group to have the physical control of the hardware, which helps the coordination and interactivity in their collaborative work, since they can carry the Handhelds while they establish a face-to-face interaction.

In an MCSCL activity, it is possible to recognize the Handhelds and the social network. While the users communicate face-to-face on the social network, they support their work with the Handhelds interconnected by a wireless network which permits a true face-to-face communication allowed by the Handhelds' network mobility. Therefore, it is of critical importance to transfer information effectively from the handheld network to the social network. For this, it is necessary an efficient interface design for the MCSCL activity (Danesh et al., 2001), so the members of the group can work face-to-face without mobility restrictions, and take advantage of the information supplied by the net.

In this paper, the background and related work are shown in Section 2. The description of two face-to-face CL activities for children without technological support, and their evaluation results showing the weaknesses encountered are depicted in Section 2. The weaknesses were solved with the design of two face-to-face MCSCL activities, using Handheld's wirelessly interconnected (Section 4). The description of MCSCL activities, their evaluations, and results are shown in Section 5. Finally, the conclusions are drawn in Section 6.

2. Background and related work

Collaborative learning has been frequently seen as a stimulus for cognitive development, through its capacity to stimulate social interaction and learning among the members of a group. Two major theoretical approaches explain the role of social interaction in the causation of CL: (a) First, the Piagetian approach considers that CL is effective because it promotes the emergence of socio-cognitive conflicts due to different opinions and strategies employed by the partners (Doise & Mugny, 1984; Perret-Clermont, Perret, & Bell, 1991); and second, (b) the Vygotskian perspective (Vygotsky, 1978; Wertsch, 1991), considers that individual change is presented as the result of an internalization of regulatory activities, such as member coordination and interaction of constructive processes, achieved by the mediation of communication between them. Both theoretical approaches present the first key components for evaluating

face-to-face CL activities: (a) the presence of conflicts, therefore, the necessity of negotiation instances to solve them, (b) the importance of coordination and interactivity, and (c) member communication.

Since face-to-face CL provides a richer social and learning experience (Bricker, Tanimoto, & Hunt, 1998; Hymel, Zinck, & Ditner, 1993), computer systems are often designed to support it (Gutwin, Roseman, & Greenberg, 1996; Hollan & Stornetta, 1992). An endeavor is the exploration of how technology can enhance and improve users' face-to-face collaborative learning interactions. This is especially important when considering children's use of technology (Mandryk, Inkpen, Bilezikjian, Klemmer, & Landay, 2001).

According to Gutwin et al. (1996) and Hollan and Stornetta (1992), a good design of CSCL activities can offer support for coordination, communication, negotiation and interactivity among group members. The computer can be seen as a mechanism to support social interaction and therefore, modify the nature and the efficacy of this interaction (Blaye, 1991; Mandryk et al., 2001). Although, several experiments report extremely positive effects on learning and social interaction of computer-based peer-to-peer interaction; also, there are other negative results (Kreijns, Krischner, & Jochems, 2002). Kreijns et al. (2002) argue that there are evaluations of the design of CSCL environments that do not completely fulfill expectations on supporting interactive, coordinated group learning and social construction of knowledge. Thus, the CSCL focus is focused on solving these pitfalls.

According to Myers, Stiel, and Gargiulo (1998) and Stewart, Bederson, and Druin (1999) PC technology can be constraining for users to support face-to-face CSCL activities. As a result, children wanting to collaborate by using computers must adapt their interactions to the single-user paradigm most PC are based on. In most classrooms today, face-to-face collaboration with children is supported by traditional interaction paradigms. These include (a) one or multiple peripherals (keyboard, mouse) on a shared computer, and (b) side-by-side computers. Research suggests that shared display provide certain advantages (Bly, 1988; Inkpen, 1999), compared to displays of side-by-side computers. Furthermore, other research suggests that users subconsciously respond to computers as social actors, potentially complicating the task of discussing shared objects located on different screens (Reeves & Nass, 1996). Besides, Scott, Shoemaker, and Inkpen (2000) explain that when the collaborative learning activities use PC, the members are limited by the fundamental one-person/one-computer paradigm.

2.1. The relationships between communication, negotiation, coordination and interactivity in CSCL

Communication is basically possible in three different ways: (a) verbal (another person receives this message through auditory or visual senses), (b) physical (by reading the other person's body language and/or movements), and (c) graphical (by using written signs and drawings), Bricker et al. (1998).

According to Kreijns et al. (2002) communication is important to establish a social interaction in which a structure can be found. This structure encompasses group relationships, group cohesion, and a sense of belonging, all of which contribute to open critical thought, supportive interaction, and social negotiation. Kreijns et al. (2002) found a pitfall that seems to account for the success of CSCL: the assumption that *social interaction can be taken for granted* and that it will automatically happen in a CSCL environment. Research has shown that this is not the case.

Johnson and Johnson (1999), for example, observed that when studying collaboration in face-to-face groups, just placing students in groups and assigning them a learning task, does not in itself promote collaboration between and among group members.

Another component of CSCL is the interaction that takes place between students. Teamwork is vital for a successful CSCL environment. Curtis and Lawson (1999) explain the many different ways for this interactivity to take place, such as the giving and receiving of help and feedback, the exchanging of resources and information and the ability to challenge and encourage other students.

Students tend to communicate effectively about the problems that arise while performing highly coordinated face-to-face tasks. There is evidence of increasing problem-solving and enjoyment when two children work closely together on coordinated computer-based tasks (Inkpen, Booth, Klawe, & Upitis, 1995). The coordination supported by CSCL seems to lead to more and better communication and vice-versa.

According to Curtis and Lawson (1999), it is clear that some group members may experience difficulties in communicating, coordinating and interacting with others they are not acquainted with. Curtis and Lawson, found that a factor that may compound these difficulties is the lack of visual contact and body language. Bricker et al. (1998) found that when the members are not restricted by the software from working together or apart, they tend to work closely together on a task. Also Bricker et al. (1998), report that users were not terribly frustrated by interactions enforced by software, and found the activity entertaining. This reduction in communication can result in a decrease of effort and workload.

According to Haythornwaite (1999), CSCL is not just *collaboration around computers* with the computer providing a means to coordinate tasks or to simulate problem-solving situations; but rather *collaboration through computer*s, where group members use the computer to structure and define their collaborative endeavors. Haythornwaite (1999) said that, communication, coordination, negotiation, interaction, and exchange of resources are the building blocks of the social networks that sustain and define work groups, learning groups, and communities. Haythornwaite argues that interacting through computers, learners, workers and community members develop *computer supported social networks*, taking advantage of the diversity of experience available from the wider range of contacts afforded by PC's. Furthermore, the anywhere–anytime characteristic of the Handhelds and its potential to support interactive communication between group members have convinced many educators to believe Mobile CSCL environments to be the promising next generation of educational tools (Danesh et al., 2001; Inkpen 1999; Soloway, Norris, Blumenfeld, Fishman, Krajcik, & Marx, 2001).

