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 six- and seven-year-old children in a month-long study. Positive effects were observed on student social interaction, motivation, and learning.
Introduction

According to Johnson & 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, Bayon, Neale, Ghali, Benford, Cobb, Ingram, O’Malley, Wilson, & Pridmore (2001) and Dillenbourg (1999), note that social interaction between peers is fundamental to achieve 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 (Roggof, 1994). According to Wood & O’Malley (1996), it is important to focus on the social interaction effects of a collaborative activity, not just 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 behavior and motivation (Miller, 2002; Ellis, Gibbs & Rein, 1991).

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 & Globerson (1989) a successful CL environment can be achieved only when the groups are effective and well functioning. Adams & Hamm (1996) and Dillenbourg (1999) have established five factors that make for effective CL, which can be summarized 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 to efficiently 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 (Adam & Hamm, 1996; Johnson & Johnson, 1999).

When computer technology is introduced to CL, thus giving rise to Computer Supported Collaborative Learning (CSCL) (Silvermam, 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), since the requirement that users remain behind their screens hinders face-to-face activities. Additionally, 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 bi-directionally 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 & Bradinath, 1994; Jing, 1999). By adding mobility to CSCL, handhelds open up a new domain in collaborative learning which we have called Mobile CSCL (MCSCL); Zurita, Nussbaum & Sharples (2003), Zurita & Nussbaum (2004a).

Collaborative learning activities have shown themselves to be especially effective with children aged 5 to 7 in helping improve social skills that are still developing at those ages (Staton, Bayon, Neale, Ghali, Benford, Cobb, Ingram, O’Malley, Wilson & Pridmore, 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 to individual training (Dillenbourg, 1999). Furthermore, it has been shown that wirelessly interconnected handhelds allow children to freely move and interact socially while working on a common task (Druin & Inkpen, 2001).

To identify common structures observed in learning activities, Santoro, Borges & dos Santos (2000) and Stahl (2002), among others, define a conceptual framework for CSCL activities. Price, Rogers, Stanton & Smith (2003) argue that such a conceptual framework has to satisfy three distinct requirements: (a) it should clearly define common concepts and terms, (b) it should be sufficiently well-structured to provide a foundation for the subsequent development of new and increasingly more refined concepts, and (c) 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 artifacts and is grounded in AT can guide the design of CSCL activities with appropriate, elaborated and unified conceptualizations in order to: (a) clarify the nature of the collaborative activities, (b) indicate how people can socially participate in them while interacting with the technology, (c) design tools to support them effectively in various contexts, and (d) develop methods to put them into practice. A conceptual framework based on AT that defines the architecture of a set of applications offers two main advantages: (a) the application specifications are given, and (b) the design obtained is extendable and adaptable.

We argue in this paper that a framework for analyzing needs, tasks and outcomes for designing Mobile CSCL activities is provided by the AT (Jonassen & Roher-Murphy, 1999), due to it is useful in designing human-computer interactions in order to provide a clear operational framework for designing collaborative activities supported by computational tools. We use the framework and its method of utilization to create an MCSCL mathematics activity for six- to seven-year-old children, which we evaluated in a month-long pilot study. The handhelds used in the study were Pocket-PCs (Compaq iPAQ™), with WiFi (IEEE 802.11b) communication.

Activity Theory

Activity Theory is a theoretical framework for analyzing 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 field of CSCL (Bødker, 1997; Mwanza, 2001; Nardi, 1996), human computer interactions (Kuuti, 1996), network communication and education (Engeström & Middleton, 1996) among others. AT is not a methodology (Jonassen & Roher-Murphy, 1999) but a theoretical framework for analyzing human practices in a given context; e.g. cannot be understood or analyzed outside the context in which 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 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 (e.g., wirelessly interconnected handhelds) or intellectual (e.g., rules and roles displayed on handhelds). Physical Tools are used to handle or manipulate objects while intellectual tools can be used to influence behavior in one way or another.

Vygotsky (1978) originally introduced the idea that human being’s interactions with his or her environment are not direct but are instead mediated through the use of tools and signs, which were developed further by Leont’ev (1981), who created a hierarchical model for analyzing an activity. Inspired by this analysis, Engeström (1987) extended Vygotsky’s original conceptualization 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 the collaborative nature of human activity, whose components are, Figure 1, : (a) Object (or objective, i.e., the goals and intentions) of the activity, (b) Subjects in the activity (i.e., the people engaged), (c) Tools mediating the activity (anything physical, e.g., computeres, or mental, like models or heuristics used in the transformation process), (d) Rules and regulations (norms that circumscribe the activity), (e) Division of labor (e.g., actions undertaken by individuals while the activity would likely be a group responsibility), (f) Community (the group of people that directly and indirectly are involved in the activity), and (g) Outcome (i.e., the resulting objectives and products).

