



PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

SCHOOL OF ENGINEERING

INTERACTIVE INSTRUCTION WITH OPEN COLLABORATIVE-INTERACTION MECHANISMS

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Thesis submitted to the Office Graduate Studies in partial fulfillment of the requirements for the Degree of Doctor in Engineering Sciences

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Santiago de Chile, November, 2015

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PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
ESCUELA DE INGENIERIA

INTERACTIVE INSTRUCTION WITH OPEN COLLABORATIVE-INTERACTION MECHANISMS

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*To Cristián, to the first day of the rest
of our life.*

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PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

INSTRUCCIÓN PARTICIPATIVA EN COMPUTADOR CON PANTALLA
COMPARTIDA Y MECANISMOS DE INTERACCIÓN COLABORATIVOS
ABIERTOS

Tesis enviada a la Dirección de Postgrado en cumplimiento parcial de los requisitos para
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DANIELA CABALLERO DÍAZ

RESUMEN

Con el avance de la tecnología, hoy es importante que los alumnos logren habilidades que les permitan enfrentarse a los nuevos desafíos que trae consigo esta realidad, las llamadas ‘habilidades del siglo XXI’. Una de las habilidades que los alumnos requieren para desempeñarse tanto en el ámbito escolar como laboral, es la colaboración. La relevancia que ha tenido el aprendizaje colaborativo ha ido en aumento en los últimos años. Esto se refleja con la importancia que PISA le ha dado a éste, ya que desde del año 2015 se comenzará a medir la capacidad de resolver problemas de manera colaborativa. Sin embargo, aún no hay claridad sobre qué es lo que diferencia a la colaboración de la cooperación, especialmente en actividades que distingan uno u otro tipo de aprendizaje. Por otro lado, la instrucción participativa es un método de enseñanza, que ha sido fundamental en la enseñanza de matemáticas en países con altos niveles de desempeño en esta materia. Sin embargo, la adopción de tecnologías que soporten este tipo de aprendizaje no ha sido totalmente efectiva, como es el caso de las pizarras interactivas o clickers. Single Display Groupware (SDG) ha surgido como una alternativa para la

instrucción participativa y el aprendizaje colaborativo, debido a los beneficios que éste trae a los participantes cuando colaboran. Esta tesis tiene como objetivo estudiar cómo se puede insertar de manera concreta la instrucción participativa en el aula utilizando la tecnología de SDG y mecanismos de interacción colaborativos abiertos. Para esto, se desarrolló un modelo para la creación de actividades colaborativas y cooperativas que permite a los diseñadores de ambientes colaborativos poder integrar el aprendizaje colaborativo en el aula. Este modelo queda determinado por dos elementos esenciales: Degree of Dependency, los que definen la interacción entre los alumnos y las Activity Structures, que articulan las componentes que son necesarias para lograr el objetivo, siguiendo una lógica específica. Así, las actividades cooperativas se diferencian de las colaborativas debido a que tienen distintos Degree of Dependency.

En segundo lugar, se llevó a cabo un desarrollo de un software que permitiera la instrucción participativa, el que fue utilizado por profesoras en sus clases regulares de matemáticas. Con esta experiencia se pudo mostrar que la instrucción participativa con aprendizaje colaborativo mediado por SDG resulta ser efectivo. Además, se observó que patrones silenciosos aparecieron en la pantalla de manera natural, lo que complementa investigaciones anteriores que hablan del concepto de ‘colaboración silenciosa’, la cual se da cuando los alumnos no pueden hablar de manera fluida por estar sentados de manera distante.

Adicionalmente, un estudio para profundizar cuándo es mejor utilizar lo observado con respecto a la colaboración silenciosa, mostró que ésta puede ser un puente concreto para la enseñanza de habilidades colaborativas, especialmente en alumnos que no les gusta

trabajar en equipo. Pues el desempeño académico de los alumnos depende de su disposición a trabajar en grupo, y este efecto es mayor cuando los alumnos se sientan contiguamente.

Por último, al final de esta tesis se sugiere una serie de trabajos futuros para poder indagar sobre la colaboración silenciosa y cómo ésta puede ser una herramienta que permita a los alumnos aprender las habilidades colaborativas que se han tornado tan importante. Además de poder estudiar cómo el modelo propuesto en esta tesis puede ser integrada en otras áreas que no sea matemáticas y lenguaje.

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

Palabras Claves: Computer Supported Collaborative Learning; Aprendizaje Colaborativo; Colaboración silenciosa; Single Display Groupware; Instructional Design

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MECHANISMS

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ABSTRACT

With recent advances in technology, it is increasingly important for students to develop so-called ‘21st century skills’, which will allow them to face the challenges inherent in the current landscape. In order to play a full role at both school and in the workplace, one of the skills that students require is collaboration. The importance of collaborative learning has grown in recent years. This is reflected in the importance given to collaborative learning by PISA. From 2015, this test will begin to measure students’ ability to solve problems collaboratively. However, it is still not clear as to what makes collaboration different from cooperation, especially in activities that differentiate between collaborative and cooperative learning.

In addition to this, interactive instruction has been a fundamental approach for teaching mathematics in top performing countries. However, the adoption of technologies that support this type of teaching has not been totally effective; such is the case with interactive whiteboards or clickers. Single Display Groupware (SDG) has emerged as a strong option for delivering interactive instruction and collaborative learning, especially given the benefits it provides to the participants when collaborating. The objective of this thesis is

to study how interactive instruction can be introduced into the classroom using SDG technology and open collaborative interaction mechanisms. In order to do so, a model was developed for creating collaborative and cooperative activities that allows people who design collaborative environments to integrate collaborative learning into the classroom. This model is determined by two essential elements: the Degree of Dependency, which defines the interaction between students; and the Activity Structures, which follow a specific logic in order to articulate the components that are necessary for meeting the objective. Cooperative activities differ from collaborative activities as they have different Degrees of Dependency.

Secondly, a piece of software was developed to enable interactive instruction and was used by teachers in their regular mathematics classes. This study showed that interactive instruction with collaborative learning mediated by SDG is effective. Furthermore, it was observed that silent interaction patterns naturally emerged on screen, complementing previous research that discusses the concept of ‘silent collaboration’. This sort of collaboration emerges when the students cannot easily speak with one another because of the way they are seated.

Additionally, a more in-depth study of when it is best to use silent collaboration showed that it could be used as a gateway for teaching collaborative skills, especially for students who do not like to work as part of a team. A student’s academic performance depends on their willingness to work as part of a group and this effect is accentuated when students sit next to one another.

Finally, a recommendation is made at the end of this thesis for future work regarding further research into silent collaboration and how this might be a tool that allows students

to acquire collaborative skills, which have become increasingly important. In addition to this, a recommendation is also made to study how the model that is proposed in this thesis could be incorporated into subjects other than mathematics and language arts.

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Key Words: Computer Supported Collaborative Learning; Collaborative Learning; Silent Collaboration; Single Display Groupware; Instructional Design

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1. INTRODUCTION

The need of practical tools that scaffold collaborative learning within the classroom motivates this thesis. The main objective is describe how collaborative learning and interactive instruction can be brought into the classroom. In particular, this thesis shows the technology Single Display Groupware as a concrete tool to the teacher, who is heavily involved and plays an active role in the teaching process.

1.1 Theoretical background

As a methodology, collaborative learning allows students to build their knowledge as a group. It is widely accepted that collaboration is one of the so-called ‘21st century skills’ and must be acquired by students at school from an early age; without this skill, students may even have problems in the workplace (Kuhn, 2015).

This is added to the fact that, nowadays, advances in technology can allow this type of learning to take place; particularly computer-supported collaborative learning. The concepts and theories that accompany the research presented in this thesis will be reviewed in the following sub-sections.

1.1.1 Collaboration

Collaboration is described by Roschelle & Teasley, 1995 as “a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem.” According to Webb (1995), collaboration has been shown to bring several benefits to educational practice. This is because when students collaborate with one another they can acquire new knowledge (Gokhale,

1995; R. T. Johnson, Johnson, & Stanne, 1985; Roschelle & Teasley, 1995) and develop (i) communication skills (Gomez, Wu, & Passerini, 2010); (ii) social skills (Lavasani, Afzali, Borhanzadeh, Afzali, & Davoodi, 2011); as well as (iii) motivation and engagement (Lavasani et al., 2011).

Cooperation vs Collaboration

Slavin's (1980) concept of cooperation is described as the opposite of competition, i.e. when students cooperate, the success of one student also helps the other students to meet their objective. Students can work cooperatively in order to meet shared objectives, i.e. each student can meet their objective as long as the other members of the group meet theirs (Johnson, Johnson, & Smith, 1998).

As there are similarities between the two, the concept of cooperation is often used as a synonym for collaboration (Dillenbourg, 1999; McInnerney & Roberts, 2004). However, there are differences between these concepts: cooperation focuses more on dividing tasks among the participants, with a focus on sub-tasks that are then completed individually (Dillenbourg, 1999). In this sense, coordination and communication come at the end of the process as a means of bringing together the individual results (Dillenbourg, Baker, Blaye, & O'Malley, 1996). As such, each person is only responsible for a fraction of the overall problem (Roschelle & Teasley, 1995). Collaboration, on the other hand, focuses more on the participants' commitment to solve a problem as a group through a coordinated effort (Roschelle & Teasley, 1995). As an example of this difference, cooperation resembles the process

of assembling a car, where each participant is only responsible for a small part of the whole; while collaboration resembles the work of a team. In this case, although each individual member is given a role and is responsible for their own work, they are also responsible for the end result and can help their colleagues tackle any issues that crop up along the way.

This confusion regarding the difference between the two types of learning leads to the need to identify factors that differentiate one type of learning from the other and, understand how this difference is evident in different types of activities. Chi (2009) suggests that there are three explicit advantages to differentiating between types of activities: (i) it can guide those who design learning environments so that they know which type of activity the students should really be engaged in; (ii) it distinguishes between the underlying cognitive process of each activity, which in turn can explain the different levels of effectiveness in learning; and (iii) it allows for an understanding of two concepts that are used synonymously, such as cooperation and collaboration.

Collaboration conditions

There are certain conditions that are required in order for both cooperation and collaboration to be effective. (Johnson et al., 1998) suggest that for cooperation these conditions include: (i) positive interdependence, i.e. the students feel they are bound to their classmates in such a way that they cannot meet their own objective unless their classmates also meet theirs; (ii) individual accountability; (iii) the students encourage their classmates to succeed; (iv) the existence of social skills; and (v) group

processing. Slavin (1988), on the other hand, suggests that there are essentially two conditions for cooperation: the existence of a shared objective and the existence of individual accountability.

In terms of collaboration, the study by Szewkis et al. (2011) structures collaboration conditions in the following way: (i) a shared objective (Dillenbourg, 1999); (ii) positive interdependence (Johnson & Johnson, 1999); (iii) communication and coordination (Raposo, Magalhaes, Ricarte, & Fuks, 2001), defined by Malone & Crowston (1990) as “the act of managing interdependencies between activities performed to achieve a goal” (p. 361); (iv) individual accountability (Johnson et al., 1998); (v) mutual support (Slavin, 1996); awareness of the group’s work (Zurita & Nussbaum, 2004); and (vii) shared rewards (Zagal, Rick, & Hsi, 2006).

For the purposes of this thesis, the conditions described for collaboration will be used, with cooperation considered a subset of collaboration.

What does it mean to collaborate?

According to Webb (1995), certain processes emerge when students collaborate, such as (i) co-construction of ideas, which provides students a new understanding based on their classmates’ ideas; (ii) conflict and controversy, which gives the students new points of view and allows them to explore different options; (iii) giving and receiving elaborated help, which helps both the person who is explaining to learn, as well as the person who is receiving the explanation; and (iv) equality of participation, where all of the students are actively involved in the process.

In order to achieve the above, the students must possess certain individual skills that allow them to carry out these processes adequately (Webb, 1995). As Johnson and Johnson (1994) suggest: “small-group skills do not magically appear when they are needed. Students must be taught the social skills required for high-quality collaboration” (p. 4).

The skills that students consider to be important include help-related skills (e.g. asking for and giving help) and those related with communication (Ladd et al., 2014). The first set of skills mainly refers to the process of giving and receiving elaborated help, described by Webb (1995). The second set of skills allows the process of equality of participation to be effective. On the other hand, team orientation (Dickinson & McIntyre, 1997; Fransen, Weinberger, & Kirschner, 2013; Salas, Sims, & Burke, 2005) is also considered an essential skill for ensuring that work groups are effective. This is achieved through coordination, as well as by stipulating rules and regulations.

Finally, in order for students to acquire these skills they must be guided through activities that allow for a process of “learning by doing” (Monteiro & Morrison, 2014). This is because teaching how to collaborate cannot be separated from the collaborative process itself.

Modelling collaboration

There is an overwhelming consensus in the literature that collaborating is not the same as working together (Blumenfeld, Marx, Soloway, & Krajcik, 1996;

Dillenbourg, 1999; Johnson et al., 1998; Roschelle & Teasley, 1995). This is why there have been several attempts made to model the design of collaborative activities that also allow students to develop the skills highlighted in the previous section. These models are based on the different elements that influence the interaction between students, as well as the quality of the collaboration and the learning that comes with it. An example of this is the study by Blumenfeld et al. (1996), where the authors suggest that the effects of group work depend on different variables, such as: (i) the way in which the group is organized, (ii) the type of tasks that are to be completed, (iii) the people who participate, and (iv) the way in which the members of the group take responsibility.

The majority of attempts that have been made to model the collaborative process and identify the elements that influence this process have culminated in a series of tips and practical guidelines for achieving effective collaboration. This is the case of the study by Cohen (1994), in which the author states that “much of this research does not contain powerfully developed theoretical frameworks” (p. 2); instead, it contains a series of testable conditions that favour small-group work. Some of the recommendations made by this study are that: (i) the interactions generated by problems with multiple solutions (i.e. ill-structured problems) and tasks that require all of the students to work are different from the interactions that stem from problems with a single correct answer (i.e. well-structured problems); (ii) heterogeneous groups will benefit if the more able students are given the opportunity to give explanations; and (iii) positive interdependence (Johnson et al., 1985) does not necessarily lead to

interaction: there can be groups where there is positive interdependence but where the tasks are clearly divided between the group members so that there is not motivation to work as a group.

Following the vein of ill-structured and well-structured problems, Jonassen (1997) proposes a teaching model to support the processes that are involved in the different types of activities. In the aforementioned study, the author focuses on firstly defining the processes that the students should follow for each type of problem (ill-structured or well-structured) so as to then provide the teachers with instructions that allow them to support these particular processes. This then culminates in a series of six steps that should be followed (these are different for ill-structured and well-structured problems). This study is particularly noteworthy because it provides concrete examples for the six steps for each of the problems. However, following the steps that are suggested is somewhat tedious. Teachers are limited to following these steps instead of being able to design different activities based on their own experience.

Finally, with regards to interaction and integrating Computer-Supported Group Based Learning (CSGBL) into the technology, one particularly noteworthy model is the one described by Strijbos, Martens, & Jochems (2004), which leads to a methodology based on the process (rather than on results). In this study, the authors identify certain critical elements that affect interaction in Computer Supported Group Based Learning (CSGBL): (i) learning objectives; (ii) type of task; (iii) level of pre-structuring; (iv) group size; and (v) computer support. This model looks to close the gap between the quality of interaction and learning. It also encourages a design process that is focused

on interaction (which the authors acknowledge as being the best way to meet academic objectives). The main outcome of this study is a six-step guide for designing activities that encourage student interaction. These six steps are detailed in Table 1-1.

Table 1-1: Six steps to designing (CSGBL) according to Strijbos et al. (2004)

<i>Nb</i>	<i>Step</i>	<i>Explanation</i>
1	Determine which type learning objective will be taught	The learning objective can be argumentation, negotiation, acquisition of basic skills, concept learning, etc...
2	Determinate the expected interaction	The expected interaction can be conceptualized as: (i) communication networks where some students are central or when one student is isolated; (ii) temporal communication structures (one-way, two-way or interactive) or (iii) communicative statements or acts
3	Select task-type with respect to the learning objective and expected interaction	There are two task-type: (i) open skills (ill-structured tasks, multiple alternatives or procedures) or (ii) closed skills (well-structured task with few or one possible solution or procedure). The teacher should observe if negotiation or coordination is required

4	Determine whether and how much structure is necessary with respect to learning objective, expected interaction and task-type	In a high level of pre-structuring, the teacher gives feedback, suggestions or help. In the other hand, in a low level of pre-structuring the interaction process of the groups have little or no teacher involvement
5	Determine which group size is best suited with respect to learning objective, expected interaction, task type and level of pre-structuring	Check if: (i) is obligatory the positive interdependence within group's members and (ii) is needed the effort of all group members in order to achieve the learning objectives.
6	Determine how computer support is best used to support learning and expected interaction	How the students should interact: all group members in one computer or one computer for each member. Also, the teacher should recognize the mean of the communication: face-to-face or computer-mediated (CM)

Although the model proposed by Strijbos et al. (2004) provides concrete guidelines, the model also considers as a valid option the fact that the groups might not meet the collaboration conditions described in the previous section. This in turn may lead to some unwanted side effects during collaboration, such as social loafing. Finally, this

model also assumes that the teacher knows the technology well enough to search for specific requirements and that they also have a range of technological resources available, allowing them to select the most suitable resource for each collaborative activity. For this reason, the study by Strijbos et al. (2004) is mainly aimed at researchers, providing a clear representation of the concepts and a practical guide, rather than a tool for designing collaborative activities. This leads to the first research question in this thesis: “What are the essential elements of a model that supports the creation of cooperative and collaborative activities?”

1.1.2 Interactive instruction

Interactive instruction is a teaching method in which knowledge is created by all of the students in the class and mediated by the teacher (Black, 2007; Burns & Myhill, 2004; Kennewell, Tanner, Jones, & Beauchamp, 2007). Knowledge creation is particularly important with this type of teaching, where the students must understand the concepts and develop their own understanding of these with their peers. Unlike the traditional teaching method, where the teacher generally speaks while the students listen (Galton, Hargreaves, Comber, Wall, & Pell, 1999), interactive instruction is not achieved by “expecting the students to teach themselves from books. It is a two-way process in which students are expected to play an active part by answering questions, contributing points to discussions, and explaining and demonstrating their methods to the class” (DfEE, 2001). In interactive instruction, the students mainly build their own knowledge instead of receiving it passively and are therefore more autonomous (Kennewell et al., 2007).

In terms of the students' relationship with the teacher, interactive instruction expects high levels of interaction between the two, which can be achieved in different ways: (i) by having the largest possible number of students participate (Burns & Myhill, 2004); (ii) when the students demand high levels of active participation in order to contribute to the collective knowledge (Tanner, Jones, Kennewell, & Beauchamp, 2005); (iii) by providing mutual opportunities to speak so that the students can have an independent voice in the discussion (Burns & Myhill, 2004); and (iv) when there is a notion of collaboration between the teacher and the students, which allows the latter to play an active role in class discussions (Black, 2007). As mentioned previously, in order to enjoy high levels of interaction, the role of the teacher is fundamental. This is because it is the teacher that must encourage the students to ask questions so that their role becomes less passive (Kennewell et al., 2007), as well as to promote meaningful dialogue, discussion and strategic thinking (Tanner et al., 2005).

Using SDG as a tool to implement interactive instruction

The most noteworthy technologies to have been introduced into the classroom include clickers or Audience Response Systems (ARS) and interactive whiteboards, which have been used frequently for interactive instruction. Clickers allow the teacher to gather real-time information on the answers given by the students to a particular question (Caldwell, 2007). In order to do so, the students are given a device with buttons that allow them to answer the questions posed by the teacher (Caldwell,

2007; Mayer et al., 2009). One of the advantages of this technology is that it can be used in classrooms of varying sizes, from 15 to 200 students (Caldwell, 2007). Although the literature has reported the academic benefits of this technology (Mayer et al., 2009), White, Syncox, and Alters (2011) suggest that it has become a standard practice for teachers to reward students for giving correct answers and to have students participate, regardless of the answers they have given. This means that the teachers use the technology more as a measure to take attendance than as a tool through which to interact with the students.

There are also several benefits to using interactive whiteboards. (Smith, Higgins, Wall, & Miller, 2005) highlight their flexibility and versatility, multimedia presentation, efficiency, interactivity and increased student participation in class. However, there are cases where this technology does not allow interactive instruction to take place. Firstly, the interactive whiteboard cannot provide interactivity if it is only considered as a tool for giving presentations (Armstrong et al., 2005). Secondly, it is easy to use an interactive whiteboard in the same way as in a traditional teacher-centred class (Kennewell et al., 2007; Tanner et al., 2005). Finally, interactive whiteboards do not naturally foster student autonomy, which is often achieved when students use individual or shared computers (Tanner et al., 2005). A technological tool must therefore be found that satisfies the demands of an interactive instruction approach in the classroom, as well as being effective.

Single Display Groupware (SDG) allows users to collaborate by using a computer with a single shared screen (Stewart, Bederson, & Druin, 1999) and an individual

input device (Stewart et al., 1999). SDG can be useful in classes using the interactive instruction approach as it increases student-student and student-teacher interactions (Stewart, Raybourn, Bederson, & Druin, 1998). Furthermore, as each student has their own input device, they can interact simultaneously (Scott, Mandryk, & Inkpen, 2003; Tse, Histon, Scott, & Greenberg, 2004). In addition to the interactivity offered by SDG, it is also a useful technology when it comes to carrying out interactive, large-group collaborative activities in the classroom (Pavlovych & Stuerzlinger, 2008). This is because it encourages collaboration that is otherwise inhibited by social barriers, as well as enriching the collaboration between students using computers (Stewart et al., 1999). It also encourages student participation and facilitates the processes of negotiation and reasoning (Liu, Chung, Chen, & Liu, 2009). Finally, SDG has been shown to be an effective tool in terms of student learning (Alcoholado et al., 2012; Szewkis et al., 2011; Yang & Lin, 2010).

Despite the reported benefits of using SDG, there has only been limited study of how this technology can be used in the classroom to improve student participation (Liu & Kao, 2007). The studies that have been conducted in this field have mainly focused on analysing the impact of different factors, such as interference between participants (Tse et al., 2004) and group size (Inkpen et al., 2005; Ryall, Forlines, Shen, & Morris, 2004), as well as comparing SDG with other technologies and analysing the effectiveness of different input devices (Hansen & Hourcade, 2010). Furthermore, few of these studies take into consideration two of the essential elements of interactive instruction: (i) the role of the teacher in the learning process (e.g. Liu &

Kao, 2007; Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009) as a mediator of classroom management, rather than of the learning itself (e.g. Moraveji et al., 2009); and (ii) large-group collaboration, with studies instead focusing on small-group settings (Ryall et al., 2004; Stewart et al., 1998; Tse et al., 2004). Despite this, the studies by Pawar, Pal, Gupta, and Toyama (2007) and Szewkis et al. (2011) can be dismissed. Although these studies use SDG in a real-life educational context, they focus on a specific part of the teaching/learning process (drilling) instead of on the role of the teacher in this process. As highlighted previously, the role of the teacher is a key element of interactive instruction.

Considering the above, in addition to the benefits of using SDG and collaboration, the second research questions asks: “How can a teaching process be implemented in a real-life educational setting using SDG, where the interaction is interactive and collaborative?” In other words, this means incorporating SDG into an educational process, where the specific characteristics of the school are taken into account, such as the role of the teacher, the educational needs, the curriculum and collaboration among large groups. Doing so would go beyond existing studies, where the implementation of SDG has been in specific situations. This is particularly relevant as one of the main barriers to adopting this type of technology is the lack of educational content (Heimerl, Vasudev, Buchanan, Parikh, & Brewer, 2010).

Teamwork, taskwork and silent collaboration

The concepts of taskwork and teamwork are defined by Pinelle, Gutwin, and Greenberg (2003) in their study, which looks at analysing the tasks that are completed in groups. Taskwork refers to the actions that are required in order to complete a task, while teamwork refers to the actions that are required in order to complete the task as a group. Wallace, Scott, Stutz, Enns, and Inkpen (2009) measure taskwork in terms of performance (e.g. the time it took to complete the task, how clear the solution is and the error rate), the resources that are used (e.g. whether or not they look at the shared screen), and satisfaction (e.g. how happy the students felt when completing the activity). Teamwork, on the other hand, was analysed in terms of communication (e.g. number of turns taken in a conversation or total number of words that were spoken), coordination and awareness of the other students' work (e.g. how aware they are of their classmates' work or how aware the other students are of their own work). Furthermore, of the studies conducted in an educational setting, some of these explicitly define the collaborative interaction patterns that students must follow in order to complete the collaborative activities correctly, i.e. they specify the elements of teamwork. Szewkis et al. (2011) use a mechanism based on exchanging objects that belong to the students as the action that must be carried out by each student in order to complete the task. In this particular case, the task involves filling out a word grid. Tal Rosen's thesis uses a mechanism based on suggestions between students, whereby there are different roles within a group: "facilitators" and "acceptors". These

roles are essential for completing the activity, which consists of filling out a paragraph. These types of mechanisms are referred to by the authors as ‘silent collaboration’, which must be prompted by the collaborative interaction patterns in such a way so as to achieve non-verbal interaction between the participants. Therefore, when classmates that must collaborate are not seated next to one another, and verbal communication is difficult, ‘silent collaboration’ is an essential mechanism for achieving collaboration in large groups (Szewkis et al., 2011).

These interaction patterns determine the relationship between students. It could therefore be interesting to research what happens when the students are faced with collaborative activities where the way in which the students must interact is not made explicit. In this case, the students must instead discover ways to interact when the activity is taking place. This is why the activities included in this thesis project do not include any explicit collaborative interaction patterns (i.e. they will be open). This therefore allows the interaction to appear spontaneously, depending on the students’ context. Finally, as research into collaborative learning has focused not only on the academic benefits, but also on “when and why groups fail and when and why they succeed” (Nokes-Malach, Richey, & Gadgil, 2015, p. 3), the third research question in this thesis asks: “With whom and when is it beneficial to use silent collaboration with SDG in a real-life educational setting?” This is mainly because silent collaboration is presented as a good alternative for meeting the group’s shared objective, as it favours coordination and communication when it comes to working in groups.

1.1.3 School integration

The ECLAC (2013) states that ICT “are not an end in themselves; rather they are instruments with which to service the needs of educational systems” (p.80) and a means with which to meet an objective of people-centred development. Countries must respond to the challenges of modern society (Jara, 2007), as ICT have brought a generation of more equal educational results, as well as huge pedagogical potential (ECLAC, 2013).

With regards to collaborative learning, it is essential for the importance that has been given to collaboration to lead to effective integration of collaborative learning into the classroom. The need for non-laboratory research set within the context of real-life educational settings is still relevant, even today (Nokes-Malach et al., 2015).

This thesis presents a series of studies that were conducted in Chile. The following section will therefore describe the reality faced by Chile and how alternatives such as Computer Supported Collaborative Learning (CSCL) and tools such as orchestration could help schools in Chile incorporate collaborative learning.

Context in Chile

The study by Jara (2007) features a review of Chile’s ICT for Education policies. In this study, the author highlights the role of Enlaces (Centre for Education and Technology) as a public policy that promotes innovation in technology. Enlaces also provides schools with equipment, internet access and teacher training, among others (Claro et al., 2012). Despite the efforts of the Centre for Education and Technology,

a study by Hinostroza, Labbé, Brun, and Matamala (2011) revealed that ICT were not being used frequently in Chilean schools, and even then only for very specific activities. Furthermore, in the last ICT SIMCE conducted by Enlaces in 2013, 46.9% of 10th grade students achieved only a basic level of digital skills, while 51.3% achieved an intermediate level, and just 1.8% an advanced level (Enlaces, 2014). Claro et al. (2012) suggest that “education plans (i.e. the national curriculum) should be designed to increase ICT use in schools with pedagogical orientations that encourage deliberative and creative use” (p. 1051).

With the aim of guiding the development of ICT skills, the Centre for Education and Technology (Enlaces, 2013) has identified and proposed a series of ICT skills that students should possess. Included among these is the skill described as “Effective communication and Collaboration”, where collaboration plays a leading role in the distance work students do with their peers: “in general, it is defined as the skill of negotiating an agreement, with mutual respect for each other’s ideas and developing content with peers via distance learning, using different digital media” (p. 19). The concept of working with peers via distance is mainly related to the use of web tools, such as wikis, blogs, word processors or websites that allow students to share ideas, debate with their peers and produce documents.

Computer-Supported Collaborative Learning and Orchestration

The main aim of Computer-Supported Collaborative Learning (CSCL) is to investigate how technology can support, facilitate and promote collaborative learning (Sadeghi & Kardan, 2015), with a particular interest in situations where people create

something new, whether it be knowledge or understanding, that their peers did not previously possess (Cress, Stahl, Ludvigsen, & Law, 2015).

Given the advances in computer technology in recent times in terms of availability and communication, CSCL has become a trend in educational research in recent years (Sadeghi & Kardan, 2015). Almost 20 years ago, Dillenbourg et al. (1996) suggested that computer-mediated interaction between peers impacts on the collaborative processes in which students are involved. Dillenbourg (1999) also suggested that CSCL is an area of research that responds to society's demands for collaborative learning.

CSCL is a complex area of research (Stahl, 2002), the main characteristic of which is its interdisciplinary nature (Dillenbourg, 1999; Stahl, 2002), as it brings together the fields of psychology, education and computer science (Sadeghi & Kardan, 2015). Furthermore, CSCL research not only focuses on effectiveness, in terms of learning, but also on identifying different collaborative contexts and how a group benefits from the activities and interaction that occur between peers (Cress et al., 2015).

Finally, a central feature of CSCL research is generating situations that make collaborative learning effective and that also increase the probability of different processes emerging. In order for this to occur, suitable tools and settings must be designed within CSCL (Cress et al., 2015). Given this, research in CSCL has placed specific emphasis on the contexts in which teaching takes place (Stahl, 2002). The concept of orchestration has been developed to address this need (Dillenbourg & Jermann, 2010; Dillenbourg et al., 2011; Nussbaum, Dillenbourg, Fischer, Looi, &

Roschelle, 2011), a concept which has been defined as “the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels” (Fischer & Dillenbourg, 2006). Orchestration is therefore presented as a tool that complements CSCL so that the teacher has a structured guideline and assistance before teaching a class. This guideline can also be changed through improvisation, should it be necessary (Dillenbourg & Jermann, 2010; Dillenbourg, 2013). For a more detailed study of how orchestration can be used as a tool to incorporate a given piece of technology into the classroom, see Annex A.

1.2 Objectives

The general objective of this thesis is to study how interactive instruction can be inserted into the classroom in practical terms using SDG technology and open collaborative interaction mechanisms that allow students to use silent collaboration spontaneously. Based on this, this thesis is based on the following specific objectives:

- a) To study and characterize cooperation and collaboration using key elements of both. To transfer these elements to a model that allows for the design of cooperative and collaborative activities, as well as to validate the model in settings in which teachers and students are faced with such activities.

- b) To study how interactive instruction with collaborative learning can be integrated into the classroom. The thesis also looks to characterize student behaviour in this setting.

- c) To study the setting(s) in which using silent collaboration is beneficial. To investigate how the students perceive the collaborative process when this is followed using intensive silent collaboration.

It is hoped that meeting these specific objectives will lead to a concrete proposal for educators, people who work in real-life educational settings, and investigators through (i) a model for designing cooperative and collaborative activities, regardless of the technology, (ii) suggestions on how to integrate SDG into the classroom by using this technology for interactive instruction and collaborative learning, and, finally, (iii) guidance on how to use silent collaboration effectively.

1.3 Research questions

The following research questions therefore guide this thesis:

- a) What are the essential elements of a model that supports the creation of cooperative and collaborative activities?
- b) How can a teaching process be implemented in a real-life educational setting using SDG, where the interaction is interactive and collaborative?
- c) With whom and when is it beneficial to use silent collaboration with SDG in a real-life educational setting?

1.4 Research hypothesis

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

- a) It is possible to identify constituent elements of cooperative and collaborative activities, allowing the activities to be clearly distinguished and represented in a model. These components can be grouped in such a way that they can be easily transferred to teachers. Furthermore, different applications of this model lead to differences in student behaviour in terms of interaction within the group.
- b) There is a way for collaboration to be effectively inserted into a real-life educational setting, i.e. in a school and for a given topic using SDG. This setting is effective in terms of learning gains.
- c) Students' preferences of group work has an impact on learning gains when working collaboratively. Silent collaboration can be used in specific contexts and is preferred by some students. Therefore, silent collaboration can provide a gateway to spoken collaboration, as a means of transitioning to collaborative work when students want to collaborate.

1.5 Methodology

The design and implementation of collaborative activities to be used with SDG is an investigative challenge and is inserted in the school context, which is both real and complex. For this reason, it was decided to use an approach based on Design-Based Research in this thesis. This approach is focused precisely on understanding the complexity of real-life practices, by considering the context to be a key part of the

learning process (Barab & Squire, 2004). Furthermore, by being highly interventionist in its nature, this approach is particularly apt for issues of innovation (Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003). Finally, this approach is characterized by being process-oriented and iterative, as well as for including the creation of a concrete design that works in complex social contexts. A process with six clearly-defined stages is therefore proposed and described below:

a) Developing a script for CSCL

An orchestration is given to the teacher to help them understand the coherence between the technological application and the class that they teach. There are several advantages to this tool, such as its robustness, efficiency, adoptability and its ability to adapt to the given technology.

b) Designing and developing the educational software and activities.

This process will also include various performance indicators that must be met by the software.

c) Validating the software

The software and activities must pass several functionality and usability tests. As this validation takes place in a limited environment the process is repeated until the software and activities meet the levels that are set out in the design.

d) Assessing the software:

Both the software and the activities are introduced into a real-life context in which they will be used. Information can be gathered during this stage that can generate new knowledge on the software and the activities. In turn, this new knowledge

reveals information on the users' assessment of the software and activities. It is worth highlighting that while problems can occur during this stage, this is a valuable input within this iterative process. Once potential issues with aspects of the activities and software have been resolved, the tests must be repeated with new participants (of similar characteristics), as the first group of participants may have been left with a negative impression of the tool, which represents an important bias.

e) Conducting the study

During this stage it is important to be able to measure the impact on learning, taking into consideration how relevant it is and how well-aligned it is with the curriculum (Cox & Marshall, 2007; Penuel, 2005; Reeves, 2008). The study is quasi-experimental, whereby the students were not assigned randomly to either the control group or the experimental group as these are already determined (i.e. the existing classes). Furthermore, assessment tools will be developed, taking into account the curricular objectives of each group. These tools will then be validated using Cronbach's alpha and must return values of over 0.7 (Bland & Altman, 1997). Only once the instruments have been validated will they be used in the study (sections 3.3 and 4.3). As is typical with Design-Based Research studies, a large amount of data should be collected, such as test scores, videos and classroom observations, among others (Cobb et al., 2003). Finally, a qualitative methodology is also considered so as to obtain data that assists exploratory research methods.

f) Analysing the data and publishing papers in scientific journals

As the final stage in this process, the data gathered in the previous stage will be analyzed. Empirical evidence will be sought in order to validate the research hypotheses (sections 2.6, 3.4 and 4.4). Finally, a research paper was written based on the results of the previous stages.

This methodological process is described in the following chapters (see Figure 1-1). With regards to designing a model for creating cooperative and collaborative activities, this was also done following an iterative process. Firstly, an initial model emerged that could be validated using students. This model was then modified having been validated in other technological contexts (Annex B and Chapter 4). Following this redesign, the model was then validated for a third time using in service teachers, or teachers about to enter service. This validation process was successful and the model enjoyed the support of the main users (teachers), and therefore the final model is detailed in Chapter 2.

