Silent Collaboration with Large Groups in the Classroom

Tal Rosen, Miguel Nussbaum, Carlos Alario-Hoyos, Francisca Readi, and Josefina Hernández

Abstract—Synchronous collaboration with large groups in a classroom requires coordination and communication mechanisms that allow students to contribute towards achieving a common goal. This paper presents an application based on an Interpersonal Computer with a shared display that promotes synchronous, non-verbal (silent) collaboration with large groups in a classroom.

Index Terms—Collaborative learning, computer-assisted instruction, silent collaboration

1 Introduction

COLLABORATIVE learning in the classroom is receiving more and more attention following the inclusion of collaborative problem solving in the 2015 PISA study [1]. Collaboration is a form of collective problem solving [2], and successful collaboration requires the presence of certain conditions [3]: a common objective, positive interdependence between peers, individual responsibility, joint rewards, awareness of other students' work, coordination and communication between students.

Adopting collaborative practices with children in the classroom is a challenge [4]. This challenge is even greater when a large group of children must work synchronously and together on the same problem (we understand a "large group" to be one composed of at least 12 students) [5]. In such cases, issues with coordination and communication often arise that can hinder collaborative learning [6]. For example, there are always some students who do not want to participate in the discussion [7] and shier children can be reluctant to share their ideas out loud. Another important issue is how to manage the significant number of verbal interactions that occur when working in large groups [8]. In the case of children, it is common for some of these interactions to have nothing to do with the collaborative activity, resulting in a noisy and chaotic environment [9]. Finally, if all of the children do eventually contribute in an orderly fashion; it is unlikely that the outcomes of the collaborative activity will be of any educational value as children are not trained to speak effectively with each other in large groups [10].

Teachers usually solve these issues by dividing large groups of children into small groups that work on the same problem independently [11]. If the problem is too complex for small groups to solve, teachers sometimes divide the problem into smaller sub-problems using collaborative patterns such as Jigsaw [12]. By doing so, each of the smaller groups only has to address one of the sub-problems in depth. However, there are certain contexts in which complex problems cannot be divided or in which teachers explicitly want children to learn to work in large groups [13]. In this case, an approach is needed to address the aforementioned issues of reluctant participants, suitable environments and effective interaction among students when working in large groups.

One approach that can address these three issues is the use of Interpersonal Computers with a shared display [14]. Such Interpersonal Computers allow students in a classroom to interact simultaneously with each other in an orderly fashion. Using a shared display within the same physical space allows teachers and students to share the same information, so that teachers can detect any problems and clarify specific concepts if necessary. Interactive tabletops are one example of using an Interpersonal Computer with a shared display to encourage participation and agreement with large groups in a classroom [15]. However, interactive tabletops are quite expensive and not every school can afford to buy one.

A much cheaper way to build an Interpersonal Computer with a shared display is to connect multiple input devices to a laptop (e.g., keyboards or mice) and use a projected screen. Researchers have previously developed software applications for an Interpersonal Computer with a shared display, using a projected screen and mice as an input device. These applications have been used when studying math to promote collaboration in small groups [11] and interactivity among students in a whole class setting [16]. Szewkis et al. [17] developed an application that uses similar technological support for studying grammar in large groups. Through this application children classify words in a *Matrix*, a two-dimensional template that defines the classification criteria in rows and columns (e.g., in Fig. 1, top right, the rows represent first letter of the word, while the columns represent the type of word). Children work in collaboration by suggesting correct answers to any of their peers using the application, while at the same time receive suggestions from other students. Such an application promotes "*silent collaboration*" as it is not necessary for the students to exchange verbal interactions in order to complete the Matrix, while the mechanisms for interaction ensure that collaboration occurs.

Whereas Caballero et al. [11] divided the students in the classroom into smaller groups to allow for a collaborative environment, Szewkis et al. [17] provided a setting for collaboration when working with a single, large group. Both were faced with the problem of a significant number of unnecessary verbal interactions, that is, pedagogically unrelated assertions like "give the word invention to me", that can jeopardize the conditions of coordination and communication that are required for collaboration. This was particularly critical in [17], where most unnecessary verbal interactions were due to the interaction pattern, i.e., the mechanism for exchanging suggestions using the application. This mechanism required the children to receive a suggestion before they could submit an answer [17]. As a result, some students became impatient and began to pressure their peers by using unnecessary verbal interactions, thus raising the volume in the classroom, and hindering the correct development of the collaborative activity. This gives rise to our first research question: *can a different interaction pattern be applied to applications for an Interpersonal Computer with a shared display to promote silent collaboration over verbal interactions when working with a large group of children in a classroom?* In order to address the first research question this paper proposes a variation on the interaction pattern presented in [17].

The interaction pattern for the exchange of suggestions in [17] was linked to a mode of representing the information on the screen: *Matrix*. This leads to the second research question: *is it possible to employ different modes of representation in an application for an Interpersonal Computer with a shared display to promote silent collaboration*

- *T. Rosen and M. Nussbaum are with the Department of Computer Science, Pontificia Universidad Católica de Chile, Santiago, Chile. E-mail: tjrosen@uc.cl, mn@ing.puc.cl.*
- *C. Alario-Hoyos is with the Department of Telematic Engineering, Universidad Carlos III de Madrid, Leganés, Spain. E-mail: calario@it.uc3m.es.*
- *F. Readi and J. Hernández are with the Department of Computer Science, Pontificia Universidad Católica de Chile, Santiago, Chile. E-mail: {freadi, jmherna1}@uc.cl.*

Manuscript received 16 Sept. 2013; revised 3 Apr. 2014; accepted 14 Apr. 2014. Date of publication 22 Apr. 2014; date of current version 2 July 2014.
For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org, and reference the Digital Object Identifier below.
Digital Object Identifier no. 10.1109/TLT.2014.2318311

