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A conceptual framework based on Activity Theory for mobile CSCL

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Abstract

There is a need for collaborative group activities that promote student social interaction in the classroom. Handheld computers interconnected by a wireless network allow people who work on a common task to interact face to face while maintaining the mediation afforded by a technology-based system. Wirelessly interconnected handhelds open up new opportunities for introducing collaboration and thereby changing classroom pedagogical practices. We present a conceptual framework and a method for the design of a mobile computer-supported collaborative learning system based on Activity Theory. An instance of the framework for teaching basic mathematics skills was evaluated with 24 6- and 7-year-old children in a month-long study. Positive effects were observed on student social interaction, motivation and learning.

Introduction

According to Johnson and Johnson (1999), classroom learning improves significantly when students participate socially, interacting in face-to-face collaborative learning (CL) activities with small groups of members. Furthermore, Staton, *et al* (2001) and Dillenbourg (1999) note that social interaction between peers is fundamental to achieving learning. These assertions are consistent with Vygotsky (1978), who establishes that knowledge is built within a community through the social interactions of its peers.

In a CL activity, three to five members taking part in a coordinated effort to learn a specific educative objective (Dillenbourg, 1999) are mutually engaged under a given set of rules and roles (Rogoff, 1994). According to Wood and O'Malley (1996), it is important to focus also on the social interaction effects of a collaborative activity, not just on the learning results of the participants. Group members in a CL experience are placed in a real social interaction context. This has been shown to produce a positive impact on learning, social behaviour and motivation (Ellis, Gibbs & Rein, 1991; Miller, 2002).

In general, to achieve learning in a CL environment the members must encourage each other to ask questions, explain and justify their opinions, articulate their reasoning, and elaborate and reflect upon their knowledge. According to Salomon and Globerson (1989), a successful CL environment can be achieved only when the groups are effective and functioning well. Adams and Hamm (1996) and Dillenbourg (1999) have established five factors that make for effective CL, which can be summarised as follows:

1. Individual responsibility. Each member is responsible for his or her own work, role and efforts to learn within the group (individual rules and roles).
2. Mutual support. In addition to being responsible for his or her own learning, each member is also responsible for helping to teach other members of the group through the frequent exercise of social skills during group interactions (group rules and roles).
3. Positive interdependence. The main aim of the activity is the group goal. Success is therefore only achieved once all team members have reached their individual goals.
4. Face-to-face social interaction. Decision making must involve discussion among the members of the group. Productivity is therefore affected by the group's ability efficiently to exchange opinions and make compromises to build a consensus answer.
5. Formation of small groups. Discussion, social interactions and consensus building can only be achieved in small groups of three to five members each (Adams & Hamm, 1996; Johnson & Johnson, 1999).

When computer technology is introduced to CL, thus giving rise to computer-supported collaborative learning (CSCL) (Silverman, 1995), the learning experience is extended to include communication and computing capabilities. CSCL activities most commonly incorporate personal computers (PCs), which support the learning environment and mediate the social interactions between the group members. However, PCs are not designed for a face-to-face conversational setting (Shen, Lesh, Moghaddam, Beardsley & Bardsley, 2001), because the requirement that users remain behind their screens hinders face-to-face activities. In addition, there is increasing evidence that many crucial aspects of a collaborative workplace occur when colleagues are not at their PCs (Belotti & Bly, 1996).

Face-to-face CSCL activities using handheld computers have been developed for both adults and children (Danesh, Inkpen, Lau, Shu & Booth, 2001; Druin, 1999; Inkpen, 1999). Handhelds supporting CL environments can be bidirectionally and wirelessly interconnected, allowing group members to collaborate both through face-to-face communication and through their handhelds. The anytime-anywhere connection provided by wirelessly interconnected handhelds creates an active, motivating and dynamic environment and allows for a better use of CSCL (Imielinsky & Badrinath, 1994; Jing, 1999). By adding mobility to CSCL, handhelds open up a new domain in CL, which we have called mobile CSCL (MCSCL) (Zurita, Nussbaum & Sharples 2003; Zurita and Nussbaum 2004a).

CL activities have shown themselves to be especially effective with children 5 to 7 years old in helping improve social skills that are still developing at those ages (Staton *et al*, 2001). Working in small collaborative groups has social and academic benefits for children (Dillenbourg, 1999; Johnson & Johnson, 1999; Wood & O'Malley, 1996). Also, there is experimental evidence that under certain conditions, CSCL activities produce a significant increase in children's learning when compared with individual training (Dillenbourg, 1999). Furthermore, it has been shown that wirelessly interconnected handhelds allow children to move freely and interact socially while working on a common task (Druin & Inkpen, 2001).

To identify common structures observed in learning activities, Santoro, Borges and dos Santos (2000) and Stahl (2002), among others, define a conceptual framework for CSCL activities. Price, Rogers, Stanton and Smith (2003) argue that such a conceptual framework has to satisfy three distinct requirements: (1) it should clearly define common concepts and terms, (2) it should be sufficiently well-structured to provide a foundation for the subsequent development of new and increasingly more refined concepts and (3) it should enable alternative designs of particular models and systems to be explicitly presented, compared and evaluated within the framework.

Gifford and Enyedy (1999) make use of Activity Theory (AT) to specify a framework of CSCL activities. According to them, a conceptual framework that incorporates models of knowledge building, perspectives and artefacts and is grounded in AT can guide the design of CSCL activities with appropriate, elaborated and unified conceptualisations to: (1) clarify the nature of the collaborative activities, (2) indicate how people can socially participate in them while interacting with the technology, (3) design tools to support them effectively in various contexts and (4) develop methods to put them into practice. Such a framework, which defines the abstract structure for supporting or enclosing a set of applications, offers three main advantages: (1) the application specifications are provided, (2) the design obtained is extendable and adaptable and (3) it can be used for analysing social and cultural practices to provide a language to describe what people do in context (Mwanza, 2001a).

We argue in this paper that AT provides a framework for analysing needs, tasks and outcomes for designing MCSCL activities, thanks to its usefulness in designing and analysing human–computer practices in context (Jonassen & Rohrer-Murphy, 1999). Furthermore, there is a growing interest in using the AT model to improve computer tool design (Mwanza, 2001a). Here, we will use the framework and its methodology to create an MCSCL mathematics activity, which we evaluated in a month-long pilot study, for 6- to 7-year-old children. The handhelds used in the study were Pocket-PCs (Compaq iPAQ™), with WiFi (IEEE 802.11b) communication.

