PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

ESCUELA DE INGENIERIA

LARGE-GROUP COLLABORATION WITH PRE-DEFINED COLLABORATIVE PATTERNS OF INTERACTION

TAL YOSEF ROSEN

Thesis submitted to the Office of Research and Graduate Studies in partial fulfilment of the requirements for the Degree of Doctor of Engineering Sciences.

Advisor:
MIGUEL NUSSBAUM VOEHL

Santiago de Chile, November, 2015

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To my loved ones; especially to my father, who I know is watching somewhere from above.

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COLABORACIÓN EN GRUPOS GRANDES CON PATRONES DE INTERACCIÓN COLABORATIVOS DEFINIDOS

Tesis enviada a la Dirección de Postgrado en cumplimiento parcial de los requisitos para el grado de Doctor en Ciencias de la Ingeniería.

TAL YOSEF ROSEN

RESUMEN

La colaboración ha sido motivo de gran interés en los últimos años, lo cual se puede ver a través de que ha sido definida como una componente esencial de las habilidades del siglo XXI y porque se ha incluido la resolución de problemas colaborativos al estudio PISA 2015. Es por esto que la inclusión del desarrollo de esta habilidad a la sala de clases es relevante.

El área de Computer-Supported Collaborative Learning (CSCL) ha demostrado en distintos ámbitos que es posible introducir la colaboración en el aula. Sin embargo, la bibliografía presenta trabajos principalmente con grupos pequeños y no con grupos grandes. Las investigaciones se han centrado en analizar cuáles son las acciones necesarias que tienen que hacer los alumnos en forma individual para completar una tarea en particular, y no en las acciones necesarias que debe realizar el grupo completo para trabajar colaborativamente. Por otra parte, cuando grupos grandes trabajan colaborativamente emergen problemas de coordinación y comunicación que hay que tener en cuenta. El objetivo de esta tesis es determinar y analizar patrones de interacción colaborativos explícitos silenciosos para grupos grandes dentro de la sala de clases, que promuevan la colaboración y faciliten la interacción de los integrantes del grupo.

Con el fin de obtener una comprensión sobre la colaboración silenciosa en grupos grandes, se realizaron diferentes estudios. El primero, siendo la aproximación inicial a estos temas, fue un estudio en el cual se analizaron las condiciones necesarias para lograr aprendizaje colaborativo en la sala de clases y en el cual se diseñó e implementó el primer patrón explicito colaborativo silencioso. De aquí, se descubrió que los patrones explícitos colaborativos de interacción sí pueden ser una solución para hacer colaborar a grupos grandes de estudiantes, pero también se encontró que al utilizar este patrón surgían problemas de comportamiento inesperados en los estudiantes. A partir de estos aprendizajes, se diseñó la siguiente experiencia. El objetivo principal del segundo estudio fue extender el dominio de los patrones de interacción explícitos, lo cual se hizo creando un segundo patrón explícito de colaboración silencioso. El último estudio se focalizó en profundizar el conocimiento sobre la colaboración silenciosa, en términos de cómo es influenciada dependiendo en donde se utiliza. Para esto el estudio se realizó en dos contextos distintos, la sala de clases y el laboratorio de computadores.

A partir de los estudios realizados, esta tesis brinda diversos resultados. Los principales son que las dinámicas de colaboración silenciosa presentan una buena usabilidad, lo que demostró que son fáciles de usar y aprender por los estudiantes. Además, estos pueden ser aplicados en diversos ambientes, con diferentes actividades y dinámicas, promoviendo la motivación y participación de los estudiantes. Por último, el espacio físico en donde se utilizan las dinámicas de colaboración silenciosa influye en la calidad de la colaboración, por lo que es relevante considerarlo al momento de llevar la colaboración al aula.

Como esta tesis estuvo enmarcada en un contexto específico en términos de edad de los estudiantes con los que se trabajó, contenidos y actividades, se proponen trabajos futuros en torno a la colaboración silenciosa en distintos niveles educativos, con distintas necesidades curriculares, y de esta manera observar el impacto y alcance que esta tiene. Por otro lado, se observó que la colaboración silenciosa puede ser un buen medio para hacer colaborar a estudiantes con necesidades educativas especiales, por lo que se propone estudiar la colaboración silenciosa en estudiantes con distintas capacidades de aprendizaje.

Esta tesis contó con el apoyo del Centro de Estudios de Políticas y Prácticas para la Educación (CEPPE-UC), CONICYT CIE-01.

Palabras Claves: Colaboración en grupos grandes; Colaboración silenciosa; Single Display Groupware; Shared Display; Computer Supported Collaborative Learning

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ABSTRACT

Collaboration has been an area of great interest in recent years. This is reflected in the fact that it has been defined as an essential component of the so-called 21st century skills, as well as the inclusion of collaborative problem solving in PISA 2015. Given this, it is important that this skill is developed in the classroom.

The field of Computer-Supported Collaborative Learning (CSCL) has shown that collaboration can be introduced into the classroom in different areas. However, the literature primarily reports studies with small groups, rather than in large-group settings. Studies have focused on analysing what actions students must carry out individually in order to complete a specific task, rather than analysing the actions that must be carried out by the whole group in order to work collaboratively. On the other hand, by working collaboratively in large groups, problems with coordination and communication arise that must be taken into consideration. The objective of this thesis is to determine and analyse explicit silent collaboration interaction patterns for large groups within a classroom that promote collaboration and facilitate the interaction of the members of the group.

In order to understand silent collaboration in large groups, various studies were conducted. In the first of these studies, which represented an initial approach to understanding these matters, the necessary conditions for collaborative learning in the classroom were analysed

and the first explicit silent collaboration interaction pattern was designed and implemented. This study revealed that explicit collaborative interaction patterns present a viable solution for having large groups of students collaborate, although it also revealed that using the pattern led to unexpected behavioural issues among the students. This latter point was taken into consideration when designing the following study. The main objective of the second study was to extend the domain of the explicit interaction patterns. This was achieved by creating a second explicit silent collaboration interaction pattern. The final study focused on providing more in-depth knowledge of silent collaboration, in terms of how it is influenced depending on where it takes place. In order to do so, the study was conducted in two different settings: the classroom and the computer lab.

Based on these studies, this thesis provides a series of results. The main findings are that the dynamics of silent collaboration appear to be highly usable, demonstrating that they can be easily learnt and used by the students. Furthermore, these dynamics can be applied in different settings, with different activities and dynamics, while encouraging student participation and motivation. Finally, the physical space in which the dynamics of silent collaboration take place influences the quality of collaboration. This is therefore important to consider when introducing collaboration into the classroom.

As this thesis was framed within a specific context in terms of the age of the students that participated, as well as the contents and activities, future work is suggested based on silent collaboration at different levels of education, and with different curricular needs, so as to observe the scope and impact of silent collaboration. Additionally, it was observed that silent collaboration may be an effective means for having students with special educational needs collaborate. It is therefore recommended that silent collaboration be studied among students with special educational needs and/or students with different learning difficulties.

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Key Words: Large-group Collaboration; Silent Collaboration; Single Display Groupware; Shared Display; Computer Supported Collaborative Learning

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1. INTRODUCTION

This thesis studies large-group collaboration within the classroom. Collaboration has been widely studied in the literature, with the findings showing that collaborative work has advantages over individual work.

There are several difficulties faced by collaborative work. One such difficulty is how to transfer collaboration to the classroom, while another, more practical, difficulty is how to find the necessary tools for collaboration. Additionally, collaborative tools have been focused on small groups, while large groups, which bring their own problems and benefits, have been left out.

1.1 Theoretical background

Collaboration has been a cause of great interest within educational research in recent years (Johnson & Johnson, 2002). It has been defined as an essential component of the so-called 21st century skills (Bruns, 2007), which, as well as the inclusion of collaborative problem solving in PISA 2015 (OECD, 2013), demonstrates the importance of incorporating such problems and skills into the classroom.

1.1.1 Collaboration

Collaboration and cooperation are two subtly different worlds. Cooperation is based more on dividing tasks among participants, with a focus on sub-tasks that are performed individually (Dillenbourg, 1999), with coordination required only at the end in order to bring together the individual results (Dillenbourg, Baker, Blaye & O'Malley, 1996). In this sense, each person is only responsible for a fraction of the problem (Roschelle & Teasley, 1995). Collaboration, on the other hand, is based on a coordinated effort to solve a problem as a group (Roschelle & Teasley, 1995).

Collaborative work is particularly interesting as there are several benefits to it over individual work. When students work collaboratively, they perform better (than when working individually) (Roschelle & Teasley, 1995; Gokhale, 1995; Laal & Ghodsi, 2012; Cen, Ruta, Powell & Ng, 2014), and develop social and communication skills (Laal & Ghodsi, 2012). These benefits are the main motivation for introducing collaborative work into the classroom.

Certain conditions must be met in order for collaborative work to take place. Firstly, there must be a common goal (Dillenbourg, 1999). Secondly, there must be positive interdependence between peers (Johnson & Johnson, 1999), which is the perception that a group member is connecting with the others in such a way that they cannot be successful unless the others are also successful. Thirdly, there must be coordination and communication between peers (Gutwin & Greenberg, 2004) in order to meet the common goal. Fourthly, there must be individual accountability (Slavin, 1996), whereby each member of the group is responsible for their own actions. There must also be awareness of peers' work (Janssen, Erkens, Kanselaar & Jaspers, 2007) so that each member of the group can be aware of the other members' progress. Finally, there must be joint rewards (Axelrod & Hamilton, 1981) so that every member of the group wins or loses equally, with the objective being that everyone wants to maximize their reward.

Collaboration in the classroom

Wallace, Scott, Stutz, Enns & Inkpen (2009) argue that working in a shared, physical space brings huge benefits, such as being more aware of the activity that is taking place and the efficiency of communication. Being in the same physical space creates a community of learners, where the students work with their classmates and teachers to meet the educational objectives, and also each student become responsible for their own learning (Brown & Campione, 1996).

1.1.2 Technology for collaborative problem solving

Collaborative learning (CL) is commonly defined as "a situation in which two or more people learn or attempt to learn something together" (Dillenbourg, 1999, p. 1). One way of achieving CL is through Computer-Supported Collaborative Learning (CSCL), which is the study of how people can learn collaboratively while being mediated by a computer (Stahl, Koschmann & Suthers, 2006). One of the most important aspects of CSCL research is that technology allows the processes of interaction and learning to be analysed in collaborative activities (Cress, Stahl, Ludvigsen & Law, 2015). Also, Roschelle et al. (2004) suggest that CSCL influences learning, motivation and engagement.

Infante, Hidalgo, Nussbaum, Alarcón & Gottlieb (2009) state that there are different ways of implementing CSCL: one such way is to use wirelessly interconnected handheld devices (Single Input/Single Display), while a second is to use Single Display Groupware (SDG) or Multiple Input/Single Display. In the former case, where each student has their own device, the network is used to create a series of small groups, thus enabling different activities to be carried out (Cortez, Nussbaum, Rodriguez, Lopez & Rosas, 2005; Zurita & Nussbaum, 2004). In the latter case, the SDG technology allows several users located in the same physical space to share a single screen using individual input devices (Moraveji et al., 2008). A cost-effective way to work interactively in the classroom is through SDG, using the mouse as an input device. Alcoholado et al. (2012) used SDG in this way so that students could work individually on mathematics exercises.

1.1.3 Large-group collaboration

The literature does not specify the exact number of students that constitute a large group within the classroom. There is a suggestion that large-scale work could be possible with up to thousands of students in an online, synchronous setting, with small-scale work taking place in groups of 2 to 3 students (Dillenbourg, Järvelä & Fischer, 2009). For this reason, large groups will be defined in this thesis as groups of at least 12 students.

The majority of studies to have used CSCL within the classroom have focused on small groups. Zurita & Nussbaum (2004) and Van Diggelen & Overdijk (2007) featured small-group collaboration; Hung, Young & Lin (2009) developed a collaborative game for learning English vocabulary; and Zea, Sánchez & Gutiérrez (2009) created a collaborative game for teaching vowels. In these cases, the research was focused on small groups, where each participant had their own input device. However, there have also been attempts to use CSCL with all of the students in a classroom. CollPad

(Nussbaum et al., 2009) is a system for building responses as a group to open questions defined by the teacher. The students first solve the problem individually, before solving it collaboratively in small groups. The whole class then arrives at a final answer, with the teacher mediating a discussion of the answers obtained by the different groups. Group Scribbles (Roschelle et al., 2007) uses a similar method, where individual work and teacher mediation are used to support and encourage teachers to use new methods of collaboration and coordination in the classroom. Both approaches are characterized by including individual participation and teacher mediation, as well as by the fact that each student has their own personal device, which is wirelessly connected to their classmates' devices.

One study that tried to encourage interaction and coordination in large groups within the classroom using tabletops (interactive tables that are used to collaborate, mainly in small groups) was Martinez-Maldonado, Dimitriadis, Martinez-Monés, Kay & Yacef (2013). However, these are quite expensive and not every school can afford themselves such luxury. When using tabletops, the teacher or the application divides the class into small groups. These groups then have to solve the same problems independently. If the problem is too complex to be solved by the small groups, it is sometimes divided into smaller sub-problems using collaborative patterns such as Jigsaw (Hernández-Leo et al., 2011). However, doing this means that each small group only solves one sub-problem in depth, thus losing perspective of the original problem. Furthermore, there are certain contexts in which complex problems cannot be divided, or in which the teachers explicitly want the students to learn how to work in large groups (Guha, Druin & Fails, 2013).

The use of CSCL supported by SDG is ideal for large-group collaborative activities within the classroom (Pavlovych & Stuerzlinger, 2008). This is particularly the case because the use of these technologies encourages interaction during an activity, as well as participation and engagement among the students (Infante et al., 2009). Using CSCL with large groups allows more robust and varied ideas to be developed (Roschelle et al., 2004). Furthermore, working in large groups provides more information and points of view than individual work, while the group can also motivate an individual student to perform better (Alavi, 1994). Additionally, being in the same physical space and using SDG improves group problem solving (Chung, Lee, & Liu, 2013), while also taking advantage of the teacher's presence in order for them to provide explanations whenever they see fit (Black, 2005).

Despite the multiple advantages, adopting collaborative practices with children in the classroom is a challenge (Boticki, Wong & Looi, 2013; Stanton, Neale & Bayon, 2002). This is especially the case when all of the students in the classroom try to solve a shared problem. In these cases, coordination and communication problems often arise, complicating the collaborative learning process (Bertucci, Conte, Johnson & Johnson, 2010). For example, there are students that refuse to participate (Marjanovic, 1999) and shy students who find it hard sharing their ideas. Furthermore, working in large groups may generate a large number of verbal interactions (Strijbos & Martens,

2001) and interactions that have nothing to do with the activity, especially when working with children. This can lead to a noisy environment (Miner, 1992) that is not suitable for learning.

One possible solution for having large groups collaborate is to use the internet. Curtis & Lawson (2001) explored learning through asynchronous online learning and discovered that, despite there being effective collaboration, there were deficiencies in the communication as it was not face to face. One solution to this was to divide the problem into smaller parts so as to facilitate communication. McBrien, Cheng & Jones (2009) studied a synchronous online distance system and tried to reduce the amount of communication problems by providing different media such as audio, video, chat and shared electronic whiteboards, among others. Despite their satisfaction, the students mentioned that the lack of non-verbal communication lessened their educational experience. Furthermore, there were often problems with the speed of the network, which led to a poor quality of audio and video transfer.

One way that can help solve the problems that are present in a distance learning setting, as well as the problems when introducing collaboration into the classroom detailed above, is to use silent collaboration interaction patterns.

1.1.4 Collaborative interaction patterns

An interaction pattern, or collaboration script (Kobbe et al., 2007), is how the interaction between students in order to solve a collaborative activity is defined. Collaboration is not an innate human skill and therefore requires learning and practice

(Dillenbourg et al., 1999). Furthermore, when a collaborative situation presents itself there is no guarantee that the expected interactions will actually occur (Dillenbourg, 1999). One way of improving the effectiveness of collaborative learning is to structure the students' interactions (Dillenbourg, 2002).

Interaction patterns can be characterized by the following:

a) Their degree of dependency, i.e. the need for each student to communicate and coordinate with the others in order to complete the activity. Weak dependency is when a student within a group can complete the activity on their own. Medium dependency is when the students need each other in order to complete the activity, but where there may be one or more member of the group that does not participate. Finally, strong dependency is when a student cannot complete the activity without active collaboration from all of the other members of the group.

b) How the rules are expressed, i.e. whether or not there are clear rules as to how the students must interact. The rules of an interaction pattern can be explicit or implicit/open. Explicit rules clearly state the way in which the students must interact. Implicit/open rules, on the other hand, leave it up to the students to find ways to collaborate, i.e. there are no pre-defined rules for interacting.

c) The type of communication, i.e. the number of people with which any given student can communicate. This can be 1 to 1, when the communication is between one student and another, and 1 to N, when the communication is between one student and the rest of the group.

d) The size of the group. The number of students that can use the interaction pattern at any one time.

e) The semantics of the action, i.e. the meaning of the actions. For example, "to click" in one interaction pattern could mean to ask for help, while in another it could mean to end a turn or move.

Examples of the aforementioned characteristics are detailed in Table 1-1 below.

Table 1-1: Examples of collaborative interaction patterns.

	Degree of dependency	Expression of the rules	Type of communication	Group size	Semantics
Caballero et al. (2014)	Medium	Open	1 to N	6	Moving the cursor means moving the vertex of a triangle
Zea, Sánchez & Gutiérrez (2009)	Strong	Explicit	1 to N	5	Filling out the sequence means building a vowel
Bonnard et al. (2012)	Weak	Open	1 to N	3	Moving a card means changing the classificati on of a shape
Rick et al. (2010)	Weak	Open	1 to N	2	Moving an object means changing the time or space
Liu & Wu (2011)	Weak	Explicit	1 to 1 & 1 to N	Not specified	There are none

In Caballero et al. (2014) the objective was to create and classify triangles. In order to do so, each student had a mouse cursor, which, when joined with the cursor of at least one other member of the group, formed the vertex of a triangle. The only possible action that could be performed by the students was to move their cursors until they formed a triangle. The degree of dependency is medium as it was possible for one of the group members not to participate and for the group to still complete the activity. The expression of the rules is open, as the way in which the students have to interact is not defined. This is because at the beginning of the activity an instruction is given to the students such as "build an isosceles triangle", but this could be achieved by communicating verbally, using signs or even communicating through the software. The type of communication is 1 to N, as every action that is carried out by a member of the group can be seen immediately by the whole group. The group size was defined as being up to 6 students and the semantics were based on the fact that moving the cursor represented a change in the position of the vertices in a triangle. The study by Zea et al. (2009) sets out a game for teaching vowels. Each student must fill out blank spaces until forming the vowel that has been requested. The degree of dependency is strong, as in order to advance from one activity to the next, all of the students in the group must complete the activity and be given feedback. The expression of the rules is explicit as there is only way to communicate, which is giving feedback and validating a classmate's work using the software. The type of communication is 1 to N, as every member of the group is aware of their classmates' work. The group size was defined as 5 students and the semantics were based on the fact that filling out blank spaces in a given sequence represents building a vowel. The work by Bonnard et al. (2012)

describes a study for teaching the classification of geometric shapes using technology through means of a projector that projects an image onto a table, as well as physical paper cards. The possible actions for the students consisted in moving the physical paper cards, which represented a geometric shape, and placing them on the projected image on the table according to the classification that was requested. The degree of dependency is weak as any student in a group could finish the activity on their own. The expression of the rules is open as there is not a clear definition of the way in which the students have to coordinate and communicate with one another. The type of communication is 1 to N as the members of the group were physically next to each other and, therefore, any communication by a group member is immediately received by the others. The group size was defined as 3 students and the semantics were based on the fact that moving each physical card represents a change in the classification of that shape. Rick et al. (2010) describe a study using tabletops to teach young children about space and time by ordering objects on the interactive table. In one activity, the students had to arrange certain events so as to demonstrate a perception of time. In another activity, they had to arrange tables and chairs within a virtual classroom in order to demonstrate a perception of space. The degree of dependency is low as any student could finish the activity on their own, without needing their classmates. The expression of the rules is open as the way in which the students have to coordinate and communicate with each other is not made explicit. The type of communication is 1 to N as the members of the group are physically next to one another, and therefore, they are able to see each other’s work. The group size was defined as 2 students and the semantics were based on the fact that moving each object on the interactive table represents a change in either time or space. The final example is the work by Liu & Wu (2011), which used an online game to teach students about software engineering through a series of questions and answers. The degree of dependency is low as the students can advance through the game without needing any help. The expression of the rules is explicit as the students can only interact with one another through the game's chat service. The communication can be 1 to 1 or 1 to N as the chat could be private or public. The group size is not mentioned, but it was designed as a multiplayer game, suggesting that it can support groups of up to at least 6 students. The game does not feature any semantics as in order to advance through the game the students had to directly answer questions relating to programming.