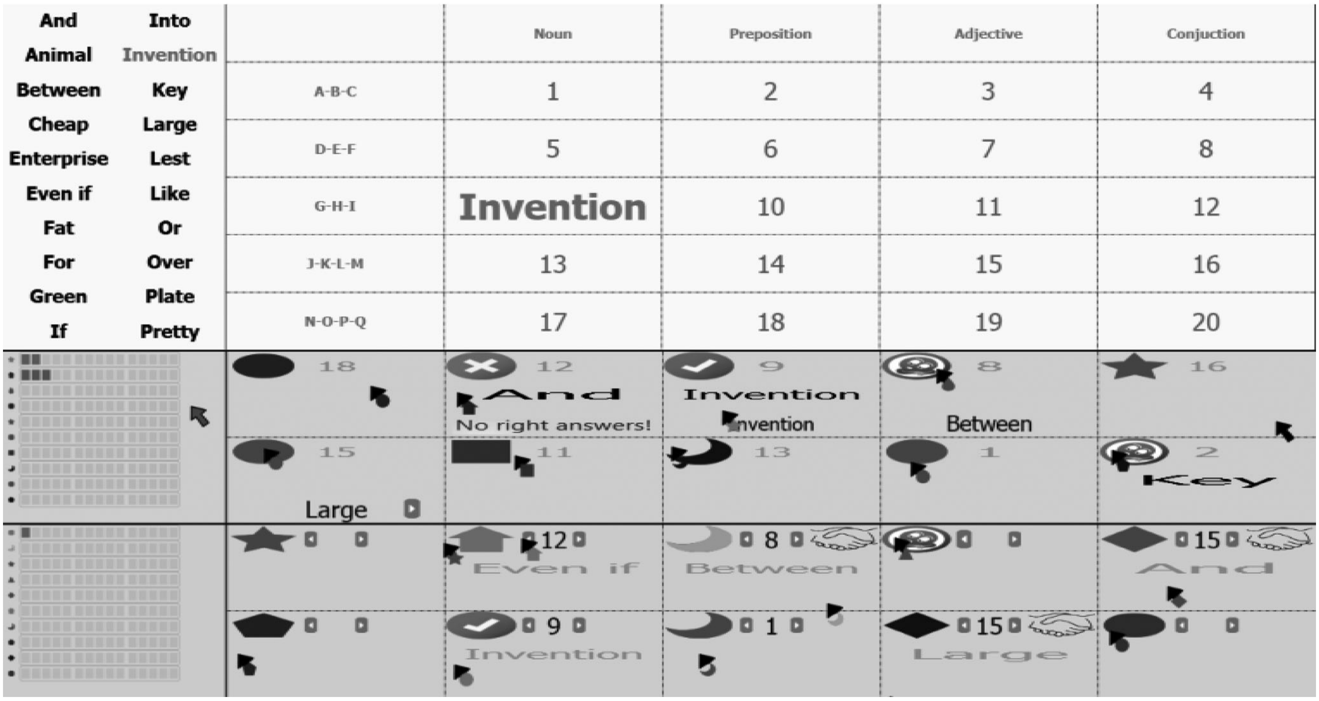

Fig. 1. Application interface for a Matrix activity that consists of classifying a set of words. The top half represents the 20 problems to solve as part of the collaborative activity. The bottom half represents a board with an acceptors' area (top two rows) and facilitators' area (bottom two rows). Each acceptor and facilitator is assigned a cell on the corresponding board. All of the students work synchronously on the board.

when working with a large group of children in a classroom? This question is addressed analyzing silent collaboration when using two modes of representation, *Matrix* and *Cloze* [18].

2 Silent Collaboration Interaction Pattern

The proposed silent collaboration interaction pattern follows the approach of submitting and accepting suggestions presented in [17], but with two key differences aimed at reducing the number of unnecessary verbal interactions detected in [17]. First, the roles are separate and students can only play one of two possible roles until the collaborative activity ends: *facilitators*, who provide suggestions to solve a given problem; and *acceptors*, who are responsible for solving the problem, and who may or may not consider the suggestions received from facilitators. Second, acceptors are not compelled to accept suggestions before submitting an answer, giving them the freedom to choose whether to solve the activities individually or in collaboration with their peers. Silent collaboration is achieved when a facilitator makes a non-verbal suggestion to an acceptor, even though the acceptor may decide not to accept that suggestion.

2.1 Overall Application Design

An application for an Interpersonal Computer with a shared display is designed to implement the silent collaboration interaction pattern. This is achieved by facilitating the synchronous, anonymous, technology-mediated submission and acceptance of suggestions among a large group of students. The fact that submissions are anonymous is intended to promote the participation of everyone, including shier children [19]. The application is designed to run in a classroom using the cheapest possible supporting technology. By requiring only a laptop, projector, screen (shared display), and one mouse per child, it allows collaborative work to take place in the classroom regardless of the school's economic condition [20].

The application supports two modes of representing the information on the screen: *Matrix*, where problems in the collaborative activity consist of classifying a set of items (words in Fig. 1); and *Cloze*, where problems in the collaborative activity consist of filling in the blanks with a set of items (words in Fig. 2). Offering two different modes of representation enables teachers to use a wider range of collaborative activities with their students. The skills children need to develop to make use of the silent collaboration interaction pattern, i.e., to be able to send or accept a suggestion, are similar in both modes.