AT-centred design

AT is a theoretical framework for analysing human practices as developmental processes with both individual and social levels interlinked at the same time (Kuutti, 1996). This framework uses 'activity' as the basic unit for studying human practices. AT has made significant contributions to the fields of CSCL (Bødker, 1997; Mwanza, 2001b; Nardi, 1996), human–computer interactions (Kuutti, 1996), and network communication and education (Engeström & Middleton, 1996), among others. AT is not a methodology (Jonassen & Rohrer-Murphy, 1999) but a theoretical framework for analysing human practices in a given context, ie, cannot be understood or analysed outside the context in which it occurs. Activity, or 'what people do', is reflected through people's actions as they interact with their environment, studying different forms of human praxis as developmental processes, both individual and social levels interlinked while at the same time providing an alternative way of viewing human thinking and activity. The AT framework uses activity as the basic unit for studying human practices and highlights the idea that the relationship between the subject and the object is not direct but rather mediated through the use of a tool. A tool can be something physical (eg, wirelessly interconnected handhelds) or intellectual (eg, rules and roles displayed on handhelds). Physical tools are used to handle or manipulate objects while intellectual tools can be used to influence behaviour in one way or another.

Vygotsky (1978) originally introduced the idea that human beings' interactions with their environment are not direct but instead are mediated through the use of tools and signs, which were developed further by Leont'ev (1981), who created a hierarchical model for analysing an activity. Inspired by this analysis, Engeström (1987) extended Vygotsky's original conceptualisation for the mediated relationship between the subject and the object by introducing an expanded version of the activity triangle model that also incorporates Leont'ev's concepts. Thus, Engeström offers a general model of human activity that reflects its collaborative nature. The model's components, shown in Figure 1, are: (1) object of the activity (or objective, ie, the goals and intentions), (2) subjects in the activity (ie, the people engaged in it), (3) tools mediating the activity (anything physical, eg, computers; or mental, eg, models or heuristics used in the transformation process), (4) rules and regulations (norms that circumscribe the activity), (5) division of labour (eg, actions undertaken by individuals within the group versus tasks that are a group responsibility, (6) community (individuals directly or indirectly involve in the tasks) and (7) outcome (ie, the results and final products of the defined objectives).

Given that it is primarily a descriptive tool, AT is geared towards practice. It embodies a qualitative approach that offers a different lens for analysing a learning process and its outcome, focusing on the activities people are engaged in.

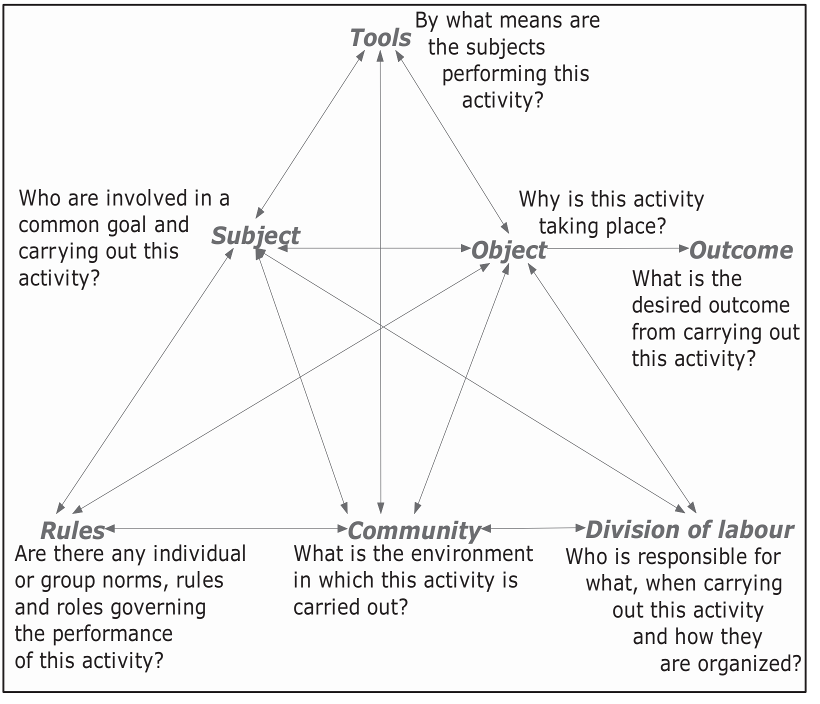

Figure 1: Engestrom's expanded Activity Theory model

To study learning situations using the AT-based analysis (as applied in the section 'Evaluation of the Math-MCSCL Activity'), the following conditions must be fulfilled (Jonassen & Rohrer-Murphy, 1999): (1) the analysis must be applied over a sufficient period of time so that human practice activities can be properly examined, (2) analysts should first seek out broad patterns and then look for narrow episodic fragments and (3) a diverse set of data collection methods (interviews, observations and video records) and points of view (subject, community and tools) should be included.

A conceptual framework for MCSCL activities based on AT

Jonassen and Rohrer-Murphy (1999) and Gifford and Enyedy (1999) have proposed AT-based frameworks for the design of CL activities, as have Collis and Margaryan (2004) for the design of courses, and Mwanza (2001a) for the design of computing systems. Profiting from the experience of Jonassen and Rohrer-Murphy (1999), we define a conceptual framework for mobile CL applications, using as basis the theoretical-descriptive AT model in order to specify the framework's components and their relationships. According to Jonassen and Rohrer-Murphy (1999), six steps are necessary to describe how AT may be used as a framework for determining the components of the activity system for designing learning activities (Figure 2): (I) clarify the purpose of the activity system, and understand the subject and the relevant context in which the activities occur, (II) analyse the activity system, defining in depth the components,

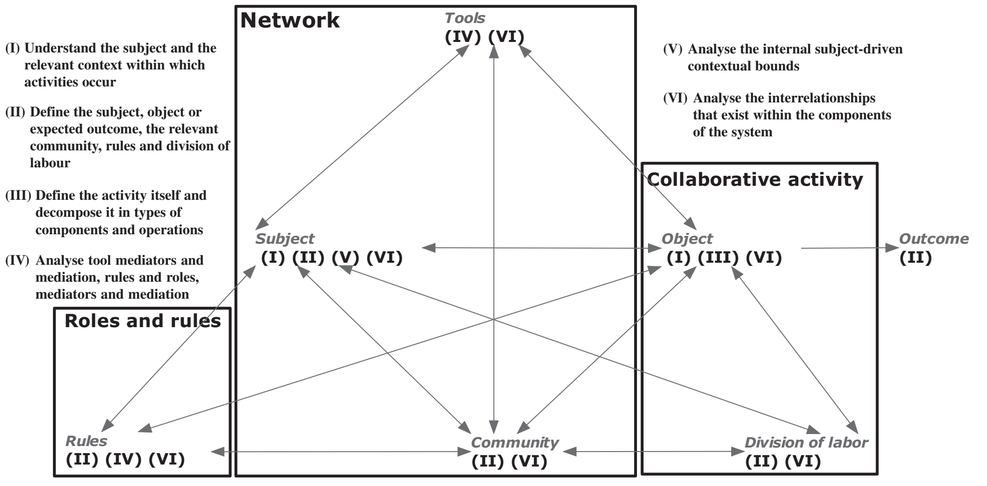

Figure 2: CSCL framework components and Engestrom's expanded Activity Theory model. CSCL, computer-supported collaborative learning

eg, subjects, objects, community, rules and division of labour, (III) analyse the activity structure, defining the activity by decomposing it into types of components and operations, (IV) analyse the tools, focusing on those that provide direct and indirect communication among subject, community and object, (V) analyse the internal subject-driven context bounds that are essential to the dynamics that exist among the components of the AT framework and (VI) analyse the AT dynamics, which requires stepping back from the system described and assessing how components affect each other, eg, analysing the interrelationships that exist within the components of the system.