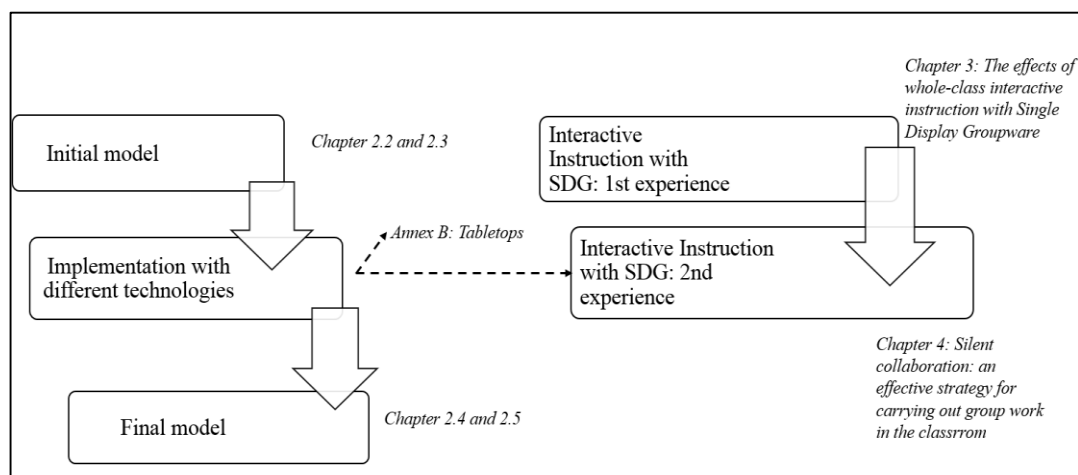


Figure 1-1: Methodological process

Finally, an iterative process was also applied to the software used by the SDG in the classroom, where interactive instruction and collaborative learning took place (Chapter 3 and Chapter 4). Initially (Chapter 3), the effectiveness of both the teaching mechanism as well as the technology could be validated in terms of student performance. Furthermore, the different silent collaboration interaction patterns that spontaneously appeared could be characterized and categorized. Having done so, another software application was designed for another area of the curriculum, maintaining the elements that had been shown to be effective and which allowed students to work together when seated next to one another (Chapter 4). The difference between the two pieces of software is shown in Figure 1-2. This allowed the silent collaboration interaction patterns observed in the previous stage to be compared with the new software, which encouraged spoken collaboration. This allowed the conclusion to be drawn that silent collaboration could act as a gateway to spoken collaboration, as differences were observed between different students with regards to silent collaboration.

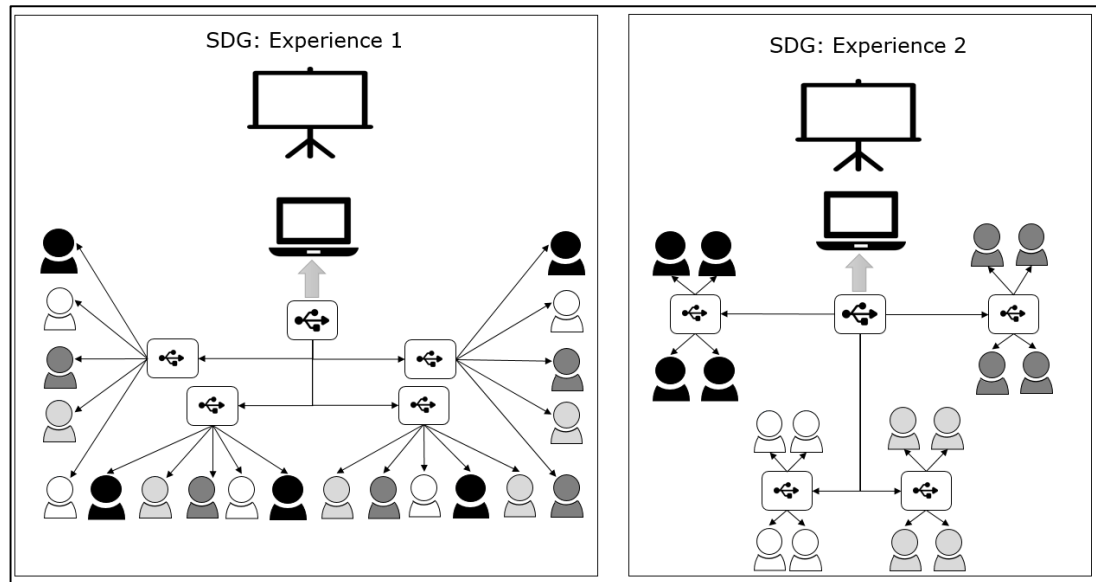


Figure 1-2: Classroom distribution for the first and second study. The different colors represent the different groups

1.6 Results

The main findings from this thesis are the following:

- a) A model for creating cooperative and collaborative activities is determined by two essential elements: the Degree of Dependency, which define the interaction between students; and Activity Structures, which follow a specific logic in order to articulate the components that are necessary for meeting the objective.
- b) Cooperative activities differ from collaborative activities in terms of their Degree of Dependency. Cooperative activities have a weak Degree of Dependency, while collaborative activities have a medium or strong Degree of Dependency.

- c) The different Degrees of Dependency have an impact on both the amount of dialogue and communication, as well as the type of leadership exercised by the group.
- d) In a case-study, the majority of teachers find this model to be easy to implement, and it therefore represents a viable addition to the teacher toolkit.
- e) Interactive instruction with collaborative learning mediated by SDG is effective in the classroom. This can be witnessed in the results obtained by the students who attended classes that were taught this methodology.
- f) Silent collaboration is a phenomenon that occurs naturally among students, through silent patterns of interaction on the screen.
- g) Students use different interaction patterns on screen; both collaborative and non-collaborative. In general, the majority of students tended to use collaborative interaction patterns.
- h) The students' academic performance depends on their willingness to work as part of a group. This effect is greater when the students sit next to one another.
- i) Students perceive silent collaboration to be an effective means for communicating with one another in order to solve a group problem.
- j) Students who report a preference for face-to-face group work tend to use fewer silent collaboration interaction patterns.

Annex A reveals a study that consisted of a review of the literature regarding orchestration and Augmented Paper Systems in Education. This shows that

technology can be incorporated into various different educational environments. Furthermore, it highlights the need for further research that goes beyond the laboratory and is instead focused on the classroom so as to be able to see the benefits of this technology for learning. This study complements research on orchestration as it highlights essential elements of this tool, which itself is fundamental for integrating technology into the classroom. These essential elements are independent of the technology and allow an understanding of how orchestration is an important tool for integrating technology in real-life educational settings, as is shown in Chapters 3 and 4.

Finally, Annex B reveals an educational game-based application for teaching fractions using Tabletops. This study consisted of designing different activities using the model presented in Chapter 2, but applied to another technology. The result of this study allowed for an iteration of the model for creating cooperative and collaborative activities that was otherwise only in an initial phase. The final model is therefore detailed in Chapter 2. The main finding from this study is that the model can be validated using technology other than SDG (as was the case in Chapter 2), extending its potential to other technologies.

1.7 Thesis outline

This thesis is based on two lines of research. One of these lines is more theoretical, where the objective is to produce a generalizable model for creating collaborative and cooperative activities. The second line of research is based on two studies conducted

in the classroom using SDG and interactive instruction. Given this, the thesis is therefore divided into the following chapters:

1.8.1 Chapter 2

The objective of this chapter is to conceptualize the differences between cooperation and collaboration and see how these differences are specified in the design of such activities. The chapter begins by demonstrating the need to allow teachers to control design elements that allow them to carry out activities in the classroom. The chapter then sets out to identify the constituent elements that influence collaboration, discovering which elements have an impact on the different collaboration conditions. Here a distinction is made between elements of the technology and elements that are inherent in the cooperative or collaborative activity itself. Following this, the chapter describes a specific implementation of the model in a real-life educational setting, where the students used different versions of this model. Finally, a study is presented where teachers used this model to design different activities using the framework that was set out. This chapter analyses the proposed model from the students' perspective, who demonstrated different behaviour according to each activity. The teachers' perspective was also analysed, as they are the main users of this model. The main outcome from this chapter is a model which differentiates between cooperative and collaborative activities using a concept called Degrees of Dependency. The degree of dependency has an impact on both the students' dialogue, as well as the type of leadership exercised by the group. Finally, a teacher workshop shows that this model is quite easy to use, with the teachers valuing the opportunity to work with their

colleagues. This chapter is based on the research paper “A model for creating small-group, cooperative and collaborative activities: An analysis in 3rd grade”, which has been submitted for publication in International journal of Computer-Supported Collaborative Learning (ijCSCL).

1.8.2 Chapter 3

This chapter showed in concrete terms how both SDG and interactive learning can be incorporated into the classroom so that the students work collaboratively. The effectiveness of this method was analysed and it was also shown that silent collaboration, a phenomenon observed in other contexts, appears simultaneously as a means for students to interact. Two groups of students were compared. The first one used technology in an interactive and collaborative classroom, the second one worked with pen and paper. Both groups worked with the very same set of activities, the only difference was the activities in the first groups were done with technology. Furthermore, the student behaviour when using this technology could also be categorized. This chapter is based on the research paper published in Computers & Education “The effects of whole-class interactive instruction with Single Display Groupware for Triangles”.

1.8.3 Chapter 4

By taking into consideration the results from the previous chapter, this chapter focuses on researching more into silent collaboration and how this is affected by the students’ preferences. Furthermore, this chapter also reveals how the students’ willingness to work as part of a group affects their academic performance when they

learn collaboratively. The main finding from this chapter is therefore that silent collaboration can be a direct gateway to learning through verbal collaboration, due to the fact that students prefer using this mechanism to communicate, even when spoken collaboration is easy to achieve. This final chapter is based on the research paper “Silent collaboration: an effective strategy for carrying out group work in the classroom” which has been submitted for publication in Computers & Education.

1.8 Thesis structure

The structure of this thesis is based on the research objectives described in section 1.4. Table 1-2 provides a summary of the hypotheses, research questions, objectives, 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

<i>Hypotheses</i>	
H1	It is possible to identify constituent elements of cooperative and collaborative activities, allowing the activities to be clearly distinguished and represented in a model. These components can be grouped in such a way that they can be easily transferred to teachers. Furthermore, different applications of this model lead to differences in student behaviour in terms of interaction within the group.
H2	There is a way for collaboration to be effectively inserted into a real-life educational setting, i.e. in a school and for a given topic using SDG. This setting is effective in terms of learning gains.

H3	Students' preferences of group work has an impact on learning gains when working collaboratively. Silent collaboration can be used in specific contexts and is preferred by some students. Therefore, silent collaboration can provide a gateway to spoken collaboration, as a means of transitioning to collaborative work when students want to collaborate.
Research Questions	
Q1	What are the essential elements of a model that supports the creation of cooperative and collaborative activities?
Q2	How can a teaching process be implemented in a real-life educational setting using SDG, where the interaction is interactive and collaborative?
Q3	With whom and when is it beneficial to use silent collaboration with SDG in a real-life educational setting?
Objectives	
O1	To study and characterize cooperation and collaboration using key elements of both. To transfer these elements to a model that allows for the design of cooperative and collaborative activities, as well as to validate the model in settings in which teachers and students are faced with such activities.
O2	To study how interactive instruction with collaborative learning can be integrated into the classroom. The thesis also looks to characterize student behaviour in this setting.
O3	To study the setting(s) in which using silent collaboration is beneficial. To investigate how the students perceive the collaborative process when this is followed using intensive silent collaboration.

<i>Papers</i>	
P1	A model for creating small-group, cooperative and collaborative activities: an analysis in 3 rd grade. Authors: Daniela Caballero, Miguel Nussbaum, Daniela Back, María Jesús Lobo and Eann Tuann, submitted for publication in ijCSCL (international journal of Computer-Supported Collaborative Learning)
P2	The effects of whole-class interactive instruction with Single display Groupware for triangles. Published in Computers & Education, authors are Daniela Caballero, Siswa N.A. Riesen, Sergio Álvarez, Miguel Nussbaum, Ton de Jong and Carlos Alario-Hoyos.
P3	Silent collaboration: an effective strategy for carrying out group work in the classroom. Authors: Daniela Caballero, Miguel Nussbaum, María Jesús Lobo. Submitted for publication in Computers and Education
P4	Annex A: Review of Augmented Paper Systems in Education: An Orchestration Perspective. Published in Journal of Educational Technology & Society.
<i>Results</i>	
R1	A model for creating cooperative and collaborative activities is determined by two essential elements: the Degree of Dependency, which define the interaction between students; and Activity Structures, which follow a specific logic in order to articulate the components that are necessary for meeting the objective.
R2	Cooperative activities differ from collaborative activities in terms of their Degree of Dependency. Cooperative activities have a weak Degree of

	Dependency, while collaborative activities have a medium or strong Degree of Dependency.
R3	The different Degrees of Dependency have an impact on the type of leadership exercised by the group.
R4	In a case-study, the majority of teachers find this model to be easy to implement, and it therefore represents a viable addition to the teacher toolkit.
R5	Interactive instruction with collaborative learning mediated by SDG is effective in the classroom. This can be witnessed in the results obtained by the students who attended classes that were taught this methodology.
R6	Silent collaboration is a phenomenon that occurs naturally among students, through silent patterns of interaction on the screen.
R7	Students use different interaction patterns on screen; both collaborative and non-collaborative. In general, the majority of students tended to use collaborative interaction patterns.
R8	The students' academic performance depends on their willingness to work as part of a group. This effect is greater when the students sit next to one another.
R9	Students perceive silent collaboration to be an effective means for communicating with one another in order to solve a group problem.
R10	Students who report a preference for face-to-face group work tend to use fewer silent collaboration interaction patterns.

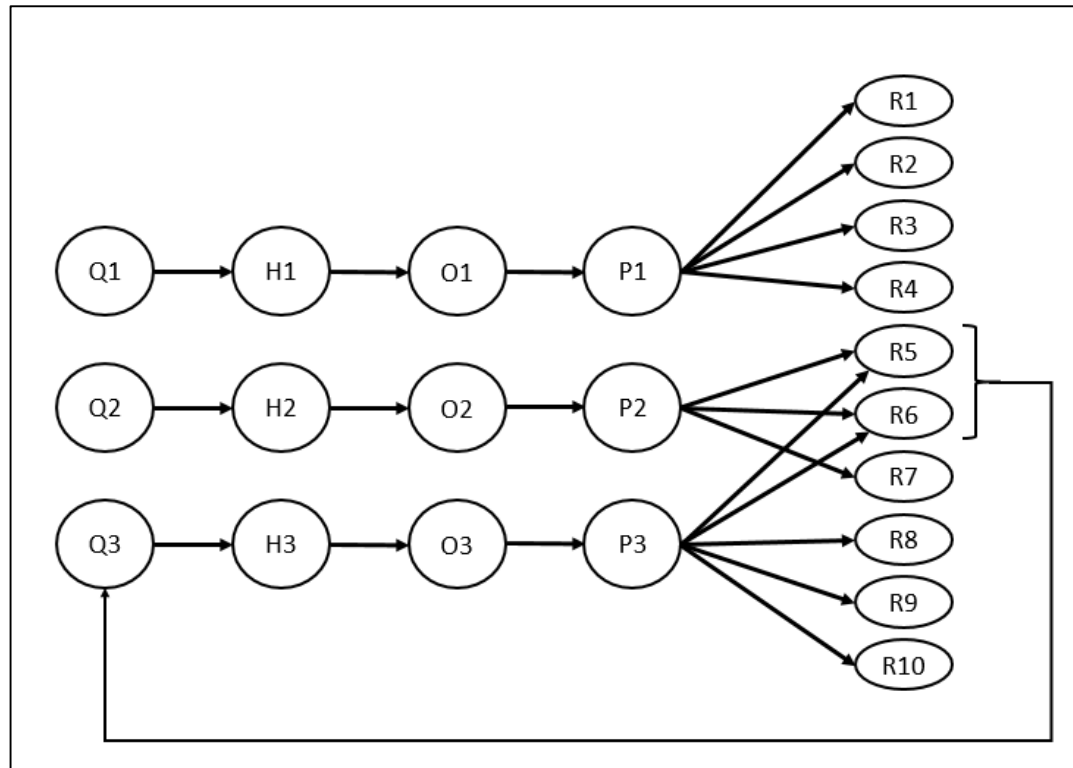


Figure 1-3: Connections between the research questions, hypotheses, objectives, papers and results

2. A MODEL FOR CREATING SMALL-GROUP, COOPERATIVE AND COLLABORATIVE ACTIVITIES: AN ANALYSIS IN 3RD GRADE

2.1 Abstract

Given the increasing importance of collaborative problem solving and the need to include teachers in the curricular design process, this study proposes a model to help create small-group, cooperative/collaborative activities that can be effectively transferred to teachers. In order to define a collaborative activity for a specific subject, we determine that it is necessary to define the Degree of Dependency, which determines the extent of interaction between peers, as well as the Activity Structure, which articulates the components that are necessary for an activity to meet its objective, following a given logic. We were able to establish the differences between individual, cooperative and collaborative activities through the presence of different Degrees of Dependency. Experimentally, and by analyzing the dialogue between students, we observed that the Degree of Dependency between students has an impact on the amount of dialogue related to coordination. Furthermore, in a practical workshop held for primary school teachers we observed how teachers consider this model to be a tool that allows them to easily design cooperative/collaborative activities. The presented model provides guidelines that can be applied to any subject; examples are provided for each Activity Structure for both Language Arts and Mathematics in 3rd grade.

2.2 Introduction

In group work, students work towards a common goal. This goal can be achieved cooperatively (Slavin, 1988) or, collaboratively (Dillenbourg, 1999). From a socio-cultural perspective, social interaction and human communication play a key role in learning (Pea, 1993), as children learn the most through active and social participation (Vosniadou, 2001).

Students who work in cooperative or collaborative conditions are better at problem solving than students working individually (Roschelle & Teasley, 1995). The PISA study has emphasized the importance of this collaborative component and, from 2015, it will measure the capacity and willingness of students to solve problems by interacting with each other (OECD, 2013).

The difference between what is considered collaboration and cooperation is somewhat unclear. There are still studies where these concepts are considered synonymous (e.g. Jacobs & Seow, 2014; Kreijns, Kirschner, & Jochems, 2003), while other authors specify the differences between the two (e.g. Karantzas et al., 2013; Sadeghi & Kardan, 2015; Shah, 2013). There is still no clear consensus regarding this matter, just as Kreijns, Kirschner, and Jochems, 2003) and (Strijbos et al., 2004) suggested 10 years ago.

Cooperation mainly refers to the division of tasks within a group, where each member is responsible for their own actions. Collaboration, on the other hand, is defined as the coordinated work by a group of individuals to solve a common problem, with all

of the members taking joint responsibility (Dillenbourg, 1999; Roschelle & Teasley, 1995).

When working collaboratively, there are several factors that contribute towards the work being effective, such as the size of the group and the task itself. Small groups work better (Gillies, 2006); social loafing by participants tends to decrease when working in small groups (Karau & Williams, 1993); the conversation is distributed equally due to the fact that competition is decreased (Bonito, 2000); and peers can help each other with explanations (Webb, 1982). Small groups are also more productive as teamwork and task work must be addressed simultaneously, something which becomes more difficult as the size of the group increases (Bertucci, Conte, Johnson, & Johnson, 2010).

In terms of the importance of the task, it has been shown that collaboration is not something that occurs spontaneously (Cohen, 1994; Leman & Oldham, 2005) and that social interaction does not come hand in hand with technology (Kreijns et al., 2003). One of the various reasons that collaboration does not occur spontaneously is related to the participants' own skills (OECD, 2013). This is because achieving effective collaboration is a social and cognitive skill that must be developed (Fischer, Kollar, Stegmann, & Wecker, 2013; Leman & Oldham, 2005) and that effective teamwork requires training (Bertucci et al., 2010). Students must therefore be cooperative, inclusive and autonomous in their learning (Gillies & Ashman, 1996). This explains the need to provide an effective collaborative environment, which in turn requires more focus on task design (Cohen, 1994).

There are three advantages to differentiating between types of activities. The first is that it guides learning environment designers when it comes to selecting the type of activity to use in the classroom. The second is that it allows for a differentiation between the underlying cognitive processes of each activity, which in turn allows for different levels of complexity to be determined. The third advantage is that it allows for an understanding of the operational differences between concepts that are used synonymously, such as cooperation and collaboration (Chi, 2009). Given the importance of the task in collaborative work and the need to specify the practical differences between cooperation and collaboration, our first research question asks: “What are the key elements of a model that helps create small-group cooperative/collaborative activities?” We answer this question in the following chapter, where we analyze the conditions that are required in order for collaboration to take place. Secondly, we reviewed the whole of the 3rd grade mathematics curriculum in order to design and categorize collaborative activities that cover an entire school subject. This allowed the key elements of task design to be identified. This in turn lead to our second research question, which asks: “What is the effect that the different Degrees of Dependency have on collaborative interaction?” To answer this question, the model is analyzed from a student interaction perspective through an experimental study using different cooperative/collaborative activities.

Finally, as the potential designers of collaborative environments, the teachers’ perspective must also be taken into consideration. Firstly, it is a challenge for them to implement activities that support collaborative or cooperative learning. It has also

been shown that teachers do not have the time to formally improve their design skills; instead they mainly develop this skill through experience (McKenney, Kali, Markauskaite, & Voogt, 2015). Furthermore, it has also been shown that more research into the process of teachers designing curricular activities is required (Kali, McKenney, & Sagy, 2015). This highlights the importance of having a model that is simple, easy to transfer and that does not require technology (e.g., Badilla Quintana & Meza Fernández, 2015). Secondly, it is important to have “templates, curricular frameworks and evaluation guidelines” when it comes to assisting teachers with the design of their classes (Huizinga, Handelzalts, Nieveen, & Voogt, 2014). According to McKenney et al. (2015), this is something which teachers are lacking. Finally, when teachers participate in the process of designing curricular activities with other teachers, it increases their self-confidence, helps change their beliefs within the classroom and also improves student performance (Voogt et al., 2011). This gives rise to our third research question: “When transferring the model for creating collaborative/cooperative activities, what do teachers most value about the proposed model?” In particular, we aim to observe whether the teacher is capable of appropriating the model, i.e. whether they can transfer the model to a classroom setting by creating collaborative activities given a specific curricular objective. This is because it has been observed that teachers lack the necessary knowledge and skills when it comes to carrying out design processes (Huizinga et al., 2014).

2.3 Model for creating cooperative/collaborative activities

2.3.1 Elements of the model

Roles involved in completing the task

The interaction between peers determines their interdependence. This interdependence can be based on roles, when the peers' responsibilities are combined or complement each other, or on tasks, when there is dependency between the actions of the group members (Johnson & Johnson, 2009; Laal, 2013).

The existence of roles when completing a task is important for learning and collaboration (Hoadley, 2010). The role defines the actions required by each participant within the task (Martel, Vignollet, Ferraris, David, & Lejeune, 2006). This is why roles become increasingly important when the group works towards a common goal which requires the existence of task division and coordination (Strijbos et al., 2004).

Within these roles, a distinction is made between emerging and scripted roles (Strijbos & Weinberger, 2010). In emerging roles, the students structure and self-regulate their collaborative processes (J.-W. Strijbos & Weinberger, 2010). As there is no pre-existing structure, the risk of over-scripting the collaborative interaction is avoided (Dillenbourg, 2002). In scripted roles, the peers' activities are predefined using a script (Dillenbourg, 2002) to support student interaction (e.g., Rummel, Mullins, & Spada, 2012). This allows the students to focus on the collaborative process (Strijbos & Weinberger, 2010) and improve the quality of the students'

argumentative discourse (Weinberger, Fischer, & Stegmann, 2005). This is why the designer of collaborative activities must choose whether to assign roles directly using scripting or to let the students discover their own roles (Hoadley, 2010).

We will consider the use of scripted roles in this model for the task work, i.e. individual actions within the task. For the purposes of teamwork (e.g. who searches for information, who is the leader, etc.), however, the roles will follow the emerging roles paradigm.

Well-structured vs Ill-structured problems

According to Jonassen (1997), the type of problem will determine the skills that are required by the student in order to solve it. Problems vary in the way in which they are presented (Jonassen, 2000), which affects interaction between peers (Cohen, 1994).

It is possible to distinguish between well-structured and ill-structured problems. Well-structured problems have a single solution, where a finite number of concepts and rules are applied that make up the task (Cohen, 1994). With ill-structured problems, on the other hand, the solutions are not predictable. In this case, the student or group must discover and produce complementary information in order to solve the problem (Jonassen, 2000).

Conditions for Collaboration

For an environment to be collaborative, it must satisfy the following conditions (Lowyck, Poysa, & van Merriënboer, 2003; Szewkis et al., 2011): (i) Common goal:

The goal for all group members is shared (Dillenbourg, 1999); (ii) Positive Interdependence: Group members are connected to one another in such a way that the goal can only be achieved when all participants fulfill their roles, which is, in and of itself, dependent upon the other members (Johnson & Johnson, 1999); (iii) Coordination and communication: Coordination is “the act of managing interdependencies between activities performed to achieve a goal” (Malone & Crowston, 1990); (iv) Peer support: Peers can only successfully complete an assignment when they teach and assess each other (Slavin, 1996); (v) Individual Accountability: A group member performs an action and all the other members observe the consequences (Janssen, Erkens, Kanselaar, & Jaspers, 2007; Johnson & Johnson, 1999); (vi) Awareness: Students need to be aware of their peers’ work to engage in the activities where they are needed most (Janssen et al., 2007); and (vii) Joint rewards: When all group members receive either rewards or punishments, they will look to maximize their joint utility and therefore generate a scenario in which collaboration will prevail (Zagal et al., 2006).

The curricular objective determines the context of the cooperative/collaborative activity. It also defines the way in which the solution and roles relate to one another, thus determining the type of interaction that students will have with one another when completing the task. The type of interaction required for the task is defined as the Degree of Dependency. This is understood as the amount of collaborative interaction that occurs between peers while solving a given task. The way in which the solution

and the roles relate to one another determines the Degree of Dependency, and can be classified as one of four types:

Zero Dependency is when there is no interaction between peers when completing the task and occurs when there is no communication or coordination between peers. Each participant performs an individual job without taking into consideration the jobs performed by their peers; with each student fulfilling all of the roles required in order to come to a solution.

Weak Dependency is when the activity only has one solution and where every student has an independent and predefined role in order to meet a common goal. The goal is only met when all of the participants have completed their work correctly.

Medium Dependency is when the activity only has one solution and the students must agree upon their roles, or when there is more than one solution but the roles are given to the students. The goal is only achieved when all of the participants have completed their work correctly.

Strong Dependency is when there is more than one solution and the roles must be agreed upon by the group. Students must first negotiate the solution and then agree on the roles to be performed by each participant. In this way, the role of each group member depends on the solution chosen by the group. The goal is only achieved when all of the participants have completed their work correctly.

The objective of the task determines how the solution and roles relate to one another, thus specifying the Degree of Dependency for the task. As stated previously, in order

for an activity to be collaborative it must meet certain conditions. The relation between these conditions and the different Degrees of Dependency is shown in Table 2-1.

Table 2-1: Relation between collaboration conditions and Degrees of Dependency

Collaboration Conditions	<i>Degree of Dependency</i>		
	Weak Dependency	Medium Dependency	Strong Dependency
<i>Common goal</i>	The group has a common goal that determines the type of solution and role.		
<i>Positive Interdependence</i>	Every participant assumes the role defined by the exercise. If work is performed effectively, the group reaches the goal.	Either the solution or the roles required to solve the problem are linked in such a way that neither one can work without the input of another peer.	Both the solution as well as the roles required to solve the problem are linked in such a way that neither one can work without the input of another peer.
<i>Coordination and Communication</i>	Coordination is required for the purpose of supervising, i.e., when the combination of individual tasks does not lead to the correct solution.	Communication and coordination is required to negotiate the role that participants must perform or oversee the solution to be developed, as well as when the combination of individual tasks does not lead to the correct solution.	Communication and coordination is required to negotiate the role that participants must perform and oversee the solution to be developed, as well as when the combination of individual tasks does not lead to a correct solution.

<i>Peer Support</i>	Support is required when one participant is not doing their job correctly, in which case their peers must guide and assist them.	Peer support is required to reach an agreement in either the roles or the solution, as well as when a participant fails to do their task correctly.	Peer support is required to reach an agreement, first with regards to the solution and then with regards to the roles, as well as when a participant fails to do their task correctly.
<i>Individual Accountability</i>	In all group activities, regardless of the Degree of Dependency among participants, every student must have a unique identifier that allows the rest of the group to identify their actions.		
<i>Awareness</i>	In all group activities, regardless of the Degree of Dependency among participants, students must be able to see the work of all the other group members, at any time.		
<i>Joint Rewards</i>	In all group activities, regardless of the Degree of Dependency among participants, reaching the goal leads to a reward/punishment that is shared by all of the students.		

Of the seven collaboration conditions presented in Table 2-1, Common Goal, Individual Accountability, Awareness, and Joint Rewards are present in the same way in all types of group activities, regardless of the Degree of Dependency. The presence of these conditions, which do not depend on the Degree of Dependency between students, must be guaranteed by the designer of the activity. With Positive Interdependence, Communication and Coordination, and Peer Support, on the other hand, differences can be identified depending on the Degree of Dependency between participants. These elements are defined by the goal of the activity, are independent of the design and are determined by the Degree of Dependency for the task.

Cooperation is a characteristic of Weak Dependency activities. This is because Positive Interdependence, Communication and Coordination, and Peer Support are

primarily focused on achieving a common goal by dividing the overall task into independent tasks, and mainly using coordination when the individual contributions do not lead to the correct answer (Dillenbourg et al., 1996). Medium and Strong Dependency activities, on the other hand, are collaborative activities. The former requires students to negotiate either the solution or their roles by themselves, while the latter requires students to negotiate both the solution as well as their roles. It is impossible to reach the solution without negotiation, which is a feature of collaborative interaction (Dillenbourg, 1999).

When identifying how the conditions are manifested according to the different Degrees of Dependency, we observed a change from cooperation in Weak Dependency to various degrees of complexity in collaborative work, when shifting from Medium to Strong Dependency.

2.4 Implementing the model

As we saw in the previous section, all collaborative activities are defined by a Degree of Dependency (Weak, Medium or Strong). To define a collaborative activity for a particular subject, it is necessary to define not only the Degree of Dependency, but also the Activity Structure. The Activity Structure articulates the components that are necessary for an activity to meet its objective.

2.4.1 Activity Structures for creating cooperative/collaborative activities

Our first attempt to implement a model for cooperative and collaborative activities starts by reviewing the curriculum for an entire school year for 3rd grade students in

mathematics (MINEDUC, 2012). In this case, the curriculum comprises the following topics: numbers and operations, patterns and algebra, geometry, measurements and data, and probability. This stage provided a set of activities that met the collaboration conditions described above. This development was based on activities with a predefined logic of Exclusion, Classification, Sequence Formation, Sequence Completion, and Exact and Multiple Associations (Nussbaum, Rosas, Peirano, & Cárdenas, 2001). However, there was a set of activities that could not be classified according to this logic and which we term as ‘Construction’ activities. Based on these seven logics, we define seven cooperative/collaborative Activity Structures that allow for the design of cooperative/collaborative activities that cover all of the needs for the 3rd grade mathematics curriculum (Table 2-2).

Table 2-2: Activity Structures for creating cooperative/collaborative 3rd grade Mathematics activities

<i>Activity Structure</i>	<i>Definition</i>
Identification / Exclusion	A group of objects that may or may not be different is presented, all following a certain kind of logic. Group members must recognize the elements that follow the defined logic (Identify), or the ones that do not (Exclude).
Categorizing Elements	A group of different objects belonging to different categories is illustrated. Group members must classify the objects within the proposed categories, or identify patterns between the objects to form new categories.
Forming Sequences	Group members must organize a set of objects according to a logic that may be predefined, or agreed on by the participants.

Completing Sequences	A set of objects organized according to a pre-established logic is presented, with some objects missing. To complete the sequence of objects, group members must put the missing elements in the correct place.
Establishing Exact Associations	Group members must establish unique connections between objects belonging to different sets.
Establishing Multiple Associations	Group members must establish multiple connections between objects that belong to different sets.
Construction	The group must create an object that follows a certain construction logic, based on other objects assigned or proposed to students, or through freestyle drawing.

Given that there are many types of learning activities within a particular subject (Harris, Mishra, & Koehler, 2009), our model is based on the subject that was studied. A collaborative activity must have Activity Structures that allow it to be implemented for each particular subject. Table 2-3 details the implementation of our model that helps create small-group, cooperative/collaborative activities that take into account the three Degrees of Dependency and seven Activity Structures, described in Table 2-2, for 3rd grade mathematics. An example for each case, applied to 3rd grade mathematics, can be found in Appendix 2-A. Appendix 2-B shows how the same model can be applied to other subjects, in this case 3rd grade language arts.

Table 2-3: Implementing the model to help create small-group cooperative/collaborative activities for 3rd grade mathematics (for Medium Dependency activities, the two possible scenarios are identified as number 1 and 2)

<i>Activity Structure</i>	<i>Weak</i>	<i>Medium</i>	<i>Strong</i>
Identification / Exclusion	There is only one solution and the role of every student is to identify which element to include or exclude.	<p>(1) There is only one solution and the students must coordinate with each other to choose the role that each will play in arriving at the solution.</p> <p>(2) There is more than one solution and students must coordinate with each other to choose a solution; then everyone must perform their given role.</p> <p>In both cases, the role consists of including or excluding certain elements.</p>	When there is more than one solution, students must coordinate with each other to choose both a solution, as well as the role that each student will perform in order to arrive at said solution. This consists of including or excluding certain elements.
Categorizing Elements	There is only one solution and the role of each student is to classify their element within a category.	<p>(1) There is only one solution and students must coordinate with each other to choose the role that each will perform in order to arrive at the solution.</p> <p>(2) There is more than one solution and students must coordinate with each other to choose a solution; then everyone must perform their given role.</p> <p>In both cases, the role consists of assigning elements to each of the categories. This will be done in such a way so as to cover</p>	When there is more than one solution, students must coordinate with each other to choose just one. They must then assign the roles that each will perform in building the solution, which in this case consists of categorizing elements.

		<p>both the elements as well as the sets.</p>	
Forming Sequences	<p>There is only one solution and the role of each student is to place their element in the correct position, for which there is also only one possible alternative.</p>	<p>(1) There is only one solution and students must coordinate with each other to choose the role that each will perform in completing the sequence.</p> <p>(2) There is more than one solution and students must coordinate with each other to choose a solution; then everyone must perform their given role.</p> <p>In both cases, the role consists of placing a certain element in a sequence.</p>	<p>When there is more than one solution, the students must coordinate with each other to define the correct sequence and then choose their positions within the sequence that is to be constructed.</p>
Completing Sequences	<p>There is only one solution and the role of the student is to find the correct position and complete the sequence.</p>	<p>(1) There is only one solution and the students must coordinate with each other to choose the role that each will perform in completing the sequence.</p> <p>(2) Although the pattern is predefined, there are various combinations of elements that fit the relevant pattern. There is therefore more than one solution, and everyone must then perform their given role.</p> <p>In both cases, this will be done by having each student place a certain element in the sequence.</p>	<p>Although the pattern is predefined, there are various combinations of elements that fit the relevant pattern. There is therefore more than one solution. Consequently, students must coordinate with each other to choose which of the possible combinations to resolve, before choosing the role that each of them will perform in</p>

Establishing Exact Associations	<p>There is only one solution and the role of the student is to associate their element with another student's element.</p>	<p>(1) There is only one solution and students must coordinate with each other to choose the role that each will perform in building the solution.</p> <p>(2) There is more than one solution. The students must therefore coordinate with each other to choose one of the possible solutions, before everyone performs their given role.</p> <p>In this case, the role consists of associating elements with each other.</p>	<p>arriving at the particular solution. There is more than one solution. The students must therefore coordinate with each other to choose one of the possible solutions, before assigning the role that each student will perform in order to arrive at the solution. In this case, the role consists of associating elements with each other.</p>
Establishing Multiple Associations	<p>There is only one solution and each student's role is to choose an element associated with one already in their possession. The group's solution can include multiple associations between elements.</p>	<p>(1) There is only one solution and the students must coordinate with each other to choose the role that each will perform in order to arrive at the solution.</p> <p>(2) There is more than one solution. The students must therefore coordinate with each other to choose one of the possible solutions, before everyone performs their given role.</p> <p>In both cases, this will consist of associating elements. The group's solution may include multiple associations between elements.</p>	<p>There is more than one solution. The students must therefore coordinate with each other to choose one of the possible solutions, before choosing the role each student will perform in order to arrive at the solution. This will also consist of associating elements. The group's solution can include multiple</p>

Construction	There is only one solution and the role of the student is to create a specific object or place an object in a specific position.	<p>(1) There is only one solution and students must coordinate with each other to choose the role that each will perform in order to arrive at the solution.</p> <p>(2) There is more than one solution. Students must therefore coordinate with each other to define the relevant solution, before everyone performs their given role in order to arrive at the solution.</p>	<p>associations between elements.</p> <p>When there is more than one solution, students must coordinate with each other to define the relevant solution. They must then choose the role that each student will perform in building the object that fits the solution.</p>
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2.5 Validating the model

2.5.1 Methodology

Given the implementation of the model described above (Table 2-3), below we analyze how interaction between peers changes with the different Degrees of Dependency (students' perspective). Furthermore, we analyze what the teachers most value about the aforementioned model and see whether it is possible for teachers to appropriate the model quickly, i.e. whether they are capable of carrying out collaborative activities for a specific topic (teachers' perspective), within the context of a workshop. Both studies fall within the realm of exploratory qualitative research and therefore a large sample is not required (Morrison, Manion, & Cohen, 2007).