In both the Matrix and Cloze modes, two work spaces are defined: an upper space, where problems are posed and solved; and a lower space, in which silent collaboration takes place (see Figs. 1 and 2). The upper work space contains the *Item List* (upper left in both cases), which includes all of the items that are needed to complete the collaborative activity (each item solves only one, unique problem); and the *Representation Space* (upper right in both cases), which includes the set of problems that make up the collaborative activity (20 in Fig. 1 and 14 in Fig. 2). The lower work space includes the *Acceptors' Area* (top two rows in Figs. 1 and 2) and the *Facilitators' Area* (bottom two rows in Figs. 1 and 2). Both areas contain a *Score Board* (bottom left), which gives feedback on the acceptors' and facilitators' performance, respectively. Each row matches a student's symbol (a unique icon used by the students to identify themselves), while the columns show colored boxes which indicate the students' correct (green) and incorrect (red) answers. Finally, both the *Acceptors' Area* and the *Facilitators' Area* include *Personal Spaces* (bottom right) where the children can work and collaborate. Each *Personal Space* is a rectangular cell (10 in the *Acceptors' Area* and 10 in the *Facilitators' Area* in Figs. 1 and 2), allocated to each child and used to submit suggestions (facilitators) or accept suggestions and submit the answer to a given problem (acceptors). It is important to note that the mode of representation only affects the *Representation Space* (upper right in Figs. 1 and 2); the *Item List*, *Score Board* and *Personal Spaces* are the same for both the Matrix and Cloze modes.

Before starting the collaborative activity, the application defines the number of *Personal Spaces* based on the total number of users detected (20 being the maximum). Then, each user is identified by

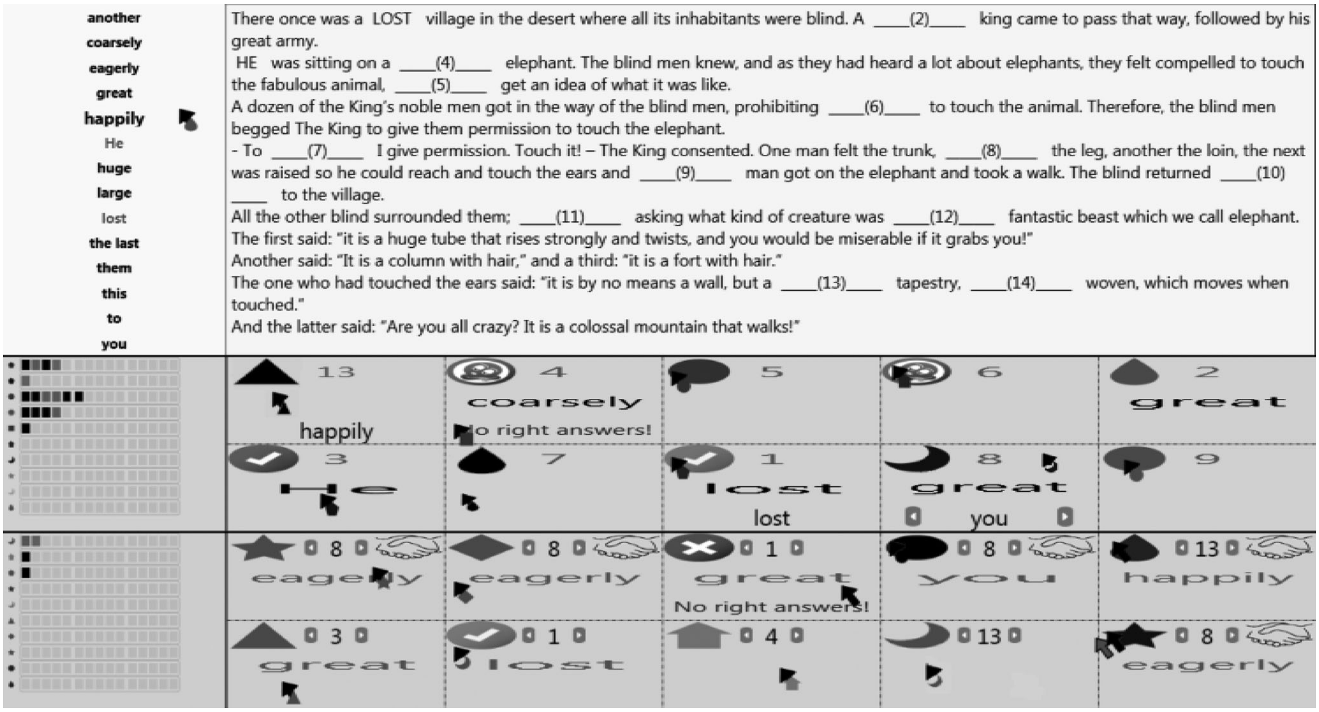

Fig. 2. Application interface for a Cloze activity that consists of filling in the blanks. The top half represents the 14 problems to be solved as part of the collaborative activity. The bottom half represents a board with the acceptors' area (top two rows) and facilitators' area (bottom two rows). Each acceptor and facilitator is assigned a cell on the corresponding board. All of the students work synchronously on the board.

their cursor and automatically placed in an individual cell. Students can move their cursors freely across the screen using their mouse, but they cannot access other students' cells. At the beginning of the activity each acceptor receives a number, which represents a problem to be solved in the *Representation Space*. In the Matrix mode, this entails finding an item that meets the conditions defined for that number, e.g., in Fig. 1, the number "18" (first row, first column) is a preposition that starts with the letter N, O, P or Q. In the Cloze mode, it entails finding an item that fits that number's corresponding blank space, for example, in Fig. 2 number "2" is an adjective to describe the king in that particular story. When the problem is solved, the acceptor is assigned a new number and must solve another problem. All of the problems must be solved in order to successfully complete the whole activity.