The aforementioned six steps are related and applied to the basic components of the framework that defines CL activities (Dillenbourg, 1999; Johnson and Johnson, 1999). These include the network components formed by the members of the group, the roles and rules components the group members must follow, and the collaborative activity component that defines the group objective. Figure 2 shows the relationship between the framework components and the six steps of the Jonassen and Rohrer-Murphy (1999) methodology. Note that Step VI is applied to all components given that the interrelationships among the system components must be analysed. Figure 3 shows the proposed MCSCL activity framework as incorporated into the expanded AT model. The following three sections describe how this framework is obtained, making use of the five factors that make for an effective CL environment, as indicated in the Introduction.

Network component

We distinguish between the *social* and the *technological* components of the network. The former is made up of face-to-face communication between the members, while the latter

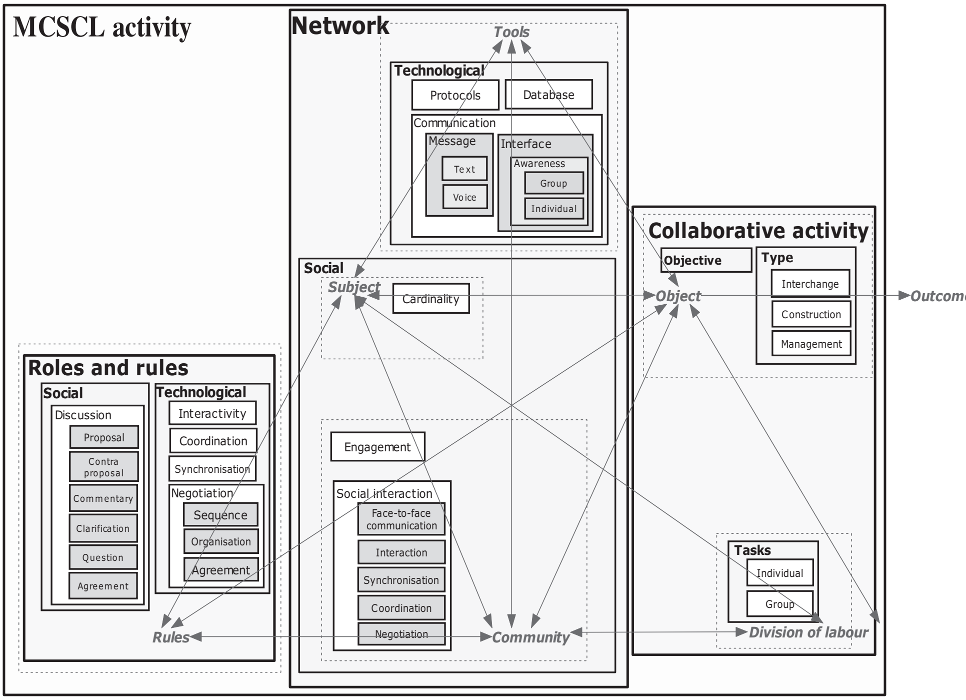

Figure 3: The MCSCL framework based on Engestrom's expanded Activity Theory model. MCSCL, mobile computer-supported collaborative learning

consists of communication between the members and the handhelds and/or between the handhelds themselves. The mobility afforded by the handhelds and the use of wireless communication increases social interaction of the face-to-face type.

Social network component

The social network component includes primarily the social interactions within the community (considering the AT model and Step II of the Jonassen and Rohrer-Murphy [1999] methodology) and defines the social environment in which the activity takes place, ie, the internal subject-driven contextual bounds (Step V). The social interactions are established by the ways in which interaction, synchronisation, coordination and negotiation (Johnson & Johnson, 1999) among the group members, working on face-to-face CL activities, are carried out. The social interactions of the CL activity must create the necessary member engagement, as conceptualised in the engagement component. The number of members (subjects in the AT model) who carry out the activity with a common goal is defined in the cardinality component. The social network component fulfils the face-to-face social interaction factor requirement, one of the five factors for effective CL.

Technological network component

The technological network component specifies the necessary interconnection protocols and models the communication elements that exist both between the members and the handhelds and between the handhelds themselves. The subjects use the handhelds as tools to perform the activity (Step IV). The data structures (stored in the handhelds) that allow information management are specified in the database component. The technological communication component establishes the ways in which group members (through their handhelds) are informed of the status of the activity. The technological communication is accomplished by the interface and message components. The messages can be multimodal, depending on the hardware characteristics, and may be voice, animation and/or text. The awareness component defines the design of the interface component (Ellis *et al,* 1991) so that the members, either as individuals or as a group, know what each member is doing and what each member should do. The awareness component influences the community members' behaviour and allows for the proper support of their social interactions, synchronisation, coordination, communication, interactivity, negotiation and discussion. The technological network component satisfies the individual responsibility and mutual support factors required for an effective CL. The mobility, as well as support for face-to-face interactions as provided by the technological network, is the distinguishing factor between MCSCL and CSCL activities.

Roles and rules component

The roles and rules component of a CSCL activity would be classified by the AT model as any individual or group norms that govern the activity (Step II for defining rules, and Step IV for analysing rules and roles, mediators and mediation). The CSCL roles and rules are divided into social and technological components. The social roles and rules component defines the collaborative relations between members, while the technological roles and rules component determines the wireless handheld network that establishes those collaborative relations between members. The roles and rules component provides the individual responsibility and mutual support factors needed for an effective CL.

Social roles and rules component

The social roles and rules component regulates the discussion between members in their collaborative relations. The effectiveness of the debate depends upon the members' conversational and social skills, which we segment into five distinct units: (1) Proposal, to start an activity, (2) Contra proposal, to put forward an alternative proposal to the previous one, either an entirely new proposal or a modification of the prior one, (3) Commentary, to make an observation on another conversational unit, (4) Clarification, to respond to a question, to give an explanation, or to ask for more information from a particular member in the conversation and (5) Agreement, a final conversational unit for establishing the agreement of the entire group.