Students' perspective: how interaction between peers changes with the different Degrees of Dependency

An experimental study was conducted. This study looked at the ways in which students work on cooperative/collaborative activities as a small group, by varying the Degree of Dependency. The aim of this was to observe the differences that are produced in collaborative interaction. In order to do so, a series of Identification activities were developed. This type of activity was chosen as it is easy to understand for the students and does not necessarily require previous experience with similar activities. This is not always the case with other types of activities, such as Construction activities, for example.

The topic used in this study was 3th grade fractions; specifically identifying fractions. It was decided to do the study in 4th grade. As the aim of this experiment was on the collaborative interaction and not in learning, we wanted that students had the necessary content knowledge, already studied the year before. The sub-topics included: (i) equivalent fractions, (ii) comparing fractions, and (iii) fractions of a whole. All of these topics were considered essential to the mathematics curriculum (MINEDUC, 2012). Each sub-topic had a corresponding Weak, Medium and Strong Dependency activity. The Medium Dependency version was for the scenario where there is only one solution and the roles are defined by the students. Table 2-4 in the Appendix 2-C describes each of the activities that was implemented and Figure 2-1 provides an example of exercises for the three Degrees of Dependency, where students have to find equivalent fractions.

There were four exercises for each of the three sub-topics and for each Degree of Dependency (Weak, Medium and Strong), i.e. 36 exercises to be solved by each group of students. Once a group completed the four exercises for a sub-topic, the students had to wait until the other groups finished before continuing with the next sub-topic. This was because a short explanation was given at the beginning of each set of exercises as to what was expected from the groups, as well as a brief review of the main concepts for each sub-topic.

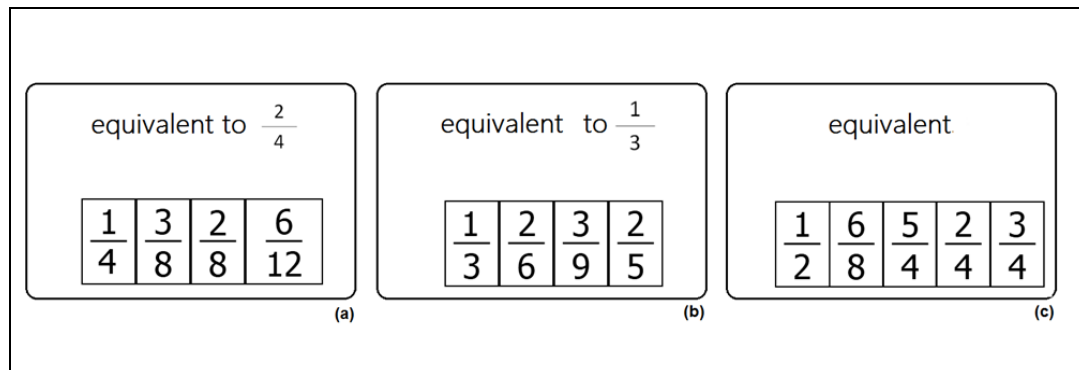


Figure 2-1: Example of Identification exercises for a Weak Dependency (a), Medium Dependency (b) and Strong Dependency (c) activity, for the sub-topic of equivalent fractions.

The study was carried out in a rural school in Valparaíso, Chile, with 16 4th grade students (7 girls and 9 boys). The students worked for a single, one-hour session. To do the collaborative work, the system described in (Caballero et al., 2014) was used. This system is based on Single Display Groupware, which uses a projected, shared display where the students in a classroom interact simultaneously (Figure 2-2(a)). The students were randomly divided into 4 groups of 4 students each, each child was given their own input device (a mouse) (Figure 2-2(b)). Each group started with a different exercise so that the groups did not copy each other's answers, as shown in

Figure 2-2(a). The students were used to working with computers; especially the system from (Caballero et al., 2014). This avoided the novelty effect that can come with the use of technology.



Figure 2-2: Set up of the experiment, (a) shared screen used by the students and (b) one of the groups working on the shared display under the teacher's guidance.

Given that the study was only conducted for one session, there was no test of student learning as the aim of this investigation was to study the students' collaborative behavior during different type of activities. The aim of the session was therefore to allow for an observation and description of the group work on each of the Degrees of Dependency (Weak, Medium and Strong).

To analyze the collaborative interactions between students, two variables were defined: dialogue and presence of leadership (or lack thereof). Firstly, dialogue has been widely studied and is considered essential for collaboration. According to Baker and Lund (1997), one type of interaction that favors collaboration is task-oriented dialogue, i.e. interaction that is focused on the task at hand, rather than on off-task

issues. On the other hand, Kreijns et al. (2003) mention that different environments should be designed that allow for off-task communication to exist, lending the collaboration a social element. Within task-oriented dialogue, it is important to identify where the aim of the dialogue is to define a role, explain content related to the task, or both. Therefore, the content of the students' spoken dialogue (i.e. utterances) that occurred during the activities was recorded and then characterized as being either off-task or task-oriented (content or coordination).

With regards to the presence of leadership or lack thereof, distributed leadership is considered as being when the roles of leadership (such as decision making) are shared by several people within a group, allowing individual decisions to be less important than collective decisions (Yukl, 1999). Distributed leadership, which avoids a single member of the group exercising too much influence over the rest of the group (Shamir, 1999), is characterized by interdependence (which mainly comes from the roles) and coordination (Gronn, 2002). Given that leadership is a role that can emerge naturally and that the existence of distributed leadership triggers particular interactions between peers (e.g. in decision making), for each exercise it was determined whether or not any leadership was present (Kieran, 2003) and, if so, whether such leadership was focused or distributed (Gronn, 2002).

Teachers' perspective: what teachers most value about this model

To answer our third research question: "When transferring the model for creating collaborative/cooperative activities, what do teachers most value about the proposed

model?”, a workshop was held for current and future primary school teachers (1st to 8th grade) covering a range of subjects (mathematics, language arts, English, etc.). An open invitation was sent to teachers who had already participated in previous workshops held by the University as part of their continuing professional development. A total of 34 teachers attended the whole workshop. Of these, the majority were aged between 26 and 35 (50%), followed by those aged under 25 (32%). The years of service ranged between 0 and 22 years, with an average of 5.46 years ($SD = 5.29$).

The workshop lasted for 4 hours (from 9:00 to 13:00) and was split into two sessions, with a 20 minute break between the two. The first part consisted of delivering guidelines for understanding collaboration and how to create an environment that fulfills the collaboration conditions analyzed in Table 2-1. The second part of the workshop was a hands-on activity, where the teachers had to design a collaborative activity and specify whether it was a weak, medium or strong dependency activity. This ensured that the teachers played the role of the students and allowed them to observe for themselves the differences between each of the activities. Having teachers assume the role of a student is recommended by Hampel (2009) for training teachers in collaboration as it means they have to collaborate as peers and put themselves in the position of the students. During the activity the teachers received just-in-time support from 3 researchers, which is the best way to foster the teachers’ design process (Huizinga et al., 2014). The collaborative activity that they had to design was based on the topic of fractions. This topic was chosen as fractions are

particularly difficult to learn (Siegler, Fazio, Bailey, & Zhou, 2013). At the end of the session the groups demonstrated their exercise to the rest of the teachers, explaining why it was collaborative and how they met the Degree of Dependency that had been requested.

Once the workshop had finished, the teachers were given a survey which used a Likert scale to ask the following questions: (i) how easy is it to design collaborative activities using the model presented in this workshop?, (ii) how easy do you think it is to implement these activities in other subjects by using the model presented in this workshop?, and (iii) is the model sufficient enough for you to be able design collaborative activities? Finally, the survey also asked the teachers what they most valued about the workshop (open ended question) and whether or not they would recommend the workshop to a colleague.

2.6 Results

2.6.1 Students' perspective: how interaction between peers changes with the different Degrees of Dependency

It could be observed in the students' general behavior that they did not have previous experience in cooperative/collaborative work; it was difficult for students to collaborate as collaborative work was different to what they were used to (Fischer et al., 2013). One of the four groups was unable to finish the activity satisfactorily because the students were unable to reach an agreement on 7 of the 36 activities. In this case, both the researchers as well as the classroom teacher had to frequently intervene so that the group could continue with their work. For this reason, it was

decided not to include this group in the analysis; the remaining three groups were able to complete the majority of the activities without needing any external help. However, activities where the teacher or researcher had to intervene were not considered, i.e. activities where the groups had to be helped in order to finish the activity. Thus, of the possible total of 108 activities for the three groups, only 106 activities were considered in the results (36 Weak, 35 Medium and 35 Strong).

Coordination and communication

Table 2-4 summarizes the analysis of the total speech (measured as the total number of utterances made by each group) and the dialogue content (off-task, task-coordination or task-content) for each of the Degrees of Dependency.

Table 2-4: Dialogue content according to Degree of Dependency

<i>Degree of Dependency</i>	<i>Number of occurrences (Mean)</i>			
	Total Speech	Off – task	Task - Coordination	Task - Content
Weak	7.58	0.83	2.25	4.5
Medium	8.94	0.6	4.46	3.89
Strong	9.83	1.11	4.57	4.14

A One-Way ANOVA was conducted to see whether the total number of utterances (dependent variable) depended on the Degree of Dependency (independent variable) for each exercise. The results show that there are no significant differences in total speech ($F(2,103) = 0.86$, $p = 0.43$), Off-task utterances ($F(2,103) = 1.14$, $p = 0.32$) or Task-Content utterances ($F(2, 13) = 0.28$, $p = 0.76$) when varying between Degrees of Dependency. What is observed is that the Degree of Dependency significantly

affects the number of utterances regarding coordination (Task-coordination) ($F(2,103) = 2.84, p = 0.063$), albeit marginally.

A Post-Hoc analysis shows that Weak Dependency activities lead to significantly less dialogue with regards to coordination (Task-coordination) than Strong Dependency activities (difference = -2.32, $p = 0.037$) and Medium Dependency activities (difference = -2.21, $p = 0.047$). There is no significant difference between Medium and Strong Dependency activities.

Leadership

Each of the activities was categorized as focused or distributed leadership (Table 2-5). In general, leadership in all of the activities came from two different sources: (i) the student had the knowledge which allowed them to give the correct answer and (ii) the student coordinated the group and supported the group's decision. This fully coincides with the study by Mercier, Higgins, and da Costa (2014), which defines leadership as intellectual and organizational, respectively. In our study, focused leadership occurred when a student knew the correct answer and also organized the group (i.e. they exercised both intellectual and organizational leadership), while distributed leadership occurred when different students demonstrated the two types of leadership. It is worth noting that a student could demonstrate focused leadership in one exercise, then no type of leadership at all in the following exercise.

Table 2-5: Leadership according to Degree of Dependency

<i>Degree of Dependency</i>	<i>Total Activities</i>	<i>Type of Leadership</i>			
		Focused		Distributed	
		Occurrences	%	Occurrences	%
Weak	36	29	80.56%	7	19.44%
Medium	35	21	60%	14	40%
Strong	35	16	45.71%	19	54.28%

A logistic regression was conducted using leadership as the dependent variable (i.e. focused or distributed) and Degree of Dependency between peers as the independent variable (i.e. Weak, Medium and Strong) so as to determine whether the type of leadership is influenced by the Degree of Dependency. This regression shows that the type of leadership (focused or distributed) does depend on the Degree of Dependency, $\chi^2 (2, N= 106) = 8.69, p = 0.013$. Furthermore, a Post Hoc analysis shows that Strong Dependency activities lead to significantly more distributed leadership than Weak Dependency activities ($p = 0.003$), whereas Medium Dependency activities report significantly more distributed leadership than Weak Dependency activities, albeit marginally ($p = 0.062$). Finally, Strong Dependency activities feature slightly more distributed leadership than Medium Dependency activities, though in this case the difference is not significant ($p = 0.23$) (Table 2-5).

2.6.2 Teachers' perspective: what teachers most value about this model

Implementing the model

The curricular objective of the activities to be designed by the teachers was to add and subtract fractions with like denominators (the denominators were 100, 12, 10, 8, 6, 5, 4, 3 and 2) in concrete terms or using pictures, as defined by the Ministry of

Education's curriculum (MINEDUC, 2012). This activity lasted for approximately 1 hour, where the teachers shared their experiences, using different materials such as different types of paper, pens and craft materials. The best examples were discussed in front of the whole group at the end of the session, which led to a successful hour-long discussion with active participation from all of the teachers.

Figure 2-3 shows an example of a Strong Dependency activity designed by a group of teachers. In this activity, there are 4 boxes and a large number of little balls (represented as circles in Figure 2-3(a)). Each student must choose one of the 4 boxes, which correspond to the numerator and denominator of a fraction (numerator 1 and 2, denominator 1 and 2 in Figure 2-3(a)). In this case, the roles are not defined and each student is responsible for representing a numerator or denominator for one of the two fractions by placing a number of balls in the respective box so as to correctly satisfy the given sum (four fifths in the example in Figure 2-3(b)). This problem has multiple solutions, one of which is represented in Figure 2-3(b): students 1 and 2 created the fraction three fifths, while students 3 and 4 created one fifth.

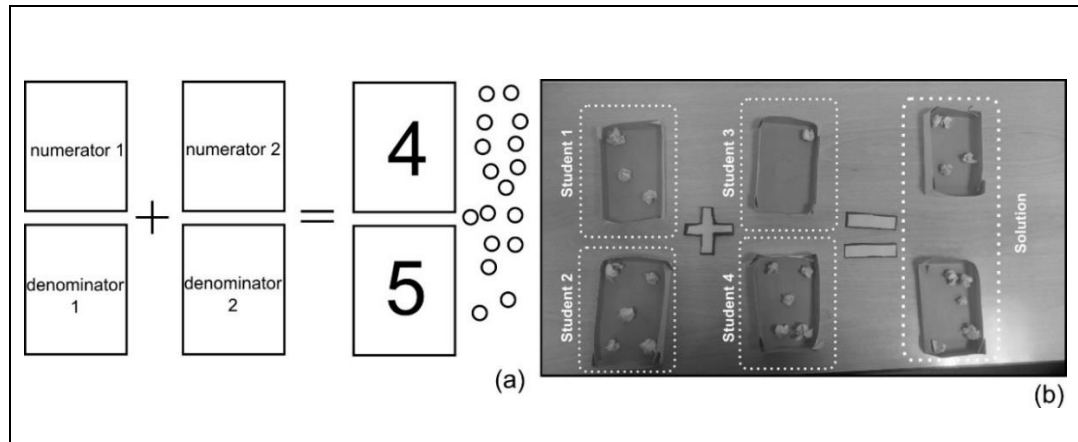


Figure 2-3: An example of a Strong Dependency activity designed by a group of teachers. Figure 3-3(a) shows the problem to be solved while 3(b) shows one of the possible solutions created by the teachers.

Perception of how useful the model is to the teachers

The answers to the survey given to the teachers at the end of the workshop can be found in Table 2-6.

Table 2-6: Teachers' answers with regards to how easy it is to run collaborative activities using the model presented in the workshop.

<i>Question</i>	<i>Very difficult</i>	<i>Difficult</i>	<i>Neither difficult nor easy</i>	<i>Easy</i>	<i>Very easy</i>
(1) How easy is it to design collaborative activities using the model presented in this workshop?	0 (0%)	5 (14.7%)	12 (35.3%)	11 (32.4%)	6 (17.6%)
(2) How easy do you think it is to implement these activities in other subjects by using the	1 (2.9%)	3 (8.8%)	16 (47%)	10 (29.4%)	4 (11.8%)

model presented in this workshop?	
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As a result of this study, the teachers suggest that the model for creating collaborative activities is perceived as being a tool that is quite easy to integrate into their existing practices (Table 2-6). Furthermore, the majority of teachers think it is quite easy to implement such activities in other subjects.

When the teachers were asked whether the model was sufficient enough for them to be able to design collaborative activities, 33 teachers (97%) answered that it was, while only 1 teacher (3%) answered that it was not. This was also the case for whether or not the teachers would recommend the workshop to a colleague. The only person who would not recommend the workshop was the same person who felt it was not overly clear as to how the model could be applied to the humanities. These results are in line with the perception that this instrument is quite easy to implement (Table 2-6).

Finally, when the teachers were asked what they most valued about the workshop, some teachers highlighted more than one aspect. Examples of the teachers' actual responses are given in italics below (each teacher was assigned an ID from T1 to T34 to ensure their anonymity). The responses were mainly focused on the following points:

- a) The practical nature of the workshop (18 responses): the teachers highlight the easily-accessible language used to conduct the workshop, the practical takeaways

and the applicability of the collaboration. For example: *“I really liked the different levels of activities that we can use with the children. I wasn’t aware of this information and I will now put it into practice in my classes”* (T29) or *“The practical nature of the workshop. As teachers we need practical tools to improve the teaching-learning process”* (T30).

b) Sharing with other teachers (8 responses): the teachers highlight how enriching it is to share ideas and experiences with other teachers. For example: *“The ability to interact with other teachers and share our experiences”* (T10), *“The collaborative work with the other participants”* (T14), or *“Being able to share experiences with other educators and those related to education”* (T15).

c) Clear explanations (4 responses): these allowed the teachers to gradually understand the model. For example: *“Clearly explaining the activity step-by-step and also highlighting the value of each activity”* (T2).

2.7 Conclusion

Our first research question asked: “What are the key elements of a model that helps create small-group cooperative/collaborative activities?” We saw that in order to define a collaborative activity for a specific subject, it is necessary to define the Degree of Dependency, which determines the extent of interaction between peers, as well as the Activity Structure, which articulates the components that are necessary for an activity to meet its objective, following a given logic.

We were able to establish the differences between individual, cooperative and collaborative activities through the presence of different Degrees of Dependency. In Zero Dependency activities, students might share the working space but still work separately. For example, in Alcoholado et al. (2012) the students share a screen but perform tasks individually using their own mouse. In Weak Dependency activities, the exercise is divided into independent tasks and coordination is only required when compiling the results, which is typical of cooperation (Dillenbourg et al., 1996). Collaboration, however, emphasizes peer-to-peer interaction during the learning process (McInnerney & Roberts, 2004) and is provided by Medium and Strong Dependency activities. For example, Medium Dependency is achieved in Szewkis et al. (2011), where students share the screen and collaborate by exchanging objects in order to arrive at the only possible solution, choosing between the roles of suggesting or accepting an object. Finally, Strong Dependency is achieved in Caballero et al. (2014), where students have to create a triangle with certain restrictions in place. In order to do so, the students must agree on the type of triangle to build and then agree on the role that each student will play in building the triangle. Although cooperative or collaborative Activity Structures are proposed for small-group activities in this paper, they are also applicable to large-group settings. Examples of this can be seen in Szewkis et al. (2011) and in Collpad (Nussbaum et al., 2009). In Collpad, first the students work individually, then they work in small groups, and finally the students discuss the results as a whole class. In the second and third step they build the solution based on the peers' previous responses, relying on

the collaborative Activity Structure of Creation with Strong Dependency. This is because dependency between participants is linked to choosing a solution and then coordinating the roles in order to arrive at the solution.

Our second research question asked: “What is the effect that the different Degrees of Dependency have on collaborative interaction?” Experimentally, we analyzed the dialogues between students, the leadership that was observed. With regards to the dialogue between students, we determined that the Degree of Dependency between students had an impact on the amount of dialogue and coordination. In particular, Weak Dependency activities feature significantly less dialogue regarding coordination than Strong and Medium Dependency activities, albeit marginally. With regards to leadership, Weak Dependency activities reveal more focused leadership, which makes the leaders “prescribe rather than describe a division of labor” (Gronn, 2002). This type of authoritarian approach, based on disputes (i.e. disagreement, individual work, and brief exchanges based on statements) and individualized decision making ensures that the students do not look for an explanation or justification for their ideas (Mercer, 1996). As the activities shift from Weak to Strong Dependency, the presence of shared leadership increases significantly. Shared leadership within the group emerges during Strong Dependency activities, which is important for joint learning (Kieran, 2003). As our experimental work was based on Identification activities for 3rd grade math, it remains as future work to verify whether the same conclusions are reached for other Activity Structures, subjects and grade levels.

The third research question asked: When transferring the model for creating collaborative/cooperative activities, what do teachers most value about the proposed model?" In order to answer this question, a workshop was held for teachers, in which they were able to carry out an activity for mathematics described in the primary school curriculum. The majority of the teachers valued the practical nature of the model and the advantages of working as a group, something which they do not often do. The majority of the teachers would recommend this workshop to their colleagues as they found the model to be a suitable tool that allows them to easily design collaborative activities.

The model presented in this study is important for the instructional design of collaborative activities (Mayer, 2003) as it provides guidelines that can be applied to any subject. Given that there are many types of learning activities within a particular subject (Harris et al., 2009), it is the subject and the respective curricular objective that define which Activity Structure should be used for the different activities. In this study, the model was implemented for 3rd grade math with years of service between 0 and 22 years. To demonstrate that this is a general model that is removed from any particular subject, we have included seven examples (one for each structure) for 3rd grade Language Arts (Appendix 2-B).

One limitation of this research is how short the experimental studies were, as well as the people that were involved. Although the studies were exploratory, it would be interesting to observe in future work how other students behave in different subjects

and whether, given more time, the teachers manage to implement collaborative activities in other subjects and using other Activity Structures.

2.7 Appendix 2-A: Examples for mathematics

Examples for each of the categories included in Table 2-3.

2.7.1 Identification/Exclusion

Examples for the identification/exclusion structure are shown in Figure 2A-1. In each example, each student is identified and represented by a shape (circle, rhombus and star). Figure 2-4 (a) shows an example of a Weak Dependency activity, where the students are asked to identify the odd number. Given that the number five is the only number that meets this criteria, there is only one solution. To arrive at this solution, all of the students must place their cursor on the number five. In this sense, their role is therefore defined. Figure 2-4 (b.1) shows an example of a Medium Dependency activity with only one solution and roles that are not defined. The students are asked to identify all of the odd numbers. Given that the odd numbers are the numbers five and seven, there is only one solution. To arrive at this solution, students must coordinate with each other in order to decide the role that each will perform in identifying the number five and seven so that, by working as a group, both of the numbers are selected. Figure 2-4 (b.2) shows an example of a Medium Dependency activity with multiple solutions and defined roles. The students are asked to select numbers that add up to 5. Each student has a defined sub-set of numbers to choose from and, with this, their role is defined. There is more than one possible solution as there are several combinations of numbers that add up to 5 (e.g. 0-1-4, 2-0-3, etc.). Finally, Figure 2-4 (c) shows an example of a Strong Dependency activity, where the goal is to select numbers that add up to five. Given that there are several possible combinations (i.e. 0-1-4, 0-2-3, 1-4, etc.), there is more than one possible solution. The students must therefore decide which combination to use. In order to arrive at the agreed solution, the students must coordinate with each other to decide on the role that each will perform, i.e. the number that each student must select in order to give a total of five.

Question		Correct Answer	
Select the odd number:		Select the numbers that add up to five	
<div><div>24568</div><div>★◆●</div></div>	<div><div>24568</div><div>◆●★</div></div>	<div><div>502</div><div>●</div></div>	<div><div>012</div><div>★</div></div> <div><div>034</div><div>◆</div></div>

(a) Weak

Question		Correct Answer	
Select the odd number:		Select the odd number:	
<div><div>24567</div><div>★◆●</div></div>	<div><div>24567</div><div>★◆●</div></div>	<div><div>502</div><div>●</div></div>	<div><div>012</div><div>◆</div></div> <div><div>034</div><div>★</div></div>

(b.1) Medium

(b.2) Medium

Question		Correct Answer	
Select the numbers that add up to five		Select the numbers that add up to five	
<div><div>502</div><div>●</div></div> <div><div>012</div><div>★</div></div> <div><div>034</div><div>◆</div></div>	<div><div>012</div><div>★</div></div> <div><div>034</div><div>◆</div></div>	<div><div>502</div><div>●</div></div>	<div><div>012</div><div>◆</div></div> <div><div>034</div><div>★</div></div>

(c) Strong

Figure 2-4: Examples of Identification/Exclusion

2.7.2 Categorizing Elements

Figure 2-5 (a) shows an example of a Weak Dependency activity, in which students are asked to classify three triangles into their respective categories (i.e. right angle triangle, isosceles triangle and obtuse triangle). There is only one solution and each student is given a triangle to classify, therefore defining their role. Figure 2-5 (b.1) shows an example of a Medium Dependency activity with only one solution and roles that are not defined. The instruction to students is the same as in the previous activity: classify three triangles into three categories. There is only one solution to this problem, but the students must agree on which triangle each student is going to classify. In this sense, their role is therefore not defined. Figure 2-5 (b.2) shows an example of a Medium Dependency activity with multiple solutions and defined roles. There are 5 triangles that must be classified by the students, although some of the triangles could be classified into more than one category. In this sense, there is more than one possible solution. Each student is assigned a category of triangles that must contain at least one element. Each student knows what type of triangle they must classify and, therefore, the role is defined. Figure 2-5 (c) shows an example of a Strong Dependency activity, where the instruction to students is the same as in the previous activity. There is more than one solution as there are several combinations that satisfy the different categories. Each student must select one or two triangles, and therefore their role is not defined. The group must therefore agree on which triangles go in each category and who will be responsible for categorizing each of them.

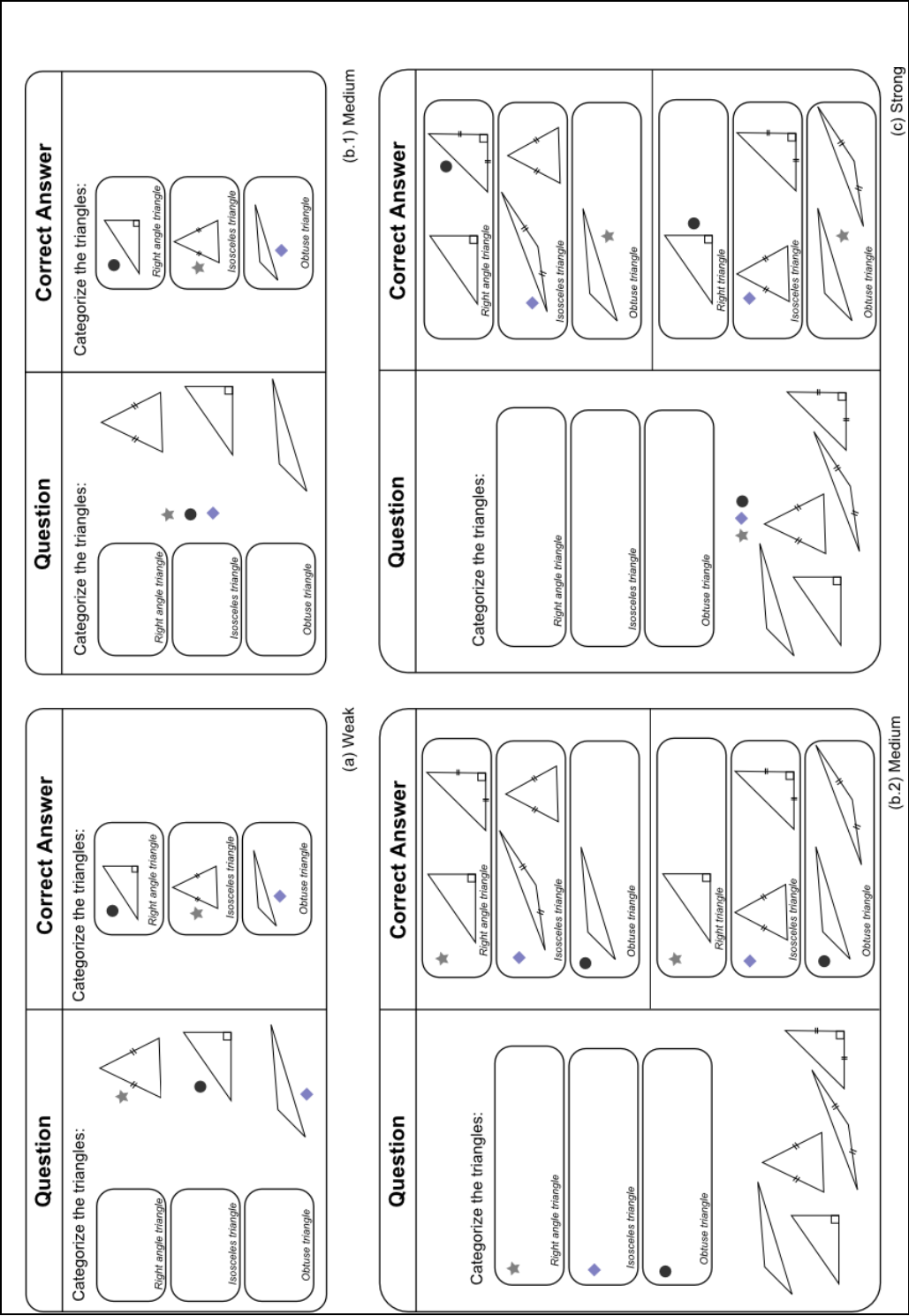


Figure 2-5: Examples of Categorizing Elements

2.7.3 Forming Sequences

Figure 2-6 (a) shows an example of a Weak Dependency activity, where students are asked to place the numbers in ascending order and where there is only one possible solution. In order to arrive at this solution, each student must place their number in the correct position (e.g. the circle has to place the numbers 12 and 5). The role of the students is therefore defined. Figure 2-6 (b.1) shows an example of a Medium Dependency activity, where there is only one solution but the roles are not defined. Students are asked to choose two numbers and then place them in ascending order. There is only one solution as the numbers are predefined. However, the students must agree on which numbers each will select and therefore their roles are not defined. Figure 2-6 (b.2) shows an example of a Medium Dependency activity with multiple solutions and defined roles. Each student is assigned a number and asked to select another number, before placing the sum of these two numbers in ascending order. There is more than one possible solution as there are several combinations of numbers that can be selected. As each student is assigned a number and asked to select another, their role is defined. Finally, Figure 2-6 (c) shows an example of a Strong Dependency activity where the goal is to choose two numbers and then place the sum of these in ascending order. There is therefore more than one possible solution and the roles are not defined as the students must choose which numbers to select. In order to arrive at the solution, the students must first decide which sequence to build and then define who will place which numbers in this sequence.

Question		Correct Answer	
Complete the pattern: numbers in ascending order		Complete the pattern: numbers in ascending order	
<div><div><div>12</div><div>5</div><div>●</div></div><div><div>1</div><div>8</div><div>◆</div></div><div><div>4</div><div>7</div><div>★</div></div></div>		<div><div>1</div><div>4</div><div>5</div><div>7</div><div>8</div><div>12</div></div> <div>◆</div> <div>★</div> <div>●</div>	

(a) Weak

Question		Correct Answer	
Complete the pattern: numbers in ascending order		Complete the pattern: numbers in ascending order	
<div><div><div>12</div><div>5</div><div>●</div></div><div><div>1</div><div>8</div><div>◆</div></div><div><div>4</div><div>7</div><div>★</div></div></div>		<div><div>1</div><div>4</div><div>5</div><div>7</div><div>8</div><div>12</div></div> <div>◆</div> <div>★</div> <div>●</div>	

(b.1) Medium

Question		Correct Answer	
Choose one number and then place the sum in ascending order		Choose one number and then place the sum in ascending order	
<div><div><div>9</div><div>7</div><div>8</div></div><div><div>◆</div><div>★</div><div>●</div></div></div>		<div><div>$7 + \textcircled{2} = 9$</div><div>$9 + \textcircled{1} = 10$</div><div>$8 + \textcircled{3} = 11$</div></div> <div><div>$7 + \textcircled{1} = 8$</div><div>$8 + \textcircled{2} = 10$</div><div>$9 + \textcircled{3} = 12$</div></div>	

(c) Strong

Figure 2-6: Examples of Forming Sequences

2.7.4 Examples of Completing Sequences

Figure 2-7 (a) shows an example of a Weak Dependency activity, where the students are asked to complete a sequence of numbers in ascending order. There is only one possible solution. In order to arrive at this solution, each student must place their number in the correct position. There is only one correct position for each student and therefore their role is defined. Figure 2-7 (b.1) shows an example of a Medium Dependency activity, where there is only one possible solution and the roles are not defined. The students are asked to complete the sequence of numbers in ascending order. In order to do so, the students must coordinate with one another to decide which number each will place in the sequence, i.e. define the role to be played by each participant. Figure 2-7 (b.2) shows an example of a Medium Dependency activity with multiple solutions and defined roles, where the students are instructed to complete the sequence of odd and even numbers. There are several combinations of numbers that can complete this sequence and each student is assigned a position within the sequence, thus ensuring that their role is defined. Finally, Figure 2-7 (c) shows an example of a Strong Dependency activity, where the goal is to complete a sequence of odd and even numbers and there is more than one possible solution. The students must first decide on the sequence before defining which numbers will be placed by each student.

2.7.5 Establishing Exact Associations

Figure 2-8 (a) shows an example of a Weak Dependency activity, where the students are asked to select a number and complete the sum. Each student is assigned a number and must match this with one of the numbers found in the middle column (3, 17 or 20). The sum must then be matched to an answer (25, 13 or 20). In this case there is only one solution and the role of the students is defined. Figure 2-8 (b.1) shows an example of a Medium Dependency activity with only one possible solution and roles that are not defined. The students are asked to match the numbers and complete the sum, for which there is only one possible combination in each case. The students must agree on the numbers they will match, i.e. define the roles that will be played by each student. Figure 2-8 (b.2) shows an example of a Medium Dependency activity with multiple solutions and defined roles. The exercise that is shown is the same as the previous exercises. However, in this case the students are assigned the number that they must match with another in order to complete the sum and therefore have a defined role. There are several combinations of numbers for each sum and therefore there are multiple solutions. Finally, Figure 2-8 (c) shows an example of a Strong Dependency activity, where there are multiple solutions. Firstly, the students must decide which pairs of numbers to match in order to arrive at the solution, and then define which student will complete each sum.