2.2. Children as users of face-to-face CSCL

Children enjoy playing together and are very good at engaging in fruitful face-to-face social interactions (Inkpen, 1995). Research has shown that social interactions in a CL environment lead to significant academic and social benefits (Hymel et al., 1993; Johnson & Johnson, 1999; Wood & O'Malley, 1996). Also, research in psychology and education has consistently demonstrated that children working in pairs, or small groups, and interacting with computers can have advantageous effects on learning and development, especially in young children (Stanton, Neale, & Bayon, 2002).

Normally, to support children working together while maintaining the existing technological infrastructure available in schools, the current systems have been extended to accommodate multiple children using one computer. This has been accomplished by using peripheral devices, such as styli (Bier & Freeman, 1991), joysticks (Bricker et al., 1998), and mice (Scott et al., 2000; Stewart et al., 1999), to provide multi-user interaction. Although providing a shared display for face-to-face collaboration seems a natural way to interact, research has not clearly demonstrated that a shared display system supports concurrent multi-user interaction, as well as alternative display configurations such as side-by-side monitors. Nevertheless, research has shown that children can become more motivated and obtain positive social and learning results when these interactions are supported (Danesh et al., 2001; Inkpen, 1999; Mandryck et al., 2001).

2.3. Handhelds as support to collaborative learning activities

As it is well known, the ability to use PCs in the classroom has changed the way of teaching. The use of techniques from laboratory experimentation to student collaboration has improved the way instructors teach and the way students learn. As computers get smaller and more "personal", they present new ways to combine these successful techniques with new and unique ideas to provide even more effective ways of teaching (Jipping, Dieterm Krikke, & Sandro, 2001).

Soloway et al. (2001) and Tinker and Krajcik (2001), establish that handheld devices offer the opportunity to provide each student with their own computer. The mobility, flexibility and instant access of Handhelds, means that they are "at hand," which allows students to engage in highly collaborative activities anywhere, at anytime.

According to Luchini, Oehler, Quintana, and Soloway (2002), handheld computers in these classrooms made an impact on collaborative work. The ease of simply aiming your Handheld at your partner's to "beam" information has turned some typically individual activities into learning opportunities involving substantive discussion and face-to-face learning. The group members use their own mobility and the mobility of Handhelds to coordinate collaboration between them, while they are exchanging information by the interconnected wireless network (Stanton & Neale, 2002).

Besides, Roschelle and Pea (2002) said that Handhelds are more affordable, making a 1:1 student-computer ratio and ready-at-hand computing feasible. Roschelle and Pea, define the Wireless Internet Learning Devices (WILDs), which students can take into the field for scientific data gathering (Rieger & Gay, 1997; Staudt & Hsi, 1999), to their study hall, on the bus, to a museum (Bannasch, 2001), or anywhere learning occurs.

Furthermore, Jipping et al. (2001) believe that handheld computers can be used in *traditional* methods of classroom teaching and that they can represent new platforms for bold and unique teaching methods. Jipping et al. believe that several core concepts need to be developed and implemented: (a) *Students need to become owners of their computing environment*. The student needs to be the centre of a computing environment— not the computer; (b) *Information needs to* seek out for the *student, not vice versa*. If the student is to be the centre of the computing environment, we need to target information for students. We need to bring information to students, not the students to the information; (c) *The tools used in the computer environment need to naturally extend a student's computer use*. Computing technology often bends a user's patterns of usage to fit the technology. Students will adapt to the computer when the new tools are natural

extensions of their experience; and (d) *Computing facilities need to empower a student to naturally become part of a larger community*. We must use the technology we have at our disposal to engender community.

Also Jipping et al. argue that collaboration and learning will only occur if the technology is designed to fit the context of use for which it is intended. With an inappropriate design, a mobile interface may equally prove to be a barrier to learning. Other researchers, like Stanton and Neale (2002), establish the importance of occasional well-structured information rather than a continuous flow of information. With a smaller, more punctuated delivery of information, children are able to attend to the environment or the collaborative task at hand, without having to monitor the screen continually.

Finally, the design of the Handhelds may enable collaborators to be aware of the state of the activity (e.g. visibility) despite the apparent restricting aspect of limited size of the Handheld's screen Roschelle and Pea (2002). A small screen size does not have to be, and indeed is not, a barrier to collaborative work (Stanton & Neale, 2002). There are forms of interface design that allow children to collaborate around a Handheld by paying attention to the detail of the interaction taking place and enabling pairs to share technological and social information.

3. Evaluation of CL activity for children without technology

To find the weaknesses of face-to-face CL activities, and have a frame of comparison to see if these were solved by an equivalent activity implemented with wirelessly interconnected Handhelds, an evaluation was performed on two collaborative activities for first graders in math and language.

3.1. Method

In order to understand children's social interactions and shared learning of face-to-face CL environments better, first we exhaustively observed children working with two (math and language) collaborative activities without technological support. Our approach was to watch the videotapes repeatedly, with the focus on how the groups behaved during the key issues described in Section 2, i.e. to find weaknesses in: (a) Coordination of the group members, (b) communication between members, (c) organization of the material by the members, (d) establishing of negotiation' instances of the members, (e) interaction realized by members, and (f) changes in the members' physical mobility.

Quantitative and qualitative data was gathered from video, field notes and interviews. The common weaknesses for each component were analyzed for every collaborative group (Table 1). For each identified weakness the video was re-analyzed and the frequency of weaknesses occurrence was calculated for all groups. The decision to employ qualitative techniques with quantitative research methods is well supported in literature. Both methods have their own strengths and are best used to address their corresponding research purposes (Maxwell, 1996). Also, both methods are empirical in that they involve rigorous and systematic inquiry that is grounded in the data. Used together, the two methods can be quite complementary (Miles & Huberman, 1994).

Table 1
Weaknesses of Math and Language CL activities without technological support extracted from the CL key components. The media and deviation standard frequencies for each weakness is shown

Weakness	Frequencies			
	Math[a]		Language[b]	
	μ	σ	μ	σ
Coordination				
The members participate interactively, but there is lack of coordination: Decision of order and of who performs specific tasks and roles in the activity	4.94[c]	1.46[c]	4.23	1.92
	7.27[d]	2.54[d]		
Communication				
Difficulty for the members to establish communication links	4.27[c]	1.96[c]	4.92	1.27
	5.23[d]	2.71[d]		
Organization of material				
Demand of effort in material-organization for the activity	6.79[c]	3.23[c]	4.26	2.21
	6.71[d]	3.07[d]		
A member stops attending the material s/he is using, therefore loses visibility of the activity status	2.42[c]	1.05[c]	2.67	0.75
	2.72[d]	1.41[d]		
Negotiation				
There are agreement conflicts in the answer which are not solved as a group	2.68[c]	1.34[c]	3.02	1.64
	3.45[d]	2.87[d]		
Interactivity				
A member takes control of the activity for longer than required and excludes the rest	2.08[c]	0.07[c]	3.66	0.28
	2.75[d]	0.04[d]		
A member wants to do all the work and continuously seeks control take-over	3.03[c]	1.87[c]	3.22	0.99
	4.21[d]	1.33[d]		
A member does not participate in the activity by free will	1.05[c]	0.43[c]	2.07	0.05
	1.65[d]	0.25[d]		
Mobility				
Physical approach of a member is blocked by the material another member handles	6.75[c]	1.37[c]	4.06	1.82
	9.85[d]	3.21[d]		
It is difficult for the members to move toward their partners, with whom s/he wants to establish a closer physical contact, since her/his displace is blocked by another member	6.16[c]	0.08[c]	5.89	2.05
	7.97[d]	2.32[d]		

[a] Groups were composed of 27 six and seven-year-old children, four groups of three members (7 girls and 5 boys), plus three groups of five members (8 girls and 7 boys).
[b] Groups were composed of 21 six and seven-year-old children, seven groups of three members (12 girls and 9 boys).
[c] Results obtained from groups of three members.
[d] Results obtained from groups of five members.