Technological roles and rules component

The technological roles and rules component establishes the key functions that the handheld network will play. When the activity members cannot achieve the necessary interaction, synchronisation or coordination to carry out the activity, the handheld network helps them to do so. Furthermore, the handheld network provides a negotiation space to resolve member disagreements. The negotiation space can help the members build a consensus in one of the following ways: (1) sequence, by choosing a progression of events, (2) organisation, by initially answering a set of questions or ordering a set of objects individually, and then coming to a consensus as a group or (3) agreement, by coming to a consensus before answering each question as a group.

Collaborative activity
The collaborative activity component defines the particular educative CL activity to be engaged in (Step III), and is specified by the objective (Step I) and the outcome (Step II), the tasks and the type of activity. The objective is the reason for the activity and is the equivalent of the object in the AT model. The tasks define the individual and group division of labor (Step II), assigning responsibility for activity tasks and outlining how the group will be organised. Finally, the type of activity (Step III) conceptualises three kinds of face-to-face CL activities that encourage social interaction: management, construction and interchange (to be detailed in Step 4 of the method described in the next section). The collaborative activity component fulfils the individual responsibility, mutual support and positive interdependence factors for effective CL.

The distinguishing element of the framework in Figure 3 is that it incorporates human practices and how they interact with technological artefacts from the AT point of view. It also specifies structure components.

The two main features of this framework are: (1) it enables the analysis of human practices using these artifacts (ie, software design and the characteristics of handhelds from the AT point of view) and (2) it specifies the structure, components and interrelationships of collaborative activities based on wirelessly interconnected handhelds, with the aim of supporting face-to-face relationships of group members.

Methodology of design and construction of MCSCL activities

To design and implement MCSCL activities, we propose a methodology to obtain an instance of the framework (Figure 4). This methodology has been adapted and extended from the CL activity structure flow-chart described in Johnson and Johnson (1999), refining it on two particular points. The first refinement allows us to make certain that the selected collaborative activity satisfies the established social and educational objectives, while the second ensures the appropriateness of the social and technological rules and roles for the activity tasks. The refined methodology stipulates the order in which each component of the proposed framework must be incorporated. In what follows, we explain each of the methodology's six steps:

1. Characterise collaborators. The subjects that carry out the activity must be characterised and contextualised by age, gender, educational level, cardinality and the criteria for selecting members. The characteristics of the social network members must be identified to make sure they have the required cognitive and social abilities.

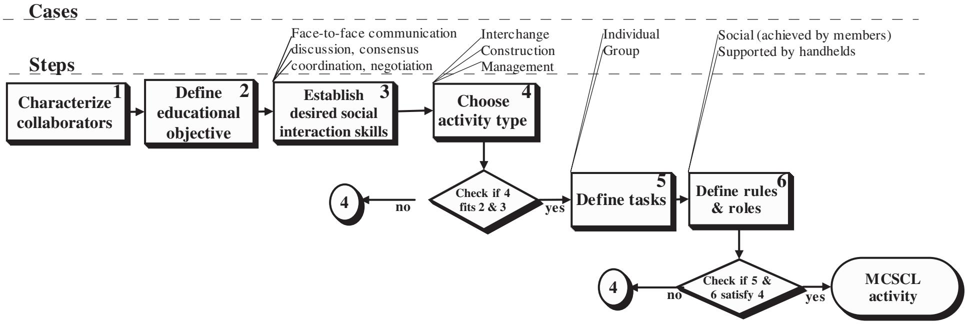

Figure 4: The six steps for designing an MCSCL activity based on the MCSCL framework. Refinement is optional Some cases are shown above the steps. MCSCL, mobile computer-supported collaborative learning

2. Define the group's educational objective. The objective of the learning activity must be appropriate to the social and cognitive characteristics of the group members.
3. Establish the desired social interaction skills. One of the goals of CL is to stimulate social interaction between members. This can be achieved through activities that require social skills (Dillenbourg, 1999) such as face-to-face communication, discussion, consensus, coordination and negotiation building. The social interaction and engagement components shown in Figure 3 conceptualise these skills.
4. Choose the type of CL activity. Social interaction is promoted by interchange, construction and management activities. The type component under the collaborative activity component in Figure 3 specifies the activities from which one is to be chosen.
   Interchange. The members must exchange objects under a given a set of rules to achieve their goals. Each member of the group of children starts with a set of objects and a specification defining the final set of objects to be obtained. The members establish face-to-face contact to discover who in the group they can exchange objects with. To successfully complete the activity, a child must not only achieve his or her own goal, but must also ensure that all the other children in the group reach theirs. (See the next section, 'Designing an instance of the framework: MCSCL interchange activity').
   Construction. The members construct the common goal from the pieces each one receives, following defined construction rules. These rules allow the child to *combine* pieces to form an object, *compose* a new object from given objects, *reconstruct* an object from predefined pieces and *order* objects following some logical criterion. The exercise creates social interaction, as each group member must find out what objects every other member has in order to perform his or her task. Only when all the members agree on the final outcome is their task considered complete (examples are described in Zurita & Nussbaum, 2004a, 2004b).
   Management. All members receive the same set of objects. The activity requires that each of the members choose the same subset of these objects. A negotiation space for building agreement must be constructed between the members to enable them to arrive at the same subset. An example activity would be one in which all group

members answer a series of questions and are required to arrive at an agreement before advancing to the next question (such an example may be found in Cortez *et al*, 2004).

5. Define activity tasks. Collaborative groups involve shared responsibilities. This means that the group members must perform a variety of tasks (assignments), either individually or together (Tasks component of Figure 3).
   Individual tasks. Each member must achieve an individual objective in conjunction with the group objective, according to the success factors of the collaborative activity and in agreement with the rest of the group members. The tasks may be either the same or different for each of the members. If the tasks are different, they must have an equivalent complexity and importance. Each member must be aware of his or her individual task before they begin the collaborative activity.
   Group tasks. The group tasks in the collaborative activity are those duties that must be performed in a synchronised and coordinated way by the group members, and include Interchange, Construction and Management tasks. These tasks encourage discussion among members and create spaces for communication and negotiation. They are highly dependent on the type of CL activity chosen.
6. Define the roles and rules. Roles and rules specify conventions and regulations that help create productive social interactions (see Figure 3).
   Social roles and rules. There are three types of relations that may arise between members when interacting socially: instructional tutoring of one member by another (which we will call R1), cognitive conflict because of diverging views between two members (R2) and social interdependency, in which the members share the group goal and each individual contribution affects the actions of the other members (R3). The roles and rules should move the members from an R1 relation to an R2 or R3 relation, and in the case of an R2 the relation must converge to an R3. The members' roles and rules allow the establishment of conversational units as outlined in the framework of Figure 3 (proposal, contra proposal, commentary, clarification and agreement). These conversational units allow the mapping of the relations R1 or R2 to the relation R3.
   Roles and rules supported by the technology. R1 and R2 relations can be identified and transformed into an R3 relation through technology. Technology provides a space to mediate potential conflicts and is especially useful when members have strong opinions. It should promote the following collaborative elements: (1) Interactivity—members' interaction in the collaborative activity, as measured by the interaction's influence on their cognitive process rather than by its frequency, (2) Synchronisation and coordination—technology helps to synchronise the face-to-face communication between the members and facilitates coordination within the group, (3) Negotiation—decision making is part of any process. The technology provides a negotiation space to support the collaborative work.