In addition to these characteristics, interaction patterns can support collaborative work in different ways. In the research by Pinelle, Gutwin & Greenberg (2003), the terms teamwork and taskwork are defined. Teamwork is defined as the actions that are required in order to complete a task as a group. Taskwork, on the other hand, is defined as the actions that are needed in order to complete a task (generally as individual students), i.e. the tasks that must be completed by an individual within a group (Wallace, 2012). This is related to interaction patterns, as different interaction patterns support teamwork in different ways, such as coordination, communication and maintaining awareness of the activity (Wallace et al., 2009). To exemplify these terms, in Alcoholado et al. (2012) taskwork is made explicit by virtue of every student having their own individual space on the shared display where they can complete mathematics exercises individually. In this case, teamwork does not exist as the students work independently. In Wallace, Scott, Lai & Jajalla (2011) a study was conducted with groups of 3 students using multiple screens. This study involved a task called Job Shop Scheduling, which consists of emulating a process for optimizing the output of a manufacturing plant. In this study, each student had a laptop which displayed information that was only visible to them and where they completed their taskwork. Furthermore, each group had a shared screen where they could discuss and negotiate the decisions made by each student, i.e. the shared screen was there to support teamwork.

1.1.5 Silent collaboration

Computer-mediated communication (CMC) is defined as any human communication that takes place using an electronic device (McQuail, 2005). Silent collaboration can be placed within the field of CMC as it uses a computer in order mediate communication, without the need for spoken communication. This is one solution that allows large groups of students to collaborate when spoken communication is difficult (Chapter 2). Silent collaboration is ideal for solving problems that arise when collaborating in large groups. Some of the advantages of CMC include giving students more time to think before giving an opinion (compared to face-to-face communication) (Moore, 2002), reducing conflicts between team members (Bhappu & Crews, 2005) and allowing students to participate more equally (Van Der Meijden & Veenman, 2005).

Given the above, our first research question asks: “How can large groups collaborate simultaneously in the classroom using an explicit interaction pattern?” Unlike the studies described above (Table 1-1), this study is based on working with large groups, rather than small groups or dividing the problem into sub-tasks.

1.1.6 Collaborative configurations

Activities are a set of planned actions led by teachers and/or students, inside or outside the classroom, individually or in groups, where the final goal is to meet the teaching aims and objectives (Recursos, 2015). Such activities can be represented in different ways. For example, when teaching Spanish grammar, activities are used in which the blank spaces in a text must be filled out, using words from a set list, or activities in which phrases from two columns must be joined so that the resulting phrase is coherent. There is a wide range of different possible activities (Harris, Mishra & Koehler, 2009). Examples of studies using activities within education include Szewkis et al. (2011), who introduces Spanish grammar activities using a word grid to classify words, and Alcoholado et al. (2012), who introduces addition activities in mathematics using number grids.

The concept of collaborative configuration will be defined as an interaction pattern and the corresponding type of activity, or mode of representation, used by an application. To exemplify the concept of collaborative configuration, the study by Caballero et al. (2014) uses a configuration that features an interaction pattern with an open expression of the rules (Table 1-1), and mathematics activities based on creating triangles.

Based on the above, our second research question asks: “Can large-group collaboration in the classroom be implemented using different silent collaboration configurations (dynamics/activities)?" Answering this question will allow the advantages of collaborating in large groups to be reinforced, as well as mitigating the aforementioned problems that come with such collaboration.

1.1.7 Settings

We define the setting as being the physical space in which an application is set and used. Today, the majority of face-to-face collaborative applications are being used in the classroom or computer lab, which generally have computers with multiple input devices (keyboard and mouse) that are set out one next to the other (traditional configuration of a computer lab) (Zurita & Nussbaum, 2004). The different physical spaces (settings), impact the use of technology (Shannon & Cunningham, 2009). Furthermore, the setting can also influence the interaction and therefore the group's learning (Mercier, Higgins & Joyce-Gibbons, 2014).

Within the literature, the researchers that have shown the most interest in how the setting influences learning have been those that work with tabletops (interactive tables that can be used for collaboration, mainly in small groups). For example, Antle, Bevans, Tanenbaum, Seaborn & Wang, (2011) studied how, when working with tabletops, different layouts change the way in which students interact with the technology. In the work of Higgins, Mercier, Burd & Hatch (2011), where the use of tabletops in education is analysed, the authors explain that the majority of existing studies are based on the interaction between the human and the computer, i.e. how people interact when using the technology, but that there is little information about how these interactions might affect learning.

Furthermore, there are few studies in which the research topic refers to directly relating learning outcomes with the setting in which the learning takes place, such is the case in Inayat, Amin, Inayat & Salim (2013). In this study, the authors look at the role of collaboration in a web-based application for college students and its impact on learning. Another example is Brooks (2011), who studied the relationship between learning environment and learning gains, by assessing two classes taught by the same teacher but changing the physical spaces.

Given the above, it could be suggested that the literature focuses on collaborative interactions and that there is little information on how this might affect learning and how it relates to the physical space in which it takes place. Furthermore, there is little information and evidence regarding the relationship between settings and silent collaboration. This gives rise to the third research question, which asks: "How do the setting (physical space) and technology affect silent collaboration?"

1.2 Objectives

The objectives of this thesis are the following:

a) To design and validate explicit mechanisms for silent collaboration interactions where large groups collaborate simultaneously in the classroom.

b) To design and validate different collaboration configurations by studying the behaviour of the different explicit mechanisms for silent collaboration interaction patterns.

c) To study how the different explicit mechanisms for silent collaboration interaction patterns behave under different conditions (technology/setting/type of activity).

These specific objectives are in line with the general objective of the thesis, which is to study explicit mechanisms for silent collaboration interaction patters that enable and encourage large-group collaboration within the classroom.

Given the above, this thesis looks to add to the literature by 1) generating explicit, silent collaboration interaction patterns, by developing new teamwork strategies, where the whole class works on the same task in large groups, and 2) analysing the advantages and disadvantages of silent collaboration and demonstrating the benefit of working with silent collaboration in the classroom or computer lab.

1.3 Research questions

The following research questions therefore guide this thesis:

a) How can large groups collaborate simultaneously in the classroom using an explicit interaction pattern?

b) Can large-group collaboration in the classroom be implemented using different silent collaboration configurations (dynamics/activities)?

c) How do the setting (physical space) and technology affect silent collaboration?

1.4 Research hypotheses

The following hypotheses were used to frame the work conducted for this thesis:

a) Explicit silent collaboration interaction patterns, allow large-group collaboration in the classroom.

b) There is at least two different silent collaboration configurations that can be implemented using explicit silent collaboration interaction patterns, while maintaining the conditions that favour large-group collaboration in the classroom.

c) The setting and technology affect the results in terms of collaboration and learning.

1.5 Methodology

The methodology that was used to carry out this project was based on Design-Based Research (Design-Based Research Colective, 2003). Design-Based Research is a model that looks to study complex problems in real-life educational settings (Alvarez, Alarcon & Nussbaum, 2011). The methodology consisted of the following steps:

a) Design and development of the interaction pattern

To start with, a review of the literature and/or real-life collaborative situations was conducted in order to look for indications as to what is essential in a collaborative interaction pattern. The pattern had to meet the conditions for collaboration and allow students to collaborate silently. This is detailed in sub-sections 2.2 and 2.3, where the necessary conditions for successful collaboration and their importance are analysed. These conditions are also mentioned in sub-sections 3.2 and 4.2, as well as in the introduction to Annex A, as the conditions for collaboration are important when it comes to designing any sort of element that is related to collaboration, whether it be the interaction pattern or type of activity.

b) Design, development and validation of the collaborative learning software

In this stage, the software was designed and implemented, based on the design from point a) above, so that that the system would adapt to the desired educational goals. The software design process can be found in sub-sections 2.4, 3.3 and 4.3, as well as in the sub-section titled ‘Description of the tools used’ in Annex A. Fulfilment of the collaboration conditions for each software is analysed in tables 2-1, 3-3 and 4-3, as well as Table 4 in Annex A. Following this, it was necessary to start with a cycle of testing, during which time it was validated that the system worked correctly. In order to do so, the system had to be tested in a setting that was as close as possible to the real setting until there were no errors and all of the established usability functions and parameters had been met. This was done at least once for each piece of software (unless errors were found) using students from a school other than the one where the study took place.

c) Design, development and validation of the educational instruments

Although the project consisted of developing collaborative systems that allowed pre-defined interaction patterns to be promoted, it must not be forgotten that this was done in an educational context. For this reason, activities that were pedagogically appropriate for the context had to be designed and developed. These activities also had to be coherent with the school's own curriculum. The activities were conducted with students in 6th grade using language arts topics such as grammar and reading comprehension. However, when designing the activities, care was also taken to ensure that they could be adapted for other topics and/or grade levels. Details of the activities that were carried out can be found in sub-sections 2.5, 3.4 and 4.3, as well as in the 'Methodology' section of Annex A. The activities included in Annex A featured activities for teaching mathematics. The types of activities that were used (matrix and cloze) can be used for multiple subjects (for example, they could be used for classifying countries and cities for geography, or for completing sequences of a process in natural sciences). In addition to the activities, as the study was conducted in an educational setting, the learning also had to be measured. In order to do so, a multiple choice and/or fill-in-the-blanks test was developed. This test was administered before the intervention (pre-test), as well as after the intervention (post-test) in order to measure possible learning gains. This is detailed in sub-sections 2.5, 4.4 and 4.5, as well as in the 'Results' section of Annex A. The aforementioned instruments had to be validated before they could be used in the full study. In order to do so, the activities were validated by teachers from the schools that participated in the study, while the test was validated in a school that was not involved in the study. This was done at the same time as the validation of the software mentioned in b).

d) Experimentation

Once the collaborative system and educational instruments had been validated, the study was conducted. In order to do so, previous coordination work had to be carried out with the school. The distribution of the experimental and/or control groups depended on whether or not the study aimed to compare two technologies and one or two interaction patterns. This process is detailed in sub-sections 2.5, 3.4 and 4.3, as well as in the 'Methodology' section of Annex A. In general terms, the study in chapter 2 featured a control group and experimental group, while the studies in chapters 3 and 4, as well as Annex A, featured two experimental groups in order to compare two technologies or two interaction patterns.

e) Data gathering

In this stage, the data obtained during the experimentation stage was gathered, classified and organized. Data was taken from the software logs, classroom observations, pre- and post-tests, as well as recordings and surveys. The logs provided the number of correct and incorrect answers and the number of silent collaboration events, among others. The observations provided information on variables such as boredom, competition, spoken collaboration, disruptions, questions about the software, and tiredness, among others. This was done so as to assess progress and differences in behaviour and collaboration for the applications that were implemented as a result of the chosen silent collaboration interaction patterns. This is detailed in sub-sections 2.5, 3.4, 4.3 and 4.4, as well as in the 'Methodology' section of Annex A.

f) Data analysis and writing papers

Finally, the gathered data was analysed so as to draw conclusions and prove or disprove the original hypotheses. This is detailed in sub-sections 2.5, 2.6, 3.5, 3.6, 3.7, 4.5, 4.6 and 4.7, as well as in the 'Results', 'Discussion' and 'Conclusions' sections of Annex A. Furthermore, this process led to papers being written, showcasing the results that were obtained.

By being based on Design-Based Research, this thesis followed an iterative design methodology, both for developing the software as well as for conducting the studies, taking into account the knowledge that was acquired during each study.

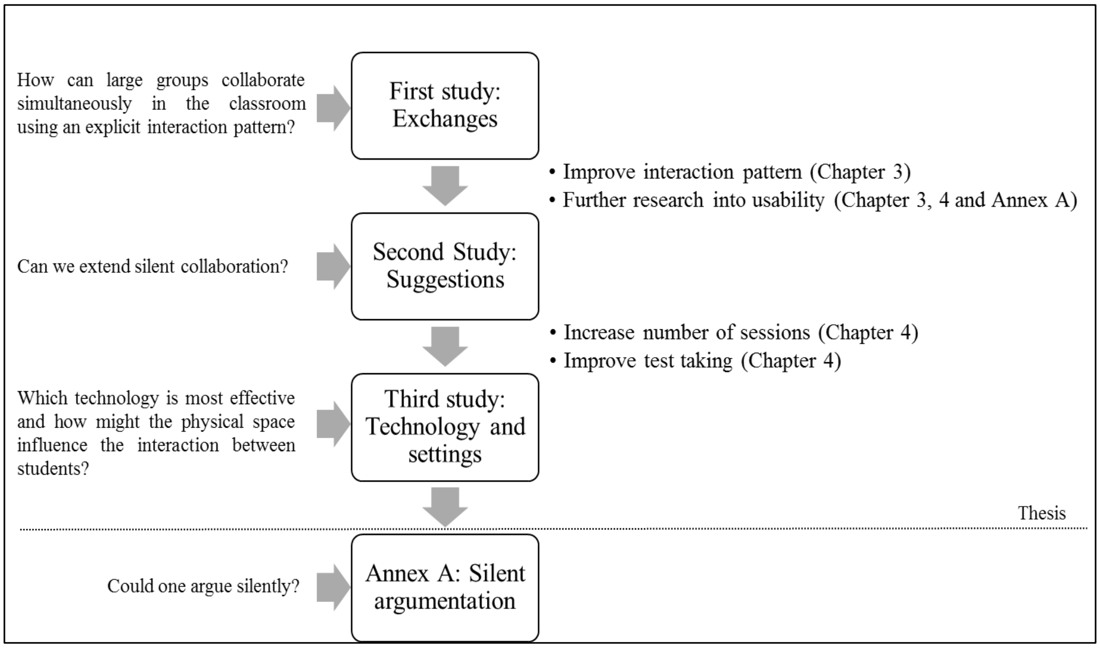

Figure 1-1: Iterative design, questions and improvements

The first iteration was useful for developing the concept of silent collaboration and creating the first pre-defined collaborative interaction pattern (Chapter 2). It was observed that the pattern served its purpose but, due to its design, the students tended to put unnecessary pressure on one another by raising their voice. This led to the creation of a second interaction pattern, as well as the question of how to extend silent collaboration (Chapter 3). Finally, having seen the potential for silent collaboration, the question was asked as to which technology is most effective for silent collaboration and how might the physical space in which the interaction pattern is used influence the interaction between students (Chapter 4). Finally, a fourth study was conducted (Annex A). Following the previous studies, it was still left as pending to show that it was possible to work with silent collaboration in various settings, grade levels and subjects. Furthermore, a more in-depth study of silent collaboration was pursued by creating a dynamic that allowed for argumentation to take place silently. This was done because exposure to collaborative argumentation can help students learn to think critically and independently about important issues and contested values, as well as contributing to deeper conceptual learning and helping develop social awareness and collaborative ability in more general terms (Andriessen, Baker & Suthers, 2013). This problem is related to the thesis as it uses silent collaboration and showed that silent collaboration can be used in various contexts. This study featured students from 3rd grade studying topics related to mathematics. The objective was to try and compare how student behaviour changes between students working in small groups through spoken collaboration, versus silent collaboration. In order to do so, the use of silent argumentation with the students that were collaborating silently was explored.

1.6 Results

The studies in this thesis have produced a series of results that are described below:

a) One solution for having large groups collaborate in the classroom is to use explicit silent collaboration interaction patterns (sub-section 2.6).

b) The dynamics of silent collaboration are easy to use and learn. Furthermore, they increase student motivation and participation, usually boosting learning (sub-sections 2.5, 2.6, 3.5, 3.6, 4.5 and 4.6).

c) There are at least two different collaborative configurations (dynamics/activities) in which silent collaboration can be implemented. Furthermore, these configurations generate an environment that is both silent and suitable for learning (sub-sections 3.5 and 3.7).

d) There is a relationship between the difficulty of an Activity and the collaboration events that arise when trying to solve the problem (sub-section 3.5).

e) When comparing SDG in the classroom with PCs in network in the lab, we observe that the technology that is used for silent collaboration and the setting or physical space in which silent collaboration takes place, has an impact on the number of collaboration events and also affects the quality of the collaboration (sub-sections 4.4, 4.5, 4.6 and 4.7).

In the fourth study (Annex A), the results showed that silent collaboration led to improved results (compared to spoken collaboration), but the silent argumentation tool that was proposed was not used as expected.

1.7 Thesis outline

This thesis is based on three studies that were carried out in order to meet the proposed objectives that are detailed above. The focus of each chapter is described below:

a) Chapter 2

The focus of this chapter is on putting forward a solution to show that it is possible for large groups of students to collaborate synchronously within the classroom. The theoretical framework of this chapter includes the conditions that are necessary for carrying out collaborative work. A collaborative interaction pattern called Exchanges was defined and tested. The experimental setting consisted of a control group where the students worked only with conventional non-digital resources, which consisted of guides for both teachers and students on the language contents to be assessed; the experimental group by contrast, spent 60% of the time with the same conventional non-digital resources and 40% of the time with the CSCL system. The ease with which the students could learn to use the software was then analysed. Following this, the manner in which the collaboration conditions were met was described and the impact on learning was evaluated. Finally, the impact of silent versus spoken collaboration was analysed. The findings of this chapter show that using explicit silent collaboration interaction patterns is one possible solution that allows large groups to collaborate within the classroom. The findings also showed that this dynamic helped increase student motivation and participation, boosting learning. The chapter was based on Paper 1: Collaboration between large groups in the classroom.

b) Chapter 3

The focus of this chapter is on showing that silent collaboration is possible through several different collaborative configurations (dynamics/activities). A new explicit collaborative interaction pattern called Suggestions was developed and tested. A usability test was conducted, as well as a comparison between silent and spoken collaboration (using two pieces of software that featured the same dynamic but differed in the type of activity that they used. This activity has similar cognitive processes from the one presented in chapter 2: to identify, sort and classify. But differs in that this activity requires an understanding of the context before it can be resolved). The way in which the conditions for collaborative learning were met was also described. The findings from this chapter show that it is possible to create different collaborative configurations using silent collaboration. They also show that these configurations promote a silent environment that is suitable for learning. Furthermore, they reveal that there is a relationship between the difficulty of a problem and the number of collaboration events that are produced when trying to solve the problem. This chapter was based on Paper 2: Silent collaboration with large groups in the classroom.

c) Chapter 4

The focus of this chapter is on analysing the impact that the physical space and technology have on factors such as learning and collaboration. A usability test was conducted and the way in which the conditions for collaborative learning were met was described. Finally, the impact on learning was evaluated and a comparison was made between spoken and silent collaboration using two applications that used the same interaction pattern but differed in terms of the physical space in which they were used. The findings from this chapter show that the technology used for silent collaboration has an impact on the number of collaboration events. They also show that the physical space affects the quality of collaboration. This chapter was based on Paper 3: The impact of technology in large group collaborative learning.

1.8 Thesis structure

The structure of this thesis is based on the research objectives described in section 1.2. Table 1-2 provides a summary of the objectives, hypotheses, research questions, papers and results that are included in this thesis. Figure 1-1 provides a model to demonstrate the connections between these components.

Table 1-2: Summary of the thesis structure

Hypotheses	
H1	Explicit silent collaboration interaction patterns, allow large-group collaboration in the classroom.
H2	There is at least two different silent collaboration configurations that can be implemented using explicit silent collaboration interaction patterns, while maintaining the conditions that favour large-group collaboration in the classroom.
H3	The setting and technology affect the results in terms of collaboration and learning.
Research Questions	
Q1	How can large groups collaborate simultaneously in the classroom using an explicit interaction pattern?
Q2	Can large-group collaboration in the classroom be implemented using different silent collaboration configurations (dynamics/activities)?
Q3	How do the setting (physical space) and technology affect silent collaboration?

Objectives	
O1	To design and validate explicit mechanisms for silent collaboration interactions where large groups collaborate simultaneously in the classroom.
O2	To design and validate different collaboration configurations by studying the behaviour of the different explicit mechanisms for silent collaboration interaction patterns.
O3	To study how the different explicit mechanisms for silent collaboration interactions behave under different conditions (technology/setting/type of activity).
Papers	
P1	Collaboration between large groups in the classroom. The authors are Szewkis, E., Nussbaum, M., Rosen, T., Abalos, JP., Denardin, F., Caballero, D., Tagle, A. and Alcoholado, C. It was published in 2011 in the International Journal of Computer Supported Collaborative Learning (6:561–575) and can be accessed digitally through DOI 10.1007/s11412-011-9123-y.
P2	Silent collaboration with large groups in the classroom. The authors are Rosen, T., Nussbaum, M., Alario-Hoyos, C., Readi, F. and Hernandez, J. It was published in 2014 in the journal IEEE Transactions on Learning Technologies (7:197-203) and can be accessed digitally through DOI 10.1109/TLT.2014.2318311.
P3	The impact of technology in large group collaborative learning. The authors are Rosen, T., Nussbaum, M., Peña, D., Contreras, J., Torres, J. and Oteo, M. Submitted for publication in the journal Educational Technology & Society.
P4	Annex A: Silent vs. Spoken collaboration in small groups for numbering practice. The authors are Rosen, T., Nussbaum, M.,

	Contreras, J., Torres, J. and Oteo, M. Submitted for publication in the journal Computer Assisted Learning.
Results	
R1	One solution for having large groups collaborate in the classroom is to use explicit silent collaboration interaction patterns.
R2	The dynamics of silent collaboration are easy to use and learn. Furthermore, they increase student motivation and participation, usually boosting learning.
R3	There are at least two different collaborative configurations (dynamics/activities) in which silent collaboration can be implemented. Furthermore, these configurations an environment that is both silent and suitable for learning.
R4	There is a relationship between the difficulty of an Activity and the collaboration events that arise when trying to solve the problem.
R5	When comparing SDG in the classroom with PCs in network in the lab, we observe that the technology that is used for silent collaboration and the setting or physical space in which silent collaboration takes place, has an impact on the number of collaboration events and also affects the quality of the collaboration.

