



PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
ESCUELA DE INGENIERIA

MOUSE-BASED INTERPERSONAL COMPUTER FOR INDIVIDUAL LEARNING

CRISTIÁN FELIPE ALCOHOLADO MOËNNE

Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering (or Doctor in Engineering Sciences)

Advisor:

MIGUEL NUSSBAUM

Santiago de Chile, August, 2013.

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To my beloved family and friends.

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ABSTRACT

The introduction of technology to the classroom can be very beneficial if it is integrated with a pedagogical intention. Among them is the possibility of increasing students' participation by generating an active learning, the capability of giving personalized feedback based on performance. One of the main restrictions regarding the adoption of technology in the classroom is the acquisition and maintenance cost of equipment. Solutions to solve this problem have tried to minimize the price of computers and provide one to each student. The main project of this trend has been the One Laptop per Child, which seeks to diminish acquisition cost of computers to 100 dollars each. This price is still prohibitive for many countries, particularly low-income nations which motivates seeking for other solutions

Shared Display Interpersonal Computer proposes an efficient usage of resources. It uses one computer, a projector and a mouse per student to achieve low-cost massive interaction in the classroom. Although this tool is attractive economically, its use has not been widely adopted. Pedagogical integration of this technology has mainly focused on group activities. This limits content provision to be performed synchronously among student without considering the work pace.

This thesis presents a model for individualized learning for the Shared Display Interpersonal Computer. It seeks to provide students a zone of interaction within the

system which allows them to work individually at their own pace. The model also proposes teacher integration within the system by its own input device. A zone dedicated for teachers contains information about students' performance and additional tools to control the system.

The validation of this model was done in the context of basic arithmetic learning. The system was used on several Chileans schools and an experience in India, all students between 8 and 10 years old. The objective was to understand the viability of the system, considering its usability and its feasibility of implementation in other cultural settings. Results showed that the system was easy to use for students and it was most beneficial for students with lower initial scores. Another goal of this thesis is to understand the difference of the Shared Display Interpersonal Computer and similar technologies. The selected technologies were laptop and laboratory desktop computers. Experimentation results showed that technologies were not the relevant factor themselves but its characteristics were. Particularly, the capability of a technology to provide instant feedback and allowance of peer-interaction were the main factors that determined learning.

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Keywords: Interpersonal computer, Shared display, Arithmetic teaching, One Mouse per Child, Multiple mouse, Interactive Learning.

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PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
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COMPUTADOR INTERPERSONAL BASADO EN MOUSE PARA EL APRENDIZAJE
INDIVIDUALIZADO

Tesis enviada a la Dirección de Investigación y Postgrado en cumplimiento parcial de los
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RESUMEN

La introducción de tecnología al aula trae múltiples beneficios si es integrada con un fin pedagógico. Entre ellos está la posibilidad de aumentar la participación de los estudiantes generando un aprendizaje activo de estos mismos, la posibilidad de dar retroalimentación personalizada en función del desempeño. Una de las principales restricciones de la adopción de tecnología en la sala de clases ha sido el alto costo de adquisición y mantención de los equipos. La principal respuesta ha sido minimizar el precio de cada computador para proveerle uno a cada estudiante. En esta línea destaca el proyecto *One Laptop per Child*, el que busca disminuir los costos a 100 dólares por computador. Ese precio es aún prohibitivo para muchos países, particularmente aquellos de escasos recursos lo que motiva la búsqueda de alternativas.

El computador interpersonal de pantalla compartida propone una forma eficiente del uso de recursos. Utiliza sólo un computador, un proyector y un mouse para cada niño, logrando interacción masiva en la sala de clases a bajo costo. Si bien esta herramienta resulta atractiva económicamente, el uso de ella ha sido relativamente acotado. La integración pedagógica de esta tecnología ha sido utilizada principalmente para actividades grupales. Esto limita a que el contenido debe ser provisto de forma síncrona a los estudiantes sin contar con un ritmo de trabajo personalizado para cada aprendiz.

Esta tesis presenta un modelo de aprendizaje individualizado para ser el Computador Interpersonal de Pantalla Compartida. Este busca proveer a los estudiantes un espacio de interacción en el cuál puedan trabajar individualmente al ritmo de cada aprendiz. El modelo propone la integración del profesor dentro del sistema con un dispositivo adicional. Este posee una zona dedicada con información sobre el desempeño de sus estudiantes y herramientas adicionales que permiten tomar control del sistema.