The following activity roles are supported by the technology: (1) working in a group structure to maximise positive interdependence and to organise and assign tasks within the group, (2) mediation of the group work through the formulation of questions and management of multiple activities, (3) initiation and redirection of the collaborative efforts in accordance with the different states of the activity and, finally, (4) monitoring of the members' performance through the technological network (so that they can be informed of both their own progress and that of other group members).

Each time one creates an instance of the framework, ie, an MCSCL activity, one must make a full and detailed description of the collaborative activity, including a specification of the rules and roles supported by the technology (the technological component in Figure 3).

Designing an instance of the framework: MCSCL interchange activity

We now demonstrate the methodology presented in the previous section, using a math-based MCSCL activity called Math-MCSCL. The six steps of the methodology are applied as follows:

1. Characterise collaborators. The members taking part in the Math-MCSCL activity are second-grade students of both genders, all aged 6 or 7 years old. Educators and psychologists maintain that by the age of 5, children are sufficiently capable to both interact socially and use computational technology (Staats, 1971). The children are split into groups of either three or five students (as suggested by Dillenbourg, 1999).
2. Define the global educational objective. The global aim is to practice addition, subtraction and multiplication in a group, using numbers from 1 to 99.
3. Establish the desired social interaction skills. The social aim is to practice face-to-face communication, interaction, coordination and negotiation among the group members, especially between those in pairs.
4. Define the type of CL activity. From the framework we select an interchange CL activity. Each member starts with a certain quantity of three different objects and a different target quantity for each object. For each object, a member can have from 1 to 10 units. At the start of the activity, the system distributes the objects among the children in such a way that each child must interact with the other children. The activity's common goal is achieved when all of the children reach their target number of objects. When a child has too many of a specific object, that child must find another group member who has too few of that object and wants to receive one. Conversely, when a child has too few of a particular object, that child has to search for another group member with a surplus of that same object who wants to dispose of one. Only one object (or set of objects) may be disposed of at a time so the children can easily keep track of their status in the activity. For example, in Figure 5 each object represents 8 units so that when Miguel sends the banana object to Gustavo he is actually sending eight bananas, reducing the quantity of his own bananas by eight (Figure 6a) while increasing Gustavo's by the same number (Figure 6b).
5. Define activity tasks.
   Individual tasks. Once a child has performed the arithmetic operation to determine his or her surplus or deficit in each object type, the child must then search for another group member who can give or take the number(s) of objects so determined.
   Group tasks. Group members must be able to talk to one another to find out what each other's needs are, then negotiate an object exchange and carry it out. All group members must collaborate to reach the goal.

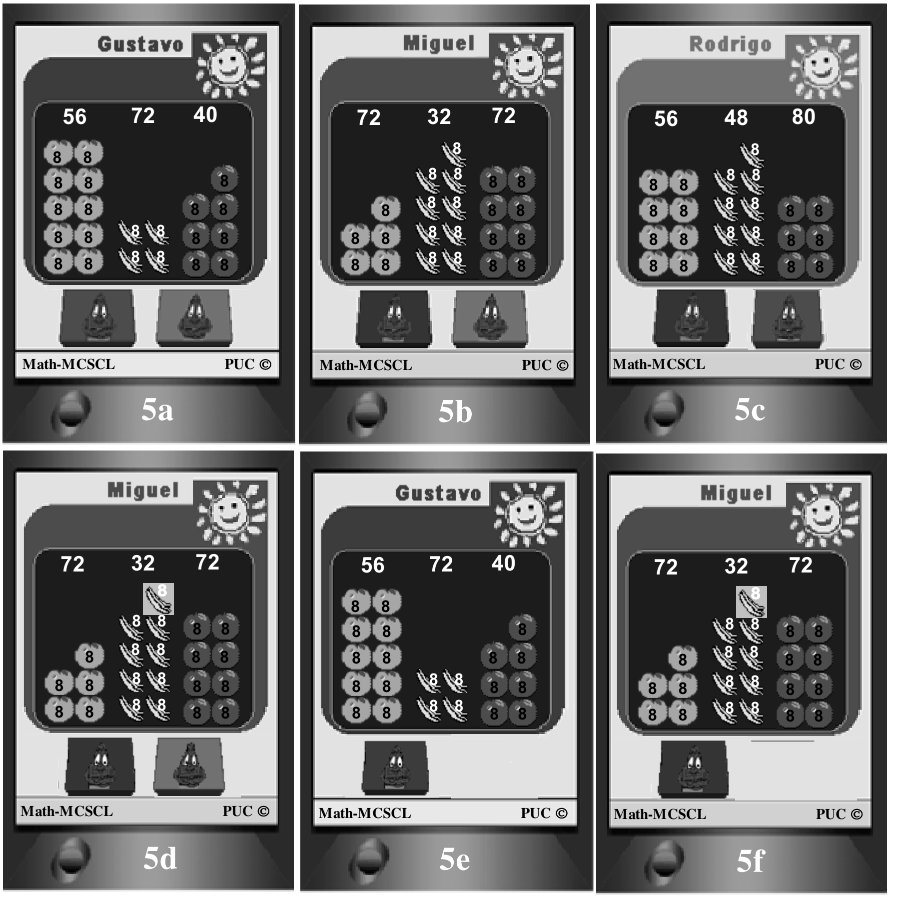

Figure 5: Screen shots of the Math-MCSCL activity implemented on handhelds for a three-member group. MCSCL, mobile computer-supported collaborative learning

6. Define roles and rules.
   Social role. The social role, which is the same for all members of a group, requires that they act as facilitators for other team members who require a given object. The social rules are also the same for all members. They define how to: (1) reach a target number of objects, (2) search for the team members who have the desired objects, (3) negotiate the object exchange and (4) carry out the exchange.
   Definition of the roles and rules supported by the technology. The handhelds support the activity by: (1) enforcing interactivity by initially distributing objects in such a way that each member of the group is required to interact with the other members, (2) coordinating the entire group through the wireless network that interconnects them, (3) synchronising the members' handhelds to exchange an object,(4) regulating the sending and receiving of objects through interconnection protocols and