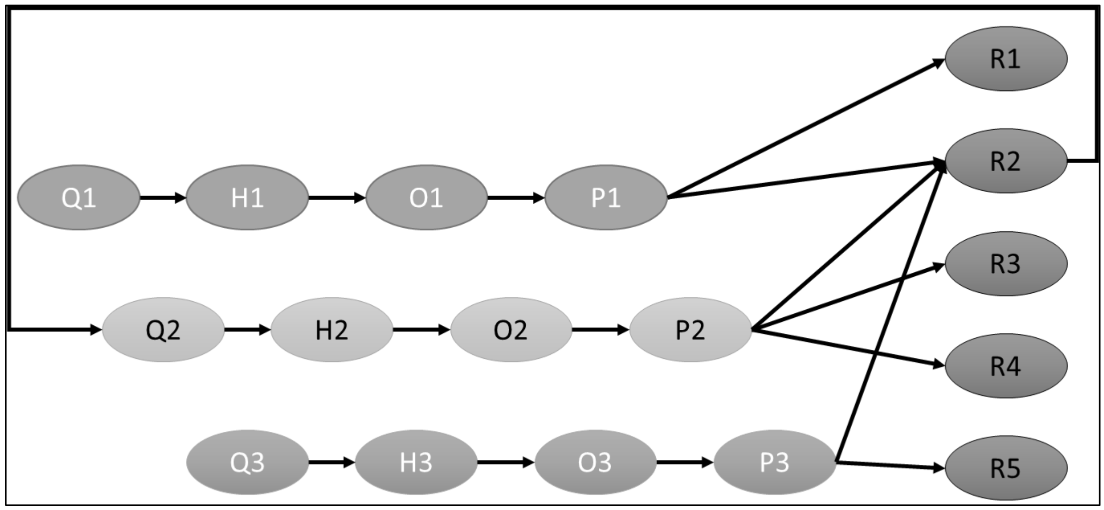

Figure 1-2: Connections between the research questions, hypotheses, objectives, papers and results.

2. COLLABORATION WITHIN LARGE GROUPS IN THE CLASSROOM

2.1 Abstract

The purpose of this paper is to show how a large group of students can work collaboratively in a synchronous way within the classroom using the cheapest possible technological support. Making use of the features of Single Display Groupware and of Multiple Mice we propose a computer-supported collaborative learning approach for big groups within the classroom. The approach uses a multiple classification matrix and our application was built for language-learning (in this case Spanish). The basic collaboration mechanism that the approach is based upon is "silent collaboration," in which students -through suggestions and exchanges- must compare their ideas to those of their classmates. An exploratory experimental study was performed along with a quantitative and qualitative study that analyzed ease of use of the software, described how the conditions for collaborative learning were achieved, evaluated the achievements in learning under the defined language objectives, and analyzed the impact of silent and spoken collaboration. Our initial findings are that silent collaboration proved to be an effective mechanism to achieve learning in large groups in the classroom.

2.2 Introduction

Many authors have claimed that collaboration has become an important subject in the area of education (Johnson & Johnson, 2002; Roschelle & Teasley, 1995). It has been defined as an essential component of twenty-first century skills (Bruns, 2007), and thus its adaptation to the classroom is crucial.

Social interaction and the ability to share and consider other points of view add a component that is not present in individual learning. Vygotskian and Piagetian researchers have inferred that “development may occur when two participants differ in terms of initial level of competence about some skill or task, work collaboratively on it, and arrive at shared understanding” (Tudge, 1992). Collaborative learning can be very effective and useful (Gokhale, 1995), because it can develop generic communication, collaboration and team building skills, as well as assisting teachers in the management of the class (Allen et al., 2006).

Computer-supported collaborative learning (CSCL) studies how people can learn collaboratively while being mediated by a computer (Stahl et al., 2006). Several initiatives have been implemented in CSCL for the classroom and some examples of these experiences are described by Zurita & Nussbaum (2004) and Van Diggelen & Overdijk (2007) who performed small group collaborations; Hung et al. (2009) who developed a collaborative English vocabulary-acquisition-game system; and Zea et al. (2009) who made a collaborative video-game to teach vowels. In these cases, the research focused on small groups, where each participant had his own device.

We can also find examples of CSCL in large groups. An illustrative case is Wikipedia, a free online encyclopedia written collaboratively by thousands of contributors from around the world (Kittur & Kraut, 2008). There are also experiments using Massively Multiplayer Online Games (MMOGs). Girvan & Savage (2010) used the virtual world Second Life in order to examine how communal constructivism could be an appropriate collaborative pedagogic tool, and Bennerstedt & Linderoth (2009) studied how collaborative interaction takes place among players in an MMOG game. A final example is Jara et al. (2009), who worked with virtual laboratories, a web-learning resource which incorporates collaborative learning practices through the Internet.

Wallace et al. (2009) argue that working in a common physical space can provide great benefits, such as “improved activity awareness and coordination, improve communication efficiency by enabling non-verbal communication such as gestures, and facilitate grounding via a shared visual reference.” A knowledge community, where students work with their peers and teachers on their goals in the same space makes all students accountable for their learning (Brown & Campione, 1996). Beers et al. (2007) indicate that for collaborative learning to be effective, individual learners have to achieve a sufficiently common cognitive frame of reference that does not appear by itself, but has to be negotiated. Technology can support this process, and (Roschelle et al., 2004) indicate that CSCL influences learning, motivation, commitment and the development of mutual understanding, and that CSCL for large groups, such as a whole classroom, allows the development of more robust and more varied ideas.

Single Display Groupware (SDG) allows multiple collocated users, each with his own input device, to share a common screen (Moraveji et al., 2008), which is useful when developing a collaborative activity where interaction with each member of a large group within the classroom is desired (Pavlovych & Stuerzlinger, 2008). It has also been shown that when several users, each with his own personal input device but with a shared screen, have to interact to complete an activity, there is greater participation and student engagement (Infante et al., 2009; Scott et al., 2003).

The quality of this engagement depends on the metacognitive awareness developed through a reciprocal process of exploring one another's viewpoints in order to construct a shared understanding. The tasks chosen need to be appropriate to the capabilities of the learners' requirements and to the collaboration process, and structured so that children must work together for successful completion (Nussbaum et al., 2009). Collaboration should occur among children with different skill levels or perspectives, which would create the socio-cognitive conflict necessary from a Piagetian perspective, and so providing the cognitive restructuring that underpins cognitive change (Fawcett & Garton, 2005; Teasley, 1995).

Besides the web-based collaborative approaches previously indicated, there have been a number of attempts at achieving CSCL with all students in the classroom. CollPad (Nussbaum et al., 2009) is an open-ended-question constructivist approach; students first solve the problem individually, then in small groups work collaboratively to reach a collective answer, based on their replies, and finally the teacher guides a classroom discussion founded in the small-group answers in order to reach the task aim. Group Scribbles (Roschelle et al., 2007) mainly uses the first and last phases of the previous method (individual work and teacher-mediated whole class discussion) and aims to support teachers in inventing and enacting new forms of collaboration and coordination in the classroom. Both approaches are characterized by the teachers' active mediation for student sequential participation in whole classroom synchronous discussion, each student having a personal device, which is wirelessly interconnected with the others. In this paper we will show that, working with one mouse per person and sharing a common screen, it is possible to get all students in a classroom to actively and collaboratively participate asynchronously in a task under teacher supervision, at a much lower cost than if each of them were using a personal device, thus making it an attractive technology, especially when resources are scarce (Pawar et al., 2006).

Making use of the features of SDG and of Multiple Mice we propose a CSCL approach for big groups within the classroom, with low hardware infrastructure costs. First, we will analyze the conditions for collaboration. Second, we will demonstrate an approach for silent collaboration using an interpersonal computer that makes use of large group collaboration in the classroom, and an application for language-learning concepts. Third, we will describe the experimental work performed as well as the qualitative and quantitative results of these experiments, and finally we will present the conclusions of this paper

2.3 Conditions for collaborative learning

It is not easy to achieve learning through massive collaboration in the classroom as certain conditions must exist that allow such activities to be conducted successfully. These are: the existence of a common goal (Dillenbourg, 1999), positive interdependence between peers (Johnson & Johnson, 1999), coordination and communication between peers (Gutwin & Greenberg, 2004), individual accountability (Slavin, 1996), awareness of peers' work (Janssen et al., 2007) and joint rewards (Axelrod & Hamilton, 1981). In what follows, we analyze the importance of each of these conditions.

Common goal: To characterize a situation as collaborative, there must be a common goal (Dillenbourg, 1999). Members of a group who make the effort to solve a problem together achieve learning through collaboration as a result of the social interactions that it generates (Zurita & Nussbaum, 2004; Roschelle & Teasley, 1995).

Positive interdependence: Positive interdependence is defined as “the perception that we are linked with others in away so that we cannot succeed unless they do” (Johnson & Johnson, 1999). Even when there is a common goal that requires peer interdependence, its effect is greater when the group-mates interact amongst themselves, as opposed to working individually (Johnson & Johnson, 2009). In positive goal interdependence, students realize they can be successful in achieving their goals only if all their peers are also successful (Brush, 1998).

Coordination and communication: Malone & Crowston (1990) define coordination as "the act of managing interdependencies between activities performed to achieve a goal". Coordination ensures that interactions occur in the right order and at the right time, avoiding the loss of communication and cooperation efforts (Raposo et al., 2001; Gutwin & Greenberg, 2004). Without proper communication, it is impossible to achieve successful collaboration (Spada et al., 2005).

Individual accountability: When a group member performs an action and all the other members observe the consequences, they are accountable before their peers for this action (Janssen et al., 2007; Johnson & Johnson, 1999). In this way the role of each individual is reinforced to ensure proper contribution to the joint work (Slavin, 1996).

Awareness: To carry out a collaborative activity successfully, there must be an awareness mechanism that allows group members to obtain information about the current state of their peers (Zurita & Nussbaum, 2004). In this way, all participants receive common feedback, which supports their decision making processes (Gutwin & Greenberg, 2004; Janssen et al., 2007).

Joint rewards: When all group members receive either rewards or punishments, i.e., depending on the result all players win or lose alike, they will look to maximize their joint utility and so generate a scenario where collaboration will prevail (Zagal et al., 2006).

2.4 Silent collaboration with an interpersonal computer

Our aim was to make a large group of students work collaboratively in a synchronous way within the classroom using the cheapest possible technological support. To achieve this we used a PC, a projector and one mouse for each group member. In this way, we built an Interpersonal Computer (Kaplan et al., 2009) that allowed personal input and feedback for each student.

The task we worked with was a multiple classification matrix, which refers to "the ability to define a class [of objects] by two or more attributes simultaneously" (Parker et al., 1971) and is considered one of the most important research topics in Piagetian theory (Inhelder & Piaget, 1964). In the activities, each student received an object (a word or image), initially positioned out of place in a cross-classification matrix. Through exchanges with other peers they must place the objects where they belong.

Game logic: Silent and spoken collaboration

Given that our goal is to make every student present in the classroom participate simultaneously using an Interpersonal Computer, we propose a "silent collaboration" approach, where students must compare their ideas to those of their classmates, through suggestions and exchanges.

The interpersonal computer presents students with a space for common interaction, where objects within across-classification matrix are initially distributed at random, Figure 2-1. Each child is assigned one of these objects, and their task is to place it in the correct position, depending on the characteristics specified by the heading of the corresponding line and column. In order to move an object, the child must exchange it for one allocated to one of their peers.

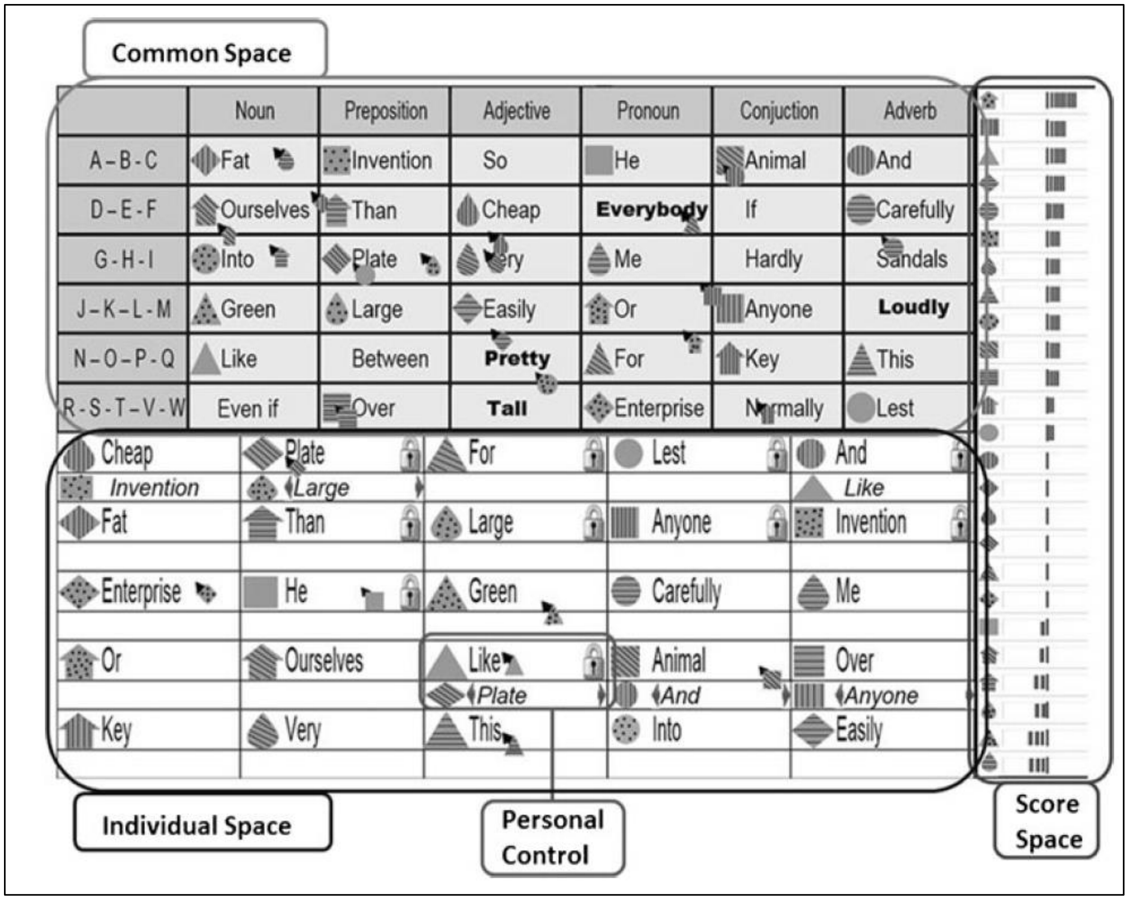

Figure 2-1: Layout of the game

Considering that students who wish to exchange objects may not be sitting next to each other in the classroom, which would make verbal communication between them difficult, we have created a simple negotiation mechanism based on suggestions, that we have called silent collaboration. The silent-collaboration process can be complemented with verbal communication among students, which we will define as “spoken collaboration.” It is important to stress that this last process is made difficult by the fact that in most cases children will have to work with a peer that is not physically close to them; e.g., in Figure 2-2 the fourth face (from right to left) is addressing someone at a distance from him.

Figure 2-2: Children interacting with the interpersonal computer

Silent collaboration occurs when a student who wishes to carry out an exchange of objects clicks on a classmate's object, within the cross-classification matrix, indicating a desire to swap. The student who is called upon to carry out this exchange can either accept or decline this proposal. The student who suggested the exchange can take back his offer, but only until his classmate makes a decision.

In this exchange process, it may occur that both objects are placed correctly, that neither of them is placed correctly, or that only one of them is placed correctly. Given that the first option isn't always possible, due to the activity's characteristics, and considering the conditions for collaborative learning -where each student must be responsible for his actions (individual accountability) and that rewards and punishments must be shared (joint rewards)- we defined a points mechanism that evaluates both players simultaneously. Thus, if one of the exchanged objects is placed in the correct position, both peers add one point to their score, and if not, they both lose the same number of points.

When one of the objects is placed correctly, it is fixed within the matrix until the end of the game, and a new object is assigned to the student who placed it, while the second player must continue with his object, until it is placed in the correct position. Once there are no more new objects available for allocation, or when a student successfully completes an exchange, a message appears in his personal space, inviting him to help those classmates who haven't yet finished (spoken collaboration). However, experimentally it was observed that spoken collaboration occurred independently of the students' completion of the activity.

When an iteration of the activity is completed, i.e., students have correctly placed all objects in the cross-classification matrix, the teacher explains this positioning to the entire group, answering questions and analyzing the main aspects of the activity. Because the assignment of objects to each student is random, the process should ideally be repeated, making students reposition objects a second, and even a third time, with the teacher reinforcing whatever aspects of the activity he finds most convenient at the end of each repetition.

Game mechanics

The first stage of the activity is the recognition stage -where the students identify themselves by assigning their names to their unique cursor icons. In the next phase -the activity stage- the screen is divided in two, as in Figure. 2-1: the upper half is the common space, and the lower is the individual space, which is further divided into equally sized rectangular boxes, each one identified by the students' personal icons (determined in the recognition phase). In the individual space there is one box for each group member, who has personal control over this box. Each student's cursor can initially only move within his personal control box. By clicking the right button, they can move into the common space. For a projector resolution of 1,280 × 1,024 pixels, a maximum of 25 personal control boxes provide sufficient space to accommodate the needs of the Multiple Classification task for each of the 25 students working collaboratively.

As illustrated in Figure 2-1, the common space represents the game board where students can suggest exchanges between one another, in order to locate the objects in their correct places, and receive points. In the personal control area, they have to decide whether or not to accept the suggestions they have received. Accordingly, the game actions are to suggest and receive objects.

Each personal control is composed of the elements shown in Figure 2-3:

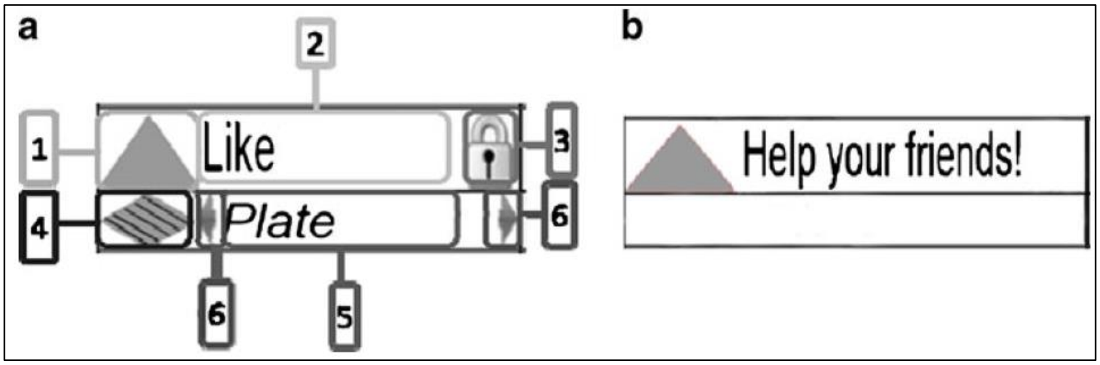

Figure 2-3: Personal control

1. Player's identifying symbol: Zone 1, Figure 2-3a, shows the student's icon. Once the player has made an exchange, the corresponding feedback is indicated in this Zone, as shown in Figure 2-4.

2. Current object: Zone 2, Figure 2-3a, displays the object the student is responsible for in the common area.

3. Committed object symbol: Zone 3, Figure 2-3a, a lock appears once the student suggests an exchange to a peer; therefore he cannot offer this object to another peer or accept an incoming suggestion unless he cancels his previous suggestion by clicking on the lock icon. This mechanism maintains consistency in the game.

4. Suggester's symbol: Zone 4, Figure 2-3a, shows the icon of the peer that wants to exchange the object in Zone 5, Figure 2-3a, with the object in Zone 2, Figure 2-3a. The student can accept the exchange by clicking on this symbol.

5. Suggested Object: Zone 5, Figure 2-3a, displays the object offered for exchange by the user corresponding to the symbol in Zone 4, Figure 2-3a.