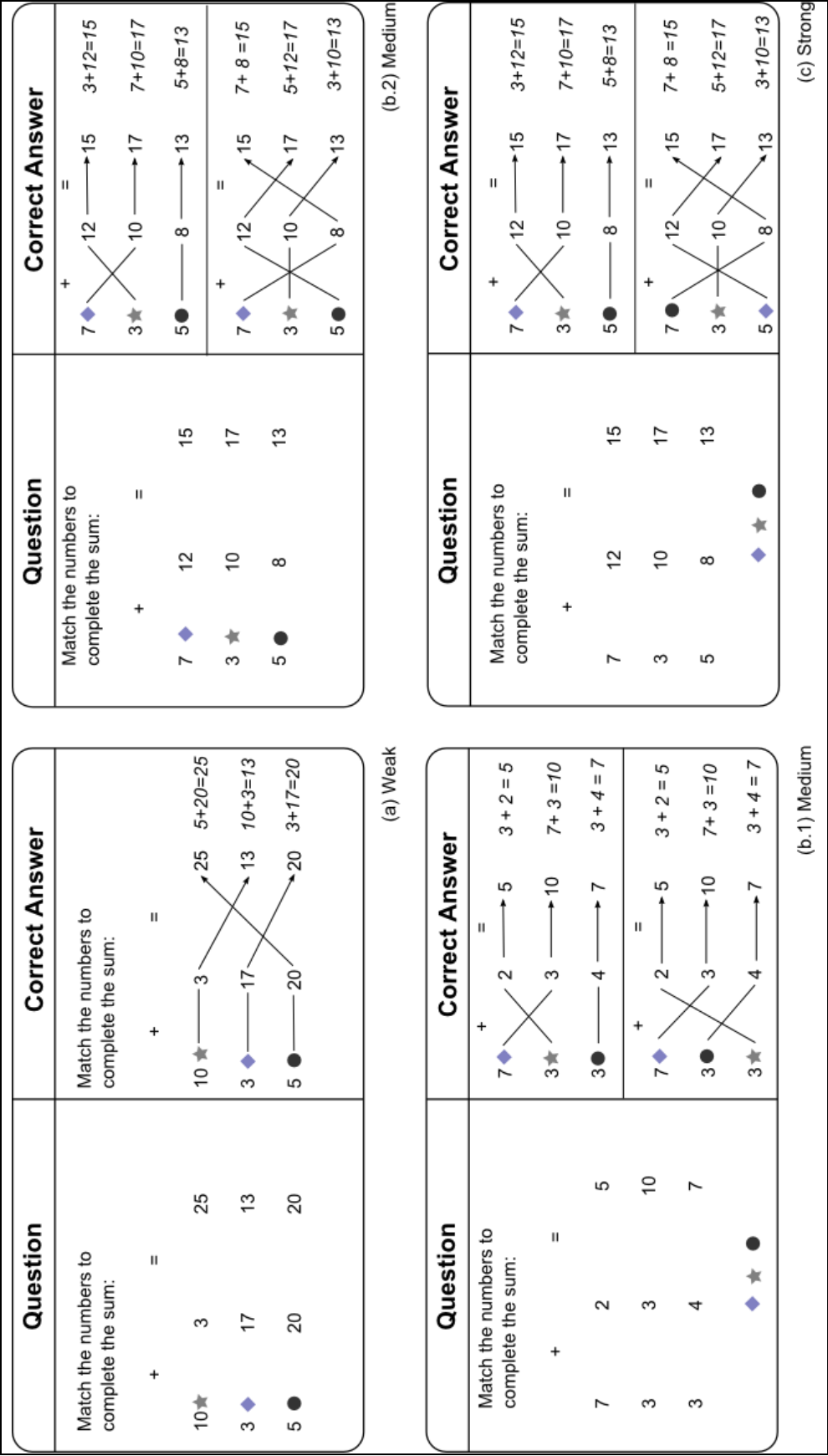


Figure 2-8: Examples of Establishing Exact Associations.

2.7.6 Establishing Multiple Associations

Figure 2-9 (a) shows an example of a Weak Dependency activity, where the students are assigned a time and asked to match this to the clock that is showing this time. There is only one possible solution and in order to arrive at this solution, each student must match their time to a clock, thus ensuring that their role is defined. Figure 2-9 (b.1) shows an example of a Medium Dependency activity, where there is only one possible solution and the roles are not defined. Students are asked to match a time with the respective clock and there is only one possible solution. In order to arrive at this solution, the students must coordinate with each other to define the role to be played by each, i.e. decide who will match which time with which clock. Figure 2-9 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. As with the previous activities, the students must match a clock with the respective time. Each student is assigned a clock with which to match a time and therefore their role is defined. However, there are several times that can be matched with each clock and therefore there are multiple solutions. Finally, Figure 2-9 (c) shows an example of a Strong Dependency activity where the goal is to match the clock with its respective time. However, there is more than one possible solution as the times are expressed in different ways (00:00, 12:00 and 24:00). Furthermore, the students are grouped in pairs for matching a clock with the corresponding time. The students must first agree on which matches to make and which pair will make each match. In this case, the pair must also coordinate with each other regarding how to make this match, i.e. who will select the clock and who will select the time.

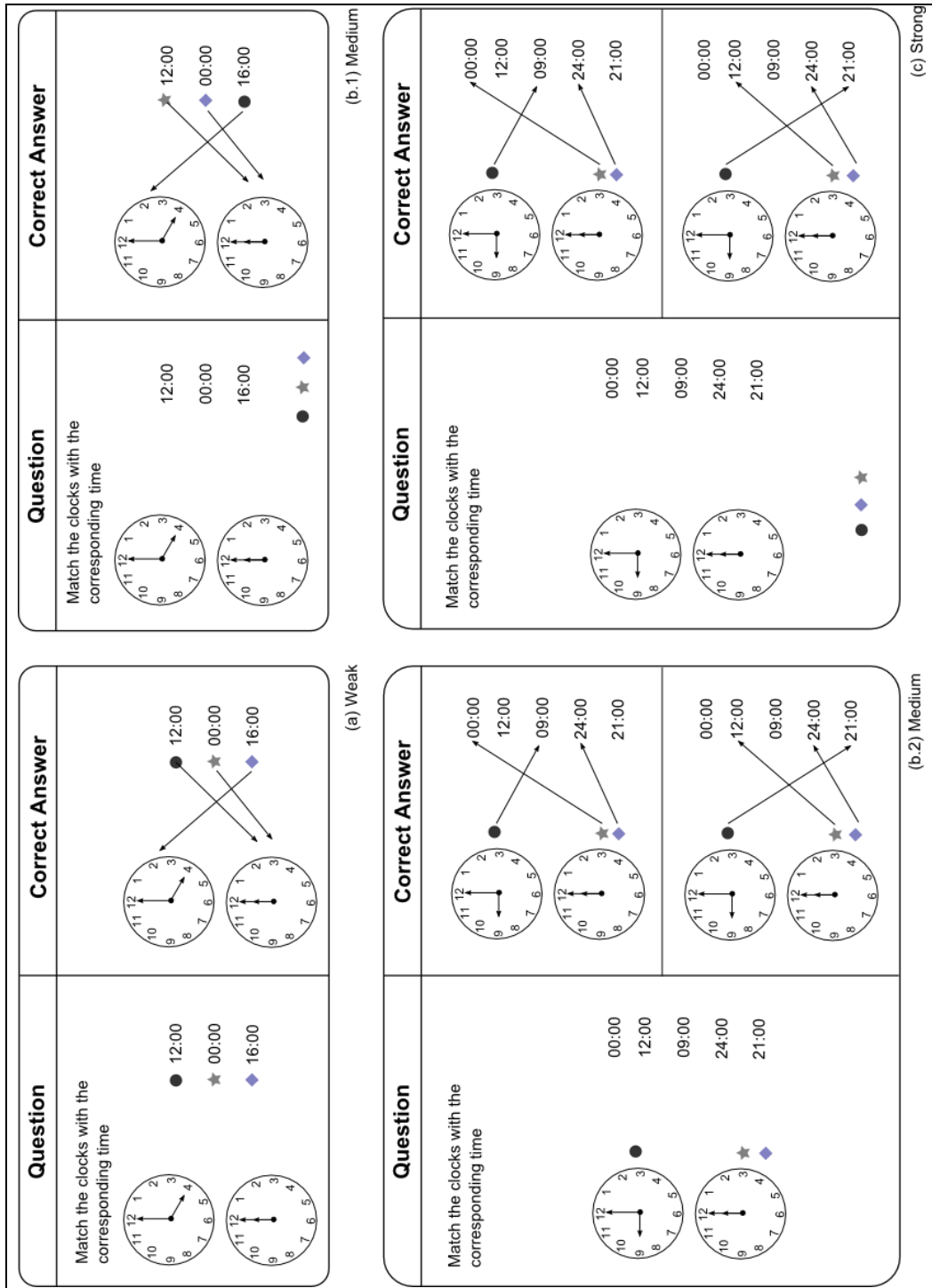


Figure 2-9: Examples of Establishing Multiple Associations

2.7.7 Construction

Figure 2-10 (a) shows an example of a Weak Dependency activity where the students must build a figure and there is only one possible solution. Each student is assigned a shape with which to build the figure and therefore their role is defined. Figure 2-10 (b.1) shows an example of a Medium Dependency activity where there is only one possible solution but the roles are not defined. Each student is assigned the vertex of a geometric figure and the goal is to build an equilateral triangle with sides of 3cm. There is only one possible solution to this problem. Each student must carry out an action as the triangle takes shape and therefore their role is not defined and will develop as the solution takes shape. Figure 2-10 (b.2) shows an example of a Medium Dependency activity where there is more than one possible solution but the role is defined. The students must build a figure and are assigned an unlimited set of shapes with which to do so, thus defining their role. There are multiple solutions to this problem as there are several combinations of shapes that can be used to build the figure. Finally, Figure 2-10 (c) shows an example of a Strong Dependency activity where, as with the previous example, each student is assigned the vertex of a geometric figure. However, in this case the goal is to build a triangle. There are multiple solutions to this problem as there are many different types of triangle (equilateral, isosceles, scalene, etc.). The students must first decide which triangle to build and then define their roles accordingly so as to carry out the necessary actions in order to arrive at the agreed solution.

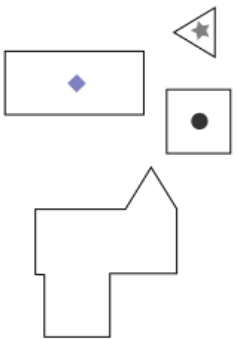
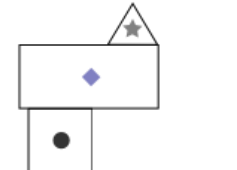

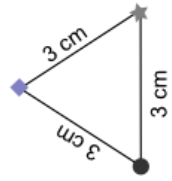
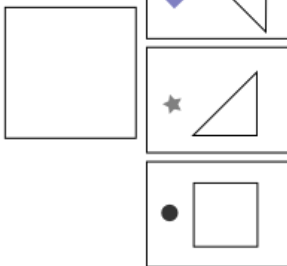
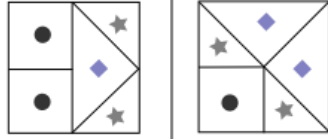

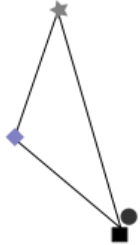
<p>Question</p> <p>Build the figure:</p> 	<p>Correct Answer</p> 
<p>Question</p> <p>Create an equilateral triangle, with sides of 3cm:</p> 	<p>Correct Answer</p> 
(a) Weak	
<p>Question</p> <p>Build the figure:</p> 	<p>Correct Answer</p> 
<p>Question</p> <p>Build a triangle</p> 	<p>Correct Answer</p> 
(b.2) Medium	
(c) Strong	

Figure 2-10: Examples of Construction

2.8 Appendix 2-B: Examples for Language Arts

All of the examples below have been taken from the Ministry of Education's website (www.mineduc.cl) for the 3rd grade. The examples are based on recommendations made by the Ministry to teachers regarding different curricular objectives.

2.8.1 Identification/Exclusion

For this example, the students must have first read a story (in this case, *The Frog Prince* by the Brothers Grimm). Figure 2-11 (a) shows an example of a Weak Dependency activity, where the students must identify the story's main character and there is only one possible solution. Each student is assigned an identifier (star, rhombus or circle) which they must place on who they think is the main character. The student's role is therefore defined. Figure 2-11 (b.1) shows an example of a Medium Dependency activity, where there is only one possible solution and the roles are not defined. The aim of the activity is to identify all of the characters from the story (again, there is only one possible solution). As with the previous activity, each student has an identifier which they must place on a character, taking into consideration that as a group they must identify all of the characters from the story. In this sense, the role of each student is not defined and will depend on how the students arrive at the solution. Figure 2-11 (b.2) shows an example of a Medium Dependency activity with multiple solutions and defined roles. The aim of the task is for the group to identify a verb, an adjective and a setting for the story in three different paragraphs, therefore presenting multiple possible solutions. The role played by each student is defined as the student is told which word family (or setting) they must identify. Finally, Figure 2-11 (c) shows an example of a Strong Dependency activity, where the instructions are the same as for the previous activity: identify a verb, adjective and setting for the story in three different paragraphs. This problem has several possible solutions as there are many words that meet these requirements. To complete this activity, the students must first decide which words

they will identify and in which paragraph, before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

<p>Question</p> <p>The Frog Prince (Brothers Grimm)</p> <p>Identify the main character:</p> <p>★ ◆ ●</p> <p>The king The barber The prince</p>	<p>Correct Answer</p> <p>The Frog Prince (Brothers Grimm)</p> <p>Identify the main character:</p> <p>The king The barber The prince</p> <p>★ ◆ ●</p>
<p>Question</p> <p>The Frog Prince (Brothers Grimm)</p> <p>Identify in the text:</p> <p>★ ◆ ●</p> <p>A verb An adjective A setting in the story</p>	<p>Correct Answer</p> <p>★ identified jumped as a verb</p> <p>◆ identified nasty as an adjective</p> <p>● identified castle as a setting in the story</p> <p>★ identified eaten as a verb</p> <p>◆ identified silly as an adjective</p> <p>● identified well as a setting in the story</p>
(a) Weak	
(b.2) Medium	
<p>Question</p> <p>The Frog Prince (Brothers Grimm)</p> <p>Identify which characters are in the story:</p> <p>★ ◆ ●</p> <p>The baker The princess Henry Iron</p>	<p>Correct Answer</p> <p>◆ identified jumped as a verb</p> <p>★ identified nasty as an adjective</p> <p>● identified castle as a setting in the story</p> <p>★ identified eaten as a verb</p> <p>● identified silly as an adjective</p> <p>◆ identified well as a setting in the story</p>
(b.1) Medium	
(c) Strong	

Figure 2-11: Examples of Identification

2.8.2 Categorizing Elements

Figure 2-12 (a) shows an example of a Weak Dependency activity, where the students must classify three words as a verb, noun or adjective. There is only one possible solution to this problem. Each student is given three words that they must place on the grid and therefore their role in the activity is defined. Figure 2-12 (b.1) shows an example of a Medium Dependency activity with only one possible solution and roles that are not defined. The aim of the activity is to classify 9 words depending on the first letter of the word and whether the word is a verb, noun or adjective. Again, there is only one possible solution to this problem. The students' roles are not defined as they do not know which words each one will classify, with the roles defined according to how the students choose to arrive at the solution. Figure 2-12 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. The aim of the activity is the same as for the previous activity, although the students choose only 2 words from each box so that there are several possible solutions. The role of each student is defined as they are told which cell to complete in the grid (in this case, the star must classify a noun beginning with the letter F and a verb that begins with S). Finally, Figure 2-12 (c) shows an example of a Strong Dependency activity where the instructions are exactly the same as for the previous activity (with the restriction of having to choose 2 words from the 3 boxes that contain the words). There are multiple solutions to this problem as there are many combinations that can fill the grid. In this case, the students must first decide which words they will classify from each box, before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

Question

Verb

Noun

Adjective

F

S

T

find

smart

tree

friendly

sun

take

floor

see

truthful

Correct Answer

Verb

Noun

Adjective

F

S

T

find

see

take

floor

sun

tree

friendly

sun

take

floor

see

truthful

(a) Weak

Question

Verb

Noun

Adjective

F

S

T

find

smart

tree

friendly

sun

take

floor

see

truthful

Correct Answer

Verb

Noun

Adjective

F

S

T

find

see

take

floor

sun

tree

friendly

sun

take

floor

see

truthful

(b.1) Medium

Question

Verb

Noun

Adjective

F

S

fight

sell

floor

smart

sun

flower

sea

friendly

fat

scary

find

see

Correct Answer

Verb

Noun

Adjective

F

S

find

see

floor

sun

friendly

smart

(b.2) Medium

Question

Verb

Noun

Adjective

F

S

fight

sell

floor

smart

sun

flower

sea

friendly

fat

scary

find

see

Correct Answer

Verb

Noun

Adjective

F

S

find

see

floor

sun

friendly

smart

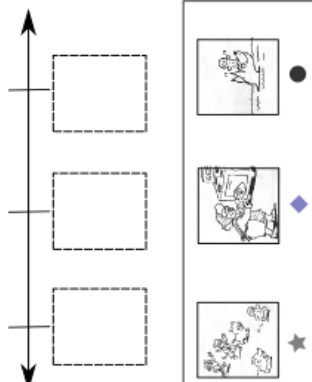
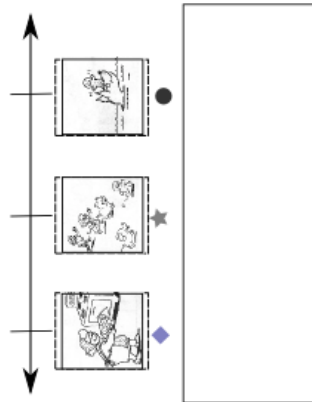
(c) Strong

Figure 2-12: Examples of Categorizing Elements

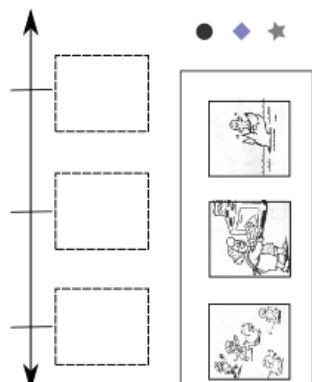
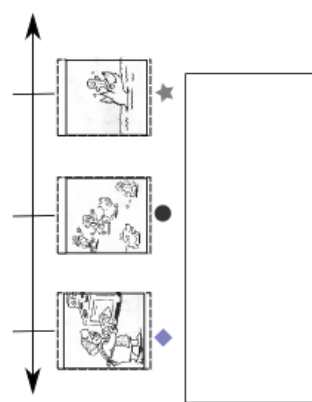
2.8.3 Forming Sequences

For the examples in this section, the students must read a story (in this case *The Gingerbread Man*). Figure 2-13 (a) shows an example of a Weak Dependency activity, where the students must place three passages from the story in chronological order. The passages are represented by images and there is only one possible solution to this problem. Each student is assigned an event which they must place on the timeline and therefore their role is defined. Figure 2-13 (b.1) shows an example of a Medium Dependency activity with only one possible solution and roles that are not defined. The aim of the activity is the same as for the previous activity, and again only has one possible solution. The students' roles are not defined as they do not know which event they must place on the timeline, something which will depend on how the students choose to solve the problem. Figure 2-13 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. The aim of the activity is the same as for the previous activity, though the students are provided with more than 3 events to choose from so that there is more than one possible solution. The role to be played by each student is defined as they are told which position on the timeline they must place one of the six events (in this case, the circle must choose an event that comes first in the sequence chosen by the group). Finally, Figure 2-13 (c) shows an example of a Strong Dependency activity, where the instructions are exactly the same as for the previous activity with more than 3 events that must be placed in chronological order. There is more than one solution to this problem as there are many combinations of events that can be placed in chronological order. The students must first decide which events they are going to place in order, before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

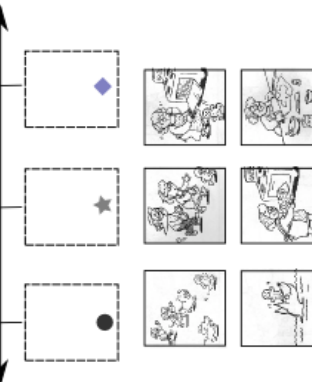
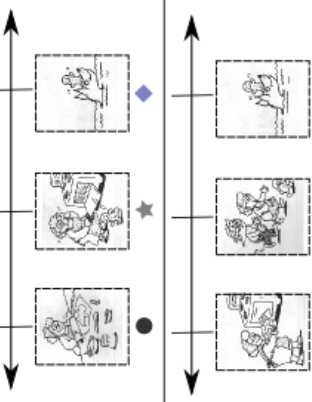
(a) Weak

Question	Correct Answer
	

(b.1) Medium

Question	Correct Answer
	

(b.2) Medium

Question	Correct Answer
	

(c) Strong

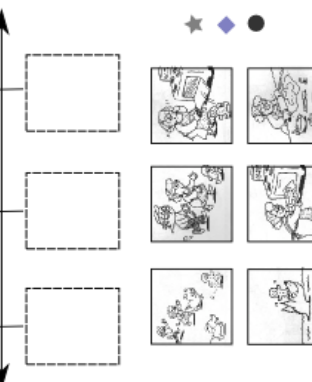
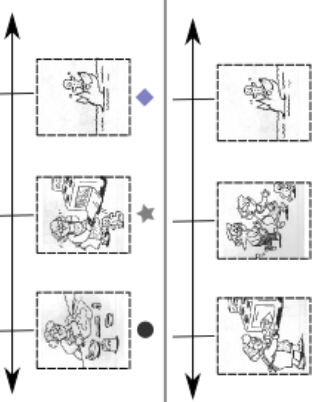
Question	Correct Answer
	

Figure 2-13: Examples of Forming Sequences

2.8.4 Completing Sequences

For the examples in this section, the students must have first read about a given topic (in this case, the Animal Kingdom). Figure 2-14 (a) shows an example of a Weak Dependency activity, where students must fill in the blanks and where there is only one possible solution. Each student is assigned a word which they must use to fill in one of the blanks and therefore their role is defined. Figure 2-14 (b.1) shows an example of a Medium Dependency activity with only one possible solution and roles that are not defined. The aim of the activity is the same as for the previous activity and again there is only one possible solution to the problem. The students' roles are not defined as they do not know which word they must place in the text, something which will depend on how the students choose to solve the problem. Figure 2-14 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. The aim of the activity is the same as for the previous activity, but the text has gaps that could be completed for different topics (reptiles or mammals) so as to provide multiple solutions. The role of each student is defined as the students are told which gap they must fill. Finally, Figure 2-14 (c) shows an example of a Strong Dependency activity, where the instructions are exactly the same as for the previous activity. There are multiple solutions to this problem as the text allows the students to answer for more than one topic (reptiles or mammals). The students must first decide which topic they will work with, before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

<p>Question</p> <p>Tortoises are _____. Unlike _____, which means they start life as eggs. Also, they are cold-blooded and therefore their body temperature depends on the environment.</p> <p>★ reptiles ◆ oviparous ● mammals</p>	<p>Correct Answer</p> <p>★ Tortoises are <u>reptiles</u>. Unlike <u>mammals</u>, tortoises are <u>oviparous</u>, which means they start life as eggs. Also, they are cold-blooded and therefore their body temperature depends on the environment.</p>
(a) Weak	(b.2) Medium
<p>Question</p> <p>Tortoises are _____. Unlike _____, which means they start life as eggs. Also, they are cold-blooded and therefore their body temperature depends on the environment.</p> <p>★ ◆ ● reptiles oviparous mammals</p>	<p>Correct Answer</p> <p>● Tortoises are <u>reptiles</u>. Unlike <u>mammals</u>, tortoises are <u>oviparous</u>, which means they start life as eggs. Also, they are cold-blooded and therefore their body temperature depends on the environment.</p>
(b.1) Medium	(c) Strong
<p>Question</p> <p>◆ _____ are _____, which means they start life as _____. They belong to the animal kingdom and are also vertebrae</p> <p>mammals viviparous oviparous living creatures reptiles eggs</p>	<p>Correct Answer</p> <p>◆ Reptiles are <u>oviparous</u>, which means they start life as <u>eggs</u>. They belong to the animal kingdom and are also vertebrae</p> <p>◆ Mammals are <u>viviparous</u>, which means they start life as <u>living creatures</u>. They belong to the animal kingdom and are also vertebrae</p>
<p>Question</p> <p>_____ are _____, which means they start life as _____. They belong to the animal kingdom and are also vertebrae</p> <p>◆ ● ★ mammals viviparous oviparous living creatures reptiles eggs</p>	<p>Correct Answer</p> <p>◆ Reptiles are <u>oviparous</u>, which means they start life as <u>eggs</u>. They belong to the animal kingdom and are also vertebrae</p> <p>● Mammals are <u>viviparous</u>, which means they start life as <u>living creatures</u>. They belong to the animal kingdom and are also vertebrae</p>

Figure 2-14: Examples of Completing Sequences

2.8.5 Establishing Exact Associations

Figure 2-15 (a) shows an example of a Weak Dependency activity, where students must match figurative language with its meaning. There is only one possible solution to this problem. Each student has to match the same figurative phrase with its meaning and therefore their role is defined. Figure 2-15 (b.1) shows an example of a Medium Dependency activity, where there is only one possible solution and the roles are not defined. The aim of the activity is to match two figurative phrases with their corresponding meaning and again the problem only has one possible solution. The roles are not defined as the student does not know which phrase they must match with its meaning, something which will depend on how the students choose to solve the problem. Figure 2-15 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. The aim of the activity is to match part of a paragraph from a poem with a type of figurative language (metaphor, personification or alliteration). This provides the problem with various possible solutions as the paragraphs from the chosen poem may contain more than one example of a metaphor, personification or alliteration. The role of each student is defined as they are told which type of literary figure they must match with a phrase from the text (in this case, the star must find a metaphor). Finally, Figure 2-15 (c) shows an example of a Strong Dependency activity, where the instructions are exactly the same as for the previous activity. There is more than one possible solution to this problem. The students must first decide which phrase from each paragraph they are going to match with a literary figure, before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

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(b.1) Medium	(c) Strong								

Figure 2-15: Examples of Establishing Exact Associations

2.8.6 Establishing Multiple Associations

Figure 2-16 (a) shows an example of a Weak Dependency activity, where students must match three words with a synonym from two given words. There is only one possible solution to this problem. Each student must match a word with its synonym and therefore their role is defined. Figure 2-16 (b.1) shows an example of a Medium Dependency activity, where there is only one possible solution and the roles are not defined. The aim of the activity is to match three words with their respective synonym and again this problem only has one possible solution. The role of the student is not defined as they do not know which word they must match with its synonym, something which will depend on how the students choose to solve the problem. Figure 2-16 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. The aim of the activity is to write three words that are synonyms of one of two words that are given. There is more than one possible solution as there are several synonyms for each word. The role of each student is defined as they are told for which word they must find a synonym (in this case, the star must write a synonym of Joy). Finally, Figure 2-16 (c) shows an example of a Strong Dependency activity, where the instructions are exactly the same as for the previous activity. This problem has multiple solutions as there are many synonyms for each word. The students must first decide for which word they will find a synonym (bearing in mind that they cannot use any of the synonyms already associated with a word), before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

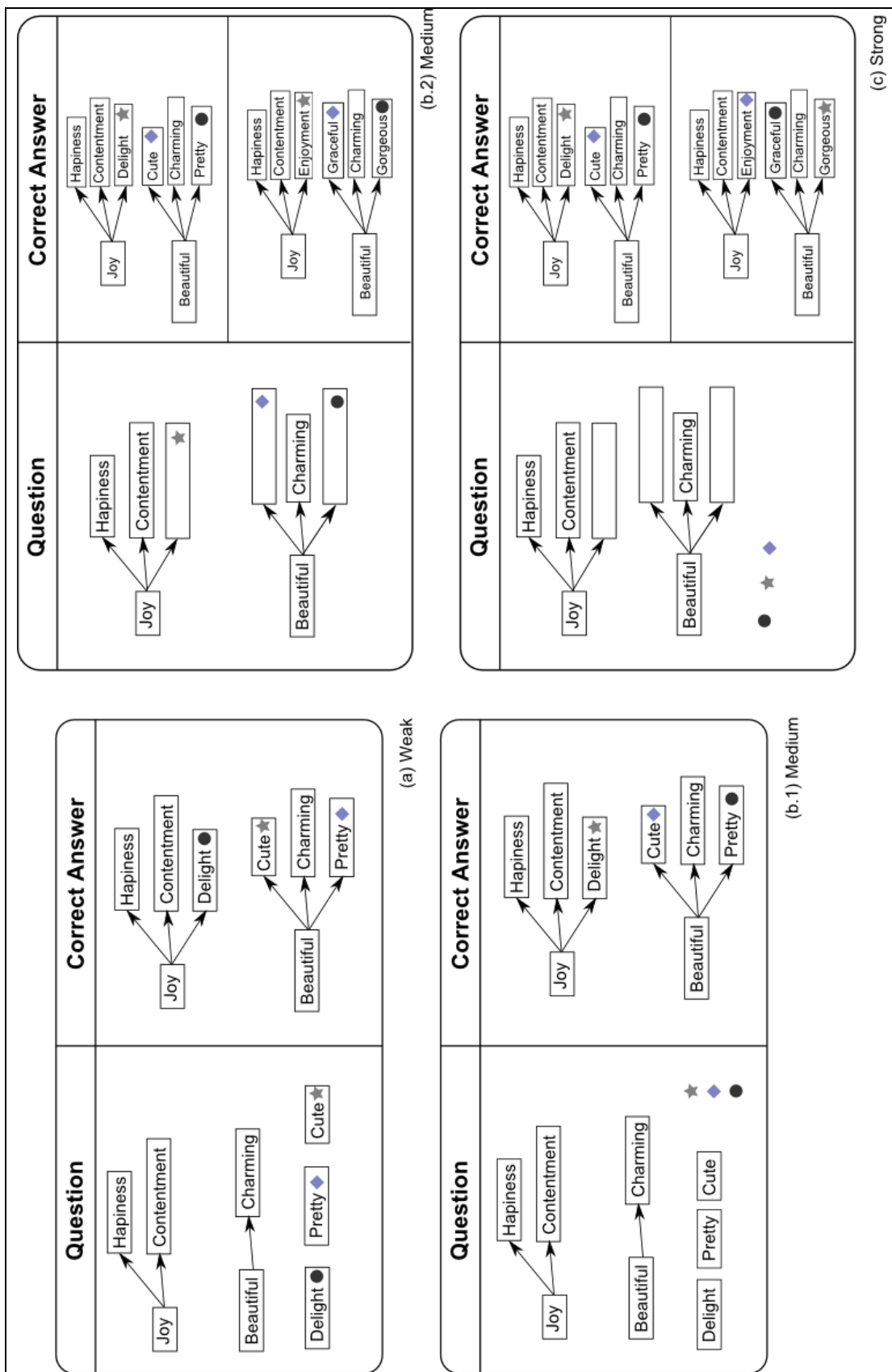


Figure 2-16: Examples of Establishing Multiple Associations

2.8.7 Construction

For this example, the students are first asked to read a text and then to make a comic strip. Figure 2-17 (a) shows an example of a Weak Dependency activity, where students must draw three scenes for a comic containing three particular situations that are predefined by the teacher (represented as “Situation 1”, “Situation 2” and “Situation 3”). There is only one possible solution to this problem as each of the students will draw one of the three situations. As each student must draw one of the three situations given by the teacher, their roles are therefore defined. Figure 2-17 (b.1) shows an example of a Medium Dependency activity with only one possible solution and roles that are not defined. The aim is to draw three predefined situations in a comic strip and again there is only one possible solution to this problem. The role of the student is not defined as they do not know which of the situations they must draw, something which will depend on how the students choose to solve the problem. Figure 2-17 (b.2) shows an example of a Medium Dependency activity with multiple solutions and roles that are defined. The aim of the activity is to draw a comic with three scenes based on a text that has been read by the students. There are multiple solutions to the activity as the students can choose any three situations from the text with which to make their comic. The role of each student is defined as they are told which of the scenes they must draw (in this case, the star must draw the first scene). Finally, Figure 2-17 (c) shows an example of a Strong Dependency activity, where the instructions are exactly the same as for the previous activity. There is more than one possible solution to this problem. The students must first decide which situations each of them will draw, before defining their roles according to the chosen solution and subsequently carrying out the necessary actions to arrive at this solution.

<p>Question</p> <div> <div>Situation 1</div> <div>Situation 2</div> <div>Situation 3</div> </div>	<p>Correct Answer</p> <div> <div>Situation 1</div> <div>Situation 2</div> <div>Situation 3</div> </div>
<p>Question</p> <div> <div>Situation 1</div> <div>Situation 2</div> <div>Situation 3</div> </div>	<p>Correct Answer</p> <div> <div>Situation 1</div> <div>Situation 2</div> <div>Situation 3</div> </div>
<p>Question</p> <div> <div></div> <div></div> <div></div> </div>	<p>Correct Answer</p> <div> <div></div> <div></div> <div></div> </div>
<p>Question</p> <div> <div></div> <div></div> <div></div> </div>	<p>Correct Answer</p> <div> <div></div> <div></div> <div></div> </div>

(a) Weak

(b.2) Medium

(b.1) Medium

(c) Strong

Figure 2-17: Examples of Construction

2.9 Appendix 2-C: Activities done in the experiment

Table 2-7: Weak, Medium and Strong Dependency activities for each of the sub-topics

<i>Sub – topic</i>	<i>Weak</i>	<i>Medium</i>	<i>Strong</i>
Equivalent fractions	Identify an equivalent fraction for a given fraction.	Identify all of the fractions that are equivalent to a given fraction.	Identify two fractions (from many) that are equivalent.
Comparing fractions	Identify which fraction is greater (or less) than a given fraction.	Identify all of the fractions that are greater (or less) than a given fraction.	Identify two fractions (from many) where the first is greater (or less) than the second.
Fractions of a whole	Identify which whole number corresponds to the fraction of a whole.	Identify which fraction of a whole number is the one that returns a particular fraction of a whole.	Identify which fraction and which whole number return a particular fraction of a whole.

3. THE EFFECTS OF WHOLE-CLASS INTERACTIVE INSTRUCTION WITH SINGLE DISPLAY GROUPWARE FOR TRIANGLES

3.1 Abstract

Whole-class interactive instruction is an instructional approach in which all of the students in a class create knowledge together in an interactive way, mediated by the teacher. The current mixed-method study compared the effects of a specific implementation of whole-class interactive instruction, Single Display Groupware (SDG), with traditional classical instruction of geometry, for 69 third grade students. In SDG students work in groups that share one area on a large display screen in front of the class. Each individual student in a group has a mouse and together the students in each group need to perform assignments by using “silent collaboration”. In the current study, the assignment for the students was to identify and create different kinds of triangles. Outcomes of interest were learning gains (quantitative) and effectiveness of "silent collaboration" (qualitative). Learning gains were significantly higher for students in the SDG condition than for students following traditional instruction. An analysis of emerging activity patterns showed that students found natural ways to silently collaborate.

3.2 Introduction

Whole-class interactive instruction is a key feature of mathematics instruction in countries with the highest levels of mathematics achievement (Reynolds & Farrell, 1996) and also seems to be successful for students in lower SES ranges (Reynolds, Creemers, Stringfield, Teddlie, & Schaffer, 2002). Whole-class interactive

instruction is a teaching method in which knowledge is created by all of the students in a class together in an interactive and collaborative way, mediated by the teacher.

Whole-class interactive instruction is interactive in the sense that it is: "... a two-way process in which pupils are expected to play an active part by answering questions, contributing points to discussions, and explaining and demonstrating their methods and solutions to others in the class" (DfEE, 2001, p. 26). This type of active processing of information is known to be important for acquiring meaningful knowledge (Mayer, 2002). In whole-class interactive instruction students also collaborate in working towards the solving of a common problem (Szewkis et al., 2011). In this way they learn from one another, because during their interactions cognitive conflicts arise, inadequate reasoning is exposed, disequilibrium occurs, and higher-quality understanding emerges (Slavin, 1996). Because the contributions and opinions of all students are equally valued and each student is encouraged to participate actively during the classes, a collective understanding is created (Graham, 1999). Students also feel responsible for each other's learning as well as for their own, with each group member accountable for the group's results (Dillenbourg, 1999; Slavin, 1980).

Several conditions must be met to reach effective whole-class collaboration. First of all, there must be a common goal to work towards (Dillenbourg, 1999). Having a common goal works as an incentive for students to help and encourage each other to make the maximum possible effort (Slavin, 1996). Second, there must be positive interdependence between peers, defined as "the perception that we are linked with others in a way so that we cannot succeed unless they do" (Johnson & Johnson, 1999,

pp. 70–71). Students are more likely to provide each other with emotional and tutorial support when they recognize that their success is dependent upon the successes of their peers (Lowyck et al., 2003). Joint rewards and/or punishments, the third condition, can aid positive interdependence between peers (Axelrod & Hamilton, 1981). When every group member receives the same treatment, they will look to maximize their joint utility and therefore generate a scenario where collaboration will prevail (Zagal, 2006). Fourth, students need to be aware of their peers' work (Janssen et al., 2007; Zurita & Nussbaum, 2004) in order to engage in the activities in which they are needed most, where they can best aid the group (Janssen et al., 2007). Fifth, it is important for there to be good coordination, defined as "the act of managing interdependencies between activities performed to achieve a goal" (Malone & Crowston, 1990, p. 361), and communication between peers (Gutwin & Greenberg, 2001). For good communication between peers, three social skills are required (Tarim, 2009): students must listen actively, be positive towards their peers, and participate actively. The sixth condition to be met is that peers must support each other (Lowyck et al., 2003). Peer support is necessary for students to feel that they are in a safe environment in which they can freely express their ideas (Muijs & Reynolds, 2000) and is positive for students' self-efficacy, goal-orientation, and the intrinsic value they place on the learning task (Lowyck et al., 2003). Seventh, students need to be individually accountable for their contribution to the group work (Slavin, 1996). This prevents the hazard of certain group members not participating, and encourages students to teach and assess one another (Slavin, 1996).