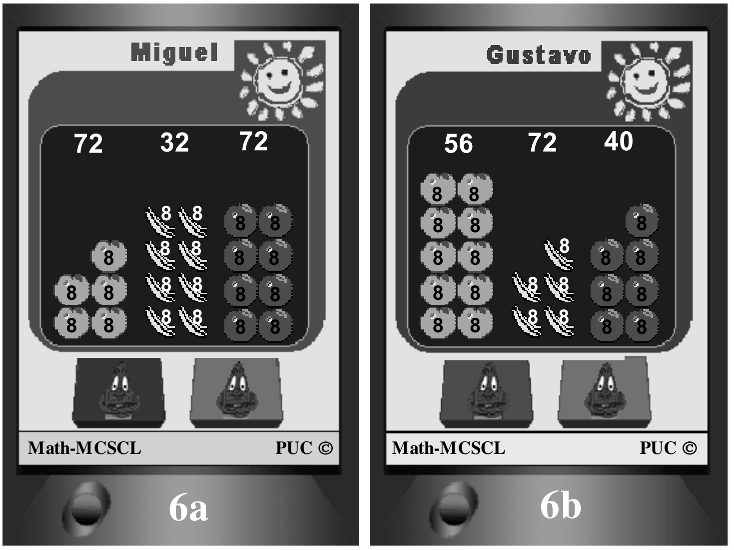

Figure 6: Screen shots of the Math-MCSCL activity after an exchange between Gustavo and Miguel. MCSCL, mobile computer-supported collaborative learning

(5) opening a negotiation space when the activity requires that members must agree to exchange an object.

Detailed description of the collaborative activity

We will now walk through an example of the activity just described to illustrate the roles and rules supported by the technology. Three children are involved in the example, each with a handheld that displays a different coloured background: purple for Gustavo, red for Miguel and green for Rodrigo (see Figures 5a, 5b and 5c, respectively). The various steps in the activity are illustrated by a series of screenshots from the handhelds shown in Figures 5 through 8.

Gustavo begins with 10 oranges, 4 bananas and 7 apples. In this example, each object represents 8 units, as indicated by the label on each fruit. Therefore, Gustavo, initially has 80 units of oranges, 32 units of bananas and 56 units of apples. As shown on his screen, he must eventually attain 56 orange units, 72 banana units and 40 apple units. The three children belong to the sun group (as shown on the upper right corner of the screen). Each child has two buttons on the lower part of his screen that identify the other two group members. Gustavo has a red button and a green button that allow him to select the other two members (red represents Miguel and green Rodrigo). Similarly, Miguel has a purple and a green button, and Rodrigo has a purple and a red button.

To exchange a given fruit object, the member who wants to send it first selects it, at which point it will be highlighted on his screen. Then, the member who wants to receive the object selects the button corresponding to the colour of the member who wants to send it. Finally, the sender selects the button representing the member to whom he wants to send the fruit. When the fruit is received, it appears on the screen of the receiver and simultaneously disappears from the screen of the sender.

If, for example, Miguel wants to send eight bananas (given that he has an excess of 40), he first selects one of the banana objects (corresponding to 8 units) as shown in Figure 5d. Then Gustavo, who wants to receive the bananas (given that he needs 40 of them), selects the red button corresponding to Miguel, changing his interface from Figure 5a to Figure 5e. In Figure 5e, the red button is darkened to indicate that Gustavo wants to send something to Miguel, and the green button that identified Rodrigo disappears from Gustavo's screen. After Gustavo's selection, Miguel's interface shows that Gustavo is the only one who wants to receive bananas because the green button corresponding to Rodrigo has disappeared (Figure 5f). Finally, Miguel sends the bananas to Gustavo by selecting the purple button that identifies Gustavo (Figure 5f). After the transfer, the quantity of Miguel's bananas has decreased (Figure 6a) while the quantity of Gustavo's bananas has increased (Figure 6b).

Because the object exchange is performed in a pair-wise fashion, some members may reach their individual goal before others. In Figure 7a Miguel has reached his goal, as indicated by a red label containing a drawing of a pen with a star on the lower part of his screen. In Figure 7b, Rodrigo's screen displays the same drawing of a pen with a star in red to the left of the sun, which means that Miguel has already reached his goal. Miguel must now wait for the other members to reach their own individual goals before he can do anything else on his machine.

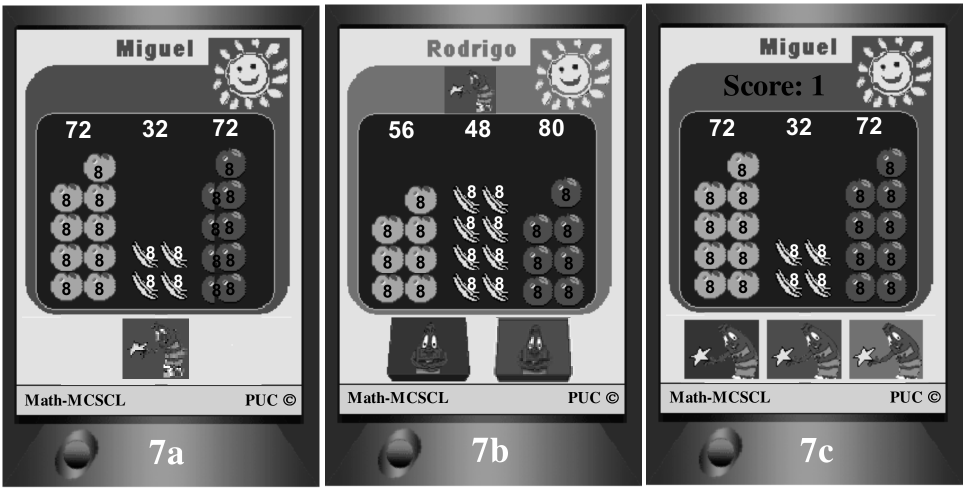

Figure 7: Screen shots of the Math-MCSCL activity showing individual and group achievement. MCSCL, mobile computer-supported collaborative learning

Figure 8: Screen shots of the Math-MCSCL activity, asking if the students wish to keep playing. MCSCL, mobile computer-supported collaborative learning

Once all members have reached their goals and each of them has a star at the bottom of his screen, as shown for Miguel in Figure 7c, an applause sound is activated and the score is shown, indicating that the activity is completed. Then each of the handhelds asks each member if he would like a new object configuration (reinforced by a voice message that asks: 'Keep playing?'), as shown in Figure 8a. If all agree to continue by pressing the 'YES' button, the activity continues. If all agree to finish by pressing the 'NO' button, the activity concludes. If no consensus is reached, the handhelds instruct the children to come to an agreement (backed up by the voice message: 'Reach an agreement!'), as shown in Figure 8b.