6. Next (previous) arrow: Zone 6, Figure 2-3a, shows the button which moves between suggestions, when there is more than one.

To perform an exchange the player has to either locate the object they own in its correct position, suggest an exchange to the current owner of that position, or accept suggestion that has been received. In Figure 2-1, the player characterized by the vertical striped circle offers the object -“And”- for exchange to the student represented by the diagonal striped square, with the object “Animal”. In this way the student with the vertical striped circle suggests a correct exchange (“And” is a conjunction), and if the student with the diagonal striped square accepts it, both receive a point. Simultaneously, the student with the vertical striped circle has received a suggestion from the student represented by the triangle (with no pattern) -the word “like”. If accepted, each would lose a point, since “like” is not an adverb. However, the student with the vertical striped circle cannot accept this exchange, since he has already suggested one, indicated by the lock icon in his personal control box. At the same time, the student characterized by the triangle (with no pattern) has received several exchange suggestions, as evidenced by both arrows, which are present in his personal control box, but he cannot accept any of these since he has already suggested one, which is indicated by the lock icon.

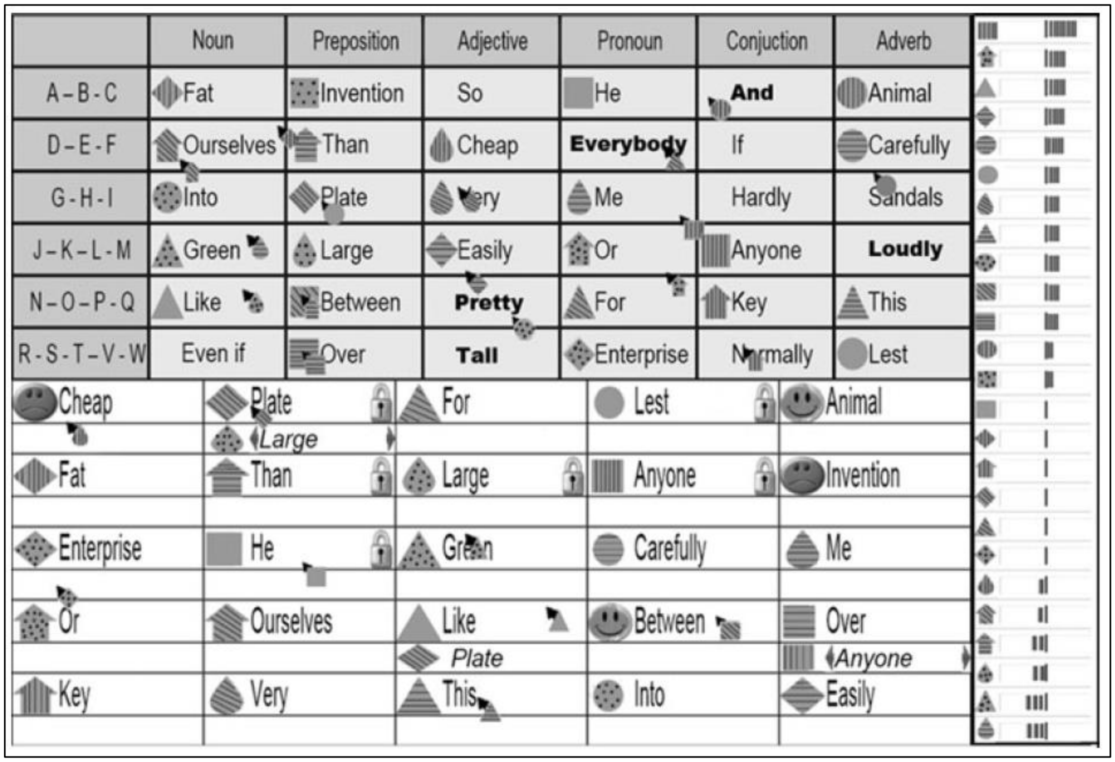

Figure 2-4: Feedbacks after exchanges have been made

When a student accepts an offered object, both objects are exchanged. We can see this by comparing Figures 2-1 and 2-4, where the object “And” is placed where the object “Animal” used to be, and vice versa. If one of the exchanged objects is placed in its correct position, both students gain a point and the object changes in color (bold in Figure 2-4) and cannot be moved from that position until the end of the game (Figure 2-4). Otherwise, both students lose one point. This is shown in the Score Space (Figure 2-4) where the points of each of the involved students are updated. Additionally, Figure 2-4 shows the personal feedback given to the students: both students receive a smile in the Personal Control box, when the exchange is correct and a sad face when incorrect. Finally, the student that receives the (correct) object (“And”) now has a new object to process (“Between”), while the student that receives the exchanged object (“Animal”) must now process this one. Also, in Figure 2-4 we can see that the students represented by a drop with a vertical stripe and a square with a diagonal stripe (Figure 2-1) have made a wrong exchange, keeping their objects, and each losing a point.

At a certain point in the game, towards the end of the activity, there will be no objects to be assigned to the players. At this point, a message will appear in their personal control box, encouraging the student to assist their classmates (spoken collaboration) (Figure 2-3b).

When the game is over and all the objects are placed in their correct positions, the teacher explains to the students why each of them is classified in a certain way and what each category means, encouraging the students to participate and ask questions (especially those that have the lowest scores). Considering that the objects are assigned randomly at the beginning of the game, the activity can be played several times with the same students, reinforcing the concepts explained by the teacher. These iterations stop once the teacher notices that (most of) the students solve the activity (almost) flawlessly, or when time runs out.

2.5 Experimental work

Design of the intervention

An exploratory study took place in 2010 at a (low income) state-subsidized school in Santiago de Chile, over 6 sessions of 45 min each. 74 students from 6th grade (43 boys and 31 girls, whose ages ranged between 11 and 12 years) were divided in to an Experimental Group (EG), of 42 students, and a Control Group (CG), of 32 students.

The study focused on language classes (Spanish), specifically on the subjects of accent rules, word classes (nouns, verbs, adjectives, prepositions, pronouns, adverbs and conjunctions), verb tenses and reading comprehension. A written pre-test covering all subjects, with a maximum score of 73 points, was administered to both groups (EG and CG) during the first session to assess the students' initial knowledge. This same test was repeated as a posttest in the final session.

During 5 weeks, six sessions were performed, each with one or more iterations per activity. The first session was devoted to familiarizing the students and teachers with the system's dynamics. Therefore, in Figures 2-5, 2-6, 2-7a, b and c only the last 5 sessions are depicted. While all the sessions were of the same duration, not all the sessions involved the same number of iterations, with 2, 1, 2, 3 and 3 respectively over the 5 sessions. Furthermore, the number of objects available for exchange wasn't necessarily the same in all of the activities, and so in order to accurately compare the activities the total number of events (exchanges) per session was used, given that each session lasted approximately the same length of time.

To assess the impact of our system we compared the CG, where the students worked only with conventional non-digital resources, with the EG that spent 60% of the time with the same conventional non-digital resources and 40% of the time with the CSCL system. In both the EG and CG the conventional non-digital resources consisted of guides for both teachers and students on the language contents to be assessed, with the aim of facilitating classes on these subjects and give both groups a similar theoretical background.

Since the system allows for up to 25 students to work simultaneously and the EG had 42 students, two randomly formed groups were defined, each monitored by a teacher as they worked simultaneously with their own hardware. This can be seen in Figure 2-2 where we see some students facing the camera, (and a screen that isn't shown), and the others facing away towards the other screen (which is visible).

The objectives of this trial were to:

1. Study the ease of use of the Software
2. Analyze if the conditions for collaboration were achieved.
3. Evaluate the achievements in learning under the defined language objectives
4. Analyze the impact of silent and spoken collaboration.

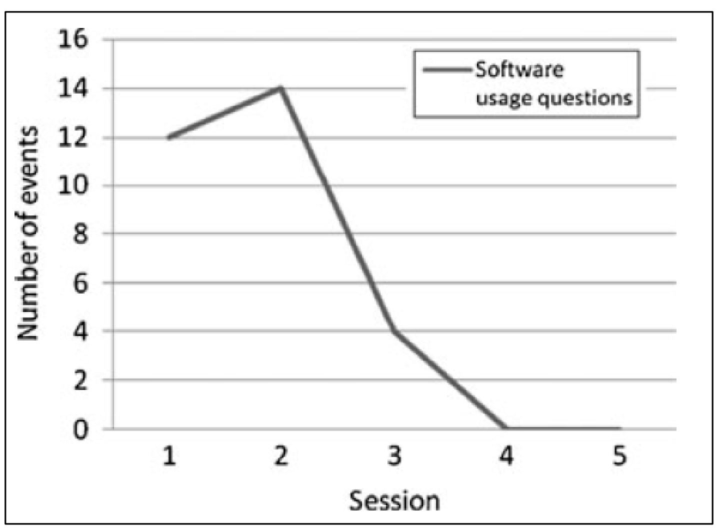

Figure 2-5: Software appropiation

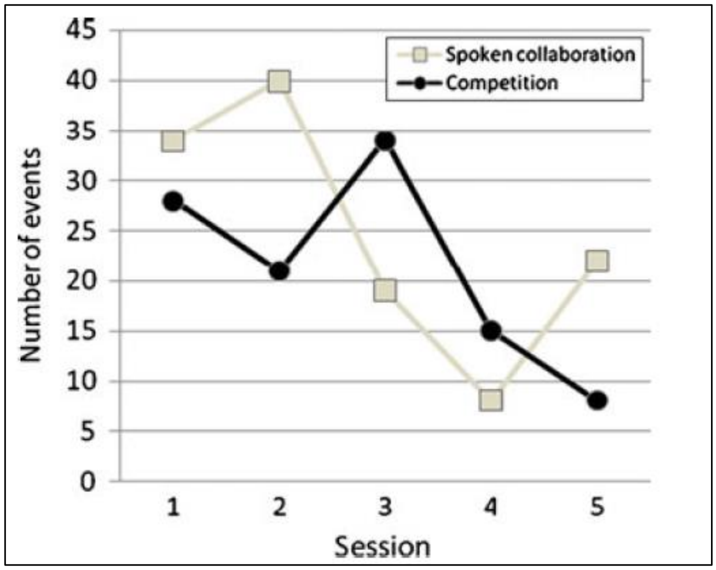

Figure 2-6: Comparison between spoken collaboration and competition

The qualitative results were gathered by four in-classroom observers, two for each group. The study was supported by a Tablet PC with software that registered the following events:

1. Competition: Number of occasions students compared themselves to their peers, by checking their position in the Score Space, or by commenting on their performance in the activity to others.

2. Spoken collaboration: Number of occasions where students verbally interacted with each other, in order to negotiate an exchange, or to decide whether it was convenient to carry out an action within the activity.

3. Software Usage Questions: Number of occasions students asked about an aspect related to use of the Software.

Each of the above points corresponds to a single student's action. Additionally, a system log monitored the following elements:

1. Cancellations: Number of times a student cancelled a suggestion.

2. Incorrect Exchanges: Number of incorrect exchanges carried out during the activity.

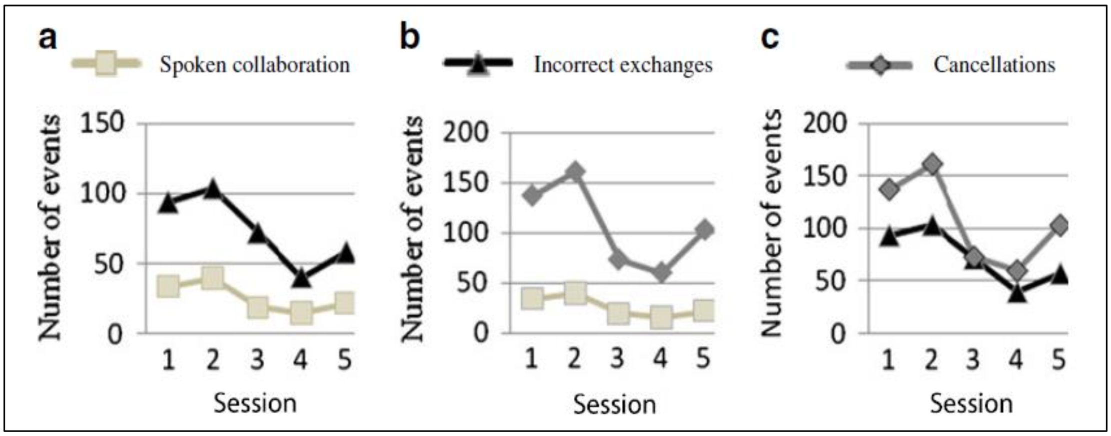

Figure 2-7: **a** Comparison between spoken events and incorrect exchanges. **b** Comparison between spoken collaboration events and cancellations. **c** Comparison between cancellations and incorrect exchanges

The number of correct answers was not registered because, since there are a finite number of objects to be placed in each activity, the number of correct answers will always be the same unless an exchange allows two objects to be placed correctly simultaneously, which can be determined by the initial random distribution of objects.

Software ease of use

We began our analysis by studying whether the software presented the children with any difficulties, because these could influence other results. The children, with each passing session, proved to handle the software very well, as shown in Figure 2-5, which illustrates the evolution of students' requests for help. We observed a peak of 14 events, for a total of 42 children -a very low figure- which would indicate that dedicating the first session to familiarizing the children with the system made it easier for them to properly interact with it in later sessions.

Achievement of conditions for collaboration

During the activity, we observed that the previously mentioned conditions to build a collaboration scenario within the classroom were met (analyzed in Table 2-1).

Evaluation of learning achievements

As a first analysis, we considered the EG students' performance on the previously mentioned written content test -both before and after the intervention -which showed a very large effect size (Table 2-2).

Secondly, we compared post-test results between the EG and CG, which showed a large effect size between both groups, as shown in Table 2-3.

Table 2-1: How the conditions for collaboration were achieved

Condition	Description
Common goal	The group had to collectively complete an activity based on a double entry chart. In order to do this, everyone had to place their object correctly so that, at the end of the activity all the elements were correctly classified.
Positive interdependence between peers	All group members actively participated in the game, as it was necessary to interact amongst each other in order to complete exchanges. Otherwise, it would have been impossible to achieve the group's goal.
Coordination and communication between peers	Students had to communicate and coordinate their actions, in order to negotiate object exchanges. For this they used silent and spoken collaboration. In the former, they communicated their suggestions and accepted or rejected those of their peers; in the latter, they verbally discussed those decisions.
Individual accountability	When a student made an incorrect suggestion, or refused a possible exchange, they were accountable for this action reflected in a loss of points, and therefore loss of credibility before their classmates.
Awareness of peers' work	Because of the Shared Display, group members had constant access to information about their classmates' situations: they knew what object others had, who they should ask to swap with, and how credible each one was, based on their score and the correct or incorrect exchanges they were making.
Joint rewards	When a correct/incorrect exchange took place, both parties gained/lost points equally.

Table 2-2: Comparison between pre-test and post-test results in the EG

	Number of students	Mean	Difference	Significance	Cohen's d
Pre test	42	31.369	11.345 (36.16%)	$p<0.001$	1.11
Post test	42	42.714			

The results shown in Tables 2 and 3 show the learning impact observed in the EG. Considering that both the EG and CG used the same non-digital resources and that the EG used the system for 40% of their available class time, we may conclude that the improvement in learning is due to the collaborative dynamic of the EG classes. However, further research should be conducted to analyze the effect of the teachers, which in this case was not controlled.

The impact of silent and spoken collaboration

Figure 2-6 shows the correlation between the number of spoken collaboration events and competition events, for each one of the activities. We can see that in sessions 1, 2 and 5, spoken collaboration prevails above competition events, while in sessions 3 and 4, the opposite occurs. During these last two sessions, where the most competition events were registered, completion time for the group was shorter (13:15 and 5:35 min respectively for the first iteration). Session 2 is where the difference between spoken collaboration and competition was most notable. Students perceived this activity as very difficult, a perception which was also reflected in their completion time (31:05 min for the only iteration), and the high number of registered reproaches, insults and signs of boredom (2, 22, 6, 5 and 2 respectively over the 5 sessions). Table 2-4 shows the correlation values for the relationship between the total spoken collaboration events per session, and the total incorrect exchanges per session (Figure 2-7a); the total spoken collaboration events per session and the total cancellations per session (Figure 2-7b); and between the total cancellations per session and the total incorrect exchanges per sessions (Figure 2-7c). From Figures 2-5 and 2-7 we observe that from session 3 on, there were fewer requests for help, fewer cancellations and fewer incorrect exchanges, indicating that sessions 1 and 2 were, in some way, still part of the training period.

Table 2-4 shows the correlation values including and excluding sessions 1 and 2; we observe that the only correlation that remains high is between the total spoken collaboration events per session and the total cancellations per session (Figure 2-7b).

This suggests that verbal discussion between classmates influenced the number of cancelled exchanges.

Table 2-3: Post-test comparison between CG and EG

Student group	Number of students	Pre-test	Post-test	Difference	Significance	Cohen's d
Control group	32	31.219	32.703	10.011 (30.6%)	$p<0.001$	0.89
Experimental group	42	31.369	42.714			

Table 2-4: Correlation values for Figure 2-7

Relation	Sessions 1–5	Sessions 3–5
Spoken collaboration- incorrect exchanges (Fig. 7a)	0.94	0.63
Spoken collaboration- cancelations (Fig. 7b)	0.99	0.95
Cancelations- incorrect exchanges (Fig. 7c)	0.89	0.36

Given that incorrect exchanges and cancellations were registered through the system log, and spoken collaboration events were noted by in-class observers, it was impossible to retrieve whether cancellations due to collaboration were correct or incorrect. Nonetheless, the system did allow us to observe that when a greater number of spoken collaboration events were recorded, despite an increase in the number of cancellations, the number of incorrect exchanges was not reduced (although the measured correlation was not even).

The above may us lead to conclude that there is no correlation between spoken collaboration and correct answers, which might make us think that silent collaboration was the mechanism that achieved increased learning. Further research must be done since it could be that the interpreted relationships among silent collaboration moves are not influencing one another as much as the task structure.

2.6 Conclusions

In this study, we have analyzed an application of Single Display Group ware with Multiple Mice and low hardware infrastructure costs -a computer, a projector, and one mouse per student- which makes large-group collaborative learning possible in the classroom. We showed how to create the conditions for collaborative learning, and our initial findings would suggest that we achieved the goals of learning and collaboration in large groups.

We determined experimentally that, in order to achieve collaboration in large groups, it is necessary to develop certain mechanisms, that we named silent collaboration. More research has to be done. We want to compare two silent collaboration mechanisms: the one presented in this paper with another that inhibits spoken collaboration, in order to fully understand the mechanisms of silent and spoken collaboration when all students collaborate inside a classroom. We also want to understand how the underlying pedagogical task affects silent and spoken collaboration by studying a second task besides the presented Multiple Classification matrix. Further research is also necessary to study how the difficulty of an activity affects the number of moves a student makes. The observation tools must be improved in order to establish the correctness of cancellations made as a result of spoken collaboration, and how the distance between peers affects the success rate of exchanges and the number of spoken collaboration events.

The EG and the CG used the same non-digital resources; the difference between them was that the EG used the presented CSCL approach for 40% of the available class time. Increases in student attainment are produced by quality content, pedagogical practices and commitment on the part of the students (Elmore et al., 1996). The determining factor in the learning process is the relationship between these, and not the individual attributes of each element on its own (Cohen et al., 2003). Further research is also lacking in order to compare our results with a CG that performs a similar non technology supported activity, to study the engagements of the students and to play with variables -such as the percentage of time assigned in the EG to the CSCL activity and the curricular topics that are covered (math, science, etc.).

3. SILENT COLLABORATION WITH LARGE GROUPS IN THE CLASSROOM

3.1 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.

3.2 Introduction

Collaborative learning in the classroom is receiving more and more attention following the inclusion of collaborative problem solving in the 2015 PISA study (OECD, 2013). Collaboration is a form of collective problem solving (Dillenbourg, 1999), and successful collaboration requires the presence of certain conditions (Johnson & Johnson, 1999): 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 (Boticki et al., 2013). 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) (Elliot, 2006). In such cases, issues with coordination and communication often arise that can hinder collaborative learning

(Bertucci et al., 2010). For example, there are always some students who do not want to participate in the discussion (Marjanovic, 1999) 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 (Strijbos & Martens, 2001). 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 (Miner, 1992). 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 (Mercer, 1995).

Teachers usually solve these issues by dividing large groups of children into small groups that work on the same problem independently (Caballero et al., 2014). 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 (Hernández-Leo et al., 2011). 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 (Guha et al., 2013). 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 (Kaplan et al., 2009). 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 (Martinez-Maldonado et al., 2013). 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 (Caballero et al., 2014) and interactivity among students in a whole class setting (Alcoholado et al., 2012). Authors in Szewkis et al. (2011) 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 Figure 3-1, 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 the authors in Caballero et al. (2014) divided the students in the classroom into smaller groups to allow for a collaborative environment, the authors in Szewkis et al. (2011) 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 Szewkis et al. (2011), 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 (Szewkis et al., 2011). 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 collabo-ration 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 Szewkis et al. (2011).