Facilitators are free to work on any problem (by choosing a number from those assigned to the acceptors), and suggest a possible answer (from those available in the *Item List)*. For example, in Fig. 1 the facilitators could choose between the numbers 18, 12, 9, 8 or 16 (first row) and 15, 11, 13, 1, or 2 (second row). The acceptors then receive the suggestions, which they may or may not accept. For example, in Fig. 1 the acceptor with number "9" (first row, third column) decided to accept the word "Invention" (see Section 2.2 for details about the meaning of the elements in each cell). If no suggestions are received, the acceptors can submit an answer which they think is correct, without having to have received a suggestion. This differs from the interaction pattern defined in [17], where it was obligatory for the students to have received a suggestion. Following the submission, the application gives immediate feedback. If the answer is correct (e.g., the acceptor in Fig. 1 with number "9"), the acceptor receives a tick which replaces their symbol, positive points, and a green box on the *Score Board*. When calculating the score, the application favors answers that have come from suggestions. Therefore, if a correct answer has come from a suggestion, two positive points are awarded, if not, only one positive point is awarded. If an incorrect answer comes from a suggestion, one negative point is received, if not, two negative points are received. Similarly, facilitators receive one positive point if suggesting an answer that turns out to be correct, and a negative point if the answer turns out to be incorrect. At the end of each activity the screen shows each child's points. By doing so, the application incentivizes silent collaboration, encouraging facilitators and acceptors to work together within a large group, in the classroom, but without requiring explicit verbal exchanges.

2.2 Interaction Pattern in the Personal Spaces

The application implements the silent collaboration interaction pattern in such a way that students can submit and accept suggestions in an orderly fashion using their *Personal Space.* In particular, an acceptor can receive suggestions from several facilitators at a time, but accept only one of them. A facilitator can only send one suggestion at a time to any of the acceptors; if facilitators wants to submit a new suggestion they need to wait for the acceptor to accept the previous suggestion or withdraw their own suggestion.

Through Figs. 3a and 3b the process of submitting and accepting suggestions in individual cells is analyzed using two specific examples. The *symbol* (labeled 1 in Figs. 3a and 3b, moon for the acceptor in Fig 3a, diamond for the facilitator in Fig 3b) represents each student and serves to identify them on the board (the cursor also features the symbol) and on the *Score Board*. Facilitators click on their symbol to submit a suggestion. Acceptors click on their symbol to submit an answer. The feedback after submitting an

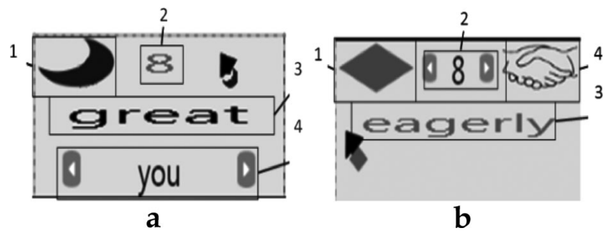

Fig. 3. (a) Example of acceptor's *Personal Space.* (b) Example of facilitator's *Personal Space.*

TABLE 1
Description of the Activities in S1-S5 for Matrix and Cloze

Session	Subject	Representation mode	Activity description	Difficulty	Duration (minutes)
S1	None (software learning)	Matrix	Ranking famous people (e.g. sportsmen, presidents, etc.).	-	12.61
		Cloze	Filling in the blanks relating to the story of Little Red Riding Hood, using a word list.	-	8.93
S2	Literary Figures	Matrix	Ranking literary figures. These are contextualized in verse and provided on paper for the pupils.	Medium	7.66
		Cloze	Choosing for each verse the corresponding literary figure, from a list of figures provided.	Medium	10.62
S3	Basic Grammar	Matrix	Ranking words by type: verb, noun, demonstrative adjective, demonstrative pronoun. These appear contextualized in sentences on handouts given to pupils.	Low	6.26
		Cloze	Filling in the blanks of a text using a list of different word types: verbs, nouns, demonstrative adjectives, demonstrative pronouns. Pupils receive a handout listing the type of word required in each blank.	Low	6.7
S4	Advanced Grammar	Matrix	Ranking words by type: qualitative adjective, demonstrative adjective, personal pronoun, demonstrative pronoun, adverb. These appear contextualized in sentences on handouts given to pupils.	High	4.5
		Cloze	Filling in the blanks of a text using a list of different word types: qualitative adjectives, demonstrative adjectives, personal pronouns, demonstrative pronouns, adverbs. Pupils receive a handout listing the type of word required for each blank.	High	13.26
S5	Simple and compound sentences with verb tenses	Matrix	Ranking sentences by type (simple, compound) and verb tense (present, past, future). Sentences are provided on a handout.	High	7.08
		Cloze	Matching sentences. One part of the sentence is found on the software and another on a handout. The different paper sentence numbers are provided in a word list.	High	12.08

answer is shown in the symbol in the form of a tick (e.g., Fig. 2, *Acceptors' Area*, cell with *problem 3*) or a cross (e.g., Fig. 2, *Facilitators' Area*, cell with *problem 1*). In addition, the symbol switches to sleep mode if a student remains inactive for a predetermined period of time (e.g., Fig. 2, *Acceptors' Area*, cell with *problem 4*). This is done so that the teacher knows which students are not actively working and approach them.

The *problem number* (labeled 2 in Figs. 3a and 3b) represents the problem to be solved. Acceptors automatically receive a problem number from the system. Facilitators can choose which problem to solve (from those that are being addressed by acceptors) by moving through the options using the left and right arrows.

The *selected item* (labeled 3 in Figs. 3a and 3b) is an item belonging to the *Item List* that facilitators select as a suggested answer to their chosen problem, or that acceptors choose as an answer to their assigned problem. In order to choose a selected item, students go to the *Item List* and click on one of the available items, which is then displayed in their individual cell.

The *suggestions* (labeled 4 in Fig. 3a) are the items sent by facilitators as potential solutions to the problem that the corresponding acceptor is working on. If there is more than one suggestion, arrows pointing to the left and right appear so that the acceptor can look through all of the suggestions. For example, in Fig. 3a, "you" is one of the suggestions received for *problem 8*, but there are arrows signaling that there are more alternatives; Fig. 2 reveals that "eagerly" (suggested three times: in the third row of the first and second columns, and in the fourth row of the fifth column) is the alternative suggestion.