Focused on the weaknesses found for each key component, we designed (Section 5.1) two correspondingly equivalent CL activities oriented to strengthen these components with the support of wirelessly interconnected Handhelds. Afterwards, we exhaustively observed children working with these two activities with technological support (MCSCL), focusing the analysis directly on

each of the previously found key component's weaknesses, counting the frequency of occurrence. With the data obtained for CL activities with and without technological support a *t*-Student statistical analysis was applied to determine if there was a significant difference (Section 5.4).

The observation results and interview forms were subjected to reliability and validity criteria (Miles & Huberman, 1994). Triangulation (Norman & Yvonna, 1994) was used as the data-gathering validation technique, by which the data obtained in the observation was compared with data obtained in the interview. If the data coincided, the instrument had obtained (somehow) accurate information. On the other hand, inconsistencies helped identify those aspects that had to be analyzed in greater detail.

3.2. Description of math and language CL activities

The language activity had as a group goal, forming words using three syllables. Each of the three group members are given a card containing one syllable, which she or he is responsible for, and is the only one who can show it to the rest of the group. Only one member of the group is in charge of giving the syllable card to the others, by extracting it from a common envelope; his or her leading role must be rotated between the group members. A shared envelope contains several cards of the same three syllables. The group members must discuss together the word they can form with each of their syllables and the arrangement the cards must have, so that a word can be built. The tasks of each member consist on suggesting any possible words to be constructed with the syllables that each one has. When they all agree, the cards must be placed on a cardboard with the necessary spaces, where the word is formed. Each member is responsible for putting her or his syllable on a cardboard. If one or two syllables are not necessary, they are not considered. Afterwards, all the members together must decide if more words with the same syllables kept on the common envelope, can be formed. If all of them agree, the process is repeated; otherwise, they take another envelop that contains another three syllables.

In the math activity, each of the three or five members has a given number of cards with three different objects, all contained inside an individual envelope. The group's goal is that each member reaches the specific number of cards for each of their objects, by exchanging the cards (objects). One member of the group at a time is in charge (role) of distributing their individual envelopes to the other partners. The exchanges are done in couples, in which both have to agree in receiving and giving (correspondingly) a card. The tasks of each member consist on looking for the objects that she or he needs, or to offer the objects that exceed the specified needs. Afterwards, the members in conjunction must decide to continue exchanging objects. If all the children agree, they can take another individual envelope that contains other cards with a different quantity of objects.

The materials used in both activities are: (a) a considerable number of cards, and (b) envelopes containing cards. A cardboard was used for the language activity.

3.3. Subjects and settings

The study took place in one low-income elementary school of Santiago de Chile, during an entire school month (20 days, 35- to 45-min activities) at the end of their first grade. There were 48 students (27 girls and 21 boys) ranging 6–7 years. Children were distributed in seven

coeducational groups: three members (with 12 girls and 9 boys) for the language activity; and four groups of three members (7 girls and 5 boys), plus three groups of five members (8 girls and 7 boys) for the math activity. None of the students had previously worked on CL activities.

3.4. Procedure

The children were invited to sit in groups around a desk during the language class time. At the first session, 10-min basic instructions on the collaborative activity were explained to all the groups (e.g. roles, rules, tasks, and global objective description). The rest of the time of the first day and the next ones, children activities were video recorded and closely observed. The activities of groups were only interrupted when help was needed. The observations and field notes were registered in a specially designed form. At the end of the twentieth day, a 15- to 20-min interview was done to all groups, based on a specific form, plus open questions that motivated their active participation.

3.5. Results

The weaknesses found for the 20-day CL activities, together with their media (μ) and standard deviation (σ) of their frequencies, are shown on Table 1. The media and standard deviation were obtained considering all the weakness frequency for every group. We present two sets of weakness frequency separately for the math CL activity: the three and five-child groups. An analysis of the results is shown on Table 1.

Coordination. There were coordination weaknesses among the members of the group. Some members take control of the activities while others are left aside, Fig. 1a. Even if decisions were taken by the group, some children presented doubts on how to proceed with the activity. Despite the established roles and rules intended to control these situations, some members of

Fig. 1. Snapshots of group members working with a CL activity without technology: (a) a child working on a language activity CL group is left aside, and (b) two children are fighting while the other is trying to work on the math activity.

the group failed to obey them in both CL activities. For the math CL activity with five members, there was a significant difference of means, $P<0.05$, with a t-Student (2-tailed, independent samples) test. This reflects the fact that if the amount of members in a group is higher, accomplishing collaborative activity coordination is more difficult.

Communication. There were communication weaknesses that considerably reduce social interaction between the group members, Fig. 1a and b. These are mainly due to the administration of materials (paper, pencils, cardboard, etc.) they take with them to develop the activity, and also because of affinity reasons (Fig. 1b). Some members need to be very close, hindering a face-to-face communication with a third one.

Organization. For both CL activities, each member must manage a considerable amount of material during the collaborative activities. This turns out to be uncomfortable for the members and delays their tasks due to the effort it takes to organize the work. If a member leaves his material to approach another, he loses visibility of what he is doing and what others are doing. This delays his realizing what part of the activity he has missed.

Negotiation. For both CL activities, some group members impose their point of view, which obstructs the activity's progress. The mediation and the negotiation space depend only on the members. The lack of a negotiation space in the interactions makes some members to carry out the goals by themselves, causing others to be left aside, turning the application into a personal, instead of collaborative one.

Interactivity. A CL activity must be interactive. However, a lack of interactivity has been observed among some members, since they do not respond to their partners' request due to social differences, lack of motivation (Fig. 1a), and attention or loss of the activity state. The other members of the group are then forced to look for other ways of reaching the aims, breaking the collaboration.

Mobility. The social interactions among the members of the group require a physically close approach. Mobility among members is obstructed by the material they have to take with them, or by the partners who obstructs another member's approach, as shown in Fig. 1b. Though a t-Student test, we were able to prove the media difference presented for both mobility problems; therefore, the higher the group is, the harder it is to make a member take advantage of mobility, due to material he has to manage ($P<0.05$), or the people who hinder his contact with others ($P<0.05$).

On Fig. 2, the media dispersion graphic of the occurrence frequency for all groups is shown. This frequency corresponds to the number of times a student takes control of the language CL activity longer than needed, and shows the results for the 20 days the experience lasted. On Fig. 2, we can observe that the frequency media tends to decrease in time since the groups are improving their collaborative work. Similar results were found for the frequency of other weaknesses found in CL activities.