The interaction pattern for the exchange of suggestions in Szewkis et al. (2011) 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 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 (Taylor, 1953).

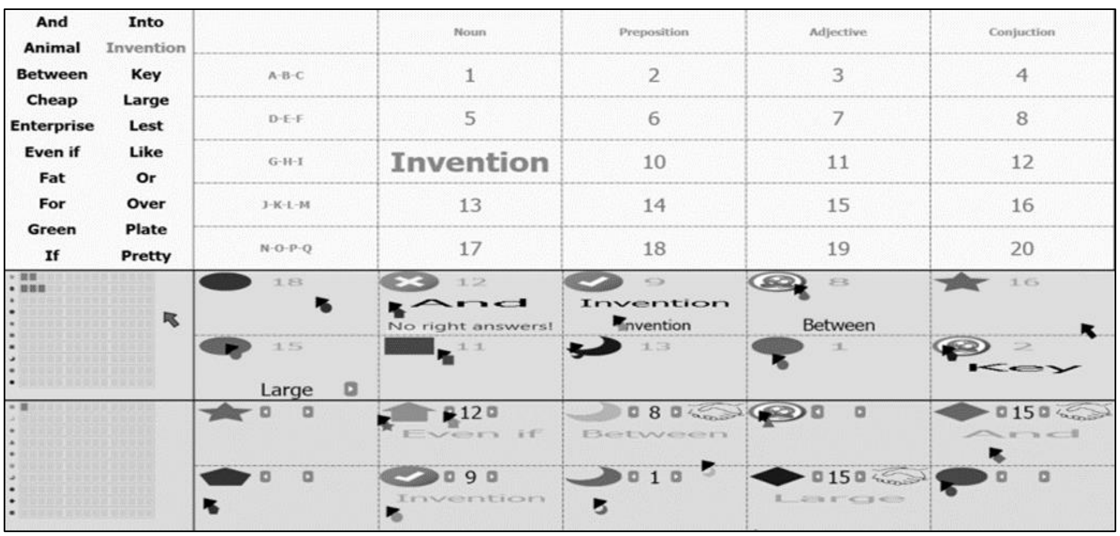

Figure 3-1: Application interface for a Matrix activity that consists of classifying a set of words. The top half represents the 20 problems to solve as part of the collaborative activity. The bottom half represents a board with an acceptors' area (top two rows) and facilitators' area (bottom two rows). Each acceptor and facilitator is assigned a cell on the corresponding board. All of the students work synchronously on the board

3.3 Silent collaboration interaction pattern

The proposed silent collaboration interaction pattern follows the approach of submitting and accepting suggestions presented in Szewkis et al. (2011), but with two key differences aimed at reducing the number of unnecessary verbal interactions detected in Szewkis et al. (2011). Firstly, 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. Secondly, 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.

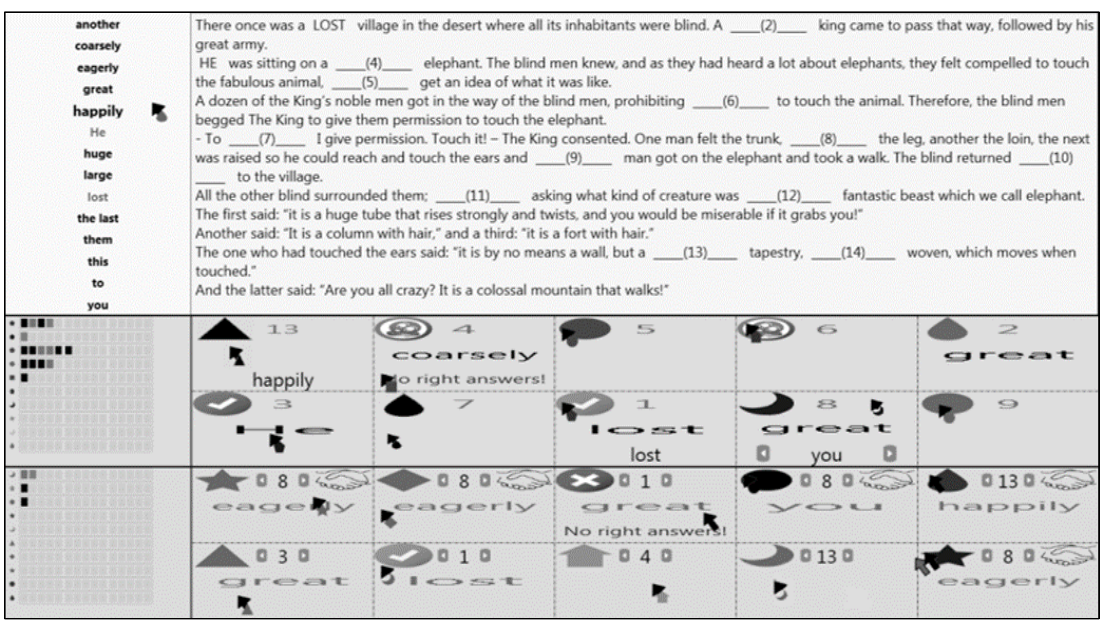

Figure 3-2: Application interface for a Cloze activity that consists of filling in the blanks. The top half represents the 14 problems to be solved as part of the collaborative activity. The bottom half represents a board with the acceptors' area (top two rows) and facilitators' area (bottom two rows). Each acceptor and facilitator is assigned a cell on the corresponding board. All of the students work synchronously on the board

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 (Jong, Lai, Hsia & Lin, 2013). 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 (Trucano, 2010).

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 Figure 3-1); and Cloze, where problems in the collaborative activity consist of filling in the blanks with a set of items (words in Figure 3-2). 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 Figures 3-1 and 3-2). 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 Figure 3-1 and 14 in Figure 3-2). The lower work space includes the Acceptors' Area (top two rows in Figures 3-1 and 3-2) and the Facilitators' Area (bottom two rows in Figures 3-1 and 3-2). 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 Figures 3-1 and 3-2), 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 Figures 3-1 and 3-2); 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 maxi-mum). Then, each user is identified by 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 Figure 3-1, 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 Figure 3-2 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 Figure 3-1 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 Figure 1 the acceptor with number "9" (first row, third column) decided to accept the word "Invention" (see next section 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 Szewkis et al. (2011), 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 Figure 3-1 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.

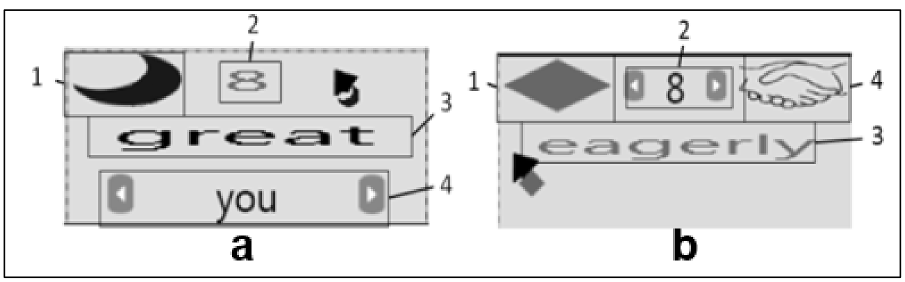

Figure 3-3: a) Example of acceptor's Personal Space. b) Example of facilitator's Personal Space

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 Figures 3-3a and 3-3b the process of submitting and accepting suggestions in individual cells is analyzed using two specific examples. The symbol (labeled 1 in Figure 3-3a and b, moon for the acceptor in Figure 3-3a, diamond for the facilitator in Figure 3-3b) 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 answer is shown in the symbol in the form of a tick (e.g., Figure 3-2, Acceptors' Area, cell with problem 3) or a cross (e.g., Figure 3-2, Facilitators' Area, cell with problem 1). In addition, the symbol switches to sleep mode if a student re-mains inactive for a predetermined period of time (e.g., Figure 3-2, 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 Figure 3-3a 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 Figure 3-3a 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 Figure 3-3a) 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 Figure 3-3a, “you” is one of the suggestions received for problem 8, but there are arrows signaling that there are more alternatives; Figure 3-2 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 Figure 3-3b) 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 Figure 3-2 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 Figure 3-3a 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 Figure 3-2 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 feed-back 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 Figure 3-2, 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.

3.4 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, 26 sixth graders participated in the study (15 boys and 11 girls, aged 10 and 11). 13 of the students worked with the Matrix mode (8 boys and 5 girls) and 13 with the Cloze mode (7 boys and 6 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 (Miller, 1987). In the first session (S1), students became familiar with the application. During sessions two to five (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 3-1. This table also shows the time per session that the students were effectively working on the collaborative activities using this application.

Table 3-1: 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 space.	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	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

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 4 to 5 students with the aim of re-cording the number of occurrences of different events. The following events were recorded (see Table 3-2): 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.

Table 3-2: 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

Only two types of events are classified as spoken collaboration, pure spoken collaboration and pressure (marked in bold in Table 3-2), 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.

3.5 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.

Usability analyses

A usability analysis typically includes: learnability, efficiency, memorability, user satisfaction, and errors (Nielsen, 1994). Learnability was measured by considering the time it took the students to complete the training session S1 (see Table 3-1). 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 3-1). 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 8 collaborative activities to be solved (4 with students as facilitators and 4 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 3-2).

Memorability was evaluated by calculating the number of questions regarding the system usage recorded in sessions 2 through 5 (Table 3-2): 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 (Bevan & Macleod, 1994). This ratio was 0.89 in the Matrix mode and 0.8 in the Cloze mode (Table 3-2). 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.

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.

Comparison of silent and spoken collaboration

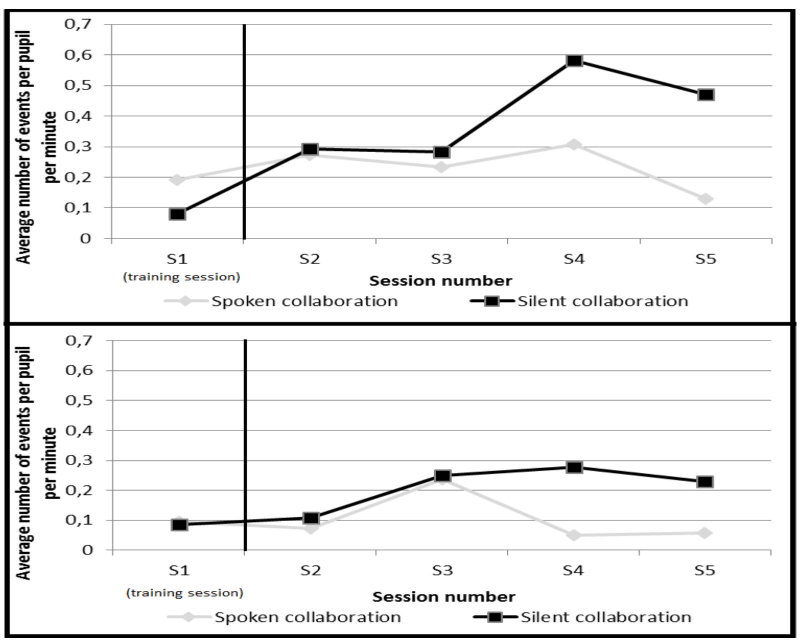

Figure 3-4: Average number of spoken and silent collaboration events per pupil per minute in the studies with Matrix (top) and Cloze (bottom)

Table 3-2 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 ($\sigma = 0.11$). Figure 3-4 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 3-1.

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 ($\sigma = 1.13$). Figure 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.

Nevertheless, silent and spoken collaboration can be compared in each of the two studies. Figure 3-4 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 3-1). 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.

Table 3-3: 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.

3.6 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 Figure 3-4). 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 Figure 4).

The two studies were designed by taking into account the collaborative conditions referred to in the introduction (see Table 3-3). 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 the usability section).

3.7 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.

4. THE IMPACT OF TECHNOLOGY IN LARGE GROUP COLLABORATIVE LEARNING

4.1 Abstract

Silent (non-verbal) collaboration is one alternative that allows large groups to collaborate within a classroom. There are two main ways of implementing synchronous collaborative work with large groups, as all students in a classroom. Each student with their own computer connected to a network, or using Single Display Groupware (SDG), where students share a big display and work with their own input device. To study how technology influences collaborative work in large groups a same silent synchronous collaborative application was implemented in a computer lab, with each student with a PC connected to a network, and inside the classroom, using Single Display Groupware (SDG). The results of the study show that there is no significant difference between the two learning environments in terms of learning gains, despite the interconnected PC group demonstrating greater effectiveness in the collaborative process. Given that there is relatively little research regarding collaboration in large groups, this study sheds light on the impact that the learning environment can have on the collaborative process of large groups.

4.2 Introduction

Integrating collaborative learning in the classroom has become an important issue for researchers. The inclusion of collaborative problem solving in PISA 2015 (OECD, 2013) has also resulted in it becoming an important topic of study.

Collaborative work has been shown to have several advantages over individual work. Some of these advantages include improved content retention (Blumen, Young & Rajaram, 2014), improved oral communication skills, increased self-esteem, improved problem-solving skills and the need for higher-order thinking skills (Laal, Naseri, Laal & Khattami-Kermanshahi, 2013). Consequently, collaboration has been viewed as a success (Johnson & Johnson, 2009), with the tendency among schools now to include collaborative activities wherever possible (Pociask & Rajaram, 2014).

In order to work collaboratively, certain conditions must be met. There must be a shared objective, positive interdependence, coordination and communication, shared information, and joint rewards (Szewkis et al., 2011). These conditions are affected depending on the physical context in which collaborative work occurs since the physical space impacts the use of technology (Shannon & Cunningham, 2009) and so influence group interaction and learning (Mercier, Higgins & Joyce-Gibbons, 2014). A shared understanding is created when every student's contributions and opinions are valued, and they are encouraged to actively participate (Graham, Rowlands, Jennings & English, 1999). It is therefore important to get a whole class working collaboratively. However, meeting the conditions for collaboration in the classroom with large groups can be a challenge. One of the main problems is the lack of synergy (Antunes, Ferreira, Zurita & Baloian, 2011), i.e. the difficulty of achieving a shared understanding of the task and sound coordination in order to carry it out successfully. There is also the issue of verbal communication as only one person can talk at a time, therefore requiring coordination between speakers (Osawa, 2006).

There are two main ways of doing synchronous collaborative work with large groups at school. The first of these is when students collaborate on their own computer connected to a network. The other, where students collaborate by sharing a common screen, i.e., Single Display Groupware (SDG) (Pavlovych & Stuerzlinger, 2008). In SDG multiple users in the same physical space share a common screen, each with their own input device (Moraveji et al., 2008). It encourages interaction between peers, student participation and engagement (Infante, Hidalgo, Nussbaum, Alarcón & Gottlieb, 2009), and can be used to collaborate silently (non-verbally) when children in a large group are not seated together (Szewkis et al., 2011). When we confront both technologies we see that in SDG a shared display allows the teacher to monitor on the shared screen all students work at once (Alcoholado, 2012), while working each student with their own computer increase the students' level of attention, since they are focusing only in their screen with no other distractions.

Given that there is relatively little research regarding collaboration in large groups, it is relevant to shed light on the impact that the learning environment can have on the collaborative process in large groups. Therefore our research question asks: How does the technology used influence the collaborative work in large groups?"

4.3 Methodology

Design

When participants that collaborate are not in the same physical place there is no visual contact, i.e., non-verbal cues that complement communication (Chiu & Hsiao, 2010).

Furthermore, as the students are on their own they can lose motivation, leading to boredom and frustration (Said, Haruzuan, Forret & Eames, 2013). Having audio and video can help remedy this situation (Kuo, Shadiev, Hwang & Chen, 2012). However, two effects can be witnessed more frequently when not in a face-to-face setting (Said et al., 2013). The first of these is the so-called "free-rider effect", where one member of a group takes advantage of the work of the others. The second is the "ganging up on the task effect", where some members of the group only look to finish the task as quickly as possible. A face-to-face synchronous option can overcome these problems mainly through the teacher's presence; they can control unwanted social behaviour, as well as monitoring and supporting the participants' work by providing individual assistance when needed (Asterhan & Eisenmann, 2011).

Silent (non-verbal) collaboration allows large group of students collaborate mainly through the scaffolding of the collaborative activity (Szewkis et al., 2011). Szewkis et al. (2011) used this technology to practice language and Caballero et al. (2014) to teach geometry. Some known dynamics to implement silent collaboration are: multiple-choice questions and short answers, which were used for math teaching (Moraveji et al., 2008); identify, classify and construct triangles, also for math teaching (Caballero et al., 2014); classification using a multiple classification matrix, for language teaching (Szewkis et al., 2011) and complete sequences or cloze, for language teaching (Rosen, Nussbaum, Alario-Hoyos, Readi & Hernández, 2014).

In order to shed light on the impact that the learning environment can have on the collaborative process in large groups, we studied two (classroom sized) groups working collaboratively, differing in the technology used. One group of students who used SDG in the classroom, and the other who used PCs connected through a network in a computer lab. With the purpose of inquiring in the impact of the technology in the collaborative work, the analysis was conducted in terms of usability, learning gain and collaboration. We used Silent Collaboration in both environments. In the first (SDG) because the students could not easily communicate with their peers, while in the second to maintain the scaffolding as similar as possible no audio was used, even this could have been possible with headsets.

Participants

The study was conducted with two 6th grade classes from a state-subsidized school in Santiago, Chile. In the SDG group 29 students participated in the study (17 boys and 12 girls, aged 10 and 11), while in the PCs in network group 34 students participated (16 boys and 18 girls, aged 10 and 11). Both groups performed the same activities. The analysis of learning outcomes was based on the results of 37 students who completed both the pre-test and the post-test, 19 of whom were from the SDG group and 18 from the PCs in network group. This drop in numbers is due to students being absent for at least one of the two tests. Given the restrictions imposed by the size of the screen, the SDG application allowed a maximum of 20 students to work simultaneously. Since the SDG group had 29 students, two smaller, randomly-formed groups were defined every time a session was held (Figure 4-1.b). Furthermore, as the school did not have big enough computer labs to accommodate a whole class, the PCs in network group was also divided into two smaller groups of students. By doing so, the conditions within both settings were similar.

Figure 4-1: (a) Lab setting with PCs (b) Classroom setting with shared display

Table 4-1: Description of the activities in S1-S7 in the SDG and PCs in network groups

Session	***Subject/Difficulty***	***Duration in SDG group (average seconds per student)***	***Duration in PCs in network group (average seconds per student)***
S1	Non-curricular activity (software training) / Low	29	33
S2	Synonyms, hyponyms and hyperonyms / Low	39.88	26.1
S3	Comparatives / Low	35.44	38.84
S4	Noun-adjective agreement / Med	38.36	28.42
S5	Expressions / Med	49.76	35.74

S6	Comparisons / High	82.05	50.92
S7	Summary (of all of the above) / High	42.85	26.48

In class activities

Contents

The activities, which lasted approximately 40 minutes, consisted of filling a table of 20 items (four columns with five rows) with the corresponding answers. The activities covered topics from the Language and Communication curriculum; specifically the use of synonyms, hyponyms, hyperonyms, expressions and comparisons (Table 1). The collaborative activities were developed by the researchers and reviewed with the school teacher, in line with the requirements specified by the school. In the first session (S1), the students familiarized themselves with the application using a non-curricular activity.

Software

The software in both settings was designed to be as close as possible between them so that they could be compared. This was done using a tool previously developed by Rosen et al. (2014). The aim of this is to work on language tasks by completing a double-entry table by sending and receiving suggestions. In this case, there are two roles: acceptors and facilitators. The acceptors (Figure 4-2.a) are responsible for solving the tasks, while the facilitators (Figure 4-2.b) provide suggestions for how to solve the tasks. Silent (non-verbal) collaboration is achieved when a facilitator sends a message to an acceptor using the software.