Teachers have a mediating role in this whole process. They should guide and actively monitor the progress of the students, which will allow them to help those that require extra attention (Muijs & Reynolds, 2000). They should address each student's needs, adapt activities quickly in reaction to students' responses, use errors and misconceptions as a teaching point for the whole class and keep students on task for longer periods of time (Muijs & Reynolds, 2000). They also need to be aware of where pupils are in the development of their understanding of the material being taught (Graham, 1999). It is important for teachers to know when students are ready to learn new material and to engage in new activities. When they fail to assess students properly, students are taught new things without being prepared (Graham, 1999).

Technology can be important in supporting whole-class interactive instruction. Single Display Groupware (SDG) is a technology in which a single display is shared by multiple collocated users, each with their own input device (Moraveji et al., 2009). It is especially useful when developing a collaborative activity where interaction among all members of a large group within the classroom is desired (Pavlovych & Stuerzlinger, 2008). Studies have shown that the use of SDG in education has a positive impact on participation, student engagement and task performance (Infante, Hidalgo, Nussbaum, Alarcón, & Gottlieb, 2009; Scott et al., 2003) as well as on collaboration and motivation (Inkpen, Ho-Ching, Kuederle, Scott, & Shoemaker, 1999), in order to encourage collaboration that could be inhibited by social barriers. When using SDG, students perceive more fairness because no one is left out (Inkpen et al., 1999); they work simultaneously on a single screen instead of taking turns

(Infante et al., 2009; K. M. Inkpen et al., 1999) which provides them with a common focus (Infante et al., 2009); and they are all able to control the screen, allowing shared leadership and forcing them to participate and be responsible for their own learning (Infante et al., 2009).

Despite the benefits of SDG, there are only a few studies on how this technology could be used in classrooms to increase student participation (Liu & Kao, 2007). The work that has been done on this topic focuses primarily on analyzing the impact of different factors such as interference that occurs among participants (Tse et al., 2004), group size (Inkpen et al., 2005; Ryall et al., 2004), comparisons with other technologies, and input effectiveness (Hansen & Hourcade, 2010).

Among the uses of SDG in large-group mathematics is the work undertaken by (Alcoholado et al., 2012) in which SDG was used to teach arithmetic. In their study, the teacher did not engage in interactive instruction and students did not collaborate but worked individually in personal spaces without interacting with their classmates, and the teacher acted as a mediator of individual rather than whole-group work. Alcoholado et al. (2012) showed that the students' knowledge increased significantly and that the approach was most effective for the weaker students.

In order to analyze the work performed as a group, it is possible to recognize task work, each task's required actions, and teamwork, the actions done by the group to complete the task (Pinelle et al., 2003). In the current study we will further investigate the value of SDG for mathematics instruction and also incorporate collaboration between students, though in a specific, silent, mode. This "silent collaboration", that is related to teamwork, has been explored before in a different domain (teaching

Spanish) by Szewkis, et al. (2011). SDG was used in their study, but because it required collaboration among students who were seated far away from one another in the large classroom, a negotiation mechanism based on non-spoken suggestions was defined, known as “silent collaboration”. Silent collaboration is a type of collaboration “in which students – through suggestions and exchanges performed through the dynamics provided by the software – must compare their ideas to those of their classmates” (Szewkis, et al., 2011, p. 561). In the work by Szewkis, et al. (2011), SDG with silent collaboration was proven to be effective for supporting learning in large classrooms where students are spread out.

In the current study, we investigated how SDG and silent collaboration can be applied to teach geometry, specifically about triangles. Our first (quantitative) research question concerned the effectiveness of SDG compared to traditional instruction and our second research (qualitative) research question concerned the way silent collaboration takes place naturally.

3.3 Method

3.3.1 Experimental Design

Two conditions were included in the study: an experimental condition ($n = 33$) that learned about triangles using specifically designed software, SDG for Triangles, (SDGT, for a full explanation see the section on SDGT) and a control condition ($n = 36$) that followed the regular lessons. Students in the experimental condition worked with their regular teacher in their usual classroom so as to avoid changing their regular environment.

The SDGT software can support four working groups per computer and display screen, with up to ten students per group. However, in previous experiments using this software, groups with more than seven students experienced difficulties with coordination, particularly when constructing triangles. To facilitate student coordination in the experimental condition the whole classroom was divided in groups such that these have up to six students in each. For the display, two screens were used with two computers, as shown in Figure 3-1. The two screens together formed one large screen containing workspaces for up to eight groups; from these in this experiment only six groups were used. The students in the experimental condition were randomly assigned to one of the six groups in each of the sessions.

Students in the control condition worked on the same content and curricular objectives as those in the experimental condition, but via traditional teaching methods. The teacher mainly taught the theoretical concepts to the students by using a (conventional) whiteboard. Each student worked individually, answering the teacher's questions as they were asked. When applicable, the exercise was carried out on a completely individual basis using pencil and paper. There was no active follow-up or general feedback from the teacher once the session had finished.

3.3.2 Participants

The participants were 8-9 year old students from two third grade classes in a state subsidized school located in Santiago, Chile. The experiment was carried out with 78 students. However, nine students missed session(s) and/or a test, which is why a total of 69 students were taken into account in the statistical analysis. Of the 69 students, 33 participated in the experimental condition and 36 in the control condition. The

experimental condition included 21 girls and 12 boys, and the control condition included 17 girls and 19 boys.

3.3.3 Instructional design

An integrated instructional design was applied to realize our instruction. Four main elements played a role in this design: a) the SDGT software; b) students' activities with the software in relation to the curricular objectives for geometry; c) the teacher's activities; and d) the way collaboration between students was shaped.

3.3.4 Single display groupware for triangles

SDG for Triangles (SDGT) is an application for interactive teaching that allows all of the students in a class to work simultaneously on identifying, classifying and constructing triangles. Figure 3-1 illustrates students in a classroom working with SGDT. The application is suitable for common computers or laptops that can have a projector attached to them and that have at least one USB-port so as to connect multiple mice to the computer with the help of hubs; one mouse for each student and one for the teacher.



Figure 3-1: Students and the teacher in the classroom working with SDGT

SDGT with one screen can currently be used for classes with a maximum of forty students. As explained in the section on Curricular Goals and Student Activities, activities are typically completed in four smaller groups of up to ten students, per screen and computer. Students are identified by a unique combination of cursor symbol and color, where the color represents the group. At the beginning of each session, a special activity in which students move their cursors to the corresponding symbol allows them to determine which symbol/color combination is theirs.

The screen is divided into four separate workspaces (Figure 3-2). Students are able to move around freely within their group's workspace but they cannot go outside of it. Teachers can move their cursor anywhere on the screen and have more options than the students, because they play a major part in controlling the class flow and the

students' learning process. The menu at the top of the screen allows the teacher to choose a specific type of activity, display information, or freeze all the mice.

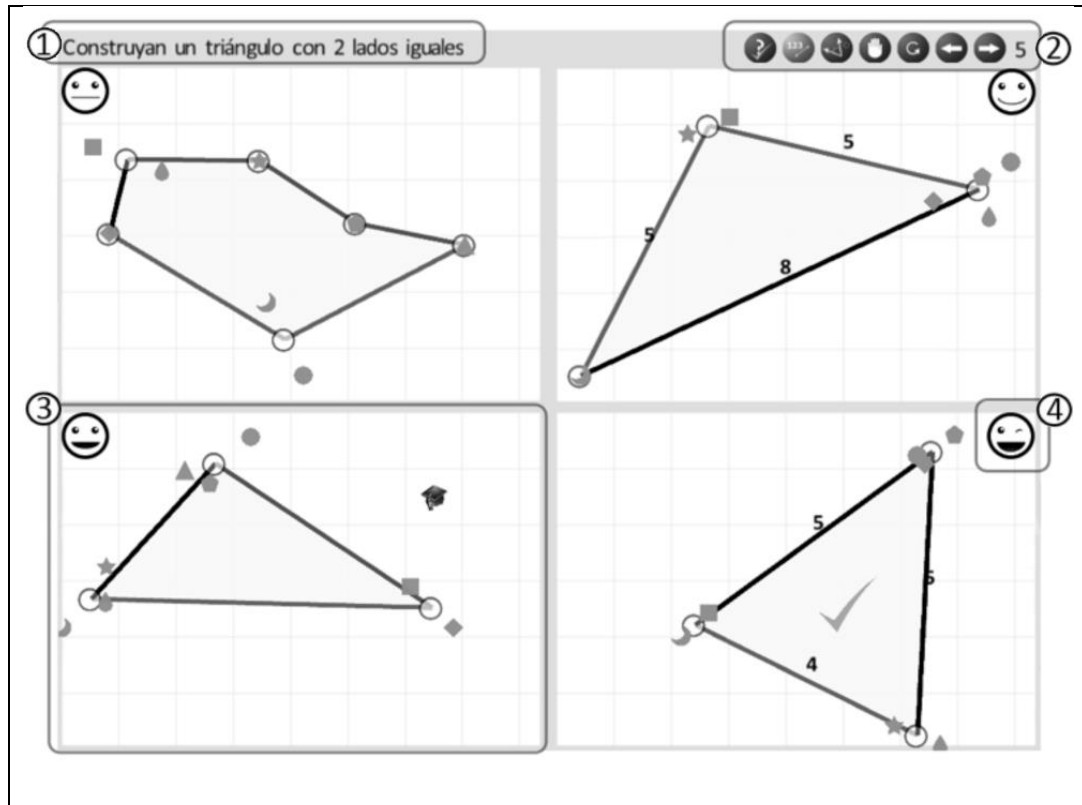


Figure 3-2: General view of the display screen showing a specific activity type (5, Table 3-2).

As shown in Figure 3-2, the screen is composed of four elements:

- a) Group workspace: four workspaces are defined in which students in a group can freely move their cursors to complete their activities (element 3 in Figure 3-2).
- b) Instruction: the assignment is provided on the top left side of the screen (element 1 in Figure 3-2). Students can see what they need to accomplish at all times.
- c) Teacher tools: a set of teacher tools is given on the top right side of the screen (element 2 in Figure 3-2). The activity is indicated with an activity number (5

in the example given in Figure 3-2). To the left of this is a set of buttons that are only accessible for teachers and that allow them to: go to the next or previous activity or slide, restart the activity with all cursors set to their initial position, stop the movement of all cursors, and provide students with additional information such as revealing the angles, revealing the length of the sides, or revealing the correct answer.

d) Group feedback: a smiley in the outer top corner of each workspace indicates how well the group is performing (element 4 in Figure 3-2). The smiley has eight states; from a neutral face (upper left, Figure 3-2) to a very happy face with a wink (bottom right, Figure 3-2). Group feedback is given graphically by indicating how close the group has come to achieving the goal of the activity, e.g. , in Figure 3-2 all cursors have to be appropriately positioned to reach the final smiley face. When the goal of building the assigned triangle is reached, a check appears in the center of the workspace to indicate that the activity has been completed correctly (bottom right in Figure 3-2).

3.3.5 Curricular goals and student activities

SDGT was developed to help third grade (8-9 years old) students learn about triangles. For this application to be suitable for the educational system, it needed to match the curricular requirements established by the Chilean Ministry of Education (MINEDUC, 2012). The main operations third-grade students needed to be able to perform were the identification and construction of triangles, which were also the two main types of activities: construction and identification activities. In construction activities students move their cursors within the 2D workspace in order to collaboratively satisfy a specific geometric condition. All of the cursors of the group

are automatically connected to each other with line segments to form a polygon. When two cursors are close enough together a vertex is formed, allowing the formation of figures with three or more vertices. A group can only successfully create the assigned type of triangle when each student participates collaboratively. Alternatively, in identification activities, students move their cursors to the object they want to select. The group is only successful when all students are on the correct object(s).

Table 3-1 summarizes the student goals to be achieved and associated activities to be completed, and the corresponding operations that make up the system. All of the activities contain multiple exercises that follow the curricular objectives, providing the students with opportunities to practice the different goals. We experimentally observed that for the kids, Activities 2, 4 and 6 had a similar level of difficulty, as 1,3 and 5 did; however 1,3 and 5 were more difficult than 2, 4, and 6. On the other side, within an identification activity (Activities 2, 4 and 6) the triangles became harder to identify as the activity progressed.

Table 3-1: Activities to be completed

	<i>(Activity #) Student goals</i>	<i>Student actions</i>
(1)	Construct a triangle	Students move their cursors within their workspace to collaboratively construct any triangle
(2)	Identify triangles in real life	Students individually move their cursors towards the figure they believe is a triangle

(3)	Construct a triangle and identify the different parts of this triangle	Students collaboratively build a triangle (3a). After the triangle is accepted by the system they individually move their cursors towards a specific part of the triangle; side, vertex, or angle (3b)
(4)	Identify specific types of triangles based on the number of equal sides	Students individually move their cursors towards the figure they believe to be the correct type of triangle (equilateral, isosceles, or scalene)
(5)	Construct specific types of triangles distinguished by the number of equal sides	Students collaboratively construct a given type of triangle (equilateral, isosceles, or scalene)
(6)	Identify specific types of triangles based on their angles	Students individually move their cursors towards the figure they believe to be the correct type of triangle (right-angled, acute, obtuse)
(7)	Construct specific types of triangles distinguished by their angles	Students collaboratively construct a given type of triangle (right-angled, acute, obtuse)

3.3.4 Teacher activities

The teachers played a pivotal part in the study. They received information about the topics to be taught, the amount of time they had for each activity, and both teachers (experimental and control conditions) received additional face-to-face instructions regarding the classroom orchestration. In order to become more familiar with the software and its orchestration, the experimental condition teacher reviewed and practiced with the software and its orchestration three times prior to the experiment.

In order to guide the teacher of the experimental condition in the integration of the software into her teaching practices, an orchestration was defined (Nussbaum et al., 2011) for all of the topics regarding triangles. The seven activities, as defined in Table 3-1, were alternated with slides that allowed the teacher to define the concepts with which the students then immediately worked. Table 3-2 describes the corresponding orchestration for Activity 4, “identifying triangles according to their sides”. An orchestration was also offered to the teacher of the control condition who was using the traditional methodology. Both orchestrations were printed out and handed to the teachers before the experiment began. They received oral instructions on how to use the orchestration.

In both orchestrations (for the experimental and control conditions), the structure of the sessions was presented to the teacher. In a first stage, the students in both conditions needed to practice the concept of triangles by identifying abstract geometric objects and triangles in real life. In a second stage, the concept of triangles needed to be defined. In the experimental condition the students and the teacher were to do this together, whereas in the control condition the teacher was to explain the concept to the students. Computer interactivity occurred only in the experimental condition, in both conditions, however, student discussion was encouraged in order to talk about the concepts and to clarify any confusion. . Finally, students needed to participate in exercises to practice their knowledge and apply it to new situations. The experimental condition did these exercises collaboratively using the software, while the control condition did them individually using pen and paper.

As Table 3-2 illustrates, the orchestrations contained five elements: the session during which the activity is carried out; the amount of time the teacher must allow the students to work on a (sub) activity or instruction; the objective of the sub-activity; the instructions the students need to receive in order to carry out the sub-activity; and the explanation of the sub-activity for the teacher.

Table 3-2 shows part of the orchestration for the experimental condition that took place during the experiment, starting with Activity 4 (defined in Table 3-1): identifying types of triangles according to the number of equal sides they contain. Once the first sub-activity had been carried out, the teacher was asked to present a PowerPoint slide in order to conceptualize the activity of classifying triangles. At the end of this presentation, the students were to continue with Activity 5, and so forth.

Table 3-2: Orchestration for identifying triangles according to their sides

<i>Session</i>	<i>Time</i>	<i>Objective</i>	<i>Student instructions</i>	<i>Teacher explanation</i>
2	5 min	To identify triangles according to the number of equal sides they have.	Collaboratively identify triangles that have three equal sides, two equal sides, or no equal sides.	Indicate that triangles can be classified according to their sides. Ask students to identify triangles with three, two, or no equal sides. Show different types of triangles, using the software, to identify triangles according to their sides.
	3 min	To understand the classification of triangles according to their sides: equilateral,	Recognize the different classifications of triangles according to their sides.	Show the “Classifying triangles” PowerPoint presentation, while analyzing the corresponding classification.

		isosceles, and scalene.		
7 min	To build different triangles at the system's request: isosceles, scalene and equilateral triangles.	Build different types of triangles.	Tell the students to collaboratively build an isosceles, scalene, and equilateral triangle.	

3.3.5 Meeting the collaboration conditions

In order to create a classroom environment conducive to collaboration, certain conditions must be met, as mentioned in the Introduction. Table 3-3 provides an overview of the conditions to be met and the manner in which these were realized in our instructional design. Here the activities of the learner and of the teacher as described in the previous sections come together.

Table 3-3: Realization of collaboration conditions

<i>Condition</i>	<i>Realization</i>
Common goal	All students from one working group received the same instructions and they all had to carry out the same operation (constructing or identifying triangles).
Positive interdependence	All students from one working group had to work together in order to succeed. Without active participation and collaboration, it was not possible to complete the assignments.

Joint rewards or punishments	<p>Everyone worked for the same purpose and received the same feedback. Success or failure depended on the entire group and rewards or punishments were given accordingly to all group members in the form of smiley faces and comments by the teacher.</p>
Awareness of peers' work	<p>Considering that all students shared the same display, students could see what their peers were doing at all times. Groups could also see the performance of other groups.</p>
Coordination and communication between peers	<p>In order to be able to create triangles collaboratively students needed to work together, because all their cursors were connected to each other in construction activities to create the assigned figures, and the feedback smiley was only happy when all students contributed successfully. It was necessary for students to communicate and coordinate, which could be done silently during the activity by moving their cursors. Verbal communication was allowed in the group discussions held by the teacher.</p>
Peer support	<p>The teacher was asked to encourage the students to support each other and to respect each other when this did not occur naturally.</p>
Individual accountability	<p>Each student was accountable for the positioning of his or her own cursor, without which the group as a whole could not succeed. The result of each peer's actions was reflected in the feedback face that changed mood according to the number of students who were in the correct place. Because of the individual symbol that was assigned to every student, the teacher was able to see who was doing well, who was struggling and who was disrupting the lesson.</p>

3.3.6 Procedure

After taking the pre-test, which all students took on the same day, both the experimental and control conditions participated in three sessions of 40-50 minutes each. Each session was carried out on a different day within the timespan of one week. Students in the experimental condition learned about triangles using the SDGT software specifically designed for this study while working in randomly assigned groups. Students in the control condition received regular classes using the traditional teaching method, and were taught the same topics, with the same activities (without the technology), as the experimental condition. To measure the knowledge acquired, both conditions took a post-test immediately after the final session.

In order to analyze how silent collaboration appears naturally, all exercises were videotaped and later analyzed in detail by an observer so as to explore how students use their devices to communicate (Stewart et al., 1998) and coordinate through silent collaboration (Tse, et al., 2004). In order to identify how often a given collaborative behavior occurred during each of the activities carried out by the students, student behavior was analyzed by the same single observer in each of the groups. The students' intentions were interpreted and labeled as a specific form of collaborative or non-collaborative behavior. These labels had already been defined as the result of a previous study. Where there were difficulties, a more in-depth discussion between the observer and two additional research team members followed until agreement was reached.

3.3.7 Measures

A test was created for this experiment to evaluate the students' growth in knowledge regarding triangles; it was used as the pre- and post-test. The test consists of open and multiple choice questions that measure the different concepts about triangles that third grades students should learn through participating in various activities specified in Table 3-1; there were 7 open questions and 8 multiple choice questions. The open questions also included sub-questions, so that the maximum possible total score was 35 points across all 15 questions; one point per correct multiple choice question, and 0, 1, and 2 points for open questions, where 0 was wrong, 1 was incomplete and 2 was correct. To reach inter reliability in the scoring, a rubric was defined. Based on the results, the Cronbach's alpha for the post-test was 0.81 for constructing and recognizing triangles based on their sides (9 items), and 0.75 for constructing and recognizing triangles based on their angles (9 items).

3.4 Results

3.4.1 Student achievement

Table 3-4 shows the mean scores (max. 35) and standard deviations of the experimental and control conditions on the pre- and posttest. Both the experimental and control conditions significantly increased their scores ($p < 0.001$ in both cases).

Table 3-4: Descriptive statistics for learning gains, with scores for the pre-test and post-test

<i>Condition</i>	<i>N</i>	<i>Pre-test</i>		<i>Post-test</i>		<i>Gain</i>	
		Mean	SD	Mean	SD	Mean	Sig
Experimental	33	5.24	2.08	14.00	7.29	8.76	<0.001
Control	36	6.67	2.47	12.03	5.62	5.36	<0.001

To determine whether there was a significant difference between the gain scores of the two conditions, a one-way ANOVA was applied with the condition (control or experimental) as an independent variable and the learning gain from pre-test to post-test as a dependent variable. These results show that condition had an effect on learning gain ($F(1, 67) = 4.58, p = .04$), with the experimental condition showing a larger gain than the control condition.

3.4.2 Student activities

Any recurring behavior across one or more activities provided evidence of emerging patterns, as documented in Table 5. This table shows all activities for the six participating groups, the number of exercises carried out as part of each activity, the time spent on each activity, the number of occurrences of each detected pattern in each activity and the total number of occurrences of each pattern. It is important to note that multiple occurrences of one pattern could occur within the same exercise, as long as they represented the behavior of different students e.g., several students trying to help another student who was not collaborating. Additionally, the behavior of one particular student could show different patterns at different points during the

exercise, for example, first playing individually with the mouse before subsequently collaborating with their peers in order to complete the exercise.

Each group of students completed 32 distinct exercises and as there were six groups, a total of 192 exercises were carried out (see Table 3-5). In some activities, various exercises of the same type were completed, e.g., in Activity 7, students sequentially constructed an acute triangle, a right angle triangle and an obtuse triangle (three exercises for Activity 7, Table 3-5). Occurrences of construction activities are marked in light gray, while occurrences of identification activities are marked in dark grey in Table 3-5. All of the activities (and their exercises) are collaborative, as described in the Curricular Goals and Student Activities section, and their successful completion required all group members to participate. Table 3-5 shows the number of successfully completed exercises, which provides evidence that collaboration was effective in 87.5% of exercises (i.e., 168 out of 192). In 12.5% of the exercises (24 out of 192) the proposed objectives were not met or required direct input from the teacher in order to complete the assigned task.

It is important to note that in order to successfully accomplish the exercises all students had to identify all requested triangles in the identification activities, or work together to successfully construct the requested triangle within the construction activities. However, even though activities required collaboration among all group members, non-collaborative patterns were identified during the realization of the exercises. It is for this reason that a distinction has been made between collaborative and non-collaborative patterns regarding student behavior.

The non-collaborative patterns identified in this analysis coincide with individual actions not necessarily oriented towards meeting the goal of the exercise. The non-collaborative patterns observed correspond to three types of actions. The first type of action observed was copying peers, but without leading to successful completion of the exercise, i.e., by either copying an incorrect object, or copying a correct triangle when further triangles remained to be identified. The second type of action was trial and error, i.e., seeking for improvement in the group's feedback (e.g., a smiley face) by moving the mouse over different objects. The third type was entropy, i.e., randomly moving the mouse around out of boredom or despair. This final pattern was particularly common in construction activities if the students failed to organize themselves after a certain amount of time. Copying peers and trial and error only applied to identification activities, as analyzing their presence in construction activities would have been very subjective.

The following collaborative patterns were observed: marking the correct location, i.e. moving the mouse persistently over a relevant figure, or over the vertex of the triangle needing construction; marking the peer who is in the wrong place, i.e. moving the mouse persistently over the symbol of a peer in the wrong place or not participating in the activity (generally until the latter reacts and begins to participate); and marking the peer who is in the wrong place and marking the correct location, i.e. a combination of the two previous patterns. All of these patterns are efforts to catch the attention of other group members, so that all students within a group cooperate in meeting the objectives. The most common collaborative pattern is marking the correct location, with 96 occurrences distributed across 72 exercises out of 192 (37.5%). Here,

students look to help their peers complete the collaborative activity through positive interdependence, rather than simply pointing out what a peer is doing wrong in the exercise. This latter case is seen with marking the peer who is in the wrong place, something that occurred just 13 times out of 142 observed collaborative patterns. Students seem to have a tendency towards being a model for their peers rather than correcting them.

Besides the aforementioned patterns, other activities were identified in some isolated cases. One example is adapting to a peer who does not wish to participate in construction activities, which occurred on numerous occasions during the first activity. In this activity, the students were able to coordinate themselves in the construction of the required triangle, leaving the isolated peer to one side on one of the vertices. Another behavioral trait that emerged in various identification exercises consisted of one student waiting for their partners to take their positions at correct answers before moving the mouse himself; the student then simply hovered the mouse over one of the selected options.

Table 3-5: Non-collaborative and collaborative patterns. Occurrences in construction activities are in light gray, while occurrences in identification activities are in dark gray.

Number of Activity			1	2	3a	3b	4	5	6	7	TOTAL
Number of Groups			6	6	6	6	6	6	6	6	6
Number of collaborative exercises in each activity			1	9	1	3	6	3	6	3	32
Collaborative exercises that were successfully accomplished			6	52	4	16	28	13	32	17	168
Collaborative exercises that were not successfully accomplished			0	2	2	2	8	5	4	1	24
Effective Time (minutes)			3	11	2	5	10	10	6	5	52
Pattern			Type of activity		Max. number of occurrences (one per student per group per exercise)						
Non- collaborative	Copying peers	Identification	-	2	-	2	15	-	23	-	42
	Trial and error	Identification	-	4	-	2	16	-	17	-	39
	Entropy	Identification and construction	3	8	4	3	18	15	9	10	70
Collaborative	Marking the correct location	Identification and construction	4	19	2	7	13	20	21	10	96
	Marking the peer who is in the wrong place	Identification and construction	2	3	1	0	1	2	3	1	13
	Marking the peer who is in the wrong place and marking the correct location	Identification and construction	0	6	2	3	7	3	10	2	33

3.5 Discussion and conclusions

The main goal of this work centered on assessing the effectiveness of interactive instruction and classroom collaboration and on how silent collaboration takes place naturally.

While students in both the control and the experimental conditions significantly increased their scores from the pre- to the post-test, this difference was significantly larger in the experimental condition, showing the effectiveness of our approach. In order to analyze the way silent collaboration takes place naturally, we identified collaboration patterns that emerged spontaneously in an environment in which peers are not necessarily physically adjacent and are not always able to verbally communicate with each other, also known as silent collaboration (Szewkis, et al., 2011). This concurs with Liu and Kao (2007), who argue that the use of shared displays produces an improvement in non-verbal interaction, such as hand signaling in reference to individual answers, thereby achieving a natural interaction between peers. Considering that each student has their own interaction device (mouse), the activity forces students to become involved in the group activity even if they do not want to, and become an active participant in the process (Infante, et al., 2009). This was reflected in students' behavior, with 168 out of a total of 192 exercises (87.5%) successfully completed.

Tse, et al. (2004) suggest that people naturally divide their work across the workspace so as not to interfere with others. However, our study shows students openly intervening their classmates' work, whether it be to help them finish the task or simply because they lose interest in the exercise. In the former case, the interference did not lower productivity as Tse, et al. (2004) would suggest. On the contrary, the multiple mice allowed the students to avoid ineffective communication (Liu & Kao, 2007); students were able to undertake collaborative and non-collaborative behavior

within the same exercise. For example, when identifying a correct triangle they would then mark it so as to help their group members.

These results have the following impacts: in analyzing teamwork, we demonstrated that it is possible to achieve synchronous collaboration among students who, in a classroom, are at a distance from each other and cannot effectively communicate orally. The collaboration achieved comes through collaborative patterns that we define as silent collaboration. The implications of silent collaboration are not just relevant for the classroom, but also for online learning. A second relevant result is the impact that this has on classroom teaching. We demonstrated that interactive instruction is possible with an entire class, in a concrete educational context. This takes on great importance given that one of the greatest barriers to adopting SDG is that little educational content is available for applications in SDG (Heimerl et al., 2010).

Despite its overall success there are still improvements to be made to the software and class orchestration. One of these concerns the fact that the time required by different groups to successfully complete an activity varied greatly. This resulted in long periods of waiting for groups that finished earlier than the specified orchestration time, during which they interrupted their classmates on many occasions, e.g. yelling or interrupting the teacher while she was giving feedback to the groups that were still working. In order to avoid this, a new activity of the same kind and level could be offered to the faster groups that are waiting for the last group to finish, so that those students can avoid waiting and receive additional practice. When all of the groups have finished at least one exercise, the teacher could then freeze the screen, analyze

the work that has been done so far, and then continue on with the next activity. This aims to avoid the situation of one group finishing early and having to wait too long for a slower group to catch up. Further, the application could be tested in a greater number of short sessions rather than a few long ones. This should lead to more concentrated, interactive, and attentive students.

Future work will examine if the same patterns of identification and construction have a general meaning. It would be useful to verify, if possible, whether or not the patterns of silent collaboration that we observed reemerge in different socio-cultural contexts and domains other than geometry and to possibly identify any new patterns that can be connected with the student learning.

4. SILENT COLLABORATION: AN EFFECTIVE STRATEGY FOR CARRYING OUT GROUP WORK IN THE CLASSROOM

4.1 Abstract

One of the key issues in Computer Supported Collaborative Learning (CSCL) is to understand when and why groups fail and when and why they succeed. We study this issue for small groups located in the same physical space, complementing face-to-face collaboration with silent collaboration. In the latter case, the interaction between peers is computer-mediated. A study was conducted with 46 4th grade students over 7 sessions. During this time the students used a software to practice fractions. The students were seated in two different configurations. In the first configuration (Adjacent) the students were sat next to one another, allowing for both verbal communication and silent collaboration. In the second configuration (Distant) the students were seated in such a way that communicating with one another was difficult. In this case, silent collaboration represented the main form of interaction between students. The results showed that there is no difference in learning between the two groups. However, it can be observed that students in the Adjacent groups who do not like to work as part of a team perform significantly worse than those who do. This is not the case in the Distant groups, where the students do not necessarily have to work or communicate verbally. A negative correlation is revealed between the number of Silent Collaboration events and the student and teacher's evaluation of the students' social skills. This suggests that the fewer social skills a student has, the more they rely on Silent Collaboration. We conclude that silent collaboration could

decrease the unevenness of student participation within a group, allowing all of the students the opportunity to work collaboratively on their teamwork skills.

4.2 Introduction

There are many benefits to introducing collaboration into the classroom. Collaborative learning has been shown to have a positive impact on learning (Gokhale, 1995; Johnson et al., 1985; Roschelle & Teasley, 1995) as well as on the students' communication skills (Gomez et al., 2010), social (Lavasani et al., 2011) and their levels of motivation and engagement (Gillies, 2003; Kutnick, Ota, & Berdondini, 2008), among others. Given the benefits of collaboration, schools have been encouraged to introduce collaborative learning into their classrooms. However, there have been mixed results as collaboration can prove to be ineffective if the group is lacking the necessary social skills (Johnson, & Johnson, 1990). This is because collaboration is not an innate skill in humans (Cohen, 1994; Kuhn, 2015; Maatta, Jarvenoja, & Jarvela, 2012). Instead, it is a skill that must be learned (Monteiro & Morrison, 2014) and that can be trained (Kutnick et al., 2008; Prichard, Stratford, & Bizo, 2006). Added to this is the fact that even when students have no previous experience of collaborative work, teachers generally assume that they already possess the necessary social skills for collaboration, which is a mistake (Ladd et al., 2014; Monteiro & Morrison, 2014).

With regards to the results reported by the literature, Nokes-Malach et al. (2015) highlight that performance within the collaborative process varies because of the difficulty students have coordinating with each other, as well as social issues, such as

social loafing (Karau & Williams, 1993) or fear of evaluation (the students are fearful of being criticized). In Computer Supported Collaborative Learning (CSCL), the interaction between peers is mediated by technology, making collaboration easier (Cress et al., 2015). This is because, in certain cases, computer-mediated communication is better than face-to-face communication. This is the case in the study conducted by Szewkis et al. (2011) with large groups, where spoken communication cannot be intensive, is ineffective, or is difficult to achieve fully. In this case, instead of relying on spoken collaboration, the students collaborate silently using the support of a computer (silent collaboration).

With respect to silent collaboration, the research by Rosen, Nussbaum, Alario-Hoyos, Rendi, & Hernandez (2014) shows that when students are in a position where it is difficult for them to have a fluent conversation, they tend to prefer silent collaboration. This tendency also increases the more students experience such situations. Finally, Caballero et al. (2014) show that different patterns of silent collaboration naturally occur among students. On the whole, these patterns tend to promote effective collaboration. Silent collaboration is therefore put forward as a strong alternative for groups to achieve a shared goal, as it facilitates coordination and communication when working in groups.

As research into collaborative learning also focuses on studying “when and why groups fail and when and why they succeed” (Nokes-Malach et al., 2015, p. 3), one question that is still unanswered with regards to silent collaboration is: “When should students use silent collaboration and what characteristics do they require in order for it to be beneficial?” This question is answered by two research questions: (i) “What

are the benefits for students of complementing face-to-face collaboration with silent collaboration?” and (ii) “What is the students’ perception of silent collaboration?”, as well as “What characterizes the students who use silent collaboration?”

4.2.1 Benefits of complementing face-to-face collaboration with silent collaboration

It is not evident that complementing face-to-face collaboration with silent collaboration is always beneficial. This is because in order to do so, at least three elements must be taken into consideration: (1) the students’ physical arrangement (room configuration), (2) computer-mediated communication vs. face-to-face communication, and (3) the students’ personal characteristics.

With regards to the first element, Mercier, Higgins, & Joyce-Gibbons (2014) showed that the way in which students are arranged in the classroom leads them to interact with one another in different ways, i.e. the groups work differently depending on the room configuration. In the aforementioned study, when classes are forward-facing and have a centered seating configuration this influences the students’ interactions, but not the teacher’s behavior (Mercier, Higgins, & Joyce-Gibbons, 2014). Secondly, it has been seen that a setting which allows for a combination of computer-mediated communication and face-to-face communication provides opportunities to improve both forms of interaction. This in turn can impact on collaboration and learning (Van Diggelen & Overdijk, 2007). Finally, a study conducted by Solimeno, Mebane, Tomai, and Francescato (2008) compared online collaboration with face-to-face collaboration, finding that students who are not as “friendly, who do not want to study

or collaborate with others” (p. 123) preferred working face-to-face, as this limited the time they had to interact with their classmates.

Given the above, the first research question in this study asks: “What are the benefits for students of complementing face-to-face collaboration with silent collaboration?” To answer this question, the physical arrangement of the students when collaborating must be taken into account. This is because in order for face-to-face collaboration to take place the students must be seated in such a way that they can communicate verbally.

4.2.2 The perceived value of silent collaboration

To analyze the value of silent collaboration, two main elements must be taken into account: (1) the ability to regulate the students’ work and interaction and (2) the students’ social skills.

When working in large groups (such as the whole class), each student has a relative status, which is determined by their academic skills or their social connection to their classmates. This can lead to uneven participation among the members of a group (Webb, 1995). Given this, it is important to have tools that help students regulate the work within a group (Järvelä et al., 2015) and the interaction between peers (Cress et al., 2015). If silent collaboration is implemented well, it allows students to communicate effectively when a fluent conversation is not possible. By doing so, it therefore facilitates regulation of the work within the group, as well as the interaction between students.

In addition to this, silent collaboration also decreases the visibility of the students’ social status as the interaction is mediated by a computer and not directly between

classmates. As an example of this, it has been found that students who are introverted prefer alternative forms of communication to verbal communication, such as social media (Voorn & Kommers, 2013). This is mainly because they feel threatened by face-to-face communication. Furthermore, these students have the perception that this alternative form of communication further facilitates collaborative learning, something which is not observed among more extroverted students (Voorn & Kommers, 2013). It is therefore important to consider the students' collaborative skills in order to measure the possible value of silent collaboration.