4. Solving weaknesses of CL activities with Handhelds: MCSCL

In this section, we analyze how computer technology can give a solution to weaknesses in CL activities (Section 4.1); also the MSCSL activity model is presented, which technologically supports the described math and language CL activities in order to address the weaknesses found (Section 4.2).

4.1. What can Handhelds offer?

in Table 2, we can observe an analysis of what PCs and Handhelds can offer to face-to-face CSCL activities, based on evidence found in experimental and exploratory studies. The type of collaborative activities taken into account in the analysis, are described in Section 3.2. The MCSCL model addresses the weaknesses encountered in the CL activities (Table 1). The coordination and interactivity weaknesses can be addressed in a natural form, if we use Handhelds instead of PCs. The CSCL activities supported by side-by-side PCs must administer an awareness mechanism that informs users of the actual state of the other members of the group. This mechanism of awareness introduces an additional load in the members' perceptions, while Handhelds can be physically carried a member, allowing them to see and show the different states of their Handhelds, in a more natural and direct way, to the rest of the members.

The necessity of mobility within the group members, to successfully accomplish their social interactions, requires machines that children can easily carry, e.g. Handhelds (Zurita & Nussbaum, submitted for revision -a). This is a substantial difference of CSCL technology implemented on PC, which forces the users to stay still behind the monitor.

4.2. A model of MCSCL activities

Kreijns et al. (2002) argue that the CL components of interaction, coordination, communication, and negotiation are important for establishing a social interaction. Kreijns et al. advocate the positive relationship between social interactions in the socio-psychological dimension/social dimension and learning performance in terms of the learning outcomes. Without this, agreement is unlikely. Once affective relationships and a sense of community have been established, enhanced task accomplishment may be achieved. Both outcomes (learning and social performance) are depicted in the model shown in Fig. 3 proposed by Kreijns et al., which has been extended to consider Handhelds support for the weaknesses found in CL activities.

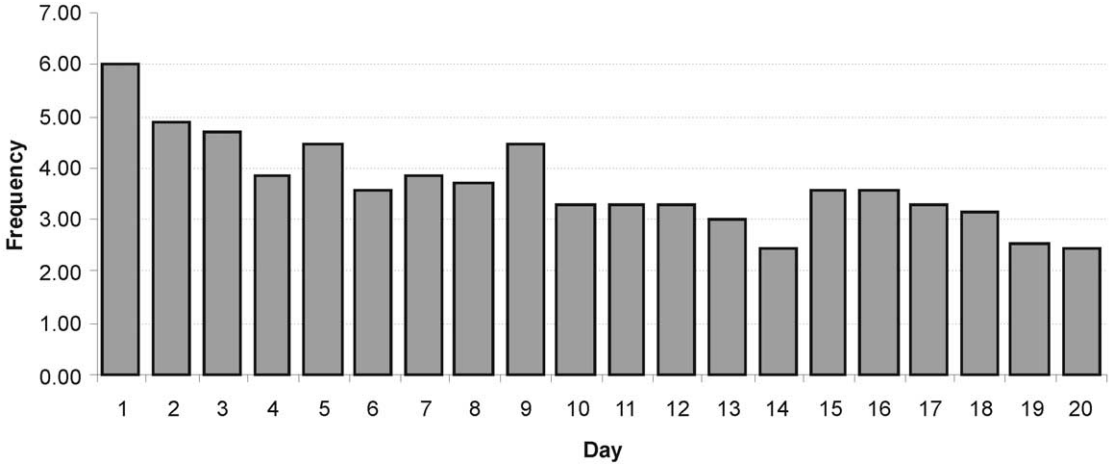

Fig. 2. Interactivity weakness of language CL activity: media dispersion of the occurrence frequency for all groups.

Table 2
Comparative analysis of PC and Handhelds used as support for face-to-face CL activities

One or multiple peripherals on a shared PC	Side-by-side PC's	Handhelds
Coordination		
The members participate interactively, but there is lack of coordination: decision of order and of who performs specific tasks and roles in the activity A member can take control of the PC peripherals; therefore the system cannot support coordination	The system can provide to each member with mechanisms to support coordination	The system can provide to each member with mechanisms to support coordination
Communication		
Difficulties for the members to establish communication links The experience is highly social, and conversation is nearly continuous during the activity. In CSCL, the members had fewer communication than CL (Steiner & Moher, 1994)	The experience was mostly individual, with long periods of silence between infrequent interactions between members. (Steiner & Moher, 1994)	The experience is highly social, and conversation was continuous during the task (Zurita, Nussbaum, & Sharples, 2003; Danesch et al., 2001) >
Organization of material		
Demands effort in the organization of material for the activity All material can be provided by the system	All material can be provided by the system	All material can be provided by the system
A member stops attending the material s/he is using, therefore loses visibility of the activity status All the members see the same. If one quits the activity, s/he can lose visibility of the state, since the other classmates can continue with the activity	All the members see the same, besides what they need. A member cannot take over the information shown, and if s/he quits the activity, the rest is forces to wait for him, and therefore visibility is not lost	All the members see the same, besides what each one needs. A member can take the information over, so that the activity can continue, and visibility is not lost
Negotiation		
There are agreement conflicts in the answer which are not solved as a group The system can provide with sport in mediation of conflicts and decisions. There is a social space for face-to-face negotiation; it does not guarantee the same possibility of decision to each member	The system can provide with support in the mediation of conflicts and decisions, offering the same possibility of decision to every member. There is a low level of social negotiation space though	The system can provide with support in the mediation of conflicts and decisions, offering all the members the same possibility of decision. A social space for face-to-face negotiation is generated. (Zurita et al., 2003)
Interactivity		
A member takes control of the activity for longer than required and excludes the rest The system provides with mechanisms of use and decision to be shared by all the members, who do not always respect the use time	The system provides with mechanisms of use and decision to be shared by all the members and gives them all the same privileges of use	The system provides with mechanisms of use and decision to be shared by all the members and gives them all the same privileges of use
A member wants to do all the work and continuously seeks control take-over The system provides with mechanisms of use and decision to be shared by all the members, who do not always respect the rules for use	The system provides with mechanisms of use and decision to be shared by all the members and also the rules of use for each one	The system provides with mechanisms of use and decision to be shared by all the members and the rules of use for each one
A member does not participate in the activity by free will The system provides with mechanisms of use and decision to be shared by all the members but one of them does not have to participate if s/he does not want to	The system provides with mechanisms of use and decision to be shared by all the members and assures all the members' participatio	The system provides with mechanisms of use and decision to be shared by all the members and assures all the members' participation

(*continued on next page*)

Table 2 (*continued*)