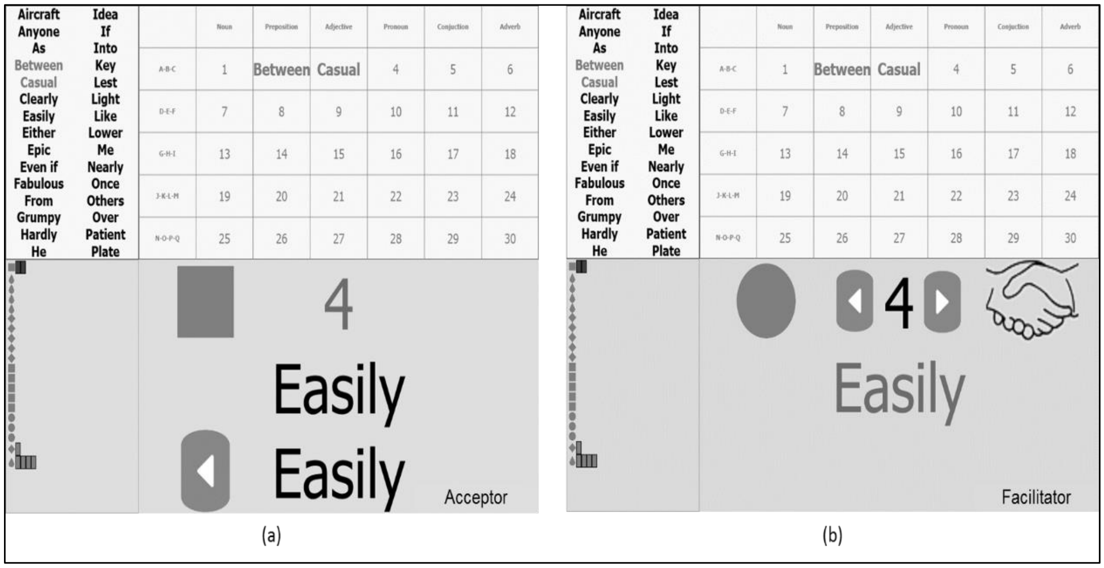

Figure 4-2: (a) PC acceptor interface (b) PC facilitator interface

The application comprises four defined spaces (Figure 4-2). The upper-left-hand part of the screen contains the word list, which provides all of the words that are needed to complete the activity (each word can only solve one problem). The upper-right-hand part of the screen contains the answer space, which shows all of the exercises that need to be completed (30 in Figure 4-2). This space consists of a two-dimensional table which uses its rows and columns to define the classification criteria for the words. The lower-left-hand part of the screen is the score board, where each student's performance is displayed. Each row features a student's symbol (a unique symbol used to represent each student consisting of a shape and colour). The columns in this space show a series of coloured rectangles based on correct answers (dark grey in Figure 4-2) and incorrect answers (light grey in Figure 4-2). Finally, the lower-right-hand part of the screen is the interaction space, where students work and collaborate. Figure 4-2.a shows the screen of a student with the role of acceptor, while Figure 4-2.b shows the screen of another student with the role of facilitator.

The activity starts when the acceptor receives a number identifying a task that needs to be completed in the answer space (upper-right-hand part of the screen in Figure 4-2). The number is housed in a cell which is classified according to the part of speech (column) and its first letter (row). With these two characteristics, the student must identify the corresponding word from among those in the upper-left-hand side of the screen (Figure 4-2). For example, in Figure 4-2.a, the acceptor was assigned the number 4, which corresponds to a word that is a pronoun and which starts with the letter A, B or C. When the task is completed correctly, the word is placed in the table (e.g. the words “casual” and “between” in Figure 4-2) and the student is assigned a new number. If the word is not correct, the exercise must be repeated.

Facilitators help acceptors by sending suggestions. Unlike the acceptors, facilitators have the option to work on any of the tasks that has been assigned to an acceptor. For example, in Figure 4-2.b, the facilitator is suggesting to the acceptor that the word needed to solve exercise 4 is “easily”. Figure 4-2.a shows that the acceptor also believes that that is the right word. In this case, both are wrong as cell 4 corresponds to a pronoun which starts with the letter A, B or C.

As well as having different roles, the acceptors and facilitators also have different ways of interacting with the activity. The acceptors can receive suggestions from several facilitators at the same time, but when they send their answer they can only follow one suggestion. The facilitators can only make a suggestion to one acceptor at a time and have to wait for the acceptor to respond in order to receive feedback. Should they not want to wait, they can cancel their suggestion and make a suggestion to another acceptor.

The application provides feedback once the acceptor has sent an answer. In this case there are two alternatives. The first is that the acceptor does not receive any suggestions from a facilitator. In this case, if the answer is correct then feedback is only given to the corresponding acceptor; the acceptor earns a point and a green rectangle is added to the score board. If the answer is incorrect, the acceptor loses two points and a red rectangle is added to the score board. The second alternative is when an acceptor has received a suggestion. In this case, if the answer is correct the acceptor receives two points and if it is incorrect they only lose one point. Facilitators, on the other hand, earn one point if they send a correct suggestion and lose a point if they send an incorrect suggestion. By doing so, the system encourages the acceptors to work with the facilitators to complete the activity using silent collaboration. When they finish the activity, the program reveals the points achieved by the students.

A detailed view of the interaction space is shown in Figures 4-3.a and 4-3.b. The symbol (1 in Figure 4-3.a and 4-3.b) represents each student on the screen and on the score board. The acceptors click on their symbol in order to submit an answer, while facilitators click on theirs in order to send a suggestion. Feedback is also given in this space. A tick appears (Figure 4-4.a) if the answer is correct, or a cross (Figure 4-4.b) if it is incorrect. Furthermore, there is a sleep mode (Figure 4-4.c) which indicates that a student has been inactive for a given length of time. This allows teachers to know which students are not actively working. The task number (2 in Figure 4-3.a and 4-3.b) represents the problem that is being completed. For acceptors, this is provided randomly by the system and cannot be changed until the exercise is completed correctly. Facilitators can choose the task number by clicking on the left arrow to go down and the right arrow to go up. The chosen word (3 in Figure 4-3.a and 4-3.b) is a word from the word list. The acceptors choose this as a possible answer to the problem they have been assigned, while facilitators use it as a possible suggestion to send to an acceptor. To choose the word, the users must select an available word from the word list. When a word is used correctly during the activity, it changes colour in the word list and is no longer available to be selected. It is also correctly placed in the answer table. The suggestions (4 in Figure 4-3.a) are all of the words that have been suggested by the facilitators to an acceptor as possible answers to the problem they have been assigned. If there is more than one suggestion, arrows appear on the screen so that the acceptor can check them all. The handshake icon (4 in Figure 4-3.b) appears on the facilitator's screen when they send a suggestion, ruling out the possibility of sending another suggestion. This icon disappears when the acceptor to whom they sent a suggestion submits their answer, or when the facilitator clicks on the handshake icon. In this case, the suggestion is cancelled and the facilitator can send another suggestion to an acceptor.

The system divides the roles (acceptor and facilitator) evenly and randomly. The activity was also repeated so that the roles rotated. In this sense, the students completed the activity (and thus met the learning objectives) from both perspectives.

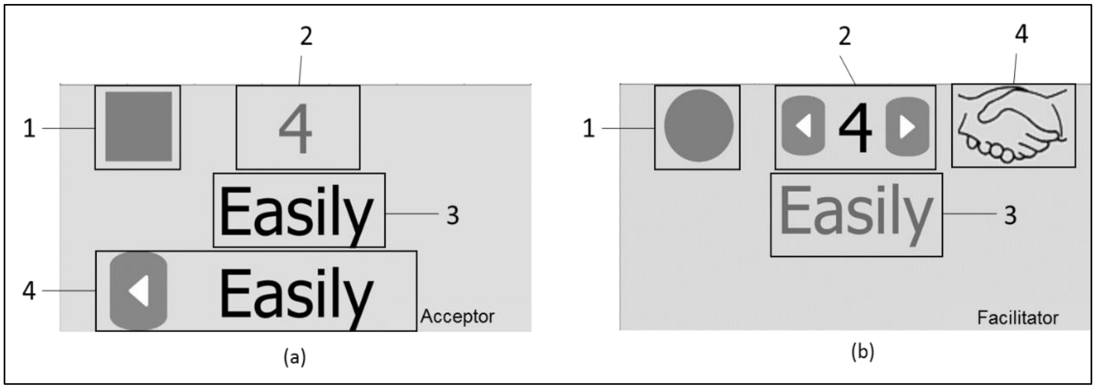

Figure 4-3: (a) Detailed view of the acceptor's interaction space (b) Detailed view of the facilitator's interaction space

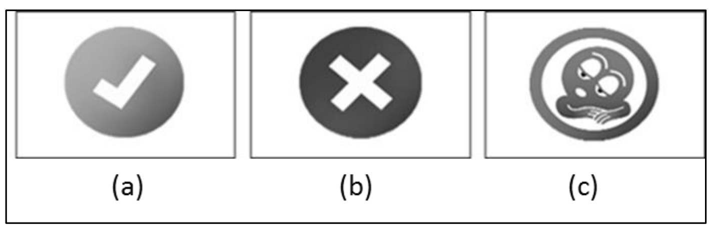

Figure 4-4: Interface statuses

In the PCs connected through a network application the public spaces (the two upper parts of the screen, plus the score board) are shared by all of the students, The only difference of the SDG application, Figure 4-5, is that the application is based on a shared display where the roles of the acceptors and facilitators are grouped on the screen so that the acceptors are in the top-half of the lower part of screen and the facilitators in the bottom-half of the lower part of the screen, with each having their own personal space. By working on a shared screen, the students can see their classmates' personal spaces.

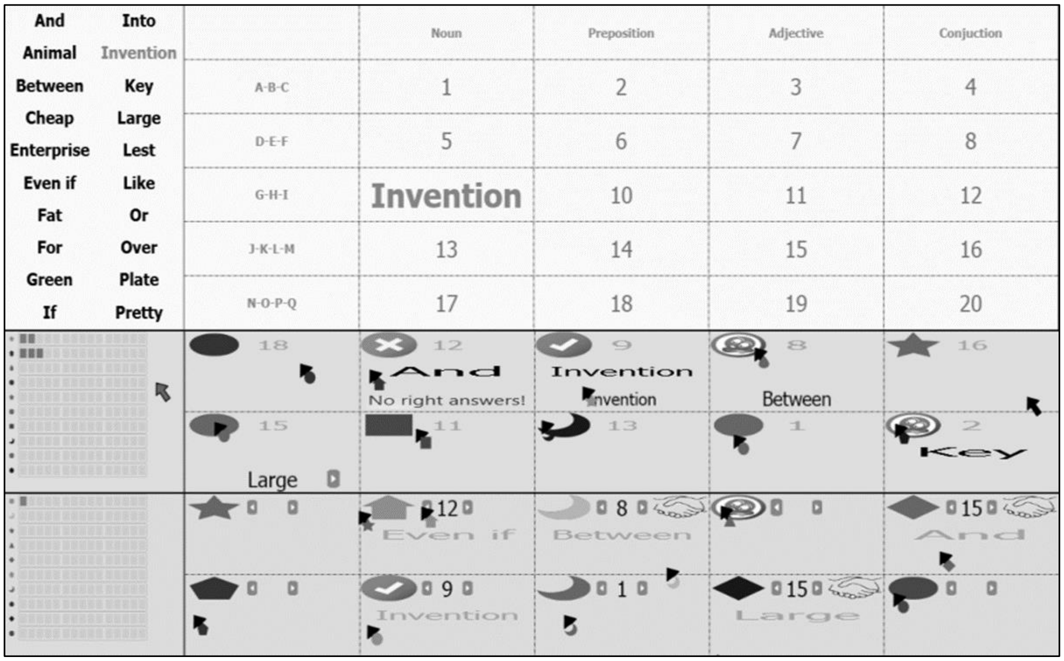

Figure 4-5: Shared display interface (Rosen et al., 2014)

Comparison between tools

Table 4-2 shows the main differences and similarities between both applications.

Table 4-2: Main differences and similarities between both applications

Functionality	PCs in network application	SDG application
Collaborative objective	Complete a double entry classification matrix.	Complete a double entry classification matrix.
Collaboration method	Classification of objects, each belonging to a student, through suggestions between facilitators and acceptors.	Classification of objects, each belonging to a student, through suggestions between facilitators and acceptors.
Arrangement of students	Students seated in front of a PC, each with their own input device.	Students seated in front of a projected shared display, each with their own input device.

Collaboration conditions

Table 4-3 shows that both applications meet the conditions required for collaboration (Szewkis et al., 2011). The conditions are similar for each application as they both have the same objective and use the same game mechanics.

Table 4-3: Theoretical fulfilment of the conditions required for collaboration

Condition	Theoretical fulfilment of the condition
Shared objective	All of the students completed the same collaborative activities. The aim for every participant was to complete the table.
Positive interdependence between roles	Each student has a role: submitting or accepting suggestions. The facilitator depended on the acceptors and the roles were rotated so that every child could play the role of acceptor and facilitator in the same activity.
Coordination and communication between roles	To complete the collaborative activities, students coordinated and communicated with each other, using silent and spoken collaboration.
Individual responsibility	Each answer (correct or incorrect) receives public feedback.
Awareness	By sharing the game spaces, the result of each member's work could be viewed by all the students.
Joint rewards	The scoring system encouraged students to work collaboratively.

4.4 Measurements and procedures

Learning

A test was administered during the first session (pre-test) and after the final session (post-test) with the aim of measuring learning gains. The test covered all of the topics covered by the software and was administered to both groups (SDG and PCs in network). The maximum possible score on the test was 46 points. Cronbach's alpha was 0.83 for the pre-test. In order to analyze the learning gain, an ANOVA and Cohen's d were calculated.

Usability

A usability analysis was conducted to check whether the students' behaviour when using the applications was an obstacle to achieving the desired dynamics and whether there were any differences in how the applications were used.

A usability analysis typically includes learnability, efficiency, memorability, user satisfaction, and errors (Nielsen, 1994).

Learnability, the system should be easy to learn so that the user can rapidly start getting some work done with the system. This was measured by considering the time it took the students to complete the training session, S1, Table 4-1. Efficiency, the system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible. This was calculated by considering the time it took the students to complete the activities in sessions 2 through 7, Table 4-1. Also we register the number of disruptions, questions regarding feedback and visualization events, Table 4-4. Memorability, the system should be easy to remember, so that the casual user is able to return to the system after some period of not having used it, without having to learn everything all over again. This was evaluated by calculating the number of questions regarding the use of the system (Table 4-4). User satisfaction the system should be pleasant to use, so that users are subjectively satisfied when using it (they like it), was assessed by calculating the ratio of positive events (motivation and positive remarks) to negative events (disruption, boredom, discontent, and negative remarks). This is similar to the assessment done in (Bevan & Macleod, 1994). And Errors, the users should make few errors during the use of the system, and if they do make errors they should easily recover from them.

Collaboration

To analyze collaboration, quantitative and qualitative data was gathered. The quantitative data, taken from the application's log, consisted of the time it took to complete the different activities, and the number of suggestions made by the facilitators through the software for the different activities. The qualitative data (Table 4-4), through classroom observations, registered the spoken collaboration events and the pressure events (highlighted in Table 4-4), since in these a student may influence another in their action. The other events of Table 4-4, were registered to analyse the usability. Each event could occur more than once for each child in each activity. If a question (regarding the feedback or use of the system) or comment (visualization, positive remarks, boredom, discontent and negative remarks) required further explanation, or several expressions of motivation or disruption were consecutive or related, then they were considered as a single event.

To gather this qualitative data, an observer monitored the work of 4-6 students and recorded the number of times certain events occurred (Table 4-4). In total, there were 3 to 6 observers, depending on the number of students and the setting.

Table 4-4: Total number of events registered from sessions S1 to S7 per participant in the PCs in network and SDG groups. Spoken collaboration events are highlighted in bold

	PCs in network	SDG
Pure spoken collaboration	5.5	3.96
Pressure	3.28	5.7
Disruption	0.08	0.64
Question regarding the feedback	0.36	0.38
Visualization	0.3	1.09
Question regarding use of the system	1.65	1.5
Motivation	4.81	5.14
Positive Remarks	1.34	1.33
Boredom	1.04	2.01
Discontent	0.58	0.4
Negative Remarks	1.04	1.47

4.5 Results

Analysis of learning

Table 4-5: Pre-test and post-test results (SD: standard deviation, Δ: difference)

	Pre-Test		**Post-Test**				
	A	*SD*	*A*	*SD*	*Δ%*	*Significance*	*Cohen's d*
PCs in network group	18.94	3.65	20.72	5.15	9%	0.120	0.403
SDG group	17.32	4.99	18.05	5.85	4%	0.339	0.137

The results show that both groups made progress. For the students in the PCs in network group, there was a small/medium effect size, while for the students in the SDG group there was only a small effect size (Table 4-5). In terms of learning, there was no significant difference between the two groups, nor for each of the groups separately ($p>0.05$). It is worth highlighting that these analyses were only performed with a reduced sample due to the number of students who missed the post-test.

Analysis of usability

As shown in Table 4-1, the learnability data was 31.18 minutes for the PCs in network group, while it was 14.15 minutes for the SDG group. These times were different as a considerable amount of time was spent explaining to the students in the PCs in network group on how to use the software.

Efficiency. Table 4-1 shows that both applications allowed the activities to be completed within the duration of a regular class (40 minutes). The total time was 98.48 minutes for the PCs in network group, and 111.1 minutes for the SDG group. Students took full advantage of the time that was available. This can be observed from Table 4-4 in the low number of interruptions that were recorded in the form of disruptions (0.08 for the PCs in network group and 0.64 for the SDG group), questions regarding feedback (0.36 for the PCs in network group and 0.38 for the SDG group), and visualization events (0.3 for the PCs in network group and 1.09 for the SDG group).

Memorability. Table 4-4 shows that 1.65 questions were asked per student in the PCs in network group (0.91 questions per student in the training session (S1) and an average of 0.12 questions in S2 to S7). 1.5 questions were asked per student in the SDG group

(0.9 questions per student in the training session (S1) and an average of 0.1 questions in S2 to S7). This suggests that both systems were easy to use and that it was easy to remember how to do so following the training sessions.

In user satisfaction the ratio was 2.24 in the PCs in network group and 1.43 in the SDG group, showing that both groups enjoyed the applications, but more in the group of PCs in network. User satisfaction is important since higher user satisfaction can lead to higher user participation, involvement and acceptance (Bergersen, 2004).

Finally, students produced any errors while the activities were being carried out.
In general, these usability analyses reveal that neither application was an obstacle to achieving the desired dynamics in the studies that were conducted. A relevant difference between the two applications is that the students in the SDG group tended to experience more disruptions (0.64 vs. 0.08) since they were sitting next to each other, and more boredom (2.01 vs. 1.04) since it took more time to finish the activities. In this case, the facilitators grew bored of waiting for a response from the acceptors. Despite this, both applications had a user satisfaction ratio of greater than 1.

Comparison between the two applications

Table 4-1 shows that the students who worked in the SDG group with a shared display took a significantly longer time ($p<0.05$) to finish the activities. Furthermore, the students in both groups reacted similarly to changes in difficulty level. In this case, the correlation between the duration of both groups is 0.81 (increases in difficulty level occurred from session S3 to S4 and S5 to S6).

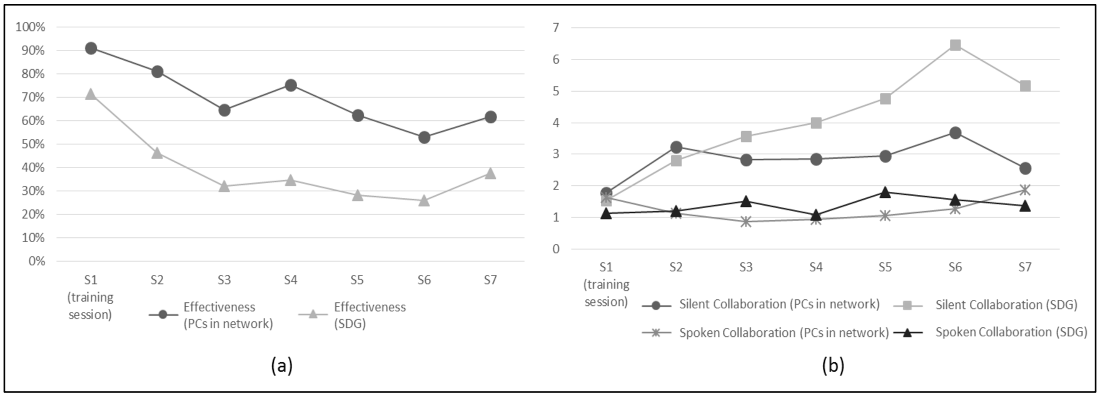

Figure 4-6: (a) Effectiveness of suggestions in the PCs in network and SDG group (b) Number of silent and spoken collaboration events per student in both groups

On average, the students in the SDG group took longer as the collaboration was less effective (Figure 4-6.a). In other words, the ratio between the number of correct suggestions and the total number of suggestions was lower, suggesting that there was more reliance on trial and error. These curves (effectiveness of suggestion in the PCs in network and SDG group) are significantly different ($p<0.05$) and have a correlation of 0.82. The effectiveness for both groups decreases from one session to another, suggesting that there was more trial and error as the sessions became more difficult.

Figure 4-6.b shows the number of spoken and silent collaboration events for both groups. It can be seen that there was less spoken collaboration than silent collaboration in both groups, and that there was no significant difference in the number of spoken events between the two groups ($p>0.05$). An analysis of silent collaboration reveals a progressive increase starting from S3, which could suggest that the students tended to collaborate more and ask for help as the activities became more difficult. An exception to this is S7, which was the summary session and did not feature any new content (Table 1). There is significantly more silent collaboration ($p<0.05$) among students in the SDG group. However, as described previously, this collaboration was not particularly effective (Figure 4-6.a).