The second research question therefore asks: "What is the students' perception of silent collaboration?", as well as "What characterizes the students who use silent collaboration?"

4.3 Methodology

4.3.1 Experimental design

The study was conducted in a voucher school in Santiago, Chile with two 4th grade classes (students aged between 9 and 10). In order to answer the first research question: "What are the benefits for students of complementing face-to-face collaboration with silent collaboration?", the students from the two classes were organized into groups that were arranged in different room configurations (Figure 4-1). In one class, the Distant groups, the students are seated in such a way that they had to rely on silent collaboration (Figure 4-1 (a)). In the other class, the Adjacent groups, the students in a group were seated next to one another (Figure 4-1 (b)), which allows for both face-to-face communication as well as silent collaboration. Table 4-1 shows the distribution of the students in each of the groups.

Table 4-1: Sample size of the Distant and Adjacent groups

<i>Group</i>	<i>N</i>	<i>Girls</i>	<i>Boys</i>
Distant	24	10	14
Adjacent	22	9	13
Total	46	19	27

It was decided to work with 4th grade students as this is when abstract concepts that are introduced in 3rd grade are covered in greater depth (MINEDUC, 2014). The concept chosen for this study was fractions; specifically writing, representing and categorizing fractions. These topics were chosen as they are difficult to learn (Siegler et al., 2013) and are required by the curriculum (MINEDUC, 2014).

In order to meet this curricular objective, the school had planned to use 9 regular sessions with the students. However, it was decided to use only 7 sessions for the study so as to give the teacher two sessions at the end of the study to review the topics that were covered. The 7 sessions using the software correspond to a month of mathematics classes for the school.

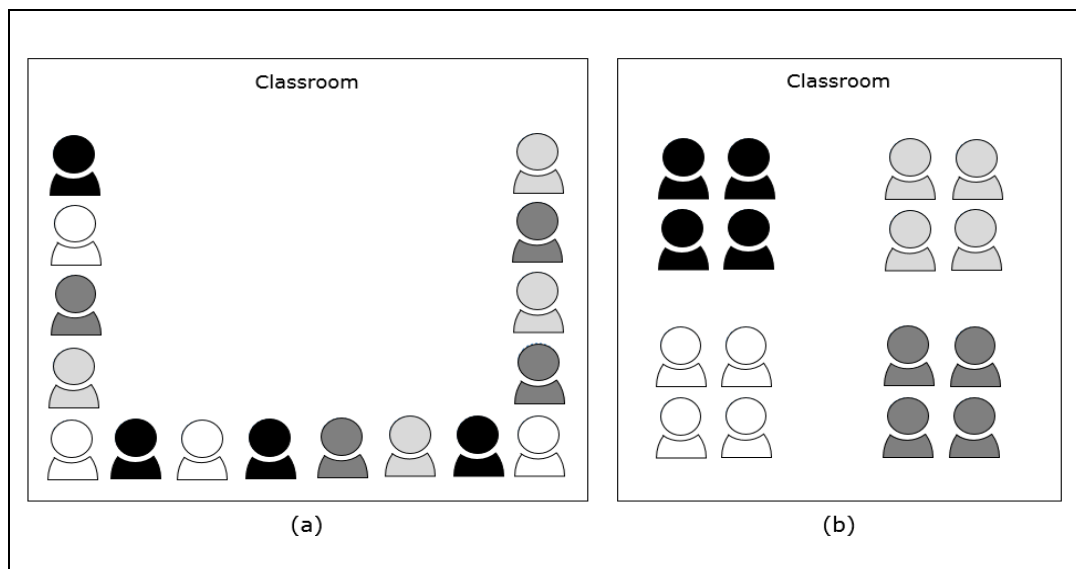


Figure 4-1: Classroom distribution for the Distant and Adjacent groups. The different colors represent the different groups.

Additionally, the classes for both groups were orchestrated (Dillenbourg et al., 2011; Nussbaum et al., 2011). The aim of this was to guide the teachers so that they successfully incorporated the technology, interactive instruction and collaboration into the classroom. The orchestrations were created and discussed with the teachers three weeks before the study started. By means of example, Annex A includes the orchestration for one of the sessions.

4.3.2 Methodology used

Both classes were taught using the interactive instruction methodology, as used in Caballero et al. (2014). In order to do so, a software was developed that was similar to the one used in Caballero et al. (2014), but based on the topic of fractions.

Interactive instruction allows the teacher to work together with the students in developing the topics that are to be studied. Following this, the students then work collaboratively on what they have been taught.

When they are working, the shared screen is divided into four areas, where a group of 4 students complete the activities that are presented. Figure 4-2 (a) shows an example of the system's interface displayed on the screen in the classroom. Figure 4-2 (b) shows the physical layout of a group of Adjacent students. Figure 4-2 (a) shows the four work spaces, belonging to four different groups of students. Each group has a work space, which includes: (1) specific instructions for the exercise, (2) an element of feedback (an emoticon that turns into a smiley face when the group has correctly completed an exercise), and (3) identifiers for each member of the group (droplet, rhombus, square and circle). In this example, the students have to identify the fraction that is represented by the picture. Additionally, the software also provides exercises on building fractions, ordering fractions from least to greatest, classifying fractions and associating fractions, among others (see Table 4-2).

Table 4-2: Activities included in the software

<i>Activity</i>	<i>Actions required by the students</i>
Identifying	The students must choose one or more of the fractions that represent a given fraction, whether it be a picture, symbol or an actual fraction.
Classifying	The students must classify different fractions, depending on whether they are greater than, less than or equal to one.

Buidling sequences	The students must order four fractions from least to greatest, or vice versa. Each student is assigned a fraction, which they must put in the right place so that they are all in order.
Completing sequences	The students must complete the sequence which allows them to write a fraction. Each student is assigned a word which allows them to complete the sequence: numerator – denominator – writing (e.g. “1”. “2”, “one”, “half”).
Associating a single fraction	Given a fraction, the students must associate it with an equivalent fraction (e.g. $1/2$ with $2/4$).
Associating multiple fractions	The students must associate all of the equivalent fractions with a given fraction (e.g. $1/3$ with $2/6$ and $3/9$).
Buidling fractions	The students must place their cursor within a picture so as to color the picture in and create a representation of a fraction.

Each of the groups, which take up a quarter of the screen (Figure 2a), work on one of four exercises that are presented in such a way that each group works on a different exercise.

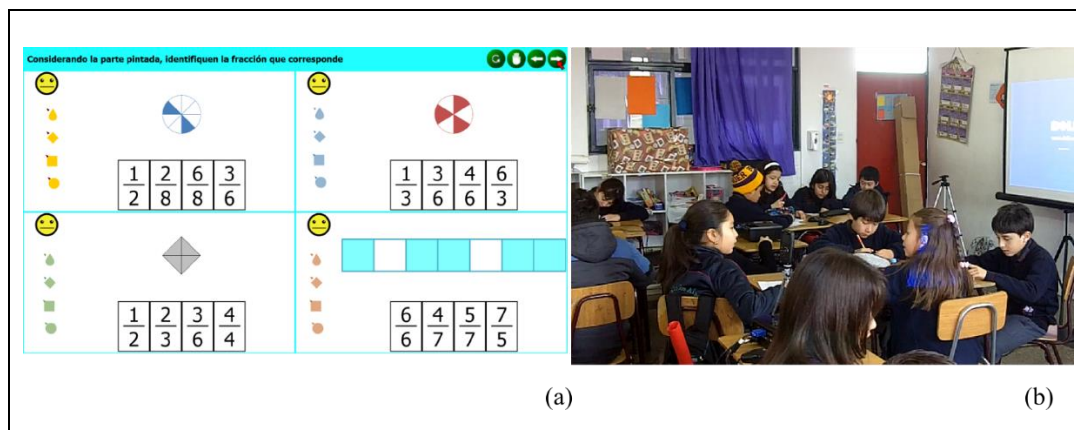


Figure 4-2: (a) System interface when working on a group activity. (b) A group from the Adjacent class.

In order to analyze the benefits of complementing face-to-face collaboration with silent collaboration, both groups used the same topics, exercises, software and orchestrations. By doing so, the variable that was studied was the room configuration (i.e. the physical arrangement of the students).

Both classes completed the same activities and the interaction between students depends on the problem to be solved (Cohen, 1994; Webb, 1995). The analysis of silent collaboration did not take into consideration all of the activities that were completed by the students; instead only a sub-set of activities with a shared structure was considered. The activities that were selected had a single solution and the students' roles were not defined. This type of activity was chosen as it requires the students to agree on the actions that must be taken by each in order to meet the objective. In total, 41 activities were analyzed for the Adjacent group and 57 for the Distant group (Table 4-3).

Table 4-3: Summary of the number of groups analyzed for each activity.

<i>Type of Activity</i>	<i>Number of Groups</i>	
	Adjacent	Distant
Building fractions	14	16
Identifying fractions	17	25
Completing sequences (number lines, order)	4	6
Associating multiple fractions with an equivalent	3	5
Associating a single fraction with an equivalent	3	5
Total	41	57

4.3.3 Instruments used

Three instruments were designed to test the students' learning and skills. The first of these was a theory test, which contained questions about fractions. The test featured 32 questions, divided into open questions and multiple choice questions. The topics covered by these questions include representing, ordering, classifying and writing fractions. The confidence levels for this test (Cronbach's alpha) were 0.52 for the pre-test and 0.77 for the post-test.

Two questionnaires using Likert scale questions were conducted in order to answer the first and second research questions. The aim of these questionnaires was to measure the students' collaborative skills and they were administered at the end of the study, i.e. at the end of the seventh session. The first questionnaire was a self-

appraisal for the students, while the second was for the teachers to give their impression of their students' collaborative skills.

Both questionnaires look to establish the students' levels of communication skills and their team orientation. The skills that the students perceive as being important are help-related (e.g. asking for help, giving help) and communication-related. They also believe it is important for the other students in their group to provide social/emotional support (Ladd et al., 2013). Furthermore, it is essential for the groups to have Team Orientation (Dickinson & McIntyre, 1997; Salas et al., 2005). Team Orientation refers to the students' attitudes and how they coordinate with one another; it is related to accepting rules. The statements used in the two questionnaires and their respective identification codes are included in Tables 4-4 and 4-5, respectively.

Table 4-4: Questionnaire of collaborative skills, as reported by the students

<i>Code</i>	<i>Statement</i>
S1	When I work with my classmates, we all express our ideas
S2	When I have an idea, I like to share it with my friends
S3	I like to work with my classmates, even if they aren't my friends
S4	No one classmate is more important than the others in a group
S5	I enjoy learning more when I'm with my classmates than when I'm on my own

Table 4-5: Questionnaire of collaborative skills, as reported by the teachers

<i>Code</i>	<i>Afirmación</i>
T1	The student is able to express their ideas
T2	The student is capable of sharing their ideas with their classmates
T3	The student works well with their classmates, even if they're not friends

T4	The student is capable of listening to their classmates' opinions
T5	When they work in a group, the student respects their classmates' opinions
T6	The student prefers working in a group to working alone

Finally, to be able to quantify the value that the students assign silent collaboration versus verbal communication (the second research question), the students were asked two additional questions at the end of the study (i.e. the seventh session). The aim of these questions was to understand the students' perception of the level of conversation and agreements that were reached (Table 4-6). These questions were also answered using a Likert scale.

Table 4-6: Questions regarding the students' perception of how fun the sessions were, the level of conversation during the sessions and agreements that were reached.

<i>Code</i>	<i>Statement</i>
C1	During the group work, we talked about the things we found hard
C2	When we worked on a task as a group it was easy to reach an agreement

4.3.4 Quantitative analysis

To answer the first research question, which looks to examine whether or not it is beneficial for students to complement face-to-face collaboration with spoken collaboration, the academic benefits were analyzed. The scores achieved on the tests by the two groups were compared in order to ascertain whether or not there were any

academic benefits. In order to do so, the pre-test scores were first analyzed to see whether the two classes were comparable, i.e. whether they had similar means and variance. Secondly, the students' scores on the post-test were analyzed to see if there were any differences within each class with regards to the skills described in Tables 4-3 and 4-4. The aim of this was to discover whether students who do not possess collaborative skills benefit from complementing face-to-face collaboration with silent collaboration. In order to do so, an ANOVA was conducted, using collaborative skills as the independent variable and academic performance as the dependent variable. In this case, collaborative skills are measured discretely using a Likert scale, allowing this variable to be used as a three-level factor.

The analysis associated with the second research question, which looks to determine the students' perception of silent collaboration, used the questions included in Table 4-5. These questions aim to assess whether the students consider silent collaboration to be seen as an effective tool for communicating. Finally, to analyze which students use silent collaboration, the number of silent interaction patterns employed by each student was counted. This could then be correlated with the different answers given to the questions in Tables 4-4 and 4-5. The aim of this is to characterize the students who use silent collaboration in terms of their social skills.

4.3.5 Gathering audiovisual data

In order to analyze silent collaboration, 7 cameras were used to record each session. In the class with the Adjacent groups, 5 cameras were pointed at the different groups so as to provide confirmation of the configuration of these groups, while the other 2 cameras recorded what was happening on the screen. The same number of cameras

was used to record the students in general in the class with the Distant groups. In this case, however, no attention was paid to which groups each student belonged to. The same 2 cameras were also used to record what was happening on the screen. In this case, in order to have a record of the configuration of the groups and to identify each student within their respective group, each student had to write their color and symbol on a sheet of paper so as to identify their on-screen actions.

The video recordings of the screens was used to conduct an analysis of the groups' silent interaction patterns, as was done in Caballero et al. (2014). This analysis consisted of coding each student's actions and observing the group's behavior in response to that action. Doing so allows the students' intentions to be identified and interpreted, which is then translated into silent interaction patterns. In order to do this, the number of silent interaction patterns per activity was calculated (i.e. the total number of silent interaction patterns was divided by the total number of activities included in the calculation). Following this, the correlation between the social skills reported by the students and the silent interaction patterns used by each student was calculated.

4.4 Results

4.4.1 Learning and social skills – first research question

Table 4-7 reveals that significant learning took place in both the class with the Distant groups, as well as the class with the Adjacent groups (only students who took both the pre- and post-tests were considered). To corroborate whether or not the Learning Gain can be considered as the difference between the pre-test and post-test scores,

Levene's test was used to test the homogeneity of variance and a t-test was used to test the difference between the means. The first test reveals that homogeneity can be assumed for the variance between the pre-test scores for each group ($L = 0.04$, $p = 0.84$), while the result of the t-test confirms that there is no difference between the means for both groups: $t(34.25) = 0.81$, $p = 0.41$.

Table 4-7: Summary of the pre-test and post-test results for the experimental and control groups

<i>Group</i>	<i>N</i>	<i>Pre</i>		<i>Post</i>		<i>Learning Gain</i>
		Mean	SD	Mean	SD	
Adjacent	20	14.5	3.72	19.30	5.16	4.8 ($p = 0.0018$)
Distant	18	13.4	4.18	19.61	5.52	6.16($p = 0.0006$)

The Distant groups increased their scores more than the Adjacent groups, although an ANOVA reveals that the difference is not significant ($F(1,36) = 1.16$, $p = 0.29$). In other words, there is no statistical difference between face-to-face collaboration complemented with silent collaboration and silent collaboration on its own.

Analyzing this in further detail, Table 4-8 reveals the results of an ANOVA that is explained in the methodology section above, allowing the first research question to be answered. This ANOVA takes the post-test score as the dependent variable and the response to statement S5 ("I enjoy learning more when I'm with my classmates than when I'm on my own") as the independent variable. There is a difference in both groups between the post-scores of students who like to work in a group (answered statement S5 with "Agree") and those who do not (answered statement S5 with "Disagree"). This difference is significant in the class with the Adjacent groups, but not for the class with the Distant groups. In other words, students who report enjoying

group work tend to perform better than their classmates who do not like to work collaboratively. This is especially true when the seating arrangement allows the groups to collaborate face-to-face, complemented by silent collaboration.

Table 4-8: Differences in performance on the post-test according to the students' response to statement S5 ("I enjoy learning more when I'm with my classmates than when I'm on my own")

<i>Group</i>	<i>Agree</i>		<i>Disagree</i>		<i>Difference</i>	<i>F and p value</i>
	N	Post-test	N	Post-test		
Adjacent	15	20.47	4	14.75	5.72	F (1,17) = 4.35, p = 0.05
Distant	9	21.3	5	16.2	5.1	F (1,12) = 3.7, p = 0.08

This therefore shows that face-to-face collaboration complemented with silent collaboration is mostly beneficial for students who like to work in groups. This is not the case for students who say they do not enjoy group work and prefer to learn on their own.

4.4.2 Collaborative work in class – second research question

To answer the second research question, which is based on studying the students' perception of silent collaboration, the questions regarding the level of conversation and the agreements that were reached were analyzed.

Perception of silent collaboration

To answer the second research question: "What is the students' perception of silent collaboration?", the level of negotiation and the agreements reached by the students was considered to be particularly important to the collaborative process (Dillenbourg et al., 1996; Webb, 1995). In the class with the Adjacent groups, the room

configuration allowed the students to have discussions and reach a consensus, mainly by themselves. In the class with the Distant groups, however, conversations were not as fluent and it was therefore harder to reach a consensus. There is a general consensus among students in both groups that they talked about the problems they found hard (Table 4-9). Although the students in the Distant groups could not speak directly with one another, they still perceive that they did indeed talk about the problems they found to be hard. This might be explained by the fact that the teacher played the role of mediator and helped students resolve their problems by speaking to the group out loud.

Table 4-9: Descriptive statistics for answers referring to the level of conversation regarding the problems the students found hard

<i>Group</i>	<i>C1: During the group work, we talked about the things we found hard</i>		
	Agree	Indifferent	Disagree
Adjacent	15 (75%)	4 (20%)	1 (5%)
Distant	14 (77.78%)	3 (16.67%)	1 (5.55%)

Table 4-10: Descriptive statistics for how easy it was to reach an agreement

<i>Group</i>	<i>C2: When we worked on a task as a group it was easy to reach an agreement</i>			
	Agree	Indifferent	Disagree	No answer
Adjacent	11 (55%)	6 (30%)	2 (10%)	1 (5%)
Distant	11 (61.11%)	4 (22.22%)	2 (11.11%)	1 (5.56%)

Finally, with regards to how easy it was to reach an agreement (Table 4-10), and albeit counter-intuitive, it can be seen that the students in the Adjacent groups found it was more difficult to work as a group than in the Distant groups. This may be because it was harder to reach a consensus in the Adjacent groups due to difficulties in the

communication between students. This allows the conclusion to be drawn that students perceive silent collaboration to be a tool that allows them to communicate and reach agreements, which answers the first part of the second research question.

Silent interaction patterns: who uses them?

The second research question also looks to categorize students who use silent collaboration. The analysis of silent collaboration was conducted in a similar way to the analysis described in Caballero et al. (2014). The summary of all of the silent interaction patterns found during the coding is included in Table 4-11.

Table 4-11: Number of silent interaction patterns that were observed and coded.

<i>Pattern</i>	<i>Description</i>	<i>Type</i>	<i>Number of Patterns</i>	
			<i>Adjacent</i>	<i>Distant</i>
NC1	A child moves the mouse violently or away from from response area	Non-collaborative	230	405
NC2	A child tries different solutions in order to change the feedback from the system until finding the correct answer	Non-collaborative	79	109
NC3	A child copies without it being effective collaboration: (a) they copy an incorrect answer or (b) they copy a correct answer but there are still other correct answers to be identified	Non-collaborative	31	58
NCT	The total number of non-collaborative patterns used by a student (NC1 + NC2 + NC3)	Non-collaborative	340	572
C1	A student indicates the correct answer on the screen	Collaborative	45	135
C2	A student indicates to another group member that they are in the wrong place (or that they	Collaborative	6	15

	are not participating) until they move			
C3	A student first catches a fellow group member's attention (C2) and then shows them the correct answer on the screen (C1)	Collaborative	15	24
C4	A student moves towards the message on screen and emphasizes part of this in order to highlight the objective of the exercise	Collaborative	3	6
CT	The total number of collaborative patterns used by a student (C1 + C2 + C3 + C4)	Collaborative	69	180

As mentioned in the methodology section, in order to characterize the students who use silent collaboration as a tool, an analysis is conducted to see whether changing the room configuration (i.e. physical arrangement of the students) affects the number of collaborative patterns used by the students. By studying the total number of non-collaborative patterns (NCT) for both groups, it can be seen that there is no significant difference between the two ($t(77.38) = -1.05$, $p = 0.29$). However, there is a significant difference ($t(95.22) = -3.00$, $p = 0.003$) between the number of collaborative patterns (CT). On average, the Adjacent groups display 1.68 collaborative patterns per activity, while the Distant groups display 3.16 collaborative patterns per activity. This shows that seating group members next to one another does not favor silent collaboration. In turn, this allows the conclusion to be drawn that when students in the Adjacent groups use face-to-face collaboration complemented by silent collaboration, they rely less on silent collaboration.

The correlations between each of the questions regarding social skills and the number of silent interaction patterns (collaborative and non-collaborative) employed by each student can be found in Annex 4-C. The findings reveal that the significant correlations between silent interaction patterns and responses regarding social skills are negative. This means that the stronger the social skills that are reported, the less students rely on silent interaction patterns.

The questionnaire items that reveal significant, negative correlations in both groups include statement S1: “When I work with my classmates, we all express our ideas” with collaborative pattern C1: indicating the correct answer: $r(18) = -0.49, p = 0.03$ and $r(16) = -0.52, p = 0.03$ for the Adjacent Groups and Distant Groups, respectively. This is also the case for statement T1: “The student is able to express their ideas” with collaborative pattern C1: indicating the correct the answer and the total number of collaborative patterns (CT). Statement T1 has stronger (and more significant) correlations with collaborative pattern C1 in the Adjacent groups ($r(18) = -0.75, p < 0.001$) than in the Distant groups ($r(16) = -0.50, p = 0.03$). This is also the case for the correlation between statement T1 and the total number of collaborative patterns (CT): ($r(18) = -0.70, p < 0.001$) for the Adjacent groups and ($r(16) = -0.48, p = 0.043$) for the Distant groups. Both of these statements (S1 and T1) are associated with expressing ideas and having strong communication skills.

It is interesting to note that in the Adjacent groups, there is a strong and significant correlation between statement S5: “I enjoy learning more when I’m with my classmates than when I’m on my own” and the total number of non-collaborative patterns (NCT) ($r(18) = -0.76, p < 0.001$). In other words, the more a student enjoys

working in a group, the less they use non-collaborative patterns. This is not the case in the Distant groups. In this case, silent collaboration is used to effectively collaborate when the students are sat far away from one another.

4.5 Discussion

The results show that the academic results in a classroom with face-to-face collaboration that is complemented with silent collaboration will not necessarily be better than in a classroom where the students can only collaborate silently ($p = 0.29$). Furthermore, room configurations that oblige students to work face-to-face (Adjacent groups) have a negative impact on student performance for students who do not like to work in groups. In this case, the difference between the performance by these students and students who do like to work in groups is significant ($p = 0.05$). This is not the case in the Distant groups, where students do not necessarily have to work or communicate with each other face-to-face.

This supports the proposals put forward on how the process should be for teaching students to collaborate, where the students must experience interactions and processes that are typical of teamwork (Cortez, Nussbaum, Woywood, & Aravena, 2009). Although a process of “learning by doing” (Monteiro & Morrison, 2014) is important, it is important to stress that there must be a balance between prior knowledge and the students’ social skills (Nokes-Malach, Meade, & Morrow, 2012). Students cannot be forced to work collaboratively if they have not developed the necessary skills. Given this, the teacher should initially provide more structure and, as the students start to feel more comfortable with these skills, gradually have them

face less structured situations with less monitoring by the teacher (McWhaw, Schnackenberg, Sclater, & Abrami, 2003), which includes communicative interaction.

We conclude that silent collaboration can decrease the unevenness of student participation within a group, providing them the opportunity to work collaboratively without it impacting negatively on them learning about teamwork.

Secondly, the results show that students perceive silent collaboration as being a tool that allows complex problems to be communicated and discussed. There is a real consensus of this, even among students who were not able to communicate verbally (face-to-face). In this group, the role of the teacher is to mediate on points that were especially conflictive for the students. This could therefore be what led the students to perceive that there was a high level of conversation about difficult problems and that it was easy to reach an agreement. In this sense, both the silent collaboration as well as the teacher's role as a mediator may have helped the students to perceive that there was cohesion between group members and that it was possible to talk about problems that were especially difficult for them.

Furthermore, the correlations between silent interaction patterns and the answers to the questionnaires regarding social skills are negative. This means the fewer social skills a student is reported to have, the more they rely on silent interaction patterns. This allows us to conclude that silent collaboration is a tool that facilitates the collaborative process for students who do not have well developed social skills.

Finally, it is interesting to note that in the Adjacent groups, the more a student likes to work in groups, the less they use non-collaborative interaction patterns. This is not

the case for the Distant group. This suggests that silent collaboration is used to achieve effective collaboration (through collaborative interaction patterns) when students are sat far away from one another.

4.6 Conclusions

The question that this study looks to answer is: “For which students and when is it beneficial to use silent collaboration?” This is answered by two research questions: (i) “What are the benefits for students of complementing face-to-face collaboration with silent collaboration?” and (ii) “What is the students’ perception of silent collaboration?”, as well as “What characterizes the students who use silent collaboration?” These questions are answered through a study of 4th grade students, who spent a month using a software that allowed for silent collaboration in order to study fractions. These students were seated in two different configurations (Adjacent and Distant).

The first research question asked: “What are the benefits for students of complementing face-to-face collaboration with silent collaboration?” The results show that when students work using face-to-face collaboration complemented with silent collaboration, the academic results are not always favorable. Students who do not like working in groups performed worse on the post-test than students who do like to work in groups (significant difference). Furthermore, the mere fact of having both forms of collaboration (face-to-face with silent) does not produce any significant benefits when compared with silent collaboration on its own.

The second research question that this study looked to answer was: “What is the students’ perception of silent collaboration?”, as well as “What characterizes the students who use silent collaboration?” Firstly, there was a strong consensus in both groups that they were able to talk about difficult problems and that it was relatively easy to reach an agreement. Silent collaboration allows students to feel that as a tool it allows them to collaborate and communicate effectively. Secondly, the correlations between the silent interaction patterns and the answers to the questionnaires regarding social skills were negative. In other words, the less a student likes working with other classmates, the more they rely on silent collaboration. This might help students who do not have well developed teamwork skills or who are still acquiring these skills.

The limitations of the study are mainly linked to the number of students and the length of the study. One element that causes problems for this sort of limitation is the fact that in order to be considered in the final analysis, the students had to have attended the whole program. For example, on several occasions groups of three students had to be formed, but these groups could not be considered in the analysis as the level of coordination required for a group of three is different than for a group of four. This is very much an exploratory study, but it would be interesting to have more time so as not to have to rely on students attending the whole program. Although the sample size is small, the length of the study is representative of what a teacher would plan in reality. In this case, the study was conducted in the same classes that the students would have studied fractions without using technology.

It remains as future work to see how effective silent collaboration is for teaching how to collaborate. One future study would be to have a group that is trained throughout

the year in using silent collaboration and not forcing the students to sit next to the other members of their group. Subsequently, the behavior of these students when they are sat next to one another could be observed. The aim of this would be to see whether their social skills improved and whether the academic performance of students who do not like working in groups is affected. With this, silent collaboration could be used as a concrete tool for teaching students how to collaborate and therefore lower the effects of the unevenness of student participation, which is inherent among groups of students in the classroom.

4.7 Annex 4-A: Planning for Session 2: Fractions in everyday life and reading and writing fractions

Objective: To continue with the concept of fractions and how they are represented.
Learning how to read and write fractions is also introduced.

Topic	Instructions for the teacher	Type of activity	Instructions	Set of exercises
Mental Maths	Start the class by practicing Mental Maths (Approximately 20 minutes)	Individual Mental Maths problems	Ask the students to complete the Mental Maths exercises	
Introduction to the collaborative system	Explain to the students how to identify themselves on the screen, as well as the group and collaborative work	Activity for familiarizing the students with the Mouse	Move your cursors to wherever your icon is	
Fractions in everyday life	Explain that fractions can be found in everyday life. Show an example and ask the students to give other examples			
	Show a slide in PowerPoint	Concrete examples of fractions are shown, as well as their concrete representations. Slides D3 and D4		
	Ask the students to represent a fraction based on a concrete situation	Collaborative identification of different fractions using Activity 3	Identify which fraction represents a real-life situation (e.g. Hugo ate some pizza. What fraction of the pizza did he eat?)	Complete at least 4 exercises from N° 3
Reading and writing fractions	Mention that the fractions that have been represented are given a specific name			
	Show a slide in PowerPoint	Examples are given of certain fractions, such as “one third, three quarters, etc.” Slide D5		
	Ask the students to represent the fractions that they asked to	Collaboratively building different	Construct a picture of a fraction based on a written fraction (e.g. draw a picture	Complete at least 4 exercises from N°4

		fractions using Activity 4	to represent three eighths)	
	Ask the students to write the fractions that they are asked to	Filling out a table by writing the corresponding fractions	Fill out a table so as to successfully write different fractions (e.g. Three quarters = $\frac{3}{4}$)	Complete at least 4 exercises from N°5

4.8 Annex 4-B: Correlations between the items on the questionnaire and post-test score

Table 4-12: Correlation between the items on the questionnaire regarding social skills and the post-test score for the Adjacent group and Distant group

<i>Statement</i>	<i>Post-test score</i>	
	Adjacent	Distant
S1: When I work with my classmates, we all express our ideas	0.06	-0.06
S2: When I have an idea, I like to share it with my friends	0.02	0.33
S3: I like to work with my classmates, even if they aren't my friends	-0.14	-0.46 (.)
S4: No classmate is more important than the others in a group	0.4 (.)	0.21
S5: I enjoy learning more when I'm with my classmates than when I'm on my own	0.44 (.)	0.39
T1: The student is able to express their ideas	0.12	0.24
T2: The student is capable of sharing their ideas with their classmates	0.28	NA
T3: The student works well with their classmates, even if they're not friends	0.002	0.12
T4: The student is capable of listening to their classmates' opinions	0.35	NA
T5: When they work in a group, the student respects their classmates' opinions	0.25	0.32
T6: The student prefers working in a group to working alone	-0.11	0.21

. $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4-13: Correlation between the items on the questionnaire regarding social skills and the post-test score for the Adjacent Group and Distant Group

<i>Statement</i>	<i>Post-test score</i>	
	Adjacent	Adjacent
S1: When I work with my classmates, we all express our ideas	-0.21	0
S2: When I have an idea, I like to share it with my friends	-0.05	0.22
S3: I like to work with my classmates, even if they aren't my friends	-0.13	-0.29
S4: No classmate is more important than the others in a group	0.29	0.28
S5: I enjoy learning more when I'm with my classmates than when I'm on my own	0.41 (.)	0.44 (.)
T1: The student is able to express their ideas	0.15	0.19
T2: The student is capable of sharing their ideas with their classmates	0.19	NA
T3: The student works well with their classmates, even if they're not friends	-0.04	-0.06
T4: The student is capable of listening to their classmates' opinions	0.22	NA
T5: When they work in a group, the student respects their classmates' opinions	0.15	0.20
T6: The student prefers working in a group to working alone	0.17	0.07

. $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.9 Annex 4-C: Summary of the correlations between silent collaboration and the answers questionnaire

Table 4-14: Summary of the correlations between silent interaction patterns and the answers to the questionnaire regarding social skills for the Adjacent group

	<i>NC1</i>	<i>NC2</i>	<i>NC3</i>	<i>CI</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>NCT</i>	<i>CT</i>
S1	-0.15	0.30	-0.04	-0.49*	0.17	-0.68***	0.12	0.04	-0.48*
S2	0.12	-0.01	0.38	-0.43	0.19	-0.38	0.14	0.16	-0.36
S3	-0.18	0.23	0.15	-0.61**	0.15	-0.68***	0.11	0.02	-0.55*
S4	-0.15	-0.34	-0.06	0.09	-0.24	-0.04	0.16	-0.33	0.08
S5	-0.53*	-0.60**	0.14	0.10	-0.35	0.28	-0.16	-0.76***	0.06
T1	0.13	0.04	0.29	-0.75***	0.10	-0.60**	0.07	0.18	-0.70***
T2	0.20	-0.39	0.11	-0.29	-0.25	-0.16	0.15	-0.05	-0.29
T3	-0.04	0.12	-0.24	-0.02	-0.11	-0.17	-0.35	0.00	-0.10
T4	0.11	0.26	-0.27	0.04	-0.24	0.07	-0.03	0.20	-0.03
T5	0.10	0.20	-0.21	0.01	-0.25	-0.01	-0.10	0.17	-0.07
T6	0.28	-0.12	-0.04	-0.27	0.17	-0.49*	-0.32	0.15	-0.34

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4-15: Summary of the correlations between silent interaction patterns and the answers to the questionnaire regarding social skills for the Distant group

	<i>NC1</i>	<i>NC2</i>	<i>NC3</i>	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>NCT</i>	<i>CT</i>
S1	-0.33	-0.14	-0.11	-0.52*	-0.32	-0.05	-0.30	-0.31	-0.45
S2	0.06	0.37	-0.11	-0.21	-0.14	0.20	0.02	0.12	-0.12
S3	0.24	-0.37	-0.08	0.10	0.24	0.38	0.02	0.07	0.20
S4	0.21	-0.13	0.18	0.29	0.19	-0.03	0.33	0.17	0.25
S5	-0.19	-0.18	0.12	-0.12	-0.12	-0.26	0.01	-0.17	-0.16
T1	-0.43	0.20	-0.23	-0.50*	-0.60**	-0.08	-0.13	-0.33	-0.48*
T2	NA	NA	NA	NA	NA	NA	NA	NA	NA
T3	-0.06	-0.10	0.11	0.01	-0.05	-0.52*	0.07	-0.05	-0.11
T4	NA	NA	NA	NA	NA	NA	NA	NA	NA
T5	-0.12	0.10	0.13	-0.12	-0.19	-0.45	0.09	-0.04	-0.21
T6	-0.27	0.27	0.17	-0.08	-0.02	-0.19	0.10	-0.11	-0.09

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.00$

5. CONCLUSIONS AND FUTURE WORK

The general aim of this thesis is to study how, in concrete terms, interactive instruction can be integrated into the classroom using SDG technology and open collaborative interaction patterns that allow the students to spontaneously use silent collaboration. In order to do so, the elements that differentiate between cooperation and collaboration were first studied and then characterized. In this sense, it was revealed that collaboration involves more interaction than cooperation. Secondly, a study was conducted of how to integrate interactive instruction with collaborative learning into the classroom using SDG.

The outcome of the research conducted in this thesis is a model that allows cooperative and collaborative activities to be created, using varying Degrees of Dependency. This model was validated in settings where it was used by both teachers and students. According to the teachers, this model is a tool that is quite easy to use, as well as being a useful addition to the teacher toolkit. Furthermore, the model sets out a continuum between cooperative and collaborative activities, with collaborative activities leading to different behaviour than cooperative activities. An example of this is related to the total amount of dialogue and coordination between students, as well as the emergence of more distributed leadership.

Secondly, the effectiveness of SDG technology was demonstrated in terms of learning when integrated into the classroom through interactive instruction and collaborative learning. Student behaviour when following the methodology was studied, which allowed situations in which silent collaboration could be beneficial for students to be identified. In this case, silent collaboration could act as a link for

teaching collaboration, as students who are not geared towards group work tend to rely more on silent collaboration.

Furthermore, it was shown that it is possible to integrate all of the actors that are present in a CSCL environment: teacher, students and technology. In order to do so, a piece of software using SDG technology (which allows interactive instruction and collaborative learning) and an instrument such as Orchestration boosted the effectiveness of this methodology.

In terms of Design-Based Research, this thesis demonstrates how this methodology allows for research to be conducted in education using technology. In this sense, both the model for creating cooperative and collaborative activities, as well as the software, were included in the iterative design process suggested by this methodology. In terms of the software, this methodology is coherent with software development methods, where an iterative process delivers a piece of software that meets the requirements of its end users as a final product, such as requirements regarding physical space (e.g. size of the classroom) and the design of the interface so that that software can be used effectively by the teachers and students. This methodology raised some lessons learnt that are shown below in the subsection 5.2.