Evaluation of the Math-MCSCL activity

A pilot study was conducted to evaluate the improvement in learning and social skills brought about by the Math-MCSCL activity. The study sample was composed of 24 6- and 7-year-old children (13 girls and 11 boys) who were students at the end of their second year at a low-income public primary school in Santiago de Chile. All children had prior knowledge of basic math skills, including adding, subtracting and multiplying.

A pretest was performed at the beginning of the pilot study, consisting of a 35-minute individual assessment of each child's previous knowledge of addition, subtraction and multiplication. The pretest contained 10 math problems designed to evaluate skills that the students would be required to use in Math-MCSCL. Two types of questions were designed:

1. Five questions of the type: 'I have *a* boxes with *b* apples in each one. I need to have *c* apples. How many more apples must I get?' In this case the value of *c* was greater

than $a \times b$ plus a multiple of b, so the student has to multiply $a \times b$ (or add a to itself b times) and then subtract it from c: Thus, $c - (a \times b)$.

2. Five questions of the type: 'I have a boxes with b apples in each one. I need to have only c apples. How many apples must I get rid of?' In this case the value of c was less than $a \times b$ plus a multiple of b, so the student had to subtract c from the product of a and b. Thus, $(a \times b) - c$.

The values of a, b and c were between 1 and 99. To grade the results, the standard Chilean grading scale was used in which a score of 1 indicates that no answers are correct while a score of 7 indicates that all the answers are correct. For example, if a student correctly responded to 2 of the 10 questions, the score would be $[(2 / 10) \times 6] + 1 = 2.2$.

The pilot study was divided into 20 daily sessions held over a period of 4 weeks. Each session was 25 minutes long and had a set of given activities as the daily goal. The first two sessions were slightly longer than normal (30 minutes) to allow the children to get used to the technology. On the first day the aim of the activity and the rules and roles were explained. By the 12th session, some groups were finishing their daily activity in as little as 20 minutes. On a few occasions, the children required assistance from the teacher, mostly for arithmetic problems. To create the groups on the first day, the children's handhelds showed them the names of the other members of their group. Because of the machines' portability and the wireless network, they were able to move freely throughout the classroom to form their groups. The groups were maintained throughout the experiment: three groups of three members each (Figure 9) and three groups of five members each (Figure 10a). During the pilot study, the students received no other form of mathematical instruction.

Figure 9: Group of three students working with the Math-MCSCL. MCSCL, mobile computer-supported collaborative learning

Figure 10: (a) a group of five students working with Math-MCSCL and (b) mobility allowed by the interactions supported by the handheld. MCSCL, mobile computer-supported collaborative learning

Each day, the students had to solve seven sets of Math-MCSCL interchange problems. The problems increased in complexity throughout the activity. Initially, each fruit object was worth 1 unit, but its value subsequently increased up to a maximum of 10 units. During the initial sessions, when the problems were easier to solve, the children invested more time in learning how to adequately use the technology. Later, when they had to solve more complicated problems with higher values assigned to each fruit object, the children invested more time on directly solving the problems. However, the children were by then already familiar with the technology and therefore did not require additional time to learn it.

At the end of the 20-day pilot study, a posttest assessment was performed using the same pretest that had been administered at the beginning of the study. As before, the

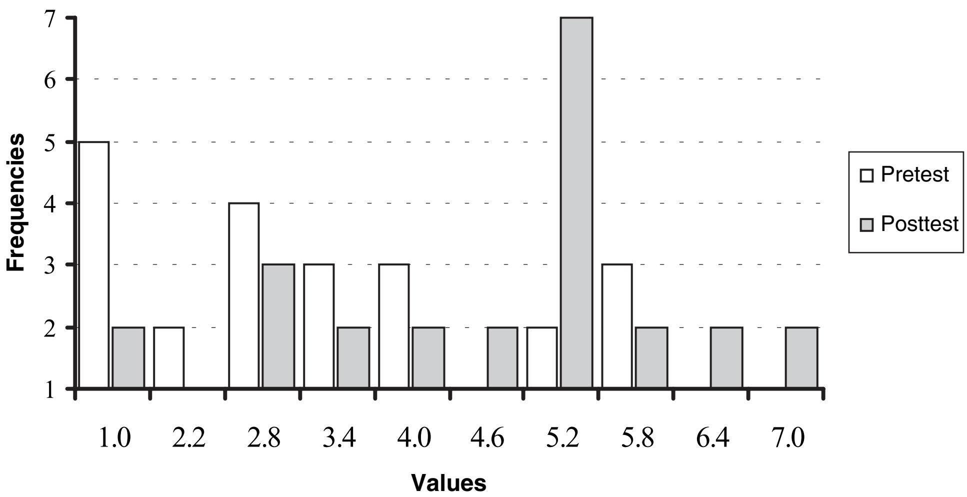

Figure 11: Frequency distribution of the pretest and posttest results. Minimum score = 1, maximum score = 7. If a student correctly responded to 2 of the 10 questions, the score would be 2.2, ie, [(2/10) × 6) + 1]

children were given 35 minutes to complete the test. Figure 11 shows a frequency distribution of the pretest and posttest data. The results of a statistical analysis using a paired-samples *t*-test to compare means are shown in Table 1. With an alpha level of 0.01, the learning effect was statistically significant, showing that students did improve their knowledge of basic mathematics during the pilot study. Interestingly, no significant difference was found between the groups of three students and the groups of five students.

To measure social interactions, four CL experts used observation guidelines that were applied during the first and last sessions. Furthermore, the entire activity was recorded on video, allowing the experts to better analyse the children's behaviour. The observation guidelines included the following qualitative aspects: (1) Communication—verbal information interchanges made with an appropriate tone of voice and volume while maintaining eye contact, (2) Interaction—the quantity of social interactions with other children that were directly related to the activity, (3) Coordination—the individual effort applied to achieving the team's goal, (4) Discussion—the ability to debate and defend one's viewpoint; (5) Negotiation—the ability to build an agreement and (6) Technology appropriation—the speed at which the child becomes accustomed to the technology.

Observations were taken to measure the presence and intensity of the six qualitative aspects listed above. To internally validate the data gathered, the same experts were used for both the pretest and posttest observations, and the experts had to agree unanimously on the results assigned. A Likert scale of 7 categories was used for measuring

Table 1: Mean comparison between pretest and posttest results using paired-samples t-*test*

	Paired-samples statistics		*Paired-samples correlations*	*Paired-samples test*
	Pretest[a]	*Posttest*[a]	*Pretest & posttest*	*Pretest & posttest*
Mean	3.40000	4.55000		1.15000[b]
Std. deviation	1.72245	1.64951		0.74891[b]
Std. error of the mean	0.35201	0.22670	0.00000	0.15287[b]
Correlation			0.90200	
Difference				
Lower				−1.57920*
Upper				−0.72080*
T				−7.52300
df				22
Sig. (2-tailed)				0.00010

Note. Results were obtained using SPSS
*$p < 0.01$
[a]$n = 24$
[b]Paired difference

the answers (1 implied total absence of the qualitative aspect and 7 implied total presence, with 2–6 as intermediate grades). Table 2 shows the pretest and posttest data assigned by the experts' observations on the six above-defined qualitative aspects recorded for the six collaborative groups.