The *handshake icon* (labeled 4 in Fig. 3b) appears in the facilitator's cell when a suggestion is submitted, disabling the submission of new suggestions. The handshake icon disappears when the acceptor accepts that suggestion or when the facilitator clicks on that icon, withdrawing their suggestion. For example, in the *Facilitators' Area* in Fig. 2 there are five active suggestions and five cells where facilitators have yet to make a suggestion.

This section is concluded with an illustrative example. The acceptor in Fig. 3a is working on *problem 8* and has chosen the word "great", which has not come from a suggestion. The corresponding problem in the *Representation Space* in Fig. 2 reveals that this answer would be incorrect and that the correct answer would be "another". If the acceptor submits the word "great" by clicking on the symbol (moon), a cross would appear, two negative points would be awarded, and the problem would have to be repeated. If there had been correct suggestions instead, one positive point would have been awarded to the respective facilitators, the acceptor would have received two negative points and the feedback showing that the correct answer was "another", this word would have been added to the Representation Space, and a new problem would have been assigned to the acceptor. Nevertheless, if the acceptor changes the selected item for "another" and then submits it, a tick would appear, the word "another" would move to the corresponding blank space in the *Representation Space* in Fig. 2, the acceptor would receive one positive point, the facilitators that wrongly suggested the word would receive a negative point and a new problem number would then be assigned to that acceptor. Although in this example the problem is solved individually, silent collaboration occurs because the acceptor is receiving suggestions from their peers, even though they choose not to consider them.

3 Experimental Design

Two independent studies were conducted in a state-subsidized school in Santiago, Chile. Each of the studies included five sessions of approximately 40 minutes each, during which time the students used the application with the Matrix mode (in one of the studies) and the Cloze mode (in the other). Despite being independent studies, they had to be carried out in the same classroom and at the same time due to school constraints. In total, 26th graders participated in the study (15 boys and 11 girls, aged 10 and 11). Thirteen of the students worked with the Matrix mode (eight boys and five girls) and 13 with the Cloze mode (seven boys and six girls). The classroom was split into two areas with the children that were working with the Matrix mode looking at a shared screen at the front of the class and children working with the Cloze mode looking at a shared screen at the back of the class. The setting also included two laptops which projected the application onto each of the screens, as well as the necessary mice.

Each session included one collaborative activity which was carried out twice so that the roles of facilitator and acceptor could be rotated. The aim of this was to foster peer collaboration, since this is usually hindered in young children by their inability to take on other people's perspectives [21]. In the first session (S1), students became familiar with the application. During sessions two to five

TABLE 2
Total Number of Events Registered from Sessions S2 to S5 Per Participant in Matrix Mode (MT) and Cloze Mode (CT), Standard Deviation Mσ and Cσ Respectively, and Average Number of Events Per Participant Per Session (from S2 to S5) in Matrix Mode (MA) and Cloze Mode (CA) (Spoken Collaboration Events Are Marked in Bold)

	MT	Mσ	MA	CT	Cσ	CA
Pure Spoken Collaboration	3.19	0.15	0.80	2.76	0.50	0.69
Pressure	2.66	0.40	0.67	0.96	0.11	0.24
Disruption	0.64	0.07	0.16	2.69	0.43	0.67
Feedback Utility	0.00	0.00	0.00	0.40	0.08	0.10
Visualization	0.00	0.00	0.00	0.31	0.11	0.08
Question regarding the system usage	0.81	0.14	0.20	1.19	0.11	0.30
Motivation	2.06	0.13	0.52	1.85	0.05	0.46
Positive Remarks	2.35	0.25	0.59	1.08	0.28	0.27
Boredom	1.87	0.20	0.47	1.75	0.27	0.44
Tiredness	0.40	0.10	0.10	0.65	0.15	0.16
Displeasure	1.06	0.18	0.26	0.70	0.30	0.17
Negative Remarks	1.60	0.28	0.40	0.56	0.08	0.14

(S2-S5), they worked on subjects related to literature and grammar. These subjects were set by the school and had to be adapted to collaborative activities that could be represented in both the Matrix and Cloze modes. During the sessions, the students could decide to exchange suggestions using the application or by speaking to one another. Due to the lack of an authoring tool at the time of carrying out the studies, the researchers were responsible for creating the collaborative activities for the application. A detailed description of the subjects, activities, and difficulty levels in the five sessions for the Matrix and Cloze modes is outlined in Table 1. This table also shows the time per session that the students were effectively working on the collaborative activities using this application.

Printed information that replicated or complemented the information shown on the shared display was distributed to the students during some of the activities. For example, there were cases in which the application could not accommodate all of the words that were needed in the *Item List*. In this case, identifying letters replaced the words, and the printed information allowed the students to associate these letters with the relevant words. In the Cloze activities, the printed information also contained the same sentences displayed in the *Representation Space*, so that the students could read them more comfortably. Using these additional pieces of paper did not alter the silent collaboration interaction pattern.

Quantitative and qualitative data was collected during the five sessions in the two studies. The quantitative data consisted of the number of suggestions made through **silent collaboration**, and came from the application's log. The qualitative data was gathered by three tablet-supported observers in the Matrix group, and another three in the Cloze group, each of whom monitored the performance of four to five students with the aim of recording the number of occurrences of different events. The following events were recorded (see Table 2): *pure spoken collaboration* (two students talking to each other about the activity, with several verbal interactions considered as a single event, so long as it involved the same two students and referred to the same exercise and/or topic), *pressure* (a facilitator putting verbal pressure on an acceptor to use their suggestion, with several verbal interactions considered as a single event, so long as it involved the same students and was regarding the same suggestion); *disruption* (anytime a student interrupted another student when they were working on the activity), *questions regarding system usage* (e.g., a facilitator saying that they did not understand how to send suggestions), *feedback utility* (e.g., a student asking about the feedback that was given), *visualization* (e.g., a student asking because they could not see the words on the screen), *motivation* (a child showing signs of enjoyment), *positive remarks* (any positive comment about the activity or the system), *boredom* (e.g., a student telling their partner that they did not want to keep working on the activity), *tiredness* (a child showing signs of tiredness), *displeasure* (a child saying that they did not like the activity), *negative remarks* (any negative comment about the activity or the system not classified as boredom or displeasure). If a question or comment required further explanation, all of the related verbal interactions were considered as a single event in the case of *questions regarding system usage, feedback utility, visualization, positive remarks, boredom, displeasure* or *negative remarks*. If several expressions of *motivation* or *tiredness* were consecutive or related, they were also considered as a single event. Each event could happen more than once for each child in each activity.