5.1 Research limitations

This thesis sets out various findings, including the fact that SDG is an effective model that helps teachers design cooperative and collaborative activities as part of a collaborative environment. However, as with any research that involves human beings, there was a series of issues throughout this research project that could not be controlled. This lead to various limitations, which are detailed below:

- a) The length of the studies: all of the studies were conducted in schools that were committed to the research and to the scheduling of the studies. However, it was not possible in any of the schools to carry out projects for longer than a month. It remains as future work to conduct a longitudinal study, where the students' learning and behaviour can be observed over a long period of time.
- b) Limited age range of the students: the studies were conducted in elementary school (3rd and 4th grade), where the students share a certain level of skill, which is different to the skill level of higher grades.
- c) Small samples: by working directly with schools problems inevitably arise, such as the sample of students in each study. This mainly happens because each sample first depends upon the particular school, and then on the students' attendance.
- d) Content specific to mathematics: other than the model presented in this thesis, where it was shown that it could be applied to language arts, this thesis mainly focuses on teaching mathematics. This is because both geometry (Chapter 3) and fractions (Chapter 4) are difficult topics to learn and results in these areas have been missing in Chile.
- e) Medium-low socioeconomic status: All of the studies were conducted with students from state schools or state-subsidized schools. This means that there is an economic bias to this thesis, where the results may or may not be replicated in other contexts, depending on the participating students' socioeconomic status.
- f) Technology and specific teaching methodology: The evidence included in this thesis is specific to SDG, and there may therefore be different levels of applicability and adoptability with other technologies, such as the case described in

Annex B, which shows that different situations arise when using technologies other than SDG and interactive instruction.

5.2 Lessons learnt

As mentioned before, the complexity of the phenomena that were studied ensures that Design-Based Research requires a lot of time for development: both in order to conduct studies as well as for future interventions and improvements. Here a list of recommendations based on the experience of using DBR methodology in an educational field:

- a) Teachers should be heavily compromised with both the technology and collaborative learning. It is important that teachers believe the technology can be used afterwards even the experiment has ended. Also, they should think that collaborative learning does not mean work together, and they should be aware of different interactions between students that arise when working collaboratively.
- b) Teachers should understand beforehand the importance of pre and post test. Even though it is important for them learning gains, they should not teach any content before the experiment starts. Otherwise conclusions regarding the effect of the treatment cannot be validated statistically.
- c) As users of the software developed, teachers should have several meetings to play with the software, suggest different activities, and recommend changes. When teaching with the software, they should be comfortable and not frightened with the technology

d) Both the school's principal and teachers should feel they are involved in an experiments that bring benefits to them and does not change drastically their schedule. It is highly recommend use their own materials and bring them into the experiment, such as exercise guides, books and powerpoint presentations.

Finally, certain elements were left pending by this thesis. These elements are left as future work and detailed below.

5.3 Future work

Future work remains for both the model for creating cooperative and collaborative activities, as well as for the analysis of silent collaboration as an effective gateway to teaching collaboration. With regards to the model for creating collaborative and cooperative activities, its applicability for different teachers still needs to be validated. The workshop that was organized in order to validate the model was held for teachers that are used to participating in training. It would therefore be important to run the same workshop for more teachers, and not just high school teachers, so as to observe whether other teachers value the model as highly. As well as increasing the number of teachers and grade levels that they teach, it would also be interesting to look into how applicable this model is in subjects other than mathematics and language arts. It would also be interesting to observe how teachers that teach subjects other than mathematics and language arts transfer this model to these subjects.

Secondly, it would be interesting to carry out a larger-scale study with more students so as to be able to generalize the results presented in this thesis. Although a large

number of activities were carried out, these were only done with a limited number of students, which compromised the number of groups. It is important to conduct similar studies with more students (from different grade levels) so as to observe their behaviour with different applications of the model, as shown in Chapter 2, and therefore observe whether or not the results obtained in said chapter can be replicated. Finally, it remains as though future work to validate sequences of this model, i.e. whether the sequence of Degrees of Dependency (Weak – Medium – Strong) is optimum for students. Different collaborative scripts, such as: (i) Jigsaw (Aronson, Blaney, Stephan, Sikes, & Snapp, 1978), Argue Graph (Dillenbourg, 2002), Concept Grid (Dillenbourg & Jermann, 2007) and Collpad (Nussbaum et al., 2009) have an established sequence that ranges from Zero Dependency activities to activities with greater Degrees of Dependency (Medium or Strong). It remains as future work to verify whether other sequences enhance the students' work. Furthermore, with regards to silent collaboration, it remains as future work to validate its effectiveness as a tool that provides a link to being able to develop collaborative skills. In other words, this means observing through a longitudinal study whether collaborative skills are developed more in a setting where students rely more on silent collaboration than in a setting where they rely on both spoken and silent collaboration.

Secondly, it is interesting to look at whether the results shown in Chapters 3 and 4 can be replicated in other educational settings, such as other subjects or grade levels. This thesis focuses on teaching mathematics and therefore the results may change if applied to other subjects, especially the qualitative results that are reported, such as the silent collaboration interaction patterns. Finally, given that collaborative skills

change as students develop, it would be interesting to observe whether the results of this thesis are replicated in higher grade levels or whether they change depending on the age of the participants.

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A N N E X E S

ANNEX A: REVIEW OF AUGMENTED PAPER SYSTEMS IN EDUCATION: AN ORCHESTRATION PERSPECTIVE

Abstract

Augmented paper has been proposed as a way to integrate more easily ICTs in settings like formal education, where paper has a strong presence. However, despite the multiplicity of educational applications using paper-based computing, their deployment in authentic settings is still marginal. To better understand this gap between research proposals and everyday classroom application, we surveyed the field of augmented paper systems applied to education, using the notion of “classroom orchestration” as a conceptual tool to understand its potential for integration in everyday educational practice. Our review organizes and classifies the affordances of these systems, and reveals that comparatively few studies provide evidence about the learning effects of system usage, or perform evaluations in authentic setting conditions. The analysis of those proposals that have performed authentic evaluations reveals how paper based-systems can accommodate a variety of contextual constraints and pedagogical approaches, but also highlights the need for further longitudinal, in-the-wild studies, and the existence of design tensions that make the conception, implementation and appropriation of this kind of systems still challenging.

Introduction

In spite of the high investments made, information and communication technologies (ICTs) are still not fully integrated in the everyday practice of our classrooms (Cuban, 2001), which are still dominated by other legacy tools like pen and paper. Human-computer interaction (HCI) researchers have long proposed to exploit this ubiquity of paper in our everyday life to better integrate computing into it (Wellner, 1993), through paper-based computing

technologies, also termed “augmented paper” (Mackay & Fayard, 1999). This broad notion includes not only the use of augmented reality (AR) along with paper objects, but also any technology that uses paper artifacts (e.g., documents) as interfaces to the digital world (Kaplan & Jermann, 2010).

Researchers have proposed to apply these technologies to education, under the rationale that paper, so deeply ingrained in educational practices, would provide seamless interaction with digital educational artifacts (e.g., augmented educational books, digital pen note-taking systems). Over the years, advances in computing power, computer vision and other related technologies have made this kind of systems increasingly affordable, to the point that we can see such products for mass market consumption (such as Sony’s Wonderbook™, <http://www.sony.com/pottermore/gb/book-of-spells>). However, even though such systems are now affordable for schools, their deployment in authentic educational settings is virtually non-existent. We cannot help but wonder about the reasons for this gap between research proposals and classroom implementation.

This paper attempts to answer that question by performing a systematic review (Kitchenham & Charters, 2007) of the research proposals that apply paper-based computing systems to education, trying to organize and classify their advantages and constraints. In a second stage of analysis, we identify those proposals that have been evaluated in authentic formal educational contexts, and try to understand what might be the missing link between the variety of research proposals and the lack of actual deployment. To aid us, we use the notion of “classroom orchestration” (Dillenbourg, Järvelä, & Fischer, 2009), which is related to the application of novel technologies in the complex multi-constrained setting of an authentic classroom (as opposed to research done in a lab or other controlled settings) (Roschelle,

Dimitriadis, & Hoppe, 2013). This paper thus concentrates on the available evidence beyond single-user usability analyses (as suggested by previous reviews of the field, Cheng & Tsai, 2013), to the wider circle of how these (paper-based) technological innovations fit in the socio-technical system of a classroom (Dillenbourg et al., 2011).

Paper-based computing

As noted by Sellen and Harper (2002), paper is still around in many of our everyday activities and settings, despite the undeniable advantages of digital media. Our schools and university classrooms are one of the clearest examples of this resilience of paper: it is very difficult to find one where books, notebooks and other paper elements are not used profusely.

Researchers have argued that this resilience is connected to the way paper has been entangled with our practices over centuries (Johnson, Jellinek, Klotz, Rao, & Card, 1993), due to paper's unique affordances: we find it easier to read compared to a screen, it is easy to annotate and organize, cheap, can be drawn on, and it is portable (Sellen & Harper, 2002; Kaplan & Jermann, 2010; Steimle, 2012). The idea of exploiting the affordances of paper in connection with the digital world can be traced back to HCI research in the nineties: Wellner (1993) proposed a hybrid digital/paper desktop environment to leverage the advantages of both digital and physical documents. Around the same time, Johnson et al., (1993) proposed to use our familiarity to handle paper as a way to control computers more easily (using classic paper forms and optical character recognition to control computer tasks, thus effectively creating a "paper user interface").

To “augment” paper, several kinds of technologies are often combined. Input devices include cameras, barcode readers, RFID readers, scanners are used to identify and locate the paper artifacts (e.g, in conjunction with visual markers like barcodes), as well as digital pens (e.g., the Anoto™ technology) that allow the capturing of freeform writing, automatically converting it to a digital equivalent. These systems use the typical range of output devices (screens, projections, sounds and, of course, paper itself through printers). These technologies can be combined in many different ways to implement concrete augmented paper applications, which roughly fit into five basic interface form factors (Steimle, 2012):

- **Augmented Cards and Post-Its:** the paper artifact is treated as a physical token that allows accessing and managing digital resources, which are represented by the (paper) physical objects (e.g., Miura, Sugihara & Kunifuji, 2009).
- **Augmented Books:** the book itself has value independently from the digital resources, although usually includes printed markers to link its contents to additional/complementary media (e.g., Chen & Chao, 2008).
- **Augmented Notebooks:** the notebook, initially empty, synchronizes a paper-based and a digital version of the same resource/contents, allowing free handwriting and sketching (e.g., Lee, Maldonado, & Kim, 2007).
- **Augmented Printed Documents:** often work with a pre-printed document, where users can fill in forms, make annotations or mark parts of the document. These actions are then translated to a digital counterpart (e.g., Kimbell et al., 2005).
- **Augmented Tables, Flipcharts and Whiteboards:** combine paper-based media with interactive tabletop and/or wall displays, allowing a close integration of paper and digital media (e.g., Do-Lenh, 2012).

These paper-based systems have been applied to a wide variety of fields: augmented cartography in tourism, worksheets in museums, desktop office work, workplace meeting applications, collaborative sketching and prototyping, air traffic control, or entertainment and “edutainment” (Choi, 2009; Huang, Hui, Peylo, & Chatzopoulos, 2013; Shaer & Hornecker, 2010; Steimle, 2012). However, in this paper we are especially interested in the application of these systems to education, given that paper is ubiquitous in our schools already. Aside from the fact that paper artifacts are cheap to produce, several authors have noted the intrinsic qualities of paper for educational settings: paper interfaces can be used to integrate computing in schools more seamlessly than mouse, keyboards and screens (Malmborg, Peterson, & Pettersson, 2007); its tangibility and flexibility allow paper to be easily manipulated, carried around, or passed from one student to another (Horn, AlSulaiman, & Koh, 2013; Luff et al., 2007); as a tangible element, paper can help learning spatial skills (Cheng & Tsai, 2013; O’Malley & Fraser, 2004; Schneider, Jermann, Zufferey, & Dillenbourg, 2011), and it can make the activity workflow visible (Dillenbourg et al., 2011). But, before we analyze educational applications of augmented paper, let us look into the notion of “classroom orchestration” and how it can help us understand the educational use and deployment of these technologies in authentic settings.

Classroom orchestration in educational technology research

We are trying to understand why paper computing solutions have not been widely deployed yet in everyday classroom practice. This gap between the variety and number of research proposals and their implementation in everyday classroom practice is actually a common

problem highlighted in educational technology research (e.g., Chan, 2011). Under the label “orchestrating learning”, it has been noted as one of the grand challenges of technology-enhanced learning research (Sutherland & Joubert, 2009).

Dillenbourg et al. (2009) define orchestration as “the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels”. Roschelle et al. (2013) note that orchestration aims at “more meaningful research by acknowledging the complexity and variability of classrooms and the mediating role of the teacher”. Dillenbourg et al.’s (2011) explains orchestration as a change in the focus of attention in the design and study of educational technologies, from individual usability or the study of small-group work, to a wider focus on the usability of educational technologies at a classroom level, including the multiple constraints (time, curriculum, etc.) present in real classrooms. A more complete discussion of the multiple dimensions of this notion can be found elsewhere (Prieto, Holenko-Dlab, Abdulwahed, Gutiérrez, & Balid, 2011; Roschelle et al., 2013; Fischer et al., 2013).

Authors highlight a variety of aspects on what orchestration is and how it should be addressed, with a large amount of overlapping with each other, but also containing marked differences (due to the different research perspectives and educational contexts their authors address). In order to help us analyze existing paper computing systems to explore their orchestration potential, we have tried to find which of these elements are key in defining orchestration, by compiling the most-often appearing elements from previous literature on orchestration. We found eight such elements, some of them marking general agreement among orchestration-related authors, others marking disagreements or tensions that can be

resolved in different ways (as noted by Roschelle et al., 2013). The agreements are mostly about:

- **Pragmatism/Constraints.** Complying with the specific contextual constraints of the (authentic) educational setting is of the utmost importance: lesson time limitations, classroom space constraints, assessment requirements, teacher energy levels, curriculum relevance, discipline constraints, etc. (e.g., Dillenbourg, 2013; Nussbaum & Díaz, 2013; Roschelle et al., 2013). Regardless of the potential of an innovation in the lab, it will never be adopted if it does not comply with these constraints.
- **Empowerment/Control/Management.** Orchestration is largely about the logistics of managing the different learning activities taking place in the classroom at different social levels, using different tools (Prieto et al., 2011; Dillenbourg, 2013). Classroom technologies should empower teachers (and students) in this management, e.g., by making it more efficient (automations), or by letting users control them easily (Cuendet, Bonnard, Do-Lenh, & Dillenbourg., 2013).
- **Visibility/Awareness/Monitoring.** The perceptual processes taking place during enactment are crucial, to know what is happening and how student learning progresses (Dillenbourg, 2013; Looi & Song, 2013; Balaam, 2013). Technological systems for the classroom should facilitate such perceptual processes, e.g., by supporting visibility of the learning activities, or their assessment.
- **Flexibility/Adaptation.** Learning situations in authentic settings often require making run-time changes to the original plan of the learning experience (e.g., Cuendet et al., 2013; Looi & Song, 2013; Tchounikine, 2013), to address unexpected events (latecomers, interruptions, etc.), and take advantage of emergent learning

opportunities and students' input (e.g., for debriefing activities). Classroom systems should be flexible enough to accommodate such changes and opportunities.

- Minimalism. Given this multiplicity of tasks and processes going on in the classroom, technologies should be simple, providing the most-often-needed functionalities (Balaam, 2013; Dillenbourg, 2013; Looi & Song, 2013).

Authors also point out other elements as being very important for orchestration, even if they do not always agree on how to address them, or how to resolve the tensions they represent:

- Teacher-centrism and sharing the load. Most authors acknowledge the crucial role that teachers play in the technology-enhanced classroom (Roschelle et al., 2013). However, different educational contexts and different moments call for different “balances of power” between teachers, students and technology. The central role of the teacher in the classroom can lead to an excessive management burden, calling for systems that allow sharing the orchestration load (e.g., with students, see Sharples, 2013).
- Designing for preparation, appropriation and enactment. Certain authors focus orchestration more on the run-time management of the learning situation (Dillenbourg, 2013), while others highlight the activities that happen prior to the classroom enactment itself, including the de-contextualized pedagogical and technological design (scripting), the customization of those designs for a concrete learning setting, as well as other preparation work regarding the appropriation of those elements by teachers and students (Hämäläinen & Vähäsantanen, 2011; Kollar & Fischer, 2013). Technological systems should make this preparation and appropriation easy.

- Multi-level integration and synergy. Orchestration is said to be about aligning or combining the multiple elements in the classroom to achieve a more effective learning experience, e.g., by combining different technologies, by combining individual, group and class activities to enhance the learning about a subject, or even by combining different learning and pedagogical theories in a sort of “theoretical ecumenism” (Dillenbourg, 2013; Kollar & Fischer, 2013; Looi & Song, 2013). This aspect also includes how the system integrates with existing classroom practices, workflows and contents, and with other technologies being used in the classroom (Cuendet et al., 2013).

From these aspects we can gather an operational definition of “technology for orchestration”, as a technology that is usable and effective within the pragmatic constraints of authentic educational settings, by supporting the perception and management of the learning activities (individual, in groups or at classroom level), and/or being flexible enough to be easily integrated in such management. To better understand the applicability of paper-computing proposals to authentic educational settings, we propose to look at existing paper-based computing systems through these eight orchestration aspects.

Review methodology

We performed a systematic literature review following the guidelines by Kitchenham and Charters (2007). The concrete goals of this review were: a) to identify and organize paper-based computing systems applied to education (to acknowledge their advantages and disadvantages); and b) to further analyze those efforts that performed evaluations in authentic formal education settings from an orchestration perspective (to assess their potential and the outstanding challenges of their use in authentic practice).

Regarding the need for such a review, several authors have performed reviews in related fields such as AR (Grasset, Dunser, & Billinghamurst, 2008; Choi, 2009; Billinghamurst & Duenser, 2012; Cheng & Tsai, 2013; Huang et al, 2013; Santos et al., 2014) or tangible interfaces (O'Malley & Fraser, 2004; Shaer & Hornecker, 2010). There also exist reviews on paper-based systems in general (Steimle, 2012). However, there exists no review systematically focusing on the educational uses of paper-based computing systems (Lim and Park, 2011, focus only on the augmented book form factor). Especially, there is no review that looks into the ecological perspective of whether these systems “work” in the context of authentic classrooms.

To find relevant literature sources, we used seven well-known online research databases related to education and technology (IEEEExplore, Science Direct, Sciverse Scopus, ISI Web of Science, ACM Digital Library, Springerlink and ERIC). Furthermore, we also queried Google Scholar to ensure the inclusion of “grey literature” (Kitchenham & Charters, 2007). Using the query string: ("paper computing" OR "augmented paper") AND (education) AND (classroom OR school OR university), we obtained 209 references from the databases, and 634 from Google Scholar. We screened these sources for relevance to paper-based computing and education, eliminating studies that did not involve a concrete system/intervention (e.g., literature reviews). After eliminating duplicates (e.g., sources with similar authors describing the same system in similar settings), and adding expert and reviewer recommendations as well as more recent work by authors and research groups detected as relevant, a total of 40 references were left. These are analyzed in the “Review results” section.

To address the two goals of the review, our analysis followed two stages. First, we synthesized the 40 educational augmented paper systems, clustering their purported advantages and affordances for educational settings. In the second stage, we analyzed the 15 references that included system implementation and evaluation in authentic formal education settings (or that tried to emulate such settings explicitly), using the eight orchestration themes presented in the previous section.

Results

Stage 1: General overview of paper-based systems in education

Among the 40 analyzed proposals (see Table A-1) we can find examples of every kind of form factor (see “Paper-based computing” section above). For instance, Bayon, Wilson, Stanton, & Boltman (2003) propose KidPad, an environment for primary school students to create and retell stories, using *augmented cards* with barcodes as placeholders for drawings, audio and other media. Shih, Wang, Chang, Kao, & Hamilton (2007) propose *augmented books* featuring barcodes which, along with PDAs, facilitate access to additional contents (including also tools for teachers to customize such content, see Figure A-1). A form of *augmented notebook* to support creation/sharing of sketches is proposed by Lee et al. (2007). Hitz and Plattner (2004) propose a generic architecture to *augment printed documents* to enable students to access additional contents using mobile devices (Figure A-2). Finally, Cuendet (2013) proposes Tinkerlamp, an *augmented table* that uses paper elements to control different simulations in logistics vocational education (see Figure A-3).

Table A-1. Summary of paper-based computing systems applied to education

Form factor	Proposal evaluation stage				Total #
	Prototype only	Usability test	Experimental / Controlled	Authentic setting	
Augmented cards/Post-Its	Ferdinand, Müller, Ritschel, & Wechselberger, 2005	Liarokapis & Anderson, 2010; Montemayor, 2003		Bayon et al., 2003; Kerawalla, Luckin, Seljeflot, & Woolard, 2006; Miura et al., 2009	6
Augmented books	Ha, Lee, & Woo, 2011; Heger & Lucero, 2008	Grasset et al., 2008; Horn et al., 2013; Wang & Chang, 2007		Chen & Chao, 2008; Martín-Gutiérrez et al., 2010; Shih et al., 2007	8
Augmented notebooks	Pietrzak, Malacria, & Lecolinet, 2010		Lai, Chao, & Chen, 2007	Alvarez, Salavati, Nussbaum, & Milrad, 2013; Lee et al., 2007; Liao, Guimbretière, & Anderson, 2007; Mitsuhashi, Yano, & Moriyama, 2010; Steimle, Brdiczka, & Muhlhauser, 2009	7
Augmented printed documents	Hitz & Plattner, 2004; Signer & Norrie, 2007	Fraser et al., 2003; Luff, Pitsch, Heath, & Wood, 2010	Alessandrini, Cappelletti, & Zancanar, 2014; Chen & Tsai, 2013; Lu, 2008; Teng, Chen, & Lee, 2011	Kimbell et al., 2005	9
Augmented tables, flipcharts and whiteboards	Döring & Beckhaus, 2007	Grammenos, Zabulis, Michel, & Argyros, 2011; Hook, Hjermslev, Iversen & Olivier, 2013	Klemmer & Landay, 2009	Bonnard, 2012; Cuendet, 2013; Do-Lenh, 2012	7
<i>Other</i>	Hannon, 2008; Huang, Gross, Do, & Eisenberg, 2009; Sharma, Liu, & Maes, 2013				3
Total #	10	9	6	15	40

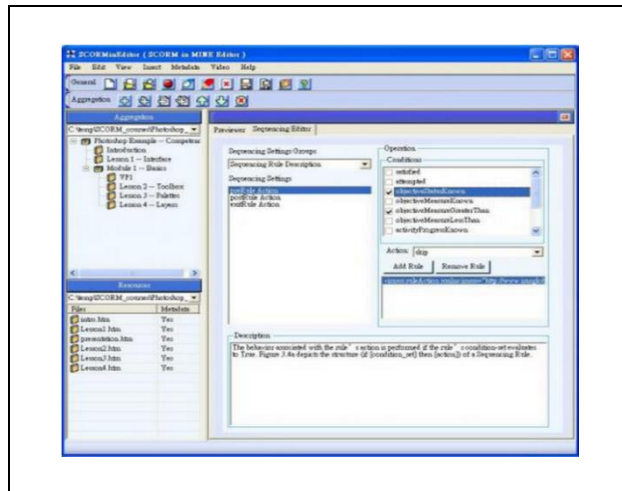


Figure A-1. Teacher authoring tool, Shih et al., 2007

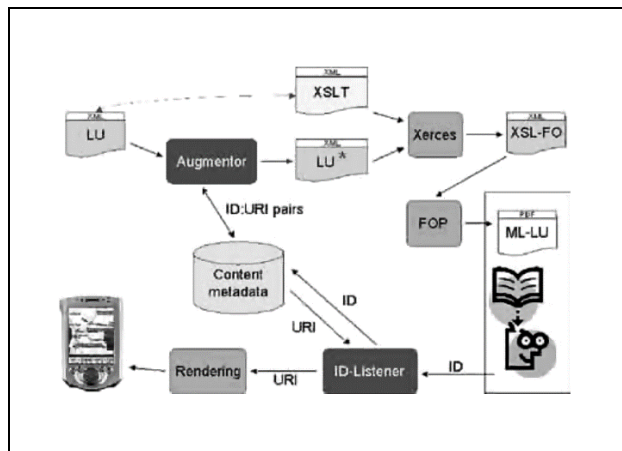


Figure A-2. Hitz & Plattner's (2004) augmented document architecture

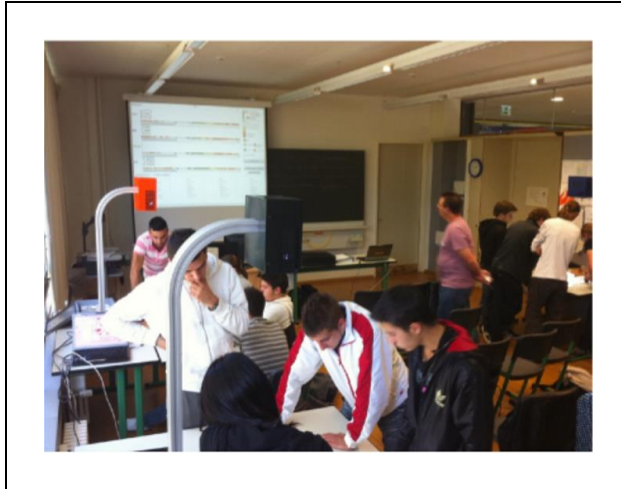


Figure A-3. Paper tabletop classroom setting, taken from Cuendet et al. (2013)

Paper-based systems have been proposed for almost every educational level: from preschool and elementary school storytelling environments (e.g., Bayon et al., 2003), to secondary education books (e.g., Wang & Chang, 2007), vocational training tabletop systems (e.g., Do-Lenh, 2012) and university-level lecturing support systems (e.g., Mitsuhashi et al., 2010). Similarly, augmented paper systems have been proposed to aid in a wide variety of subject matters, including math (e.g., Sharma et al., 2013), science (Kerawalla et al., 2006), history (e.g., Fraser et al., 2003), etc. Other efforts focus on specific skills rather than subject content: storytelling (Bayon et al., 2003), spatial skills (e.g., Martin-Gutierrez et al., 2010) or even guitar playing (Liarokapis & Anderson, 2010). Yet others are aimed at supporting activities more peripheral to learning, such as note-taking (e.g., Pietrzak et al., 2010), and thus could be applied to learning multiple kinds of content/skills. The proposed systems cover learning activities throughout the whole spectrum of social planes: from individual activities (e.g., Chen & Chao, 2008) to small group activities (e.g., Hook et al., 2013) or even whole-class collaborative learning activities (e.g., Alvarez et al., 2013).

Table A-2: Synthesis of augmented paper advantages for education, including examples

Advantages	Role of paper	Paper documents contain hyperlinks (e.g., visual markers)	Contents of paper are synchronized with digital resources	Paper as a tangible token to access/control digital content	Hybrid of augmented document and tangible controller
From paper's intrinsic properties					
Tangibility or manoeuvrability		<i>Augmented books</i> [Heger & Lucero, 2008]	<i>Augmented printed documents</i> [Luff et al., 2010] <i>Augmented paper notebooks</i> [Lee et al., 2007]		<i>Augmented paper cards with digital pens</i> [Miura et al., 2009]
Flexibility		<i>Augmented books</i> [Ha et al., 2011; Zhao et al., 2014] <i>Augmented printed documents</i> [Hitz & Plattner, 2004]	<i>Augmented paper notebooks</i> [Hong & Jung, 2005]		<i>Augmented paper cards with digital pens</i> [Miura et al., 2009]
From digital resources' intrinsic properties					
Immersive experience with visual, audio and other multimedia		<i>Augmented books</i> [Ha et al., 2011; Heger & Lucero, 2008]	<i>Augmented tables</i> [Grammenos et al., 2011]		
Learning process and outcomes become more explicit and accessible		<i>Augmented books</i> [Shih et al., 2007]			<i>Augmented tabletop</i> [Do-Lenh, 2012]
From mutual advantages of paper and digital					
Enables complex interaction preventing cognitive/visual overload			<i>Augmented paper notebooks</i> [Pietrzak et al., 2012]		
Bridges the gap between physical and virtual to enhance visual/spatial ability				<i>Augmented paper cards with digital pens</i> [Ferdinand et al., 2005; Kerawalla et al., 2006]	<i>Augmented tabletop</i> [Bonnard, 2012; Cuendet, 2013; Do-Lenh, 2012; Grammenos et al., 2011]
Management of documents in an effective way		<i>Augmented books</i> [Zhao et al., 2014]	<i>Augmented paper notebooks</i> [Lai et al., 2007; Lee et al., 2007; Mitsuhara et al., 2010; Steimle et al., 2009] <i>Augmented printed documents</i> [Lu, 2008]		

If we look at the system rationales and advantages portrayed by their authors, we can synthesize several augmented paper affordances for education (see Table 2 for more details and example references). Some of these advantages directly stem from *paper's intrinsic properties*. Paper can be easily and intuitively used, and thus can provide a means for

interaction with less perceived effort, e.g., the ease of navigating through content by flipping pages on an augmented book (*tangibility or manoeuvrability*). Paper can also support a range of activities (e.g., passing it around to others, or moving it in the area of a desk), thus making it simple to configure digital systems by moving paper around (*flexibility*).

Other systems leverage *digital resources' intrinsic advantages*. Since digital resources can be linked or animated at a distance, and they can be easily searched, shared, duplicated or archived, these systems can enable an *immersive experience including visual, audio and other media* (e.g., enhancement of a paper map with multimedia content). They also can *make the learning process and outcomes more explicit and accessible*, through recording and tracking interactions with the systems (e.g., recording of the sequence of logistic simulation parameters tried out by a group of students).

Authors also mention other advantages of these systems, which relate to the benefits of *combining paper and digital media*. The expansion of *the interaction space resulting from linking paper documents and digital resources* enables *complex interaction without excessive cognitive overload*. These systems also *bridge the gap between physical and virtual objects*, which may assist in *enhancing students' visual and spatial abilities* (e.g., projecting abstract notions like angle measures over a paper polygon). Also, the seamless transition between paper and digital documents enables *effective information searching, quick navigation, or convenient conversion, storage and retrieval*.

However, what kind of evidence do we have of all these advantages? Many of the analyzed proposals (47.5%, see Table 1) only provided a first prototypes of the system, or preliminary pilots or user studies (and thus there is little evidence of their affordances in actual educational use). Other studies perform controlled experimental designs, often in a lab

setting (15%), and thus their ecological validity in an authentic, non-controlled setting is limited.

In fact, only 15 of the selected studies (37.5%) depict the usage of the system in an authentic setting, or try to mimic real classroom constraints (in terms of space, time, curriculum, etc.). We could ask ourselves to which extent those affordances are useful for teachers and students within the multiple constraints of actual classrooms.

Stage 2: Orchestration analysis of paper-based classroom interventions

From the 15 studies that had been evaluated in authentic or authentic-like settings (see Table 3), we can also extract several features. Most of them are relatively recent, maybe indicating that only lately the involved technologies have been reliable and affordable enough to be studied out of a controlled lab setting. The studies use a variety of research designs and methodologies, from quasi-experimental designs with a control group to design-based research and participatory longitudinal studies. Although the studies report a wide range of findings, there is a notable lack of studies actually studying learning effects of using the technology, with many of them rather focusing on other constructs like usability (Bayon et al., 2003) or student engagement (Alvarez et al., 2013; Miura et al., 2009). From those studies that try to measure learning effects, many do not find statistically significant results when compared with learning the same material using other methods (e.g., Cuendet, 2013).

Among these 15 systems there are also representatives of all five interface form factors. The proposals provide different levels of learning activity support: some focus especially on the provision of subject matter content (e.g., the 3D models in Martín-Gutiérrez's augmented book, 2010), others on the content-independent support of a specific task (e.g., Bayon et al.'s

environment for storytelling in which teacher and students create freely the contents to be added, 2003), and yet others focus on supporting a learning activity as a whole (e.g., Cuendet's tabletop system provides both contents and task support to enhance carpenters' spatial skills, 2013). Looking at these 15 studies from the point of view of the eight key orchestration elements (see the 'Classroom orchestration' section above), we notice the following:

Pragmatism/Constraints

The analyzed efforts comply with many of the constraints of the real classrooms they were designed for. Most of the studies used curriculum-relevant contents and activities, often co-designed with teachers (e.g., Bonnard's geometry activities based on the Swiss primary school curriculum, 2012). They also considered classroom space constraints (e.g., using webcams and displays already existing in the classroom, in Kerawalla et al., 2006) and time constraints (e.g., lesson length of a typical lecture in Miura et al., 2009). The impact of the system/intervention into teachers' energy levels is less clearly addressed in general: while some studies appear to have no impact on teacher effort (e.g., Lee et al.'s student note-taking system, 2007), or even appear to require less effort than the traditional enactment alternative (e.g., Alvarez et al.'s automation of the data flow between digital pens and shared display, 2013), several others mention a certain teacher effort involved in the preparation of materials (Mitsuhara et al., 2010), or the improvisation of debriefing activities (Chen & Chao, 2008). Interestingly, several studies mentioned how the limited range of applicability of the system (e.g., the fact that their usage covers only a small part of the curriculum) may affect adversely system adoption (Bonnard, 2012; Kerawalla et al., 2006).

Table A-3. Summary of the augmented paper systems used in authentic settings

Form factor	Study	Aim	Subject	Main findings
Augmented paper cards with digital pens	Bayon et al., 2003	Enhance children's creativity and collaboration	Storytelling	<ul style="list-style-type: none"> * It was easier to draw with pen/paper, rather than with the mouse * The story created by kids was easily archived and accessed later in the classroom
	Kerawalla et al., 2006	Incorporate AR content into UK primary school lessons	Earth sciences	<ul style="list-style-type: none"> * Child participation and engagement lower in AR role-plays * AR sessions seemed easier to control than traditional role-plays * Inflexibility of the AR content * Children found difficult to focus on doing several things at once
	Miura et al., 2009	Facilitation of collaborative and interactive learning in regular lectures	(Generic)	<ul style="list-style-type: none"> * Improved student motivation/enjoyment (enjoyable competition) * Increased visibility of student work progress, not always liked due to privacy concerns * Increased participation and interaction among students
Augmented books	Shih et al., 2007	Compare ubiquitous, multimodal e-Learning with alternatives	(Generic)	<ul style="list-style-type: none"> * Increased information overload when using augmented books * Learning disorientation turned up easily when reading online * Learners easily distracted while reading conventional textbooks
	Chen & Chao, 2008	Explore context-aware learning support to assist in paper textbook comprehension	Programming	<ul style="list-style-type: none"> * Recommended annotations may assist in knowledge construction * Students' motivation and behavior influenced by community members probably (conformity with class status) * Hyperlinks and contextual messages can be relevant to the learning tasks (right resources at the right time)
	Martín-Gutiérrez et al., 2010	To investigate the use of AR for improving spatial abilities of engineering students.	Engineering	<ul style="list-style-type: none"> * AR application was helpful for improving student spatial abilities * The majority of the students considered that it was best to carry the activities out in the computer

				laboratory (although they have the possibility to do it at home).
Augmented paper notebooks	Alvarez et al., 2013	Support New Media Literacies teaching and curriculum in classroom	Math	<ul style="list-style-type: none"> * The system can be well integrated in classroom teaching * Fosters the development of collective intelligence, distributed cognition and transmedia navigation in different domains.
	Lee et al., 2007	Ecologically valid paper-based system and effects on design culture	Design education	<ul style="list-style-type: none"> * Longitudinal impact of augmented paper interactions on design practice * Team dynamic effect upon technology appropriation
	Liao et al., 2007	Combine physical artifacts (paper) with communication and archival infrastructure	Engineering	<ul style="list-style-type: none"> * Feasibility of paper interface to support student-instructor communication in active learning.
	Mitsuhara et al., 2010	Compare learning effects and note-taking behavior of augmented paper system and alternatives	(Generic)	<ul style="list-style-type: none"> * Changes in note-taking behavior: less changes in gaze direction, less time spent writing * Little difference in learning effects observed * Weak inference or statistical power over student parameters like cognitive load
	Steimle et al., 2009	Improve classroom annotation, review, and collaboration	(Generic)	<ul style="list-style-type: none"> * Efficient support for student annotation * Easily integrated into current annotation practice.
Augmented printed documents	Kimbell et al., 2005	Supporting creativity and learning in collaborative design work, preserving paper sketching practice	Design	<ul style="list-style-type: none"> * The system supported the users' usual interactions, with the advantage of collecting, storing data digitally * The graphic design of the test supported direct collaboration between students
Augmented tables, flipcharts, whiteboard	Bonnard, 2012	Investigate usage, teaching and learning with an augmented paper interface	Geometry	<ul style="list-style-type: none"> * Paper is visible to users even if it is not detectable by the camera * Continuous mapping of activity feedback considered more usable * Better learning gains when the feedback was restricted in time * Tangible paper interface supports the exploration of a problem
	Cuendet, 2013	Explore TUIs for acquisition of spatial skills in classroom scenarios	Carpentry	<ul style="list-style-type: none"> * TUIs can help train spatial skills, several factors affect training

			<ul style="list-style-type: none"> * Design principles of integration, flexibility, empowerment, awareness, minimalism... * Dangers of cluttered user interface (Hutchins threshold) * Feasibility of low-cost TUIs for schools/personal use
Do-Lenh, 2012	Design and enactment guidelines for enabling high-level thinking in authentic settings	Logistics	<ul style="list-style-type: none"> * Tangible tabletops enable fruitful interactions, but also can lead to lack of student reflection. * Teacher orchestration is crucial and is related to reflection <ul style="list-style-type: none"> * Supporting reflection and orchestration requires tools to facilitate fluid transition between activities at different levels and contexts

Empowerment/Control/Management

Several issues come to our attention when we analyze the management of classroom activities using paper-based systems. In many of the analyzed systems the teacher is the central “manager” of the flow of the class. However, only a few of the systems provided teacher-specific user interfaces with special capabilities (e.g., Do-Lenh, 2012; Steimle et al., 2009). Certain proposals are specifically designed to facilitate the management of emergent activities like debriefing (Kimbell et al., 2005). Regarding the mode of activity management (socially vs. technology-mediated), very often the proposed systems are managed flexibly in a social manner, without intervention from the system (e.g., Alvarez et al.’s social regulation of the use of the digital pens by students when needed, 2013). Several systems were conceived for easy/flexible navigation, without a specific activity flow (e.g., Lee et al., 2007), although an order is sometimes suggested by the paper binding of a book (as in Martin-Gutierrez et al., 2010). In fact, certain systems did use the paper elements to embody the class workflow (e.g., in Bonnard’s sheets printed with the activity description - see Figure

4), which can even be taken out of the classroom to interact with external actors (Do-Lenh, 2012).