4.6 Discussion

The usability study shows that the main difference between the two applications lies in user satisfaction. In particular, this is reflected by the greater number of signs of disruption and boredom in the SDG application (Table 4-4). During the study, it was observed that the students working with a PC concentrated on the task more and were not distracted by their classmates' work, which is what happened with the students using the shared display. Furthermore, as the students working with the SDG application were seated next to one another, they disrupted each other more and spoke more about issues not related to the activity. This led to an increase in the time required to complete, as well as a decrease in the quality of work, i.e. they made more mistakes. The in class observation showed that the groups who worked with PCs in a network had more task involvement (i.e., the degree to which individuals concentrate on and become absorbed in an activity (Garris, Ahlers & Driskell, 2002). The low amount of disruption and boredom events (Table 4-4) shows us that they also focused more on the task, and their higher effectiveness (Figure 6a) lead us to conclude a better engagement (i.e., the participation in education practices (Quaye & Harper, 2014).

Is it possible to have a situation of an active class where children stop bothering each other? Games enhance students' motivation (Erhel & Jamet, 2013), which led to greater attention and retention (Garris et al., 2002), in addition to an increase in intrinsic motivation and increased learning gain (Habgood & Ainsworth, 2011). It remains as a future work to see if the activity had more game components, it would solve the problem of the high amount of disruption events and distraction in the SDG group.

The results from the pre- and post-test show that both groups made progress. The Lab group, where each student had their own PC, made more progress and had a higher Cohen's d. These results are similar to those found by Alcoholado, Diaz, Tagle, Nussbaum & Infante (2014), where a study was conducted using a non-collaborative programme to practice mathematics in order to compare the effect on learning for students working with a PC, a shared display, and with a pencil and paper. That study also failed to find significant differences in the progress made by students working with a PC or with a shared display. It remains as a future work to make an analysis in different contexts (individual and collaborative), with bigger groups randomly assigned and with a greater number of sessions so to be able to generalize the findings.

4.7 Conclusions

To study how technology influences collaborative work in large groups a same silent synchronous collaborative application was implemented in a computer lab, with each student with a PC connected to a network, and inside the classroom, using Single Display Groupware (SDG). The results from the pre- and post-test show that the group of students that worked in the computer lab with their own individual PC made more progress than the group that worked with the SDG in the classroom. However, even it had a higher Cohen's d, this difference was not statistically significant. The amount of silent collaboration was lower among students who had their own PC, though the quality of this collaboration was higher as the students made fewer mistakes. Finally, the application used in the computer lab (which was similar to the one used in the classroom) had better usability.

We obtained similar results as Alcoholado et al. (2014) in a similar comparison but with individual work, where there was no significant difference in learning outcomes between PCs and SDG. We conclude that when doing synchronous collaborative work with large groups of students, it is better to do it with PCs. This is because the students focus more on the activity, fulfilling their role within the collaborative process (as acceptor or facilitator), without interrupting their classmates.

Our main limitation is the sample size. As future work the sample size has to be representative of a given population and the study be performed in different topics to deduce conclusions that are general.

5. RESEARCH LIMITATIONS, CONCLUSIONS AND FUTURE WORK

Research Limitations

Despite the results obtained in this thesis, which provide evidence to suggest that explicit mechanisms of silent collaboration interaction patterns can promote large-group collaboration within the classroom, it is important to mention the limitations that have been identified.

a) All of the studies were conducted in schools in Santiago, Chile, where the students were of low-to-middle socioeconomic status. It is important to note that this is a limited context. In order to better generalize the results, studies would have to be conducted with students of various socioeconomic statuses and in other countries, and see whether the results are the same.

b) Furthermore, all of the studies in this thesis were conducted with students from 6^{th} grade and mainly focused on activities for practicing Spanish grammar (with the exception of the supplementary study described in Annex A). This choice was driven by the low results that Chile has obtained on standardized tests in this subject in recent years for that grade.

c) Given the limited time and resources, the study samples in the schools were small. In particular, in order to analyse learning gains a pre- and post-test must be applied. In many cases, a student was absent for either one of these tests and therefore had to be removed from the sample in order for the analysis to be conducted. This is one variable that reduced the size of the sample, but which could not be controlled. In order to have more robust results, similar studies should be repeated with a larger number of students.

d) Effectively measuring educational tools and strategies is not only a complex task; it also requires a long period of assessment in order to reach robust and generalizable conclusions. The studies conducted for this thesis were short and carried out at specific times of the year.

Therefore, although this thesis reveals some interesting findings, it is lacking a large-scale system for testing and measuring. It would be important to replicate the studies described in this thesis using a large-scale system for testing and measuring, i.e. over a longer period of time and with a larger number of participants, so as to see how robust and generalizable the results are.

e) The results were obtained from studies that used SDG technology and are therefore linked to this particular technology. It would be important to replicate the interaction patterns using other relevant technologies, such as tabletops, mobile phones or tablets.

Conclusions

The objective of this thesis is to study explicit mechanisms of silent collaboration interaction patterns that enable and promote large-group collaboration within the classroom. It was shown that silent collaboration is one alternative that allows large groups to collaborate in the classroom and that it helps reduce problems with communication, coordination and noise, as well as encouraging all of the students to participate. Furthermore, a low-cost technology was used and can therefore be incorporated into schools of any socioeconomic status.

This thesis contributed to the literature by generating two explicit silent collaboration interaction patterns, developing new teamwork strategies in which the whole class simultaneously works on a shared tasked. Furthermore, the study in Annex A showed that it is possible to work in more than one subject (Spanish and mathematics) and using more than one type of activity (matrix and cloze).

The findings from this thesis can be divided into three main areas: pedagogy, technology and methodology.

In terms of pedagogy, it was seen that the teacher can have a significant influence when it comes to introducing technology into the classroom, as they can help mediate the interaction with the technology, as well as the interaction between students when using the technology. Although the role of the teacher was not considered in this thesis, it is important to take this into consideration when designing software using new technology.

Introducing technology into the classroom is difficult. It requires careful coordination between various actors (the establishment, teachers and students) and it is difficult to satisfy everyone's needs. The establishment has deadlines to meet, the teacher wants their students to learn, and the students often just want to enjoy themselves. Despite this, it is possible to incorporate technology into the classroom that is in line with the school curriculum and whereby the technology is a means for learning and not just for enjoyment. Activities that met the curricular needs of each school were developed and implemented, while the students enjoyed working collaboratively. The usability tests revealed that the students made good use of the software and, by analysing the logs and the way in which the collaboration conditions were met, it could be observed that the children worked collaboratively, despite being hard to achieve at times.

The main technology used was SDG. The main advantages of SDG include being able to collaborate in large groups with only limited resources. SDG does not require an internet connection and, given its characteristics, helps the teacher when it comes to explaining something to all of the students at the same time. Despite this, it was seen that using SDG with a mouse as an input device in the classroom is difficult in practice. If there is no dedicated room within the school, setting up SDG means moving large amounts of equipment that then has to be assembled and disassembled every time a session is to be conducted, which can take some time. Furthermore, there is a limit on how rich the contents of the program can be as the more users there are, the less space there is on the screen to display and interact with the content.

Other issues related to methodology also arose when conducting the research in the classroom. As explained above, the process of coordinating the use of technology is complicated. This is because schools regularly have various activities, which are often non-academic, and especially for the younger children. This implies always having a backup plan in case things do not go according to plan. This includes things such as not being able to administer the pre-test when needed, seeing long periods of time in which students do not participate, or students not participating in the study as they are busy with other things that had either not been contemplated or that appeared spontaneously. Furthermore, working in a school brings with it implicit limitations, such as the number of students or sample that can be used, as well as the randomness of the groups. There are a set number of students per grade, and these are divided into pre-determined classes. All of this implies there being difficulties when it comes to wanting to show results using statistical methods and that the results be statistically significant. This is because large samples and randomly-selected groups are required if statistical bias is to be avoided.

Finally, regarding design based research, we learned the importance of the literature review, which allowed us to solve the problems encountered through the experience of others researchers before confronting a new solution. Through the iterative process, we learned to improve not only methodologically, as the in classroom process, but also, user related ones like usability aspects.

Conceptually, this thesis used the collaboration conditions in order to design all of the applications that were used. The degree to which these conditions were met was then analysed from practical experience, i.e. using software in a real educational setting. Furthermore, the concepts of silent collaboration and collaborative configurations were developed, and an exploratory theoretical framework was proposed in order to characterize the collaborative interaction patterns.

Future work

The experimental results obtained from this thesis are valid for the context in which the studies were implemented: Chilean schools of low-to-middle socioeconomic status, with students in 6th grade and activities to practice topics mainly related to Spanish grammar. Furthermore, the studies lasted for approximately 5-6 weeks and featured groups of around 20-30 students (a typical class in a Chilean school). Some future work should consist of applying the same interaction patterns but changing one variable at a time, such as the age of the students, curricular content, the country/culture in which the software is used, or the time of the school year when the study is conducted. This would lead to more general and robust results.

Correlations were used in order to analyse some results. Causing the greatest impact on the results of this study were those used in Chapter 2: "The above may us lead to conclude that there is no correlation between spoken collaboration and correct answers, which might make us think that silent collaboration was the mechanism that achieved increased learning" and Chapter 3: "To see the impact that the difficulty level had on silent and spoken collaboration, the correlations were studied…This suggests that there is a relation between difficulty level and silent and spoken collaboration, although further research needs to be done". Although they were used to give clues, and were not used to draw explicit conclusions, there is a way to improve the analysis. As future work we propose using regression analysis, which helps to explain the causality of the variables in question, in order to draw deeper conclusions.

In the study described in Annex A, there was a student with Asperger syndrome. This syndrome causes problems for the student to relate with other students and, on occasions, can lead to socially inappropriate behaviour (NINDS, 2014). It was observed that, despite their difficulties, the student was able to communicate and coordinate with the other students in their group transparently and without any problems by using silent collaboration. This leads to the suggestion that silent collaboration may be one way to start teaching students that have difficulties interacting with their classmates how to collaborate. Furthermore, it remains as future work to use silent collaboration interaction patterns with students that have, for example, hearing problems or difficulties with speech.

Finally, integrating technology into the classroom represents a huge challenge, as it requires coordination and bringing together many variables and actors, such as the school, the teacher and the students. Despite understanding the importance of the teacher in the teaching-learning process, the role of the teacher did not fall within the scope of this thesis. It remains as future work to create tools that allow the teacher to develop activities that support pre-defined collaborative interaction patterns, as well as having them participate in the design and collaborative process from the beginning, and to see how such involvement might influence learning.

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A N N E X E S

ANNEX A: SILENT VS. SPOKEN COLLABORATION IN SMALL GROUPS FOR NUMBERING PRACTICE

Abstract

There are several advantages to collaborate in groups when students are located in the same physical space. However, it becomes more of a challenge when the students are not seated together. Silent (non-verbal) collaboration is one alternative that allows participants to collaborate without necessarily being seated together. Given that silent collaboration has already been studied among large groups, our research questions asks: How does the collaborative behaviors of peers change with silent and spoken small group collaboration? A study was performed with 3rd graders practicing numbering, sharing a personal screen (spoken collaboration) or a big screen for the whole classroom (silent collaboration), using two different applications for practicing numbering that had the same collaborative objective and game mechanics. The results showed the progress made by students who collaborated silently was close to the margin of significance; their outcome was also more accurate as the students made fewer mistakes. It remains as future work to analyze whether these results can be replicated when students collaborate silently on the internet.

Introduction

Collaboration has been defined as an essential component of the 21st Century (Bruns, 2007; Pellegrino & Hilton, 2013). The inclusion of collaborative problem solving in PISA 2015 (OECD, 2013) has resulted in it becoming an important topic of study.

There are certain advantages to collaborative work that are not provided by individual work. When students work collaboratively, their performance improves in comparison to individual work (Roschelle & Teasley, 1995; Gokhale, 1995). In addition to this, they also develop social and communication skills (Laal & Ghodsi, 2012). There are several advantages to collaborating in groups when students are located in the same physical space. Collaboration itself helps improve academic achievement and student attitudes, as well as helping students retain the knowledge acquired (Campisi & Finn, 2011). Working in groups provides more information and points of view than working individually. Groups can also motivate individual students to improve their performance (Alavi, 1994). Furthermore, being in the same physical space improves group problem solving (Chung, Lee & Liu, 2012) and allows the teacher to offer explanations based on their observations (Black, 2005).

In order to work collaboratively, certain conditions must be met by the activity that is being carried out. There must be a common objective (Dillenbourg, 1999), positive interdependence (Johnson & Johnson, 1999), coordination and communication (Gutwin & Greenberg, 2004), shared information (Janssen, Erkens, Kanselaar & Jaspers, 2007), as well as shared rewards (Axelrod & Hamilton, 1981).

Adopting collaborative practices with groups of children in the classroom is a challenge (Boticki et al., 2013; Stanton et al., 2002). There are often problems with coordination and communication that can hinder the collaborative learning process (Bertucci et al., 2010). For example, some students may refuse to participate, while others may be shy and find it hard to share their ideas (Marjanovic, 1999). The large number of verbal interactions that can be produced can also hinder coordination (Strijbos & Martens, 2001). Furthermore, these interactions might not be related to the activity and can therefore interfere with the learning process (Miner, 1992).

Silent (non-verbal) collaboration is one alternative that allows large groups of children to collaborate when they are not seated together or when verbal communication proves difficult (Szewkis et al., 2011). One way of implementing silent collaboration is through the use of Single Display Groupware (SDG). This allows several users located in the same physical space share a single screen, with each user having their own input device (Moraveji et al., 2008). This technology facilitates group collaborative activities in the classroom (Pavlovych & Stuerzlinger, 2008) as it encourages interaction during the activity, as well as participation and commitment from the students (Infante et al., 2009). This technology also enables collaboration with minimal equipment (i.e. a computer, a projector, and one mouse per student), which makes it a low cost technology and eases the technical support (Alcoholado et al., 2012).

As a Computer-mediated communication (CMC) (Allbritton & Carayannis, 1997), silent collaboration compared to spoken collaboration, allows learners to have more time to think deeply before giving opinions (Moore, 2002), it reduces the conflicts between the team members (Bhappu & Crews, 2005) and produces greater equality of participation (Van der Meijden & Veenman, 2005). In this kind of learning environment, the teacher becomes a facilitator rather than the main source of information (Vrasidas & McIsaac, 2000), which can reduce the constant teacher presence that may inhibit children's interactions (Clements & Sarama, 2007).

Given that silent collaboration has already been studied among large groups, our research questions asks: How does the collaborative behaviors of peers change with silent and spoken small group collaboration?

In this paper we analyze silent and spoken collaboration by studying groups of students working in the computer lab and the classroom. The students in the computer lab were seated together and could talk to one another, while the students in the classroom were seated apart and found verbal communication difficult. Secondly, we describe the experimental work that was conducted, as well as the qualitative and quantitative results of these experiments. Finally, we present the results and conclusions of this paper.

Methodology

Figure 1. Different settings for the applications

Experimental design

The study was carried out with two 3rd grade classes from a state-subsidized school in Santiago, Chile. Since the aim was to study the learning and the small group collaborative behavior when students could and could not exchange utterances to understand the relation between silent and spoken collaboration, two groups were randomly formed. In the Lab setting 27 students participated (15 boys and 12 girls, aged 7 and 8); sub groups of three students randomly seated behind a PC sharing its screen, each with their own mouse were formed (Figure 1a). In the Classroom setting 23 students participated in the study (13 boys and 10 girls, aged 7 and 8); the size of the screen allowed a maximum of 18 students work comfortably (6 groups of 3), so the class was splinted in two, each sub group sharing a big screen (Figure 1.b). In both the lab and the classroom, the same exercises were performed, and for each of the eight 40-minute sessions, groups were chosen randomly to avoid the formation of social patterns in group behavior.

Table 1. Description of the activities in S1-S8 in the Classroom and Lab settings

Session	***Subject/Difficulty***	***Duration in classroom (average minutes per group)***	***Duration in lab (average minutes per group)***
S1	Counting numbers in ascending and descending order (0-100) (software learning) / Low	18.68	9.72
S2	Counting numbers in ascending and descending order (0-100) (software learning) / Low	26.25	-
S3	Counting numbers in ascending and descending order (0-300) / Low	18.13	7.92

S4	Counting numbers in ascending and descending order (300-700) / Med	14.92	7.68
S5	Counting numbers in ascending and descending order (700-1000) / High	17.33	7
S6	Number patterns in ascending and descending order (0-300) / Low	30.05	10.55
S7	Number patterns in ascending and descending order (300-700) / Med	26.62	13.6
S8	Number patterns in ascending and descending order (700-1000) / High	23.8	10.85

In both settings, the eight sessions each consisted of a set of 25 exercises based on the topics taken from the Counting and Number patters units (Table 1) in the math syllabus. The collaborative activities were developed by the researchers, in line with the requirements specified by the school. In the first two sessions (S1-S2) for the Classroom setting group, and in the first session (S1) for the Lab setting group, the students familiarized themselves with the application. The Classroom setting group needed a further session to master the mechanics involved in the communication space (Section 2.2).

Recorded data

To assess the impact of our system a written pre-test was administered. This test was created by a teacher from outside the participating school and covered all the topics included in the applications, with a maximum score of 50 points. The test was administered to both groups (Classroom and Lab setting) before the first session in order to assess the students' prior knowledge. This test was repeated as a post-test after the final session. Cronbach's Alpha was used to assess the validity of the test, with a score of 0.985 on the pre-test and 0.984 on the post-test.

Quantitative and qualitative data was collected throughout the sessions in the two studies (Rosen et al., 2014). The quantitative data consisted of the number of messages sent via the communication space in the classroom application, taken from the application's log. The qualitative data was gathered by observers using tablet computers. The number of observers varied from 3 to 6 depending on the number of students and setting. Each observer monitored the performance of 4 to 6 students, with the aim of recording the number of times that different events occurred. The events that were recorded are shown in Table 2.

Table 2. Total number of events registered from sessions S3 to S8 per participant per minute in the Lab and Classroom settings. Spoken collaboration events are highlighted in bold

	Lab	**Classroom**
Pure spoken collaboration	1.09	0.33
Pressure	0.71	0.15
Disruption	0.20	0.02
Question regarding the feedback	0.00	0.00
Visualization	0.04	0.07
Question regarding use of the system	0.03	0.02
Motivation	0.28	0.16
Positive Remarks	0.07	0.01
Boredom	0.14	0.15
Discontent	0.02	0.01
Negative Remarks	0.03	0.01

If a question or comment required further explanation, all of the related verbal interactions were considered as a single event. This was the case for questions regarding use of the system, feedback, visualization, positive remarks, boredom, discontent and negative remarks. If several expressions of motivation or disruption were consecutive or related, they were also considered as a single event. Each event could occur more than once for each child in each activity.

Only two types of events were classified as spoken collaboration, pure spoken collaboration and pressure (highlighted in bold in Table 2). This is because they involve at least two students and can influence how the activity is completed as a result of verbal suggestions. These were the only two types of events considered for comparing silent and spoken collaboration. The other events that were recorded allowed the usability of the applications to be analyzed, the results of which are presented in the results section.

Description of the tools used

To answer our research question, two applications were developed. Both of these applications had the same collaborative objective: ordering numbers in a sequence (Zurita & Nussbaum, 2004). The only difference between the two applications was the manner in which they allowed students to collaborate. The first application was based on spoken collaboration, with groups of students seated together in front of a PC, each with their own input device (Figure 1.a). The second application was based on silent collaboration as the students were not seated together and collaborated using a projected shared display and individual input devices (Figure 1.b). The objective of both applications is to work in groups of three to arrange a series of numbers generated by the software in ascending and descending order. If the number of students was not a multiple of three, the applications allowed students to work in twos, while maintaining the same functionality. A detailed description of the applications is included below.

Lab application

The first stage of the activity involves acknowledging the players, where each student must identify themselves on the screen. In order to do so, each student is assigned a unique symbol according to their name.

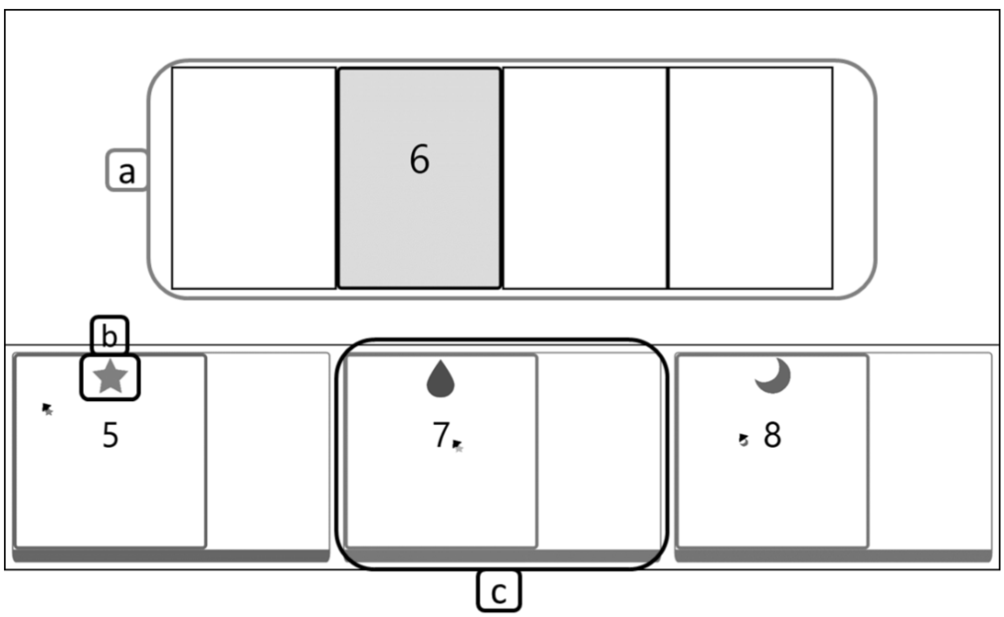

Figure 2. Application interface for each group in the Lab setting

In the following stage, the activity proper, the screen is divided into several sections (Figure 2):

• Common space (Figure 2.a): The space where the numbers must be arranged in ascending or descending order. At the beginning of the activity there are three blank cells, plus one number that is fixed and has a different color background. This number provides the students with a reference (e.g. In Figure 2.a, the reference is the number 6).