One or multiple peripherals on a shared PC	Side-by-side PC's	Handhelds
Mobility		
Physical approach of a member is blocked by the material another member handles Three or more members, working on the same computer, block a third member from approaching the rest	In order for a member to approach another, he needs to leave his/her computer and also the PC supported collaborative activity	Each member can attend her/his Handheld while s/he carries it anywhere s/he needs it, while participating in the activity
It is difficult for the members to move toward their partners, with whom s/he wants to establish a closer physical contact, since her/his displace is blocked by another member If there are three members, it is possible that more physical contact is not necessary. If there are more, there will be problems to move around the PC	Even though a member can displace, the collaborative activity supported by her/his PC, together with the material, is left behind	The members can approach any classmate, and carry their collaborative work supporting tool with them
Ubiquitous		
Transparency of the technology to facilitate social interaction among members The PC is not a tool designed for children. The keyboard and the more present difficulties. Some researchers have noticed that it is difficult for children to perform mouse operations that require persistent pressure on the mouse button. (Inkpen et al., 1995). Sometimes it is difficult for the members to share the input device, but working together on one machine can have a significant benefit over working side-by-side on PC's (Inkpen et al., 1995). When two or more children must share a mouse and control over one cursor on the screen, it may result in an unequal balance between them (Stanton et al., 2002). Besides, for children sharing a PC with one of their peers, the experience was less social, and conversation was nearly continuous during the task than children working without computers	Using side-by-side PC's, the experience was mostly individual, with long periods of silence between infrequent interactions with their partners (Steiner & Moher, 1994). Also, other researches suggests that members subconsciously respond to computers as social actors, potentially complicating the task of discussing shared objects located on different screens (Reeves & Nass, 1996). Scoot et al. (2000) explain that when the CL activities use PC, the members are limited by the underlying one-person/one-computer paradigm	For children, Handhelds are more useful and ubiquitous than a PC (Zurita & Nussbaum, submitted for revision-b). It is easier and more natural for the children to control a Handheld with the "touch screen" system. A system that allows children to work together as well as maintain the ability for individual exploration may be an important advance in CSCL (Inkpen et al., 1995). Each Handheld a child from the group has can be seen from one computer that allows them to share resources as well as work separately and approximately on their individual tasks. The Handheld's anywhere-anytime characteristic and its potential to support interactive communication between group members have convinced many educators to believe Mobile CSCL environments to be the promising next generation of educational tools (Danesh et al., 2001; Inkpen, 1999; Soloway et al., 2001)
Transparency of computer network		
There is no computer network	The PCs have been designed for children. The PCs net formation is not transparent	Wireless interconnected Handhelds provide with a transparent computer network for children

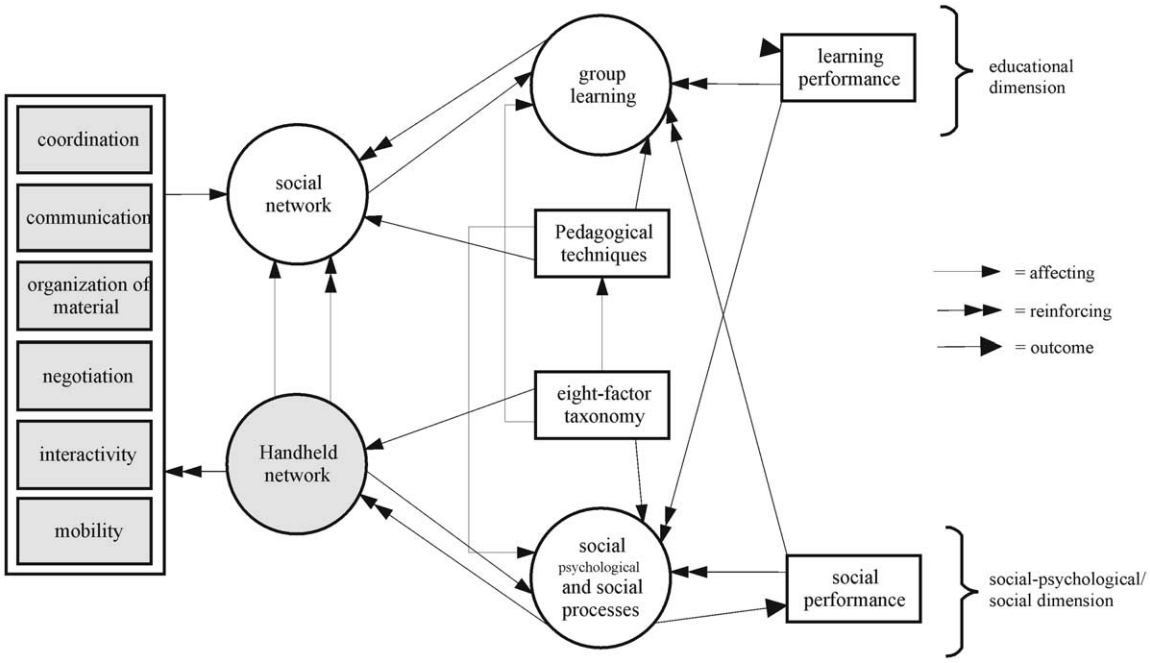

Fig. 3. Model extended with support of Handhelds of the dimensions of learning in CL groups with their outcomes.

The model of Fig. 3, depicts a MCSCL activity. The eight taxonomy factors are: (1) appropriate teacher behavior; (2) appropriate member behavior; (3) nature of the learning tasks; (4) member roles; (5) task materials that enable execution of the task; (6) CL goal definition; (7) formative evaluation with feedback from peers or from educators; and (8) additive evaluation and reward structure. The outcomes and factors are boxes, processes are circles, and dark boxes and circles represent our extension of the Handhelds support. All the CL components (interaction, coordination, communication, and negotiation), plus mobility and organization of material are grouped, since there is dependency among them. For example, negotiation needs communication instances, coordination is required to achieve interactivity, mobility favors communication, etc. Besides, the handheld network is shown as a tool, which strengthens the weaknesses found in CL activities, providing the movement property needed by the members. Each member had a Handheld with wireless interconnection capabilities, with which she or he extends her or his area of communication throughout the wireless network; while the member can move and displace with her or his Handheld. Not only can members socially interact among themselves (social network), but they can also do it with the Handheld's network.

5. Evaluation of two MCSCL activities

As done for the CL activities (Section 3), the occurrence frequencies found in math and language MCSCL activities will be counted, for the weaknesses found in both activities. The aim

is that children work collaboratively on an educational objective, through the use of their interaction, communication and negotiation skills, with Handheld support.

5.1. Description of math and language MCSCL activities

A 240×320 pixel resolution display with touch screen was available (Pocket PC, Compaq iPAQ with Wi-Fi communication card). Both activities were built for Spanish-speaking kids. The interfaces were designed considering the principles of simplicity, familiarity, obviousness, satisfaction and affinity, so that children can collaborate with the Handhelds (Stanton & Neale, 2002). In both activities each child worked with his or her own Handheld.

In the language MCSCL activity groups of three children were formed. Each Handheld shows a syllable that has to be combined with the syllables of the other two children to form as many words as possible (syllable "si" within the cloud, Fig. 4a). In Spanish, a set of syllables can form more different words than in English.

Fig. 4. Interface snapshots of the language activity.

Each member contributes with her or his ideas, promoting a discussion with the others, using her or his Handheld together with the Handhelds of the rest of the group, to perform their word formation. The members can move one next to the other so that they can form a word with the syllables of their Handhelds.

Once members agree upon the word to be formed, they have two buttons available to form the word in a sequence. The "cloud" button with their syllable on the top left part of the Handheld (Fig. 4a), makes it possible to choose the syllable. The button with the face (lower right of Fig. 4a) allows the child to indicate that she or he is not considering the syllable to form a word.