Activity theory focuses on practice, being primarily a descriptive tool, is a qualitative approach that provides a different lens for analyzing a learning process and its outcome, focusing on the activities in which people are engaged.
According to Jonassen & Roher-Murphy (1999), six steps are necessary to describe how the AT may be used as a framework for determining the components of the activity systems for designing learning activities (applied in section “Methodology of Design and Construction of MCSCL activities”): (1) clarify the purpose of an activity system (i.e., understand the relevant contexts where the activities occur); (2) analyze the activity system (i.e., define in depth the components: subjects, objects, community, rules and division of labour); (3) analyze the activity structure (i.e., individuals, collaborative actions and chains of operations that describe the organization under study); (4) analyze tools and mediators (focusing on the tools that provide the direct and indirect communication among subject, community and object); (5) analyze the context (which is essential for the dynamics that exist among the components of the AT); and (6) analyzing the AT dynamics (i.e., a feedback that requires stepping back from the system described and assessing how components affect each other)

To analyze learning situations, the analysis based on AT (applied in section “Evaluation of the Math-MCSCL Activity”), has to assume certain characteristics (Jonassen & Roher-Murphy, 1999): (a) has to be applied enough time; (b) analysts should first pay attention to broad patterns and then consider narrow episodic fragments; (c) use a diverse set of data collection methods (interviews, observations, video-records), and points of view (subject, community and tools).

A Conceptual Framework for MCSCL Activities based on Activity Theory

Following the experience of Gifford and Enyedy (1999), we specify a conceptual framework for mobile collaborative learning applications based on the descriptive model of AT in order to obtain a structure for specifying the framework’s components.
The proposed MCSCL Activity framework, as incorporated into the expanded AT model, is shown in Figure 2 and will be described in the following three sections. The components of the framework include the basic units of a collaborative activity (Dillenbourg, 1999; Johnson & Johnson, 1999): (a) the network formed by the members of a group, (b) roles and rules to follow by the members and (c) the collaborative activity that defines the group objective. Additionally, we indicate how the five factors that make for effective CL environments, enumerated in the previous section, are considered in the framework.

**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 consists of communication between the members and the handhelds, and/or between the handhelds themselves.

*Social Network component*

The Social Network component includes primarily the social interactions within the Community (in terms of the AT model), and defines the social environment in which the activity takes place. The social interactions are established by the ways in which interaction, synchronization, 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 conceptualized 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 fulfills 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. 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, Gibbs & Rein, 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’ behavior and allows for the proper support of their social interactions, synchronization, coordination, communication, interactivity, negotiation, and discussion. The Technological Network component satisfies the individual responsibility and mutual support factors required for an effective CL.

Roles and Rules Component

The Roles and Rules of a CSCL activity would be classified by the AT model as any individual or group norms that govern the activity. 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 that are 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: (a) *proposal*, to start an activity; (b) *contra proposal*, to put forward an alternative proposal to the previous one, either an entirely new proposal or a modification of the prior one; (c) *commentary*, to make an observation on another conversational unit; (d) *clarification*, to respond to a question, to give an explanation, or to ask for more information from a particular member in the conversation; and (e) *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, synchronization,* 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: (a) *sequence*, by choosing a progression of events; (b) *organization*, by initially answering a set of questions or ordering a set of objects individually, and then coming to a consensus as a group; or (c) *agreement*, by coming to a consensus before answering each question as a group.

Collaborative Activity component

The Collaborative Activity component defines the particular educative CL activity to be engaged in, and is specified by the *Objective*, 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*, assigning responsibility for activity tasks and outlining how the group will be organized. And finally, the *Type* of activity conceptualizes 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 fulfills the individual responsibility, mutual support and positive interdependence factors for effective CL.

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 3). This methodology has been adapted and extended from the CL activity structure flowchart described in Johnson & 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 methodology so refined 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. Characterize Collaborators. The Subjects that carry out the activity must be characterized and contextualized by age, sex, educational level, cardinality, and the criteria for selecting members. The characteristics of the Social Network members must be identified in order to make sure they have the required cognitive and social abilities.

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 Interaction and Engagement components shown in Figure 2 conceptualize these skills.

4. Choose the type of collaborative learning activity. Social interaction is promoted by interchange, construction, and management activities. The Type component under Collaborative activity in Figure 2 specifies the activities among 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/her own goal, but also ensure that all the other children in the group reach theirs. (See 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 each other member has in order to perform his or her task. Only once all the members agree on the final outcome is their task complete (examples are described in Zurita & Nussbaum, 2004a; and Zurita & Nussbaum, 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, Nussbaum, Santelices, Rodriguez, Zurita, Correa & Cautivo, 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 2).

*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 synchronized and coordinated way by the group members, and include interchange, construction, and management tasks. These tasks encourage discussion among members and create spaces of 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 2).

*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 call R1), Cognitive Conflict due to 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 2 (proposal, counterproposal, commentary, clarification, 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: (a) *Interactivity.* Members’ interaction in the collaborative activity, as measured by the interaction’s influence on their cognitive process rather than by its frequency; (b) *Synchronization and Coordination.* Technology helps to synchronize the face-to-face communication between the members and facilitates coordination within the group; (c) *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: (a) working in a group structure to maximize positive interdependence and to organize and assign tasks within the group, (b) mediation of the group work through the formulation of questions and management of multiple activities, (c) initiation and redirection of the collaborative efforts in accordance with the different states of the activity, and finally (d) 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, that is, 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 2).
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. **Characterize Collaborators.** The members taking part in the Math-MCSCL activity are second grade students of both genders, all aged six or seven years. Educators and psychologists maintain that by the age of five, 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 pairs of children.