• Identifier (Figure 2.b): The unique symbol associated to each student (e.g. In Figure 2.b, the identifier is a star). The symbol is also linked to each child's mouse pointer so that they can identify their pointer on the screen.

• Personal space (Figure 2.c): The space containing the information handled by each child (e.g. In Figure 2.c, the student whose identifier is the droplet must place the number 7 in the sequence. Each student is only able to move their allocated number with their personal mouse). The 'OK?' button also appears in this space, which allows the group to confirm their answer once all of the participants have placed their number in the sequence (Figure 3.a).

• Student feedback: The feedback given by the system once the exercise is completed. A tick appears if the group answered correctly, with a cross if they answered incorrectly (Figures 3.b and 3.c).

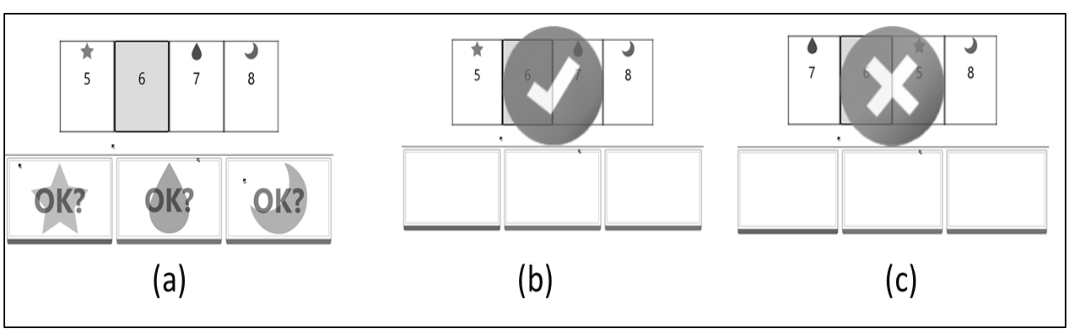

Figure 3. Different statuses displayed by the application interface

Classroom application

The classroom application also features a shared display, but in this case every group's information is projected onto a single screen. As with the lab application, each child also has their own mouse (Figure 1.b, with groups of students looking at their projected display).

As with the lab application, the students are divided into groups of three. However, in this case the three students are not seated together and therefore cannot easily communicate verbally. Each group's work space (Figure 4) is displayed on the shared screen, together with the other groups' work spaces.

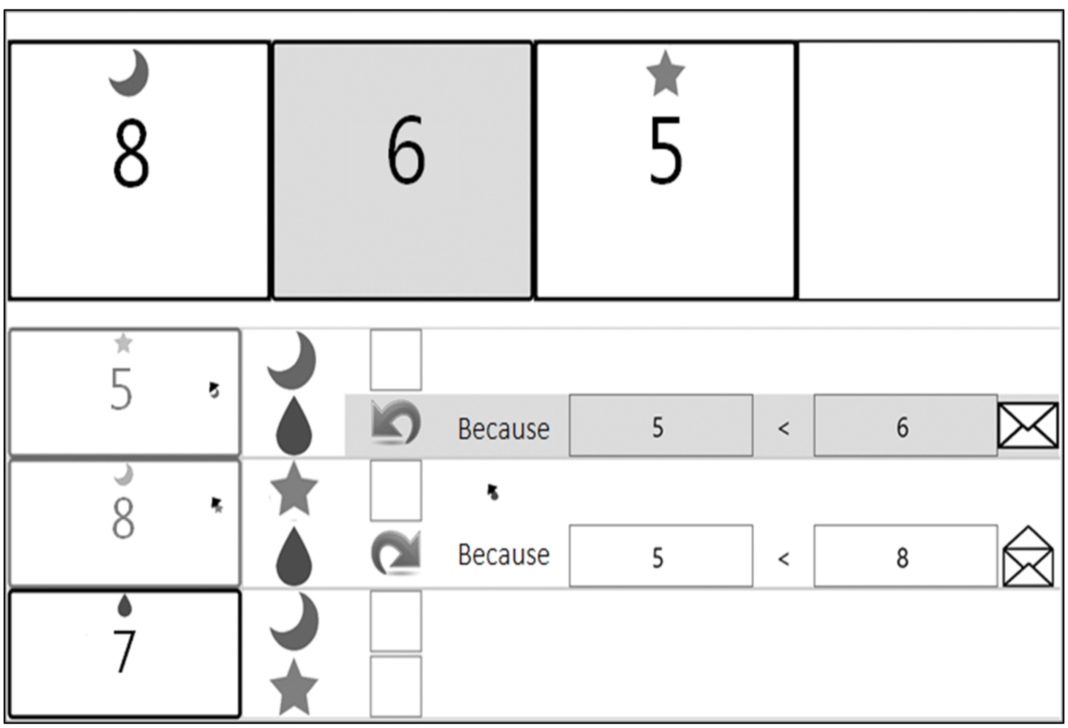

Figure 4. Application interface for each group in the Classroom setting

As with the previous application, each student starts by identifying themselves on the screen. In each group's work space (Figure 4) there are certain elements that are also found on the lab application (the common space, identifiers and personal space). However, the personal space is different. In the classroom application, this space contains not only each student's number, but also the communication space (Figure 5), where silent collaboration takes place.

The game mechanics are the same as those described in the previous section, with the only difference being the use of the communication space. Given that the students are not seated together, they must use this space in order to communicate and coordinate among themselves. Each student can send a message to any other member of their group. A message is constructed by identifying the student who wishes to send the message (Figure 5.a), plus the message itself. The message starts with an icon (Figure 5.b). This icon can be a clock (Figure 6.a), indicating that "it's your turn to place your number"; a forward arrow (Figure 6.b), indicating that "your number goes further along than where you placed it"; or a backward arrow (Figure 6.c), indicating that "your number goes further back than where you placed it". If the student does not want to send the message, they can leave it as an empty box (Figure 6.d). In order to be sent, the message must be backed up with an argument. Figures 5.c and 5.c' show the argument that accompanies the message. The 'less than' symbol (<) is fixed, while any of the numbers from the exercise can be used to construct the argument. For example, in Figure 4 the student with the droplet symbol is indicating to the student with the star symbol, who has the number 5, that their number goes further back in the sequence.

This is done by selecting the backward arrow and stating that the number 5 (Figure 5.c) is less than the number 6 (Figure 5.c’). Once the message has been constructed, the student sends it by using the send button (Figure 5.d). The message flashes and is highlighted with a colored background so that the students realize that there is a new message.

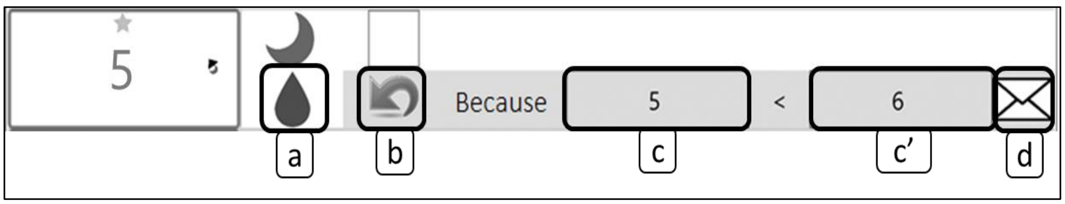

Figure 5. Communication space in the classroom application

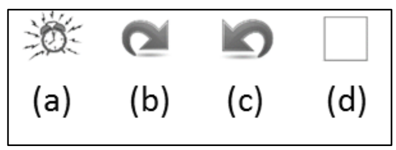

Figure 6. Message icons in the communication space

The communication space shown in Figure 5 was not required by the Lab application. This is because the students were seated together and could therefore communicate these messages verbally.

Comparison between tools

The main differences and similarities between both applications are shown in Table 3, where the scaffolding of collaboration and communication is explicit.

Table 3. Comparison between applications

Functionality	Lab application	Classroom application
Collaborative objective	Ordering numbers in a sequence.	Ordering numbers in a sequence.
Arrangement of students	Groups members seated together in front of a PC, each with their own input device.	Groups members seated separate from each other in front of a projected shared display, each with their own input device.
Collaboration method	Ordering of objects, each belonging to a student, selected so there is interdependence between roles which have to be solved through spoken collaboration.	Ordering of objects, each belonging to a student, selected so there is interdependence between roles which have to be solved independently; peers silently indicate where they ban or approve their peer's action.
Argumentation	By talking.	By sending messages via the application.

To be able to compare both groups collaborative behavior, we had to assure that the collaborative software was the same for both groups. Table 4 shows that both applications meet the conditions required for collaboration (Szewkis et al., 2011); the differences between the two are not relevant as both applications have the same objective and game mechanics.

Table 4. Theoretical fulfilment of collaboration conditions in the two studies

Condition	Theoretical fulfilment
Common objective	The aim in both activities is the same for every member of the group.
Positive interdependence between roles	Each student has a role: placing their number in the sequence that has to be built by the group.
Coordination and communication between roles	Considering that the ordering is performed sequentially, the students have to communicate in order to coordinate and construct an answer.

Individual responsibility	Each answer (correct or incorrect) receives public feedback.
Awareness	By sharing a screen, the work of each member of the group could be viewed.
Joint rewards	If one student in the group was wrong, the whole group needed to repeat the exercise. Thus, everyone wanted to win.

Results

Analysis of usability

A usability analysis was conducted to check whether the students' behavior when using the applications was an obstacle to achieving the desired dynamics and whether there were any differences in how the applications were used. A usability analysis typically includes learnability, efficiency, memorability, user satisfaction, and errors (Nielsen, 1994). Learnability was measured by considering the time it took the students to complete the training session. As shown in Table 1, this was 9.72 minutes (S1) for the Lab setting group, while it was 18.68 and 26.25 minutes (S1-S2) for the Classroom setting group.

Efficiency was calculated by considering the time it took the students to complete the activities in sessions 3 through 8 (Table 1). Both applications allowed the activities to be completed within the duration of a regular class (40 minutes). This time was 57.6 minutes for the Lab setting group, and 130.85 minutes for the Classroom setting group. Table 2 shows that the students took full advantage of the time that was available. This can be observed in the low number of interruptions that were recorded in the form of disruptions (0.20 for the Lab setting and 0.02 for the Classroom setting), questions regarding feedback (0.00 for the Lab setting and 0.00 the for Classroom setting), and visualization events (0.04 for the Lab setting and 0.07 for the Classroom setting).

Memorability was evaluated by calculating the number of questions regarding use of the system (Table 2). 0.03 questions were asked per student per minute in the Lab setting (0.19 questions per student in the training session (S1) and an average of 0.04 questions in S3 to S8). 0.02 questions were asked per student per minute in the Classroom setting (1.24 and 0.76 questions per student in the training sessions (S1-S2) and an average of 0.08 questions in S3 to S8). This suggests that both systems were easy to use and that it was easy to remember how to do so following the training sessions.

User satisfaction was assessed by calculating the ratio of positive events (motivation and positive remarks) to negative events (disruption, boredom, discontent, and negative remarks). This is similar to the assessment made by Bevan & Macleod (1994). This ratio was 0.89 for both the Lab and Classroom setting groups. It is interesting to note that overall there were more negative events than positive events. This is mainly due to the large number of disruptions in the Lab setting, where the students were seated together, as well as signs of boredom in both settings. The signs of boredom were due to the fact that the groups who finished first had to wait for the other groups to finish solving the remaining problems. Despite this, the observers noted that the students were highly motivated while performing the activities in both settings. This can be seen from the large number of signs of motivation that were recorded (Table 2). Finally, neither application produced any errors as the activities were being carried out. In general, these usability analyses reveal that neither application was an obstacle to achieving the desired dynamics in the studies that were conducted. A relevant difference between the two applications is that the students in the Lab setting tended to express their opinions more, both positive and negative (0.40 vs. 0.20 positive events per student per minute and 0.20 vs. 0.17 negative events per student per minute). Despite this, the results do not reveal any notable differences in terms of usability.

Analysis of learning

The Lab setting group did not reveal any progress between the pre-test and post-test, while the Classroom setting group revealed some progress, without being significant (Table 5).

Table 5. Pre-test and post-test results (SD: standard deviation, Δ: difference)

	Pre-Test		**Post-Test**				
	A	*SD*	*A*	*SD*	*Δ%*	*Significance*	*Cohen's d*
Lab setting	39.41	9.01	39.41	7.68	0%	1.000	0
Classroom setting	34.74	8.89	37.52	8.1	8%	0.273	0.326

An ANOVA was conducted to compare the progress made by students in both settings. The results, which were close to the margin of significance (p=0.055), showed that students in the Classroom setting made more progress than students in the Lab setting.

Comparison between the two applications

To analyze the efficacy of both applications we analyzed the amount and quality of the performed work.

Table 1 shows the average time taken per group to finish each session. These times were greater for groups in the Classroom setting. This is because constructing a message to communicate and collaborate silently required more actions than in the Lab setting, where communication was direct and via spoken collaboration. Because times were very different, analysis was made per group or student.

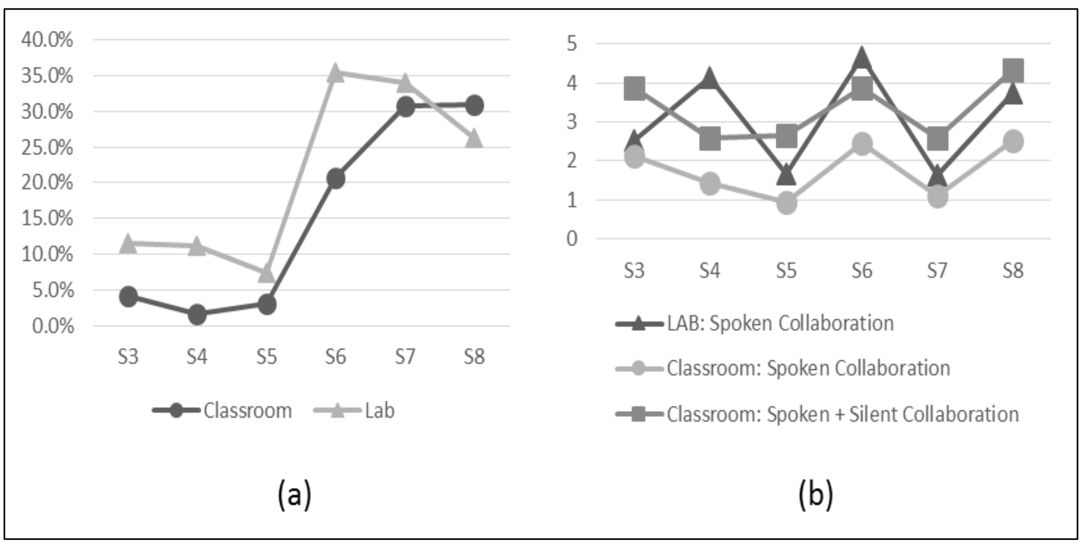

Figure 7. (a) Average percentage of mistakes made per group in the Lab and Classroom settings (b) Average number of collaboration events per student in the Lab and Classroom settings

Although the time required to complete the sessions was greater in the Classroom setting, the level of active participation, or use of the software, was similar in both settings. This was measured by calculating the average quantity of numbers placed in a sequence by each group, with an average of 129 in the Lab setting and 119 in the Classroom setting.

Figure 7.a shows the average percentage of mistakes made per session per group in the Lab and Classroom settings. While groups in the Classroom setting take twice as long to finish the exercises in each session (Table 1), they also make fewer mistakes. In other words, there is less trial and error in the Classroom setting. There is also a noticeable increase in the number of mistakes made from S6 onwards. This is because the topic in sessions S6-S8 was number patterns, which the students found more difficult than the topic of counting in S3-S5 (Table 1).

Significant correlations ($p<0.05$) were found between the time taken by the groups in the Lab setting to complete the exercises in each session and the number of mistakes made (0.712, 0.652, 0.832, 0.531, 0.754 and 0.941 for sessions S3-S8, respectively). This correlation was not observed in the Classroom setting. This suggests that groups in the Lab setting spent more time repeating exercises because of mistakes, while groups in the Classroom setting spent more time on communication.

Figure 7.b shows the average number of silent and verbal collaboration events per student in each setting. In the Lab setting, collaboration could only occur through

spoken collaboration. In the Classroom setting, on the other hand, the main mechanism for working together was silent collaboration. In the latter case, although students were not seated together, they did communicate verbally (with some difficulty). It can be observed that spoken collaboration tends to decrease from session to session in the Classroom setting. This is with the exception of S6, where there was a change of topic, and S8, which was the most difficult session in the study. In terms of overall collaboration, the results behaved similarly for both applications (a difference of less than one event on average). This was with the exception of sessions S3 and S4, where the increased differences could be attributed to the fact that the students were still getting used to the application and the collaboration mechanism.

Discussion

The progress made by the groups in the Classroom setting, who collaborated through silent collaboration, was close to the margin of significance ($p=0.055$). This was measured by comparing the progress made by students between the pre-test and post-test and comparing it with the students in Lab setting, who collaborated through spoken collaboration. The groups in the Classroom setting took longer to complete the exercises in each session. This was because more actions were required in order for students to communicate with their classmates using the messages sent via the application. Furthermore, if the teacher had to explain the topic that was being covered or how to use the system, they had to stop all of the groups as they all used the same screen. The groups in the Lab setting made more mistakes. Although the tasks were defined so there was interdependence between roles, it was observed that sometimes one peer took a leadership role and therefore there was little exchange of ideas to arrive at a consensus regarding the correct answer. There were also more signs of trial and error in these groups than in the Classroom setting. Future research has to find out if students with more experience in collaborative work reach a balanced consensus.

The argument builder proposed in the application section to complement the sending of a message through silent collaboration did not have the use that was expected. It was observed that the main icon used for silent collaboration was the clock (76.4% of silent collaboration). This icon was used to indicate to students that it was their turn to place their number. Furthermore, it was observed that other classic mechanisms of silent collaboration were also used during the sessions (Caballero et al., 2014). These include using the mouse pointer to circle numbers and indicate correct or incorrect positions. It remains as future work to study how to encourage greater use of an argument builder and see whether this has an impact on both learning and acquisition of higher level cognitive skills.

Even though both applications met the conditions for collaboration detailed in the introduction, there was a difference in the behavior observed for positive interdependence, as well as coordination and communication. It was observed on some occasions that in the Lab setting one student in each group imposed their leadership on the other students and completed the activity on their own. In some cases, this student would even take control of the other students' mice in order to complete the activity. This was not possible in the Classroom setting as the students were not seated together.

Given that the study was conducted in a specific context, the results cannot be generalized. Future research is required using a larger sample, more sessions and different topics.

Conclusions

A study was performed with 3rd graders, sharing a personal screen (spoken collaboration) or a big screen for the whole classroom (silent collaboration), using two different applications for practicing numbering that had the same collaborative objective and game mechanics. The purpose was to answer the question: How does the collaborative behaviors of peers change with silent and spoken small group collaboration?

The results from the pre-test and post-test reveal that progress made by the students who collaborated silently was close to the margin of significance. The overall level of collaboration was similar in both settings, with the quality of the silent collaboration being higher. This was because the results of the work done through silent collaboration contained fewer mistakes. As such, we can conclude that it is more beneficial to use silent collaboration when teaching certain aspects of number ordering in mathematics to small groups. A reason for this result can be that the children had no previous experience in collaborating; the silent collaboration mechanism could have favored the collaborative process, Future research has to validate this hypothesis and analyze other domains.

Work with synchronous collaboration has previously been done online (Kohlmann, & Lucke, 2014; Kongcharoen, Hwan, Prasunpangsri, & Kanyacome, 2014; Oztok, Zingaro, Brett & Hewitt, 2013). However, students indicate that the lack of face-to-face verbal communication negatively affects the educational experience (McBrien, Cheng & Jones, 2009). It remains as future work to analyze whether these results can be replicated when students in different locations collaborate silently over the internet.