The results demonstrate that at the beginning there were minor technological appropriation problems, but that by the end of the pilot study all of the children had become expert users in the activity. All groups improved their performance once they were accustomed to the technology, especially in the interactivity and negotiation aspects. In the early stages of the study interactivity improved daily, as the children found it immensely satisfying to reach the global goal. They quickly realised that in order to reach that goal they had to work together and that mutual support was fundamental. The portability of the handhelds allowed them to move freely, thus facilitating communication. Interactivity and coordination were eased by the task rules, because only one object could be exchanged at a time and only when both members agreed. This also favoured the discussion and negotiation aspects of the activity. The children frequently asked their group members for support. This support was sometimes reluctantly given, as it was observed that some group members came to rely on it.

The students proved to be highly motivated. Their teacher reported that they showed much more interest in the collaborative activities than they did in regular class activities. All of the children expressed a desire to participate in the collaborative activities. Absentees during the 4 weeks of the pilot study were almost zero. In an open questionnaire given to the students, 21 of the 24 participants indicated that they enjoyed work-

Table 2: Qualitative results of social interaction observations of the Math-MCSCL activity

	Groups[a]					
Session	*1*[b]	*2*[b]	*3*[b]	*4*[c]	*5*[c]	*6*[c]
Face-to-face communication						
First	3	4	4	3	4	4
Last	4	5	5	5	4	5
Interaction						
First	2	3	2	2	2	3
Last	4	5	4	4	5	4
Coordination						
First	3	3	3	4	3	4
Last	4	5	5	5	4	5
Discussion						
First	3	4	3	3	3	4
Last	3	3	4	4	4	4
Negotiation						
First	2	3	2	1	2	3
Last	4	5	4	4	4	5
Technology appropriation						
First	4	3	4	4	4	4
Last	5	5	5	5	5	5

Note. Score ratings ranged from 1 (minimum) to 7 (maximum)
[a]Groups were composed of 24 6- and 7-year-old children (13 girls and 11 boys)
[b]Three-member group
[c]Five-member group
MCSCL, mobile computer-supported collaborative learning

ing in groups, while the remaining three complained about the time they spent waiting for the other members to complete their job or to understand the task rules. On certain occasions the children asked the teachers for support, especially when the value of the fruit objects was higher (6, 7, 8, 9 or 10).

There were no substantial differences in the qualitative aspects measured for groups of different sizes. However, a few small differences were observed. On average, the bigger groups (five members) took over 10% more time to complete the activity than the smaller ones (three members). However, the bigger groups appeared to be more motivated and enjoy themselves more.

Handheld mobility facilitates communication and social interaction between group members. This was particularly noticeable in those groups of five members each, because to establish face-to-face conversations they had to approach each other. When an activity is conducted using PCs, with the students topologically distributed in a ring formation, the monitors obstruct their face-to-face view, and when they are arranged topologically in a line, those at the extremes can barely communicate.

Discussion

Handhelds can be considered as AT tools that support MCSCL activities by performing the following functions:

1. Scaffolding the coordination between CL activity members (effective-CL factor: mutual support), thanks to the mobility and portability of the technological network.
2. Supporting both the social network of the members (the core of the CL activity) and the activity tasks through face-to-face communication. The number of members in each group should be small (effective-CL factor: formation of small groups). The activity tasks should be defined by the group objective and should be performed collaboratively (effective-CL factor: positive interdependence).
3. Facilitating the individual tasks of each member to support the achievement of the group objective. These individual tasks are defined by the activity rules and roles (effective-CL factor: individual responsibility) in order to achieve the joint educational objective (effective-CL factor: mutual support).

The proposed framework supports MCSCL activities in several ways. To begin with, the network component facilitates face-to-face interaction by allowing the children to move freely throughout the classroom with their wirelessly networked handhelds. The network component also supports the formation of small groups (from three to five members), because it is a distributed entity that permits changes in the group's size. The roles and rules component, which defines the handhelds' activity, facilitates interactivity and positive interdependence because the children must use the handhelds to carry out their required tasks. The framework is general enough to permit its specification for any face-to-face MCSCL activity that involves one or more of interchange, construction or management. Other instances of the framework are described in Table 3. The first four steps of the framework methodology in Figure 4 are shown for four collaborative MCSCL activities, while the last two steps are left for the reader to find in the corresponding references.

In this study we obtained results in two areas. First, activity participants increased their knowledge of basic math. Second, the use of handheld computers facilitated the participants' social interactions and increased their interest in learning. Wirelessly interconnected handhelds facilitate not only the teaching of academic content but also the strengthening of communication and social skills.

Mobile computing can generate various new ways to support face-to-face CSCL environments. The proposal offered here aims at taking advantage of state-of-the-art technologies to create effective mobile CL. This opens up opportunities for changing classroom pedagogical practices, as children using handhelds can move freely throughout the classroom to engage in collaborative activity while receiving the support of computer technology with a wireless network.

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Table 3: Application of the framework methodology in Figure 4 to four different MCSCL activities

Activity/steps	*Math-MCSCL*	*Ord-MCSCL*	*Syllable-MCSCL*	*Physics-MCSCL*
(1) Characterise collaborators.	Second-grade students of both genders, all aged 6 or 7 years old. The children are split into groups of either three or five students.		Second-grade students of both genders, all aged 6 or 7 years old. The children are split into groups of three students.	Second year of secondary school, all students aged 15 or 16 years old and split into groups of three.
(2) Define the global educational objective.	The global aim is to practice addition, subtraction and multiplication.	The global aim is to order numbers.	The global aim is to recognise as many words in Spanish as possible from three given syllables.	The global aim is to answer a set of multiple-choice questions collaboratively.
(3) Establish the desired social interaction skills.	The social aim is to practice face-to-face communication, interaction, coordination and negotiation among the group members.			
(4) Define the type of collaborative learning activity.	Interchange collaborative learning-type activity (Figure 3).	Construction collaborative learning-type activity (Figure 3).		Management collaborative learning-type activity (Figure 3).
Detailed description of the collaborative activity.	Section entitled 'Methodology of design and construction of MCSCL activities' in the present paper.	Zurita, Nussbaum, & Sharples (2003)	Zurita & Nussbaum (2004b)	Cortez *et al*, (2004)

MCSCL, mobile computer-supported collaborative learning, Ord-MCSCL, a MCSCL Ordering numbers activity.

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