Only two types of events are classified as **spoken collaboration**, *pure spoken collaboration* and *pressure* (marked in bold in Table 2), since they involve at least two students and can influence how the activity is solved as a result of verbal suggestions. Even though only these two types of events are useful to compare silent and spoken collaboration, the other events that were recorded allowed for an analysis of the application's usability, presented in the following section.

4 RESULTS

This section first presents the results of the two usability analyses carried out for the application with the Matrix mode and for the application with the Cloze mode. Secondly, a comparison is made of silent and spoken collaboration observed in the two studies.

4.1 Usability Analyses

A usability analysis typically includes: learnability, efficiency, memorability, user satisfaction, and errors [22]. Learnability was measured by considering the time it took the students to complete the training session S1 (see Table 1). It took 12.61 minutes in the Matrix mode and 8.93 minutes in the Cloze mode. In both cases it is only a short time, considering that a class typically lasts 40 minutes.

Efficiency was calculated by considering the time it took the students to complete the activities in sessions 2 through 5 (see Table 1). In the Matrix mode this time was 25.5 minutes, and in the Cloze mode it was 42.66 minutes. With these data, both the application with the Matrix mode and the Cloze mode can be considered to have been efficient, since they enabled eight collaborative activities to be solved (four with students as facilitators and four as acceptors) in a large group in about the length of a regular class (40 minutes). Students took advantage of the working time, since a low number of interruptions were recorded in the form of *disruption* (0.64 for Matrix mode and 2.69 for Cloze mode), *feedback utility* (0.00 for Matrix mode and 0.40 for Cloze mode), and *visualization* (0.00 for Matrix mode and 0.31 for Cloze mode) (Table 2).

Memorability was evaluated by calculating the number of *questions regarding the system usage* recorded in sessions 2 through 5 (Table 2): 0.81 questions per participant in Matrix mode (17 in total in S1 and an average of 2.5 questions in S2 to S5), and 1.19 questions per participant in Cloze mode (18 in total in S1 and an average of 3.75 questions in the following sessions). This indicates that the use of both systems is easy to remember after the first session.

User satisfaction was assessed by calculating the ratio of positive events (*motivation* and *positive remarks)* to negative events (*boredom*, *tiredness*, *displeasure*, and *negative remarks)* similar to the assessment made in [23]. This ratio was 0.89 in the Matrix mode and 0.8 in the Cloze mode (Table 2). It is interesting to note that there were more negative events in total due to the high occurrence of *boredom*. Most of the occurrences of *boredom* that were recorded were due to the fact that acceptors who finished first had to wait for their peers to solve the remaining problems. However, the observers also noted that the students were highly motivated while performing the activities in both studies.

Finally, neither the application with the Matrix mode nor with the Cloze mode had any errors as the activities were being carried out.

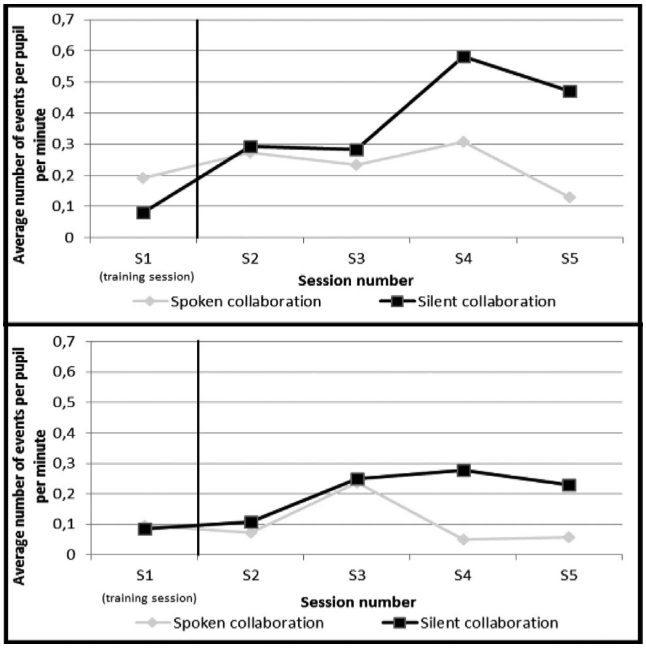

Fig. 4. Average number of spoken and silent collaboration events per pupil per minute in the studies with Matrix (top) and Cloze (bottom).

All in all, these usability analyses reveal that the application with the Matrix mode or with the Cloze mode were not an obstacle to achieving the desired dynamics in the studies that were conducted.

4.2 Comparison of Silent and Spoken Collaboration

Table 2 includes the total number of spoken collaboration events (both *pure spoken collaboration* and *pressure*) per participant from sessions S2 to S5 in the two studies: 5.85 in Matrix mode, which is the result of adding a total of 3.19 pure spoken collaboration events per participant ($\sigma = 0.15$) and 2.66 pressure events per participant ($\sigma = 0.4$); and 3.72 in Cloze mode, which is the result of adding a total of 2.76 pure spoken collaboration events per participant ($\sigma = 0.5$) and 0.96 pressure events per participant ($\sigma = 0.11$). Fig. 4 shows the average number of spoken collaboration events per participant per minute in each session for the studies with the Matrix mode (0.23 average total events per participant per minute from S2 to S5) and with the Cloze mode (0.09 average total events per participant per minute from S2 to S5). This normalization over time is needed in order to compare spoken collaboration across the sessions, since the sessions had different durations, as reported in Table 1.