Fig. 4(b–d), shows a possible configuration of 3 Handheld', after that each of the button "cloud" has been pressed in the sequence. In this case, the three views correspond to one member at a time, but in three different states, according to the way the syllables were chosen by each member. Once the word is formed (Fig. 4d), a voice message ("Do you agree"), is sent to each of the members to confirm that all agree on the constructed word as a valid one. Two options can be chosen, the correct and incorrect button of Fig. 4d; at this point the activity waits for a unison answer among the members of the group. If someone in the group does not agree then a voice message ("Re-agree on a new answer") is sent to re-agree on a new answer (Fig. 5a), and the activity will return to the state shown in Fig. 4d. If the word formed is correct, i.e., stored in the Handheld's database, each Handheld of the members will show this, Fig. 5b, with the corresponding formed word. Afterwards, there is an option to continue forming new words with the same syllables, by using the "si" (yes) button, on the left, or "no", on the right, provided that all of the members agree on the same action (Fig. 5c). Besides, a voice message is activated telling the member if he or she wants to continue forming new words ("Do you want to form new words"). If they do not agree, the Handhelds show the disagreement (Fig. 5a) and ask that an agreement should be made, returning to Fig. 5c. Those words correctly formed can be displayed (Fig. 5d) when pressing the left button illustrated by a booklet on Fig. 5a.

The upper right corner of the interface identifies a set of members, a sun on Fig. 4. In case a member changes to another group, this drawing is changed according to the group she or he has to work with.

For the math MCSCL activity, groups are made of three and five members. As in the CL activity of Section 3.2, the activity consists on each group member having a set of given objects and achieving the specified number for each of the objects by sending and receiving these from another member of the group. For example in the Fig. 6a, the child has one orange, three bananas and two apples shown in the central (blue) box, and has to reach two oranges, four banana and three apples shown in the upper part of central (blue) box.

Each member is identified by a given color, used as the main background. The others members are identified by the colors of the buttons on the bottom section of the display (Fig. 6a, purple with red and green buttons; Fig. 6b–d, red with purple and green buttons).

The child selects the button that corresponds to the group member from whom she or he wants to receive an object (Fig. 6). The child who sends the object first selects it from the object windows in the screen center, and then chooses to which member she or he wants to send it, pressing the button of the corresponding color. This button will be available for the child who wants to send an object, only if the other child previously selected the receiving button from the corresponding color.

For example, purple (Fig. 6a), when wanting to receive an apple, should specify from whom wants to receive it, the red one for instance. To perform this action, she or he should choose to press their red button at the lower end of the display. Then red (Fig. 6b) will choose the apple to give, (changing to configuration of Fig. 6c) and only with purples acknowledge to receive. Only then, the give button activates itself to perform the giving. After choosing the purple button, the quantity of red's apples is decreased (Fig. 6d) while the quantity of purple's apples is increased, and the state changes to be able to choose new members from whom to receive an object (Fig. 6b). On the contrary, if red (Fig. 6d) wants to give an object, then she o he should mark the object so that their state changes (Fig. 6c) with the colored buttons of members who want to receive the object.

It is possible that some members reach their individual goal while others have not. Fig. 7a shows the red member's interface that already reached his/her objective (see the red icon with a star on the lower part), fact also shown to the member with purple and green color (Fig. 7b and c), using a red icon with a star in the upper part of the display. Only when all members reach their

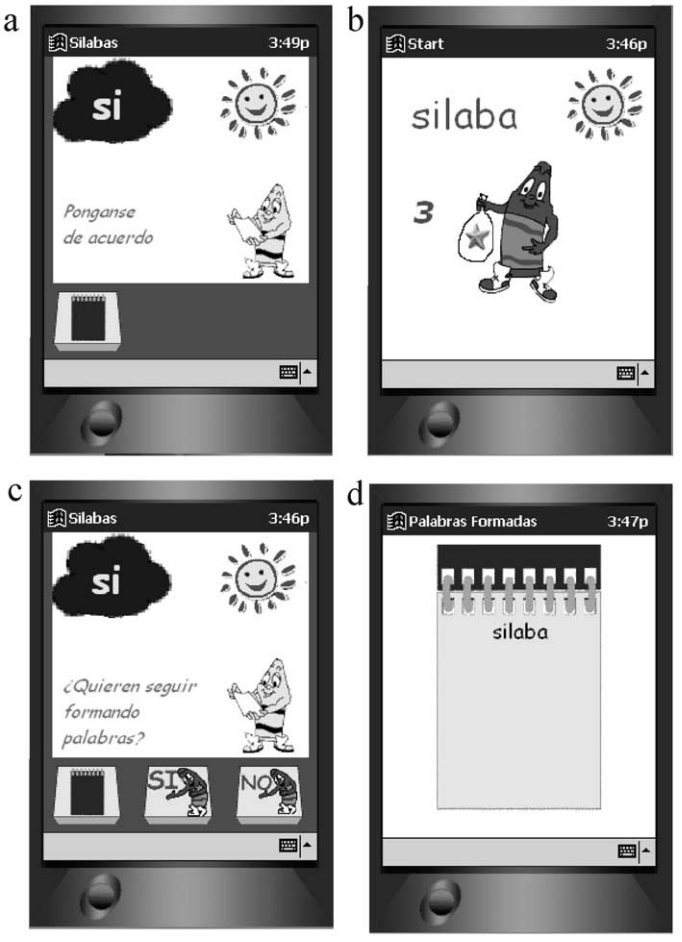

Fig. 5. (a) Lack of agreement, (b) correct result, (c) more words, (d) formed words.

goal, the three buttons in the bottom section of the display Fig. 7d (for the green member) appears to all of them, since the aim is the global object, and not the particular one.

5.2. Subjects and settings

Similarly to the evaluation of CL activities, the study for MCSCL activities took place simultaneously in the same elementary school, during the same period of time, with 48 students (25 girls and 23 boys) in the same age range. Children were distributed in coeducational groups; seven groups of three members (with 11 girls and 10 boys) for the language activity; and four groups of three members (6 girls and 6 boys), plus three groups of five members (8 girls and 7 boys) for the math activity. None of the students had previously worked on a CL activity or experienced with Handhelds devices.