4. **Define the type of collaborative learning activity.** From the framework we select an *Interchange* collaborative learning 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 4 each object represents 8 units so that when Miguel sends the banana object to Gustavo he is actually sending 8 bananas, reducing the quantity of his own bananas by 8 (Figure 5a) while increasing Gustavo’s by the same number (Figure 5b).

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 other to find out what each other’s need are, then negotiate an object exchange and carry it out. All group members must collaborate to reach the goal.


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: (a) reach a target number of objects, (b) search for the team members who have the desired objects, (c) negotiate the object exchange, and (d) carry out the exchange.

Definition of the Roles and Rules supported by the technology. The handhelds support the activity by: (a) enforcing interactivity by initially distributing objects in such a way that each member of the group is required to interact with the other members; (b) coordinating the entire group through the wireless network that interconnects them; (c) synchronizing the members’ machines in order to exchange an object; (d) regulating the sending and receiving of objects through interconnection
protocols; (e) 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 colored background: purple for Gustavo, red for Miguel and green for Rodrigo (see figures 4a, 4b and 4c, respectively). The various steps in the activity are illustrated by a series of screenshots from the handhelds shown in figures 4 through 7.

Gustavo begins with ten oranges, four bananas, and seven apples. In this example, each object represents 8 units, as indicated by the label on each fruit. Gustavo, therefore, 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 identifying 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 color 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 4d. 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 4a to Figure 4e. In Figure 4e, 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 4f). Finally, Miguel sends the bananas to Gustavo by selecting the purple button that identifies Gustavo (Figure 4f). After the transfer, the quantity of Miguel’s bananas has decreased (Figure 5a) while the quantity of Gustavo’s bananas has increased (Figure 5b).

Since the object exchange is performed in pair-wise fashion, some members may reach their individual goal before others. In Figure 6a 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 6b, Rodrigo’s screen displays the same drawing of a pen with a star in red to the left of the sun, meaning 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.

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 6c, 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 7a. 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 7b.
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 six- and seven-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 pre-test was performed at the beginning of the pilot study consisting of a 35-minute individual assessment of each child’s previous knowledge of adding, subtracting and multiplying. The pre-test 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 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 answers are. For example, if a student correctly responded to 2 of the 10 questions, their score would be ((2/10)*6)+1= 2.2.

The pilot study was divided into 20 daily sessions held over a period of four weeks. Each session was 25 minutes long and had a set of given activities as the daily goal. The first 2 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 (Figure 8) and three groups of five members (Figure 9). During the pilot study, the students received no other form of mathematics instruction.

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 one 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 directly on solving the problems. However, the children were by then already familiar with the technology and so did not require additional time to learn it.

At the end of the 20-day pilot study, a post-test assessment was performed using the same pre-test that had been administered at the beginning of the study. As before, the children were given 35 minutes to complete the test. Figure 10 shows a frequency distribution of the pre-test and post-test 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 3 students and the groups of 5 students.

To measure social interactions, four collaborative learning experts used observation guidelines which were applied during the first and last sessions. Furthermore, the entire activity was recorded on video, allowing the experts to better analyze the children’s behavior. The observation guidelines included the following qualitative aspects: (a) Communication, verbal information interchanges made with an appropriate tone of voice and volume while maintaining eye contact; (b) Interaction, the quantity of social interactions with other children that were directly related to the activity; (c) Coordination, the individual effort applied to achieving the team’s goal; (d) Discussion, the ability to debate and defend one’s viewpoint; (e) Negotiation, the ability to build an agreement; and (f) 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 pre-test and post-test observations, and the experts had to agree unanimously on the results assigned. A Likert scale of seven categories was used for measuring 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 pre-test and post-test 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 of 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 realized 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, since only one object could be exchanged at a time and only when both members agreed. This also favored the discussion and negotiation aspects of the activity. Frequently, the children asked their group members for support. This support was sometimes reluctantly given, since 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 than they did in regular class activities. All of the children without exception expressed a desire to participate in the collaborative activities. Absentees during the four weeks of the pilot study were almost zero. On an open questionnaire given to the students, 21 of the 24 participants indicated that they enjoyed working in groups, while the remaining 3 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 size. However, a few small differences were observed. The bigger groups (five members) took over 10% more time, on average, to complete the activity than the smaller ones (three members). However, the bigger groups appeared to be more motivated and enjoy themselves more.

Discussion

Handhelds can be considered as Activity Theory 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 collaborative learning 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 freely move throughout the classroom with their wirelessly networked handhelds. The Network component also supports the formation of small groups (from three to five members), since 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 to any face-to-face MCSCL activity that involves one or more of interchange, construction or management. Other instances of the framework are described in Cortez, Nussbaum, Santelices, Rodriguez, Zurita, Correa and Cautivo (2004), where a management activity is used to teach physics, and Zurita & Nussbaum (2004b), which describes a construction activity for teaching basic reading.

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 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 collaborative learning. 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.
References