Logs from the application were captured during S2 through S5 revealing a total of 9.97 silent collaboration events per student in Matrix mode ($\sigma = 0.66$), and a total of 9.26 silent collaboration events per student in Cloze mode ($\sigma = 1.13$). Fig. 4 also details the number of silent collaboration events per student normalized over time for the studies with the Matrix mode (0.41 average total events per student per minute from S2 to S5) and the Cloze mode (0.22 average total events per student per minute from S2 to S5). S4 was the session in which the most silent collaboration events occurred (0.58 events per student per minute with the Matrix mode and 0.28 events per student per minute with the Cloze mode).

The explanation as to why greater overall collaboration (both silent and spoken) was achieved in the study with the Matrix mode lies mainly in the types of activities carried out. In the Cloze mode, the students always had to understand sentences or even paragraphs before submitting suggestions, while in most activities with the Matrix mode they only had to understand the criteria defined by the rows and columns. Thus, the collaboration within the two studies is not comparable.

TABLE 3
Fulfilment of Collaboration Conditions in the Two Studies

Condition	Fulfilment
Common objective	Working together, all of the students undertook the same collaborative activity in both the Matrix and Cloze modes.
Positive interdependence	The application ensured that success depended on everybody contributing. Each acceptor had to solve at least one problem (the first assigned) and facilitators helped with suggestions. Roles were rotated so that every child could play the role of acceptor and facilitator in the same activity.
Coordination and communication	To complete each activity, students coordinated and communicated with each other, primarily using silent collaboration.
Individual responsibility	Each answer given (correct or incorrect) received public feedback, linked to personal points on the score board.
Awareness	By sharing a screen, each student's work could be viewed by all of the students, as could the score board.
Joint rewards	The scoring system encouraged acceptors to make use of the facilitators' answers.

Nevertheless, silent and spoken collaboration can be compared in each of the two studies. Fig. 4 shows that, as the sessions progressed, the students tended to make more suggestions using the application than through verbal interaction. This is mainly due to the fact that the students felt more and more comfortable using the application and that they took advantage of a scoring system that encouraged silent collaboration. This is justified by the data that was collected since in both studies the questions regarding the software usage decreased as the sessions went on, while the positive remarks, motivation and total number of points obtained predominantly increased.

The contents in each session had to be adapted to the school curricula and, as a consequence, the difficulty of the collaborative activities varied from S2 to S5 (Table 1). To see the impact that the difficulty level had on silent and spoken collaboration, the correlations were studied. Of all of the possible correlations between activity difficulty and silent and spoken collaboration, it is only worth mentioning the correlation between activity difficulty and spoken collaboration in the Cloze mode, which was -0.91 (p-value $= 0.04$), and the correlation between activity difficulty and silent collaboration in the Matrix mode, which was 0.87 (p-value $= 0.94$). Although only the first correlation is significant, it is interesting to note that as difficulty increases, verbal exchanges decreases in the Cloze mode, and non-verbal interactions increase in the Matrix mode. This suggests that there is a relation between difficulty level and silent and spoken collaboration, although further research needs to be done.

5 Discussion

These two studies allowed us to show that the proposed interaction pattern, in which there is a clear separation of roles, promoted silent collaboration over verbal interactions when working with a large group of children in the classroom (first research question); to answer this question we developed an application for the Interpersonal Computer with a shared display that was instrumental in implementing the silent collaboration interaction pattern. These two studies also served to show that it is possible to work with different representation modes (Matrix and Cloze) using this application. Both the Matrix and Cloze modes promoted silent collaboration over spoken collaboration when working with a large group of children in the classroom (second research question). In the Matrix mode there was a progressive increase in the difference between silent and spoken collaboration across the sessions, with this difference remaining positive from the second session on (see Fig. 4). In the Cloze mode, although it did not always increase, the difference between silent and spoken collaboration was also positive from session 2 on (see Fig. 4).

The two studies were designed by taking into account the collaborative conditions referred to in Section 1 (see Table 3). However, these studies were constrained by the context in which they were conducted, including the size of the groups (13 students), the number of sessions (5), and the subjects (literature and grammar), thus conditioning the results that were obtained to a very specific context. Further studies are therefore required with other group sizes, numbers of sessions, and subjects. Examples of collaborative activities in subjects other than literature and grammar that can be carried out include classifying animals in a Matrix according to their habitat and diet in biology; classifying countries in a Matrix according to their continent and Human Development Index in geography; and filling in the blanks in a Cloze exercise to show the results of an arithmetic operation in math.

Despite the aforementioned constraints, the two studies conducted were successful since the students completed of all the activities that were agreed with the school by collaborating and in a reasonable amount of time (as discussed in Section 4.1).

6 Conclusions and Future Work

Large groups need complex coordination and communications mechanisms to collaborate, especially when all of the children in the same physical space work together. Interaction patterns that promote silent collaboration aim to structure the communication between peers and facilitate coordination when solving collaborative activities. This paper has proposed an interaction pattern that helped promote silent collaboration over verbal interactions when studying literature and grammar, showing that it is possible to make large groups of students collaborate in an orderly fashion, and where everyone has to participate. This pattern has been implemented in an application for the Interpersonal Computer with a shared display, in which collaborative activities can be represented in a Matrix or as a Cloze exercise. For the two studies conducted, students could decide to interact using the application or through verbal exchanges. We detected that as they mastered the application, silent collaboration was the preferred method of interaction.

Although this paper presents interesting findings, these were constrained by the particular context of the studies. More research is needed in order to discover the impact of the interaction pattern in both the learning process and collaboration when working with large groups of different sizes and/or activities from different subjects. Moreover, studies that analyze how the difficulty of the activity impacts the collaboration process, and how the mode of representation influences the collaboration are planned for the near future. Finally, an ongoing study addresses the implementation of an authoring tool so that teachers can create their own collaborative activities.