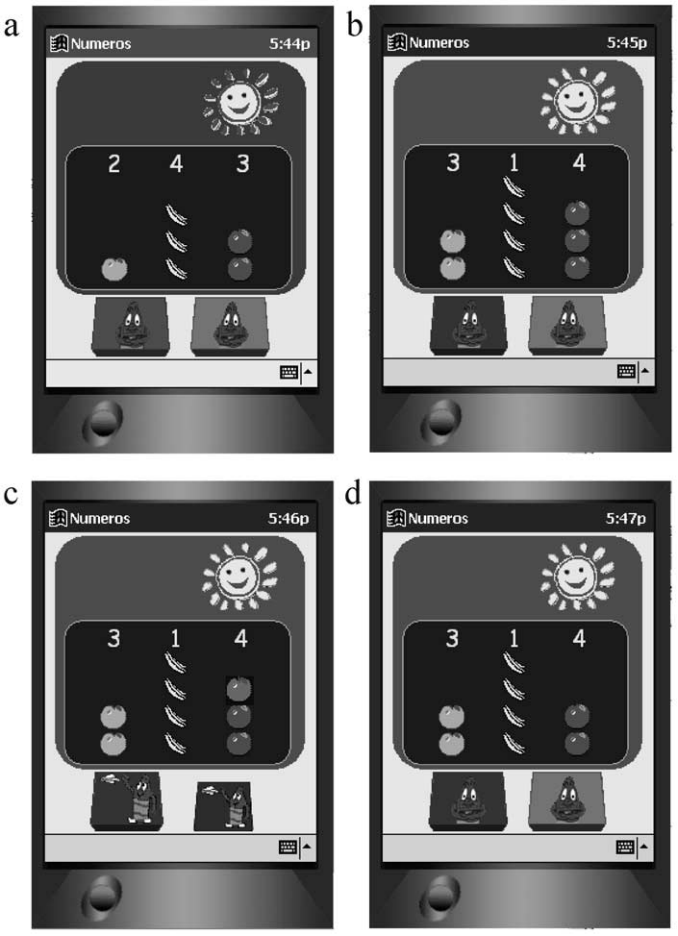

Fig. 6. Interface snapshots of the math activity.

5.3. Procedure

The main difference with the CL procedure was the possibility for the children to take a Handheld anywhere in the classroom, and that only the corresponding child could use her or his Handheld. All the children had the same role, individual activities, and a main objective as CL activities. Some instructions on handling the machines were given at the beginning of the experiment. The observations and interviews were targeted to analyze the children's behavior and the users' behavior towards other children and towards the machine.

5.4. Results

The evaluation applied to the MCSCL activities, showed that the weaknesses of coordination, communication, organization, negotiation, synchronicity, interactivity and mobility found in CL

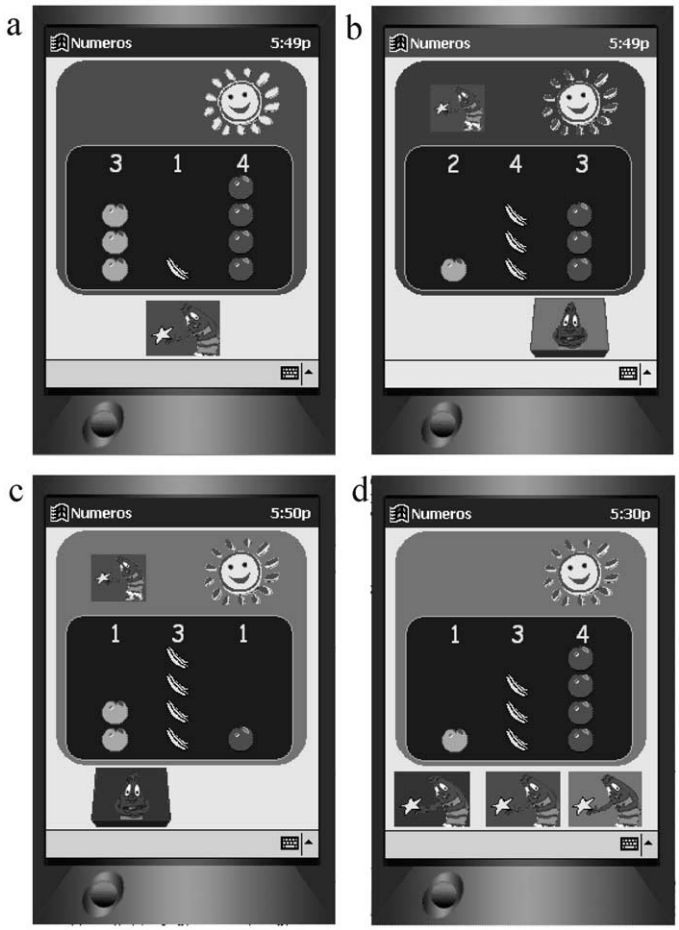

Fig. 7. (a) Red, (b) purple and (c) green, with partial objective achieved; (d) green, with global objective achieved.

activities without technology, were overcame with the help of the Handheld properties of portability and mobility, and also by the interface design of the MCSCL activities.

For the math MCSCL activity, the results on Table 3 show that there are no significant differences for three or five members of a group (using the *t*-Student test), in the media found in coordination and mobility, which exist in the equivalent CL activity (Table 1). This shows that the Handhelds are tools that facilitate coordination of a greater number of members transparently, apart from transparently supporting mobility to the members who need it.

The support given by the Handhelds does not imply that coordination, communication, negotiation and interactivity are granted (Johnson & Johnson, 1999), since the members of the group are who definitely carry it out. According to the proposal of Haythornwaite (1999), we provide with an environment that facilitates collaboration. The design of software interfaces of the MCSCSL activities (Stanton & Neale, 2002), together with the portability and mobility properties of the Handhelds, allow solving the weaknesses found as follows:

Coordination. For coordination among children, the Handheld's have been used as mediation elements to coordinate their activities to assure that all of the members participate. For example, in the language activity (Fig. 4), it forces each member to press the "cloud" or "pass" button only once (in the lower right part). This requires the participation of all the members within the group, where none of them should take control over the others, since everyone has their own Handheld. If a wrong word was formed, an error message is displayed (Fig. 9), which makes all the members return to a similar state from Fig. 4a.

In order to continue forming words, all children must agree by choosing all of them the "si" (yes) button (Fig. 4d). If a member does not agree, then the activity will show a message warning that all members must agree (Fig. 5a). This way, the necessity of coordination is achieved by the technology, forcing to fulfill the correct use of roles and rules, Fig. 8a.

For the math activity, Fig. 6 shows a scenario that regulates the interchange rules. This way, unwanted exchanges by a member are avoided, as illustrated by the previous example in Section 4. In case a member rejects the reception of a given object by another one, the interface of the member, who wanted to give her or his object, won't show her or him this option, because she or he will not have the possibility to choose the button with the color of the corresponding member.

Communication. The communication weaknesses between the members of the group, due to information management and personal affinity issues, when not backed by technology, are easily solved by MCSCL. In the language activity, the wireless network verifies the word correctness, showing the outcome simultaneously to all members of the group, and registering the words already formed (Fig. 5b and c). Regarding the math activity, the Handheld's interface (Fig. 6) shows the members all of the available objects, which facilitates decision of giving and receiving objects.