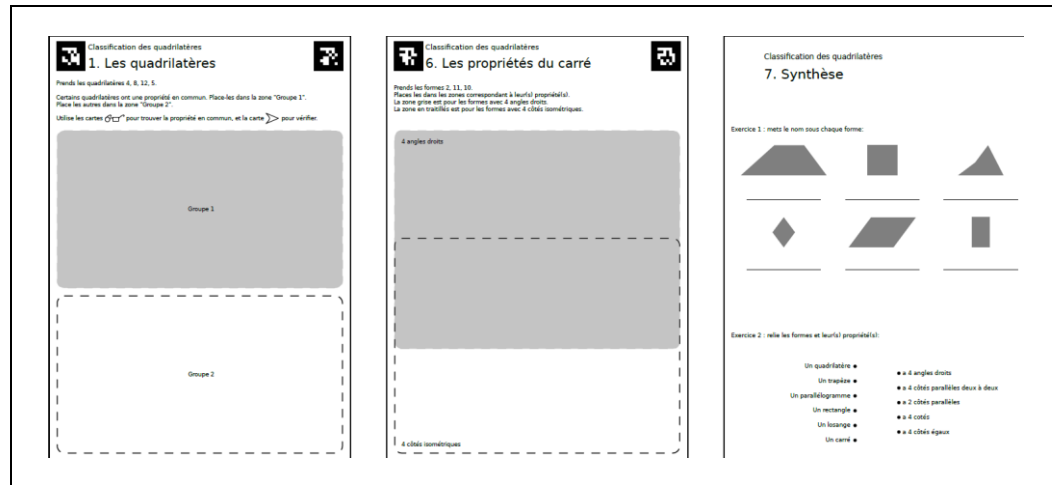


Figure A-4. Bonnard's (2012) printed sheets including activity description

Visibility/Awareness/Monitoring

Several levels of awareness are possible in the classroom, related to the social plane at which the learning activities happen (individual, small-group or classroom-wide). Digital pen systems often provide very limited visibility beyond the individual; tabletop systems such as Bonnard (2012) normally have good individual or small-group visibility, but not so good classroom awareness from a distance. Thus, there are systems that complement the paper-based system with a shared display in the front of the classroom, as a collective memory and to help teachers be aware of student actions (e.g., Alvarez et al., 2013; Miura et al., 2009). Some authors note that the physical layout of the system elements (e.g., the paper pieces) in the class may help signal aspects of classroom workflow (e.g., Cuendet, 2013). Aside from shared displays, a few systems include specific tools for teacher awareness (e.g., to follow the navigation patterns and learning outcomes of possibly distant students, in Shih et al.,

2007). Several systems also provide automated feedback about the learning task to students/teachers (e.g., Chen & Chao, 2008; Cuendet, 2013).

Flexibility/Adaptation

A paper-based system can be flexible and adaptable in many different ways. Many of the portrayed systems are flexible to navigate, thanks to paper's handling ease (e.g., using barcodes on paper cards to freely navigate between a story's events, in Bayon et al., 2003). However, the fact that some systems provide multimedia learning content poses a limitation to this flexibility, as the lesson cannot step out of the previously prepared contents (as in Mitsuhashi et al., 2010). Conversely, systems that are content-independent (e.g., Alvarez et al., 2013; Steimle et al., 2009) may have a larger range of applicability. Other systems use paper elements like cards to flexibly adjust system features and the difficulty of learning tasks (Cuendet, 2013), and the automatic recording of student information and learning outcomes can be used for spontaneous debriefing activities (e.g., Miura et al., 2009).

Minimalism

The reviewed systems comply with this guideline to different degrees. To obtain a simple activity flow, certain systems propose simple, modular activities without many inter-dependencies among them (e.g., Bonnard, 2012). Several systems try to minimize their feature set by doing away with the notion of login/identification, which often are not essential for learning itself (e.g., Do-Lenh 2012; Kerawalla et al., 2006). Strategies to minimize orchestration load include the automation of the workflow (e.g., transparent/automatic sharing of student outcomes in Lee et al., 2007). Yet, we also find

systems breaking this simplicity principle, either increasing user perception of cognitive load (e.g., Shih et al., 2007), veering towards clutter due to the multiple tangible interface elements (noted by Cuendet, 2013) and shared student artifacts (Liao et al., 2007). Certain works also mention teachers' rejection of complex technology setups (e.g., upon Cuendet's suggestion of using multiple augmented tabletops in a classroom).

Teacher-centrism and sharing the load

Paper-based systems can support very varied role distributions among actors, depending on the classroom dynamic to be supported. In a teacher-centric situation, several systems support “traditional” roles such as teachers lecturing with students as passive receivers (as in Mitsuhashi et al., 2010), although more often teacher is seen as a facilitator (especially in creative activities, like storytelling in Bayon et al., 2003). On the other end, certain systems are designed to work independently of the presence of a teacher, for student individual study or problem resolution (e.g., Martín-Gutiérrez et al., 2010; Shih et al., 2007). Some of the systems actually provide more flexible orchestration roles, enabling teachers to share with students a part of the orchestration “power”, for example in the form of cards enabling certain features (e.g., Bonnard, 2012; Cuendet, 2013). We observe also a great variety of balances between teachers and researchers, especially regarding who (if anyone) has to handle the preparation of the learning activity and its materials (see also the following aspect).

Designing for preparation, appropriation and enactment

Although the design and implementation of all the proposed systems was done by researchers/specialists, the customization and preparation of the learning activities for the concrete classroom took different forms (although it is often insufficiently described). Certain systems require very little physical preparation, especially those that rely more on student input like note-taking (Alvarez et al., 2013; Steimle et al., 2009) than in the provision of multimedia content or feedback. Other systems, however, require a researcher or specialist to intervene during preparation (e.g., of augmented slides before the lectures in Liao et al., 2007). How this preparation is performed varies greatly, and normally no authoring tool is provided (with the exception of the one depicted in Shih et al., 2007). Only a few systems allow for the rapid and flexible preparation of activities just before the lesson (as in Bonnard's symmetry exercises, 2012), which can lead to easier appropriation of the system by teachers.

Multi-level integration and synergy

Generally, the proposed systems are well integrated with existing classroom workflows, practices and tools (especially paper-based ones, but not only): using paper as a free drawing tool (e.g., Lee et al., 2007), or as a permanent memory (e.g., use of activity sheets, Do-Lenh, 2012). Other systems infiltrate the use of existing elements like rulers and other drawing tools (Bonnard, 2012, Cuendet, 2013 – see Figure 5). Another common tool synergy involves paper-based elements (for more natural individual/group work) and a shared display (for classroom awareness), as in Do-Lenh (2012) or Alvarez et al. (2013). Other systems try to integrate ubiquitously with existing student practices (such as mobile device-based support

for individual study, Chen & Chao, 2008). Many of the proposed systems support some kind of transition between the individual, group and classroom social planes (e.g., in Alvarez et al., 2013, the activity flow includes collaborative problem solving at all three levels). However, the interoperability of augmented paper data and activities with other technological tools and systems (e.g., online LMSs) is much less discussed, aside from the physical persistence of paper artifacts themselves.

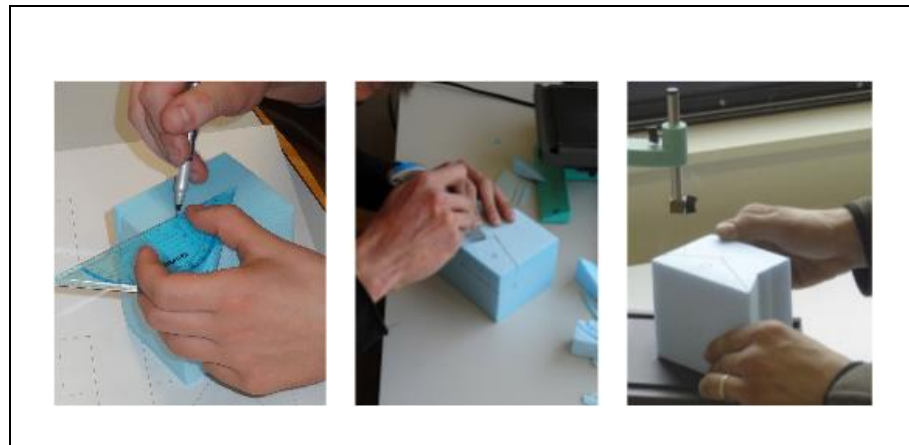


Figure 5. Variety of tools used in Cuendet's (2013) system

Discussion

As we have seen, researchers have proposed augmented paper (in its many forms) as more subtle way to enhance the classroom with digital media. From the first stage of our systematic review, we elicited several potential affordances of this kind of systems, like tangibility or manoeuvrability, the ability to manage documents in an effective way, or to bridge the gap between physical and virtual worlds. We also saw how paper-based computing applications for education is still a field in flux, exploring creatively divergent lines of research and system form factors, but with little continuity beyond preliminary usability/engagement studies with a few subjects. Strangely enough, the actual affordances

for learning itself often are not thoroughly investigated, and comparatively few studies address teachers' perceptions and system compliance with real classroom constraints. As noted by Cheng and Tsai (2012) and Santos et al. (2014), despite initial evidence of benefits for learning of spatial skills or science conceptual understanding, the number of studies is still small, especially for longer, in-the-wild measurements of learning (an issue also highlighted in Lee et al., 2007; Shaer & Hornecker, 2010).

In this paper we have focused specifically on this dimension of usage and adoption in authentic educational settings, through the analytical lens of classroom orchestration. Our orchestration-based analysis of the systems evaluated in authentic settings was limited by the lack of descriptions or explicit consideration of certain orchestration aspects. In latest works, however, classroom usage and the learning value of the technology have begun to be taken into consideration (e.g., Alvarez et al., 2013, Do-Lenh, 2012, and others). Nevertheless, the available studies confirm paper's protean qualities for classroom use, accommodating a variety of classroom dynamics and multi-level activity integration. However, as noted before, the learning effects of the proposed systems often have not been thoroughly studied yet, with clear benefits present only in certain tasks with an important spatial component.

As technology designers, we could take an alternative approach and focus on the orchestration advantages of paper-based systems at the classroom level, rather than on the individual learning effects (although, of course, studies should ensure that learning is not hampered by using the system in a classroom). In this sense, paper-based systems have also shown to be able to accommodate a variety of pragmatic classroom context constraints. The technology design of the augmented paper systems leveraged different paper-based

affordances and advantages: intuitive interaction, accommodating emergent debriefings and flexible navigation sequence, as well as the awareness properties of the different system elements at group and classroom social levels (e.g., paper elements as visible workflow, often in synergy with a shared display for further classroom awareness).

From an educational technology designer perspective, we should note that this compliance with the classroom constraints was the consequence of long and careful co-design processes. Paper-based technologies are still difficult to design and prototype, and it is even more difficult to design systems that let end-users (e.g. teachers, students) appropriate them. As Santos et al. (2014) mention, some systems are starting to provide this kind of end-user support. We foresee that the advances in web technologies and mobile devices can make this kind of features possible, as already hinted by mobile AR browsers (see Muñoz-Cristóbal et al. for an example of a system that applies such technologies to let teachers and students shape their learning activities, 2013) and online paper/tangible solutions (e.g., Cuendet, 2013).

Our review also uncovered certain remaining challenges in this field, which represent interesting directions for future research in this area: a) the design space defined by augmented paper advantages and system form factors (see Table 2) is still sparsely populated, indicating potential paths for the design of novel systems of this kind; b) teachers' understandable resistance to more complex technical setups, the increased length of the co-design processes in order to address these real classroom constraints, and the limited range of applicability of many of the resulting systems point towards the need of specific design guidelines and processes for the conceptualization and implementation of this kind of systems; c) addressing the design, preparation and customization of the learning activities

before enactment itself is also unresolved, as it often requires quite specialized technical knowledge and careful interaction design – augmented paper toolkits and user-created paper UIs are another promising avenue of future work.

Finally, the analyzed systems also illustrate certain design tensions (Tatar, 2007) in applying paper-based systems to the classroom: a) flexible, easy to use paper UIs can quickly become scattered (with interface clutter breaking the minimalism principle); b) designing the system as a scarce, unique resource in the classroom, versus having one-to-one setups, in which increased access to technology has to be balanced with minimalism and teachers' natural fear of complex setups that can break down or become uncontrollable; c) paper's natural affordance for flexibly navigating through content is counterbalanced by the need of such content to be prepared by teachers or specialized staff; d) the need to support awareness at different social levels, often using an ecology of different devices, again is in tension with the preference for a minimalist setup; e) computers' ability to provide automated feedback is somewhat hampered if we make use of paper's power as a flexible input source (due to the difficulty in converting freeform drawing to computer-interpretable form). These and other design tensions also mark pathways to be explored in future research work (e.g., through comparative studies in different classroom settings. Paper is making a comeback to the classroom, only it never really went away.

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ANNEX B: SINGLE LOCUS OF CONTROL IN A TANGIBLE PAPER-BASED TABLETOP APPLICATION: AN EXPLORATORY STUDY

Abstract

Multiple loci of control is one of the main affordances of tangible tabletop UIs due to the capability of simultaneous manipulation. However, there is a tension between the efficiency given by simultaneous manipulation and the need to coordinate and reflect in group activity. We implemented a central point of control to synchronize the group work and afford opportunities for equal participation in a tabletop application. In this study, we analyzed log and video data of 7 groups of primary students using the application. The results show that the position and rotation of the central control can be a predictor of equal participation. We also gained insights about interpreting group performance based on log data about the central control distribution. Finally, we discussed the implication of such findings for facilitating teacher monitoring group collaborative processes.

Keywords: Multi-tabletop, collaboration

Introduction

Unlike most educational technology, interactive tabletops allow multiple users to interact simultaneously [12]. Multiple loci of control is one of the main affordances of Tangible UIs (TUIs) due to simultaneous manipulation. However, there is a need for group activity coordination and reflection. Coordination is important when working with children, because compared with adults, children seemed less aware of others' interaction when working on multi-touch table activities [11].

This study is concerned with whether and how a tangible central control affects equal participation. We implemented a central point of control to synchronize the group work and afford opportunities for reflection, and thus avoid unequal participation. It was embedded in our system for fraction learning which is built on the TinkerLamp (see [1]). Considering group dynamics, we investigate how primary students in small groups use the single central control to complete their group tasks, through examining the position and rotation of the central control.

Background

Tabletops have been studied in an isolated manner from the perspective of collaboration [2]. An assumption often made is that multi-touch tabletops provide higher opportunities for equal participation. When students participate equally in group work, each group member has the opportunity to contribute, manipulate materials, ask questions or provide explanations, and thus improve their knowledge and skills. One approach to avoid unequal participation, is encouraging positive interdependence. Positive interdependence exists when group members realize that they need to work together, to make a decision and to achieve their common goal [5].

Within the shared tabletop workspace, [13] identified three different territories: personal, group and storage, and provided empirical evidences to support that collaborators use these three types of territories to help coordinate their interaction. Findings from [11] showed that while children participate in tabletop-based activities, they took more responsibility for the objects closer to their relative position. Besides the position, the orientation of objects also affects participants' interaction. (e.g., [6]; [13]). Subtle changes in movement or rotation of an object can indicate a user's intention to share information, to indicate territoriality, or to

invite participation [4]. Furthermore, [6] proposed that the orientation of the objects has three roles during collaboration: comprehension, coordination and communication.

Concerning collaboration process, we would like to support it while taking into account the technology design. As [9] suggested, one coordination policy to avoid conflicts in a global way is to provide privileged objects, which initiate a change of state and are not available for all the participants. Moreover, in a multi-touch tabletop environment, embedding a central control element can help synchronize the group work and afford opportunities for reflection [3].

System for Augmented-Paper Fraction Learning

Interactive tabletops are effective in geometry learning in primary schools [1]. Using the same technology, we developed a system for fraction learning which used several paper-based fraction manipulatives. Manipulatives are concrete objects used to help students understand abstract concepts, providing students the opportunity to explore concepts visually and tactilely [10]. Moreover, when students are provided with multiple representation, they are more likely to perform at higher levels [8]. Finally, [7] has evidenced the importance of multi-representation and manipulatives for facilitating fraction learning. The main aim of the system is to help students to compare fractions in a game-based form (see Figure B-1). Students have to move a ladybug to its home by comparing fractions.

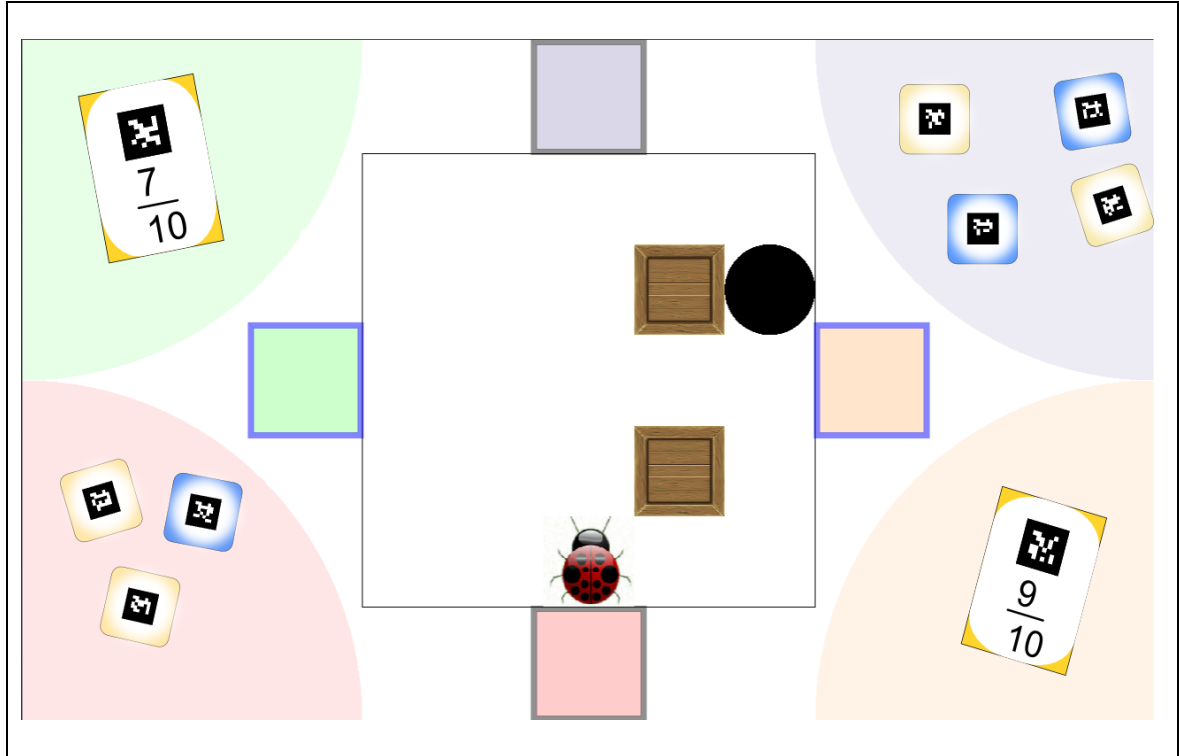


Figure B-1: Game interface. Each corner has one fraction representation

The system is composed of (1) an interactive lamp that projects a map where the ladybug moves, (2) paper-based fraction manipulatives (Figure B-2), (3) hint cards, and (4) a central control (GO card with timer) to synchronize the group actions (Figure B-3). In terms of territoriality, each corner was defined as private space, where students can work with their manipulatives; while the map area provides group space. As shown in Figure 1, a group of four students (one for each corner) put a manipulative in their respective corner to express a fraction. For each axis (X and Y) the fractions will be compared and then the movement of the ladybug in each axis will be determined. For example, if the top fraction is greater than the bottom one and the left one is greater than the right fraction, the ladybug will move up and left.

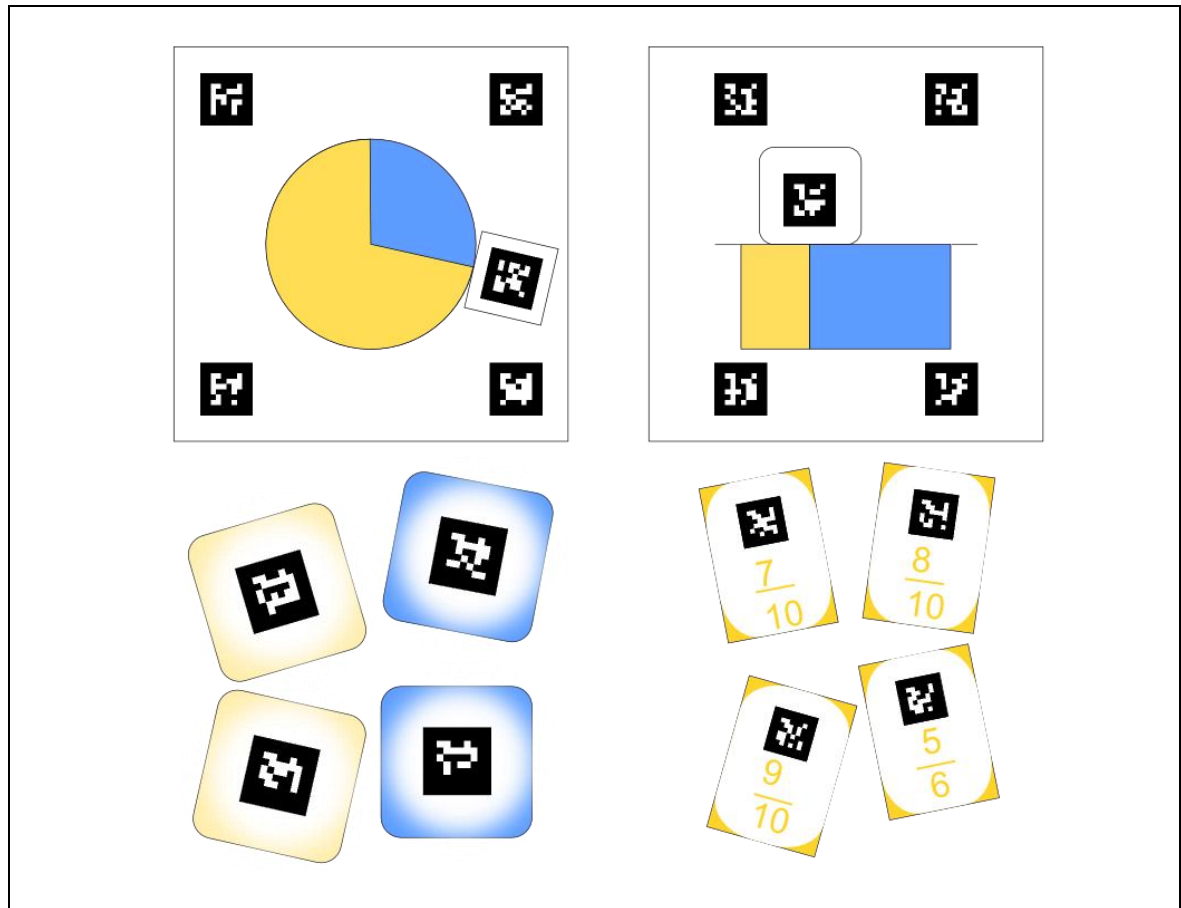


Figure B-2: Paper-based fraction manipulatives. Continuous circular and rectangular (top), discrete (bottom left) and abstract (bottom right)

As mentioned before, the GO card was designed to support coordination and equal participation. The group had only one GO card to move the ladybug, so children need to make a group-level decision.



Figure B - 3: GO card states. (1) Initial state, the card is not showed to the lamp, (2) Timer to let the students reflect, (3) The card can be flipped by the students

Exploratory User Study

We conducted an exploratory user study during an open doors event in our lab. A total of 6 classes of 14-25 students from different local primary schools (10 - 12 years old) participated. In each session, one class was separated in groups of 4-6 students to work for 25 minutes in one lamp to complete the fraction game. First they practiced and learned how to make a movement, then they gradually used the different manipulatives.

Regarding the data gathering, each lamp provided log data and had a top camera for recording the hands-on activity of students. At the end of the session, each group was asked to answer a survey in which they had to write down the strategy they used in the game.

To analyze the position of the GO card, we divided the working area into 4 quadrants (upper right, upper left, bottom right, bottom left). Regarding the rotation, we divided the working

area into 8 directions (4 for each corner and 4 for each side of the table). We first computed the proportion of log events where the GO card was in each quadrant and inside the map. Secondly, we calculated the rotation of the GO card for each position. Video data helped to verify whether the group work was predominated by one students through coding the frequency of touching and pointing manipulatives. Finally, the group performance was assessed based on whether students were able to correctly elaborate the strategy in the survey (e.g. answer referring fraction comparison), and the video-based observation regarding students' discussion and the movement of the ladybug (e.g. whether students made a consensus before making a movement).

Results

While we presumed that the design of the single central control would help to stimulate equal participation, preliminary analysis of video and observations in situ showed that such equal participation didn't happen in all the groups. In order to explain this, we selected 7 groups which went through all the tasks we proposed and didn't have too much intervention of the researchers (e.g. to explain how the game works or help them to finish one activity). First, based on the log data, we noted that all the groups used the GO card inside the map area. Further video analysis showed that a dominant student could be observed in 3 out of 7 groups. Supplementary qualitative data helped to explore some insights that may relate to group performance.

Groups with a dominant student

The dominant student of a group was the one who frequently flipped the GO card and tried to manipulate the manipulatives belonged to other students' spaces (quadrants). In some groups, it was also observed that the student spoke aloud own ideas about the ladybug

movements with pointing materials on the tabletop. Based on all 7 groups' log data, we found that there were 3 groups with 58.8%, 99.9% and 67.7% of the locations of the GO card inside one quadrant and it was oriented towards mainly 1 or 2 directions. Posterior video-based data also revealed that these 3 groups were the groups with a dominant student.

The empirical data supported that the group's single control remained in one quadrant (with more than 58.8% of the location of the GO card inside one of the 4 quadrants) indicating that the group has a dominant student. Two examples are provided in Figure B-4 and Figure B-5 with the location of the dominant student.

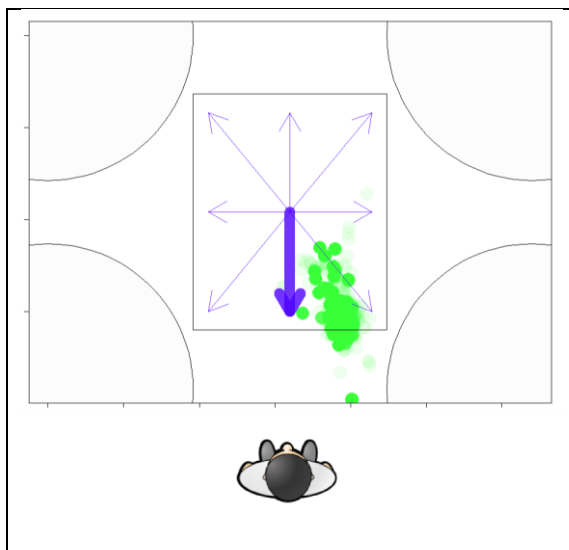


Figure B-4: Distribution of the GO card
condensed in one point in groups
dominated by one student

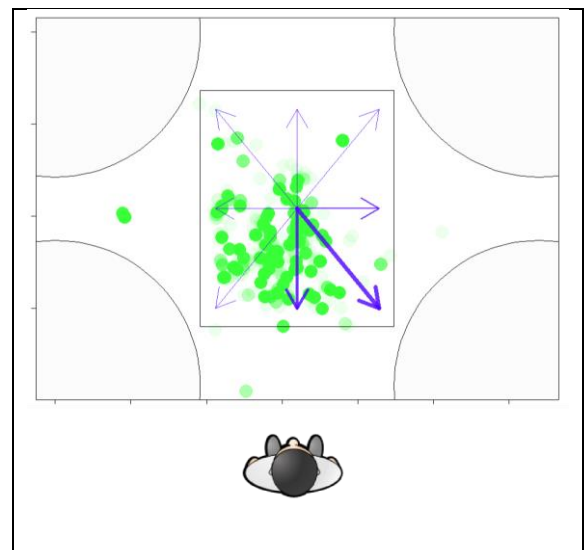


Figure B-5: Distribution of the GO card
dispersed in several points in groups
dominated by one student

According to the figures, the difference between the position distributions of these two groups' GO card is salient as well. The position distribution was highly condensed in one point in Figure 4, while it was quite dispersed in Figure B-5.

According to the post-activity survey data and our video-based observation, it was found that the group shown in Figure B-4 had a good performance in the activity. They made explicit how to construct fractions to move the ladybug correctly in the post survey. Although the GO card was mainly kept in one point, it was observed that students took turns to flip the card. Moreover, they discussed a lot, before work with the manipulatives and flipped the GO card. On the contrary, in the group shown in Figure B-5, although it was observed that the dominant student tried to explain how to move the ladybug, it seemed that not all the group member got the idea about how to use the manipulatives. Sometimes, they tried to move the ladybug through flipping the GO card by themselves without making a consensus with one another. Furthermore, their feedback in the post survey indicated that the group did not get a clear idea about how to move the ladybug. Therefore, the findings of these two groups revealed that there was not necessarily a connection between equal participation and good group performance.

Groups without a dominant student

In groups without a dominant student, the GO card was dispersed in two or more quadrants. Unlike the groups with a dominant student, it was difficult to find a clear preferred rotation to manipulate the GO card. One out of four groups rotated mainly towards two directions, one towards three directions and two towards 4 directions (out of 8). This finding also has been triangulated by the video data.

We can further separate the GO card distribution without a dominant student into two categories, depending on whether the actions took place in the private space or not (Figure B-6 and Figure B-7).

We can see in Figure B-6 that the GO card was manipulated mainly in two quadrants, but at some moments, it was manipulated inside a private space of two student (upper and bottom left). Also, it was rotated mainly towards three different directions. In the qualitative video analysis, some misbehaviours of the group could be observed, for example one student kept flipping the GO card around his/her own private space when some other students were still manipulating other materials, which means bad poor coordination at a group level.

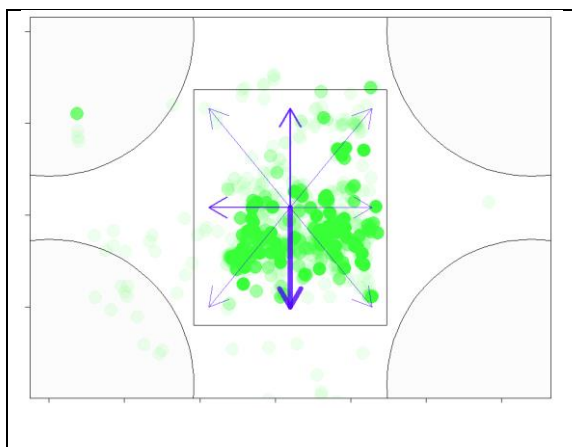


Figure B-6: Distribution of the GO card spreading in private spaces in groups without dominant student

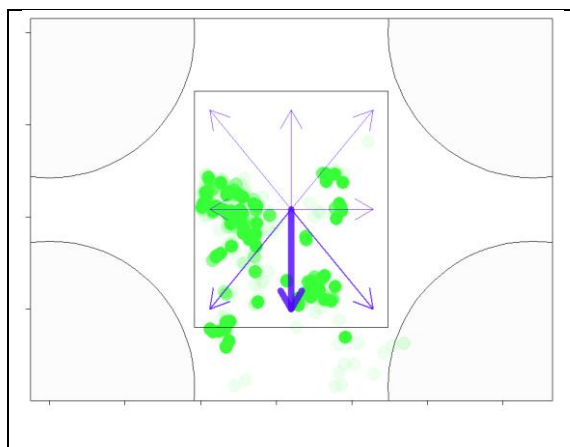


Figure B-7: Distribution of the GO card without spreading in private spaces in groups without a dominant student

The group shown in Figure B-7, however, mainly manipulated the GO card in their group working area and it was looking towards one side of the table. According to the video data, it was observed that similar to the group shown in Figure B-4, in which students discussed first, used manipulatives together and then took turns to manipulate the GO card.

The findings of these two examples supported that there was no necessary connection between equal participation and good group performance as well.

Discussion and Conclusion

In general, the initial empirical data of this study showed that embedding a central point of control in Tabletop systems can enable children to coordinate and reflect in their group activity, but not guarantee it. Even under similar instruction, group dynamics influences the way to bring the tool into use.

With the triangulation of both log data and qualitative video data, this study showed that measuring the position and rotation of the central control object can be a predictor of whether a group has a dominant student (unequal participation) or not. The dominance observed doesn't mean poor group performance. We observed cases where the dominant student helped to explain the concepts to others, and each group member still had opportunities to be engaged in the activity, leading to a good performance as a group. While some groups with no dominant student showed a group-work much more disorganized.

Through examining the group distribution of the central control object and group performance, this exploratory study also provided us some insights to interpret the visualized log data. For example, if the position and rotation of the control object was too widely distributed, it perhaps refers to the group work proceeded without a good coordination. If the control object was positioned in individual private space frequently, it might indicate that the group students had no sufficient awareness of each others' work.

The findings of this study can help researchers and teachers to interpret information about the group work progress. The visualization of on-going collaboration amongst students can provide a version of a cockpit's view for the teacher to orchestrate classroom activities. For example, since the classroom time is limited, with such kind of monitoring can help teachers to identify which group needs his/her intervention (e.g., the group with too widely

distribution of the control object). In other words, it has potential for providing teachers with the necessary information to arrange time and adjust instructions to meet concrete needs.

In the future work, we would like to provide and test such kind of visualization and its corresponding feedback in real classrooms to examine whether it helps teachers to facilitate group work in a better way. Besides, non-oriented content \cite{Kruger2004} of the central control may also influence the findings of this study. In our further study, we will also try to change the GO card from current a non-oriented content to a strongly-oriented content, to examine whether the findings are still consistent.

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