Acknowledgments

This work was funded by CONICYT-FONDECYT 1120177, TIN2011-28308-C03-01, S2009/TIC-1650, and the postdoctoral fellowship Alianza 4 Universidades.

References

[1] (2013). PISA 2015 draft collaborative problem solving framework Tech. Rep.[Online]. Available: http://www.oecd.org/pisa/pisaproducts/pisa2015draftframeworks.htm

[2] P. Dillenbourg, "What do you mean by collaborative learning?," in *Collaborative Learning: Cognitive and Computational Approaches*, P. Dillenbourg, ed., Oxford, UK: Elsevier, pp. 1–19, 1999.

[3] D. W. Johnson, and R. T. Johnson, "Making cooperative learning work,", in *Theory Into Practice,* New York, NY, USA: Springer-Verlag, 1999, vol. 38, no. 2, pp. 67–73.

[4] I. Boticki, L. H. Wong, and C. -K. Looi, "Designing technology for content-independent collaborative mobile learning," *IEEE Trans. Learn. Technol.*, vol. 6, no. 1, pp. 14–24, Jan.-Mar. 2013.

[5] M. Elliott, "Stigmergic collaboration: The evolution of group work," *M/C J.*, vol. 9, no. 2, 2006, http://journal.media-culture.org.au/0605/03-elliott.php

[6] A. Bertucci, S. Conte, D. W. Johnson, and R. T. Johnson, "The impact of size of cooperative group on achievement, social support, and self-esteem," *J. General Psychol.*, vol. 137, no. 3, pp. 256–272, 2010.

[7] O. Marjanovic, "Learning and teaching in a synchronous collaborative environment," *J. Comput. Assisted Learning*, vol. 15, no. 2, pp. 129–138, 1999.

[8] J. W. Strijbos and R. L. Martens, "Group-based learning: Dynamic interaction in groups," in *Proc. 1st Eur. Conf. Comput.-Supported Collaborative Learning*, 2001, pp. 569–576.

[9] R. Miner, "Reflections on teaching a large class," *J. Manage. Educ.*, vol. 16, no. 3, pp. 290–302, 1992.

[10] N. Mercer, *The Guided Construction of Knowledge: Talk Amongst Teachers and Learners*. Philadelphia, PA, USA: Multilingual Matters, 1995.

[11] D. Caballero, S. A. N. van Riesen, S. Álvarez, M. Nussbaum, T. de Jong, and C. Alario-Hoyos, "The effects of whole-class interactive instruction with single display groupware for triangles," *Comput. Educ.*, vol. 70, no. 1, pp. 203–2011, 2014.

[12] D. Hernández-Leo, R. Nieves, E. Arroyo, A. Rosales, J. Melero, P. Moreno, and J. Blat, "Orchestration signals in the classroom: managing the jigsaw collaborative learning flow," in *Proc. 6th Eur. Conf. Technol. Enhanced Learning: Towards Ubiquitous Learning*, 2011, pp. 153–165.

[13] M. L. Guha, A. Druin, and J. A. Fails, "Cooperative inquiry revisited: Reflections of the past and guidelines for the future of intergenerational co-design," *Int. J. Child-Comput. Interact.*, vol. 1, no. 1, pp. 14–23, 2013.

[14] F. Kaplan, S. DoLenh, K. Bachour, G. Yi-ing Kao, C. Gault, and P. Dillenbourg, "Interpersonal computers for higher education," in *Interactive Artifacts and Furniture Supporting Collaborative Work and Learning*, P. Dillenbourg, J. Huang, and M. Cherubini, eds., New York, NY, USA: Springer-Verlag, 2009, pp. 129–145.

[15] R. Martínez-Maldonado, Y. A. Dimitriadis, A. Martínez-Monés, J. Kay, and K. Yacef, "Capturing and analyzing verbal and physical collaborative learning interactions at an enriched interactive tabletop," *Int. J. Comput.-Supported Collaborative Learning*, vol. 8, no. 4, pp. 455–485, 2013.

[16] C. Alcoholado, M. Nussbaum, A. Tagle, F. Gomez, F. Denardin, H. Susaeta, M. Villalta, and K. Toyama, "One mouse per child: Interpersonal computer for individual arithmetic practice," *J. Comput. Assisted Learn*, vol. 28, no. 4, pp. 295–309, 2012.

[17] E. Szewkis, M. Nussbaum, T. Rosen, J. Abalos, F. Denardin, D. Caballero, A. Tagle, and C. Alcoholado, "Collaboration within large groups in the classroom," *Int. J. Comput.-Supported Collaborative Learning*, vol. 6, no. 4, pp. 561–575, 2011.

[18] W. L. Taylor, "Cloze procedure: A new tool for measuring readability," *J. Quart.*, vol. 30, pp. 415–433, 1953.

[19] B.-S. Jong, C.-H. Lai, Y.-T. Hsia, and T.-W. Lin, "Effects of anonymity in group discussion on peer interaction and learning achievement," *IEEE Trans. Educ.*, vol. 56, no. 3, pp. 292–299, Aug. 2013.

[20] M. Trucano, (2010) One mouse per child. *EduTech: A World Bank Blog on ICT use in Edu.* [Online]. Available: http://blogs.worldbank.org/edutech/one-mouse-per-child

[21] M. Miller, "Argumentation and cognition," *Social and Functional Approaches to Language and Thought,* M. Hickmann, Ed. San Diego, CA, USA: Academic, 1987, pp. 225–249.

[22] J. Nielsen, *Usability Engineering*. New York, NY, USA: Morgan Kaufmann, 1994.

[23] N. Bevan and M. Macleod, "Usability measurement in context," *Behaviour Inform. Technol.*, vol. 13, no. 1–2, pp. 132–145, 1994.