Organization. In both MCSCL activities social behavior is regulated by the Handheld's, Fig. 8b. In the language activity they all have to work together, while in the math activity, the initial configuration of the activity and the network defines who is going to interact. With the Handhelds, the problems of visual contact and body language (Curtis & Lawson, 1999), necessary in the establishment of communication, disappear. The three different channels of communication were used by children: verbal, physical (they interact with the Handhelds using

Table 3
Weaknesses results of Math and Language MCSCL activities with technological support. The media and deviation standard frequencies for each weakness are shown

Weakness	Frequencies			
	Math[a]		Language[b]	
	μ	σ	μ	σ
Coordination				
The members participate interactively, but there is lack of coordination: Decision of order and of who performs specific tasks and roles in the activity	0.29[c]	0.16[c]	0.23	0.12
	0.32[d]	0.19[d]		
Communication				
Difficulty for the members to establish communication links	0.17[c]	0.10[c]	0.19	0.17
	0.21[d]	0.12[d]		
Organization of material				
Demand of effort in material-organization for the activity	0.24[c]	0.17[c]	0.22	0.11
	0.26[d]	0.22[d]		
A member stops attending the material s/he is using, therefore loses visibility of the activity status	0.15[c]	0.12[c]	0.21	0.15
	0.18[d]	0.15[d]		
Negotiation				
There are agreement conflicts in the answer which are not solved as a group	0.18[c]	0.14[c]	0.26	0.24
	0.25[d]	0.21[d]		
Interactivity				
A member takes control of the activity for longer than required and excludes the rest	0.26[c]	0.31[c]	0.28	0.27
	0.29[d]	0.36[d]		
A member wants to do all the work and continuously seeks control take-over	0.63[c]	0.28[c]	0.99	0.84
	0.57[d]	0.32[d]		
A member does not participate in the activity by free will	0.75[c]	0.51[c]	0.83	0.45
	0.79[d]	0.65[d]		
Mobility				
Physical approach of a member is blocked by the material another member handles	0.15[c]	0.07[c]	0.13	0.08
	0.18[d]	0.11[d]		
It is difficult for the members to move toward their partners, with whom s/he wants to establish a closer physical contact, since her/his displace is blocked by another member	0.12[c]	0.09[c]	0.20	0.14
	0.15[d]	2.11[d]		

[a] Groups were composed of 27 six and seven-year-old children, four groups of three members (6 girls and 6 boys), plus three groups of five members (8 girls and 7 boys).

[b] Groups were composed of 21 six and seven-year-old children, seven groups of three members (11 girls and 10 boys).

[c] Results obtained from groups of three members.

[d] Results obtained from groups of five members.

their fingers) and graphic (the children show the information they have on their Handhelds to the other children. In both activities, to minimize the effort of properly *organizing* the members' work, the Handhelds always provide all the information they need, keeping visibility and availability, Figs. 4, 6, 8a. The information the, members need is provided by though the Handhelds, instead of making the members search for it in the Handhelds (Jipping et al., 2001). Furthermore, the Handhelds used in the MCSCL environment are a natural extension of the group members. The group members took ownership of the Handhelds, so the members were the centre of the activity.

Negotiation. In the MCSCL language activity, negotiation spaces are established (Fig. 4d and 5c). All members of the group have to agree to continue with the following stage. This is a great support for a CL application with children, since they have problems reaching an agreement and the consensus depends only on the member's mediation capacity. MCSCL offers each member a tool that assures her or his participation in taking group decisions, Fig. 8a.

In the math activity, a bi-personal procedure of agreement was implemented. Two members of the group should assent an exchange. The negotiation space (Fig. 6), guarantees that both members agree on the transaction. In a collaborative activity without technological support, the transaction is guaranteed by a rigid dependence to the roles and rules. These are frequently not obeyed by all the members, especially when children are present.

Interactivity. To assure interactivity between participants, in the language activity each member has an object that they require to construct the common aim, i.e., a syllable (Fig. 4a). This information must be shared with the other members to form the words, Fig. 8b. This forces members to interact with their partners, avoiding other members to take control. In the math activity (Fig. 6), the teacher determines the number of objects each of them initially has and to which they have to reach, which forces the interaction among specific members.

Fig. 8. Snapshots of children working with MCSCL activities: (a) children working with a language MCSCL activity, and (b) five children working in a math MCSCL activity.

Table 4
Means (μ) and standard deviation (σ) of the pretest and posttest results, for the math and language activities with (MCSCL) and without technological (CL) support

	CL Language activity		CL Math Activity	
	Pretest	Posttest	Pretest	Posttest
μ	2.672	3.179	3.523	3.951
σ	1.453	1.792	1.165	1.212
	MCSCL Language activity		MCSCL Math Activity	
	Pretest	Posttest	Pretest	Posttest
μ	2.506	4.473	3.342	4.633
σ	1.228	1.621	1.273	1.425

Fig. 9. Error warning, wrong word.

In both MCSCL activities, the members of the group can take the technology with them, which encourages face-to-face social interactions, Fig. 8a. The anytime-anywhere characteristic of Handhelds supports interactivity between members (Danesh et al., 2001; Inkpen, 1999; Soloway et al., 2001), when working on MCSCL activities.

Mobility. The mobile network facilitates face-to-face work and the capacity to freely move while the members take their records with them, which allowed the members to displace naturally, Fig. 8a. This favors the mobility of the members of the group while working with the group partners, in both MCSCL activities.

5.5. Math and language learning results

For all the members of each group depicted in Sections 3.3 and 5.2, individual written pre-tests and post-tests were applied on math and language abilities related to the objectives of CL activities with (MCSCL) and without technological support, in order to measure the learning results. The same pre-tests applied before the activities began, were used as post-tests at the end of both collaborative activities. The language activity test consisted of eight questions about construction of words based on syllables. The math activity test consisted of ten questions related to addition and subtraction operations. All test lasted only 30 min. The results obtained are shown in Table 4. Two analysis of covariance were run to evaluate the effect of the intervention on math and language abilities specifically related to each CL activity with and without technological support. In both cases, pre-test scores on the specific sample tested were introduced as covariant in order to control for initial levels of ability. We obtained a significant effect on post-test for math and language, controlling for pretest ability. The comparisons showed that in both cases there was a statistically significant difference with an alpha level of 0.05 between score means of the tests. Therefore students did improve their knowledge of math and language with the MCSCL activities.

6. Conclusions

The evaluation of two non-technological CL activities helped us to identify those weaknesses of the activity that could be improved with Handhelds support. An evaluation showed that the MCSCL activities overcome the weaknesses detected in CL activities. Only one usability problem, related to the technological characteristics of the Pocket PC, was detected. At the beginning of the activity, problems were observed (4 out of the 48 children) when pressing a button in the touch screen, because it got triggered when releasing the finger from the display, which is not a natural way to operate a button, and the children where expecting immediate feedback. The use of Handhelds was ubiquitous for all the children, and the voice synthesis in the platform supported the reinforcement of visual messages.

The use of wireless networks in CL activities opens a new world of possibilities, where the interface design is a central element. The MCSCL activities support transparently the collaborative work by strengthening the: (a) organization of the managed material; (b) social negotiation space of group members; (c) communication among the group members, through the wireless network that supports the social face-to-face network, Fig. 3; (d) coordination between the activity states; (e) possibility to mediate the interactivity; (f) encouraging of the members' mobility. The last two make a difference in how collaboration is supported between MCSCL and CSCL activities, due to the use of Handhelds that offer a manageable solution for the coordination, communication and interactivity, which is possible on PC's, plus the participants' mobility.

Also, MCSCL activities manage and encourage tasks that include: (a) organization of information, (b) enabling students to collaborate in groups, (c) monitoring real-time progress with respect to learning objectives and (d) controlling the interaction, negotiation, coordination and communication. Handheld computers are emerging as a flexible and portable solution that provides students with "at hand" support to engage in collaborative activities anytime, anywhere.

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