La validación de este modelo fue realizada en el contexto del aprendizaje de aritmética básica. Se utilizó este el sistema en diversas escuelas de Chile y una experiencia en India, todas con alumnos de entre 8 y 10 años. El objetivo era comprender la viabilidad del sistema, tanto en su usabilidad como la factibilidad de implementación en otros contextos culturales. Los resultados obtenidos muestran que el sistema fue fácilmente utilizado por los estudiantes y resultó más beneficioso para los estudiantes con peores resultados iniciales. Otro objetivo de esta tesis era el de entender las diferencias entre un Computador Interpersonal de Pantalla Compartida con otros sistemas similares. Las tecnologías seleccionadas fueron, computadores portátiles y computadores de escritorio en un laboratorio de computación. Los resultados experimentales mostraron que las tecnologías no eran en sí los elementos clave para la ejercitación, sino sus características. Particularmente, la capacidad de las herramientas de proveer retroalimentación instantánea y la posibilidad de los pares de interactuar determinaban directamente el aprendizaje.

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Palabras Claves: Computador Interpersonal, Pantalla Compartida, Enseñanza de Aritmética, Un Mouse por Niño, Múltiples Mouse, Aprendizaje Interactivo.

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I. INTRODUCTION

Technologies rapid evolution has affected our lives over the past decades; communication has become instant, entertainment systems have penetrated our houses and most jobs can be performed or controlled over a computer. Opposite to this, classrooms have not changed at the same pace being primarily centered on a one-directional teacher-based classroom, leaving students not able to be participants of their own learning. Technology has been promised to change this. It can augment participation, make activities more engaging and achieve individualized learning for each student. Several organizations have set their goals to achieve a 1:1 model, which is providing each student a laptop of its own. Governments from around the world have spent plenty of resources to achieve this model with mixed results. This level of expenditure is not possible for most countries particularly for developing regions which center their few resources on food and health. To deal with this issue, several solutions have tried to diminish the cost of technology, mostly meaning cheaper laptops.

The interpersonal computer is a solution that has been used over past years. It deploys a single computer with multiple input devices to create massive interaction on a shared display. Investigators have applied this model for educational purposes with mixed results. They were able to achieve massive interaction within the classroom but have found difficulties in providing feedback to each student due to the lack of space on screen. This thesis presents a model that allows individualized feedback for each student using the abovementioned system. It seeks to place the interpersonal computer as a real alternative for educational purposes by studying concerns such as its usability and its capability to achieve individualized learning.

This chapter is divided in two sections; (1) fundamental bases of the thesis and (2) related work. Section 1 starts by presenting a theoretical background, which covers a literature review of discussion and arguments related to the main topics of the thesis. This is followed by a listing of the hypothesis, research questions and objectives based on the presented literature. The methodology used to achieve research goals is also detailed. Finally, this section relates the findings of the thesis with the theoretical basis as well as the limitations of it. Section 2 includes related work to the thesis outside the investigation itself. At first, it includes details on system architecture and technical aspects on the implementation of the thesis software. Finally, it presents a study originally intended for this thesis as well as work done on other other uses of the Interpersonal Computer.

I.1 Theoretical Background

I.1.1 Interactive learning

Classroom teaching has usually been based on the one directional interaction of teachers to their students (Pontefracta & Hardman, 2005), centered mainly on the transmission of knowledge, a practice that has not been proven to be effective to guarantee learning (Shechtman & Leichtentritta, 2004). The introduction of technology to the classroom seeks to change this paradigm by allowing interactive learning, enabling student participation and augmenting the amount of reflexive thoughts (Beauchamp & Kennewell, 2009). Nevertheless, introduction of technology into the classroom is not enough to achieve a better quality of learning (Robertson, 2003).

Wood & Malley (1996) state that technology provides powerful tools to achieve interactive and collaborative classroom experiences, which can generate pedagogical

benefits. The role of technology in education can amplify the resources of the classroom, augment student motivation to perform curricular task and mediate thinking and learning (Deaney, Ruthven, & Hennessy, 2006).

Educators and specialists consider that student participation generates better conditions for learning (Lim, 2008; Ahles & Contento, 2006). Active participation of students in their own learning process generates better results (Zurita & Nussbaum, 2004), improving their perception of self-effectiveness (Hamman, Fives, & Olivarez, 2007) and developing reflexive meta-cognitive processes, increasing student commitment to their own learning (Dede, 2009). The quality of active participation is one of the main focuses of studies of nowadays educational proposals (Shulman, 2005).

I.1.2 Feedback

Learning is commonly conceptualized as a process whereby students actively construct their own knowledge and skills, as opposite to the old vision of a simple acquisition process based on teacher transmission (DeCorte, 1996; Barr & Tagg, 1995). Under this focus, feedback in performance is arguably the basis of formal and informal learning (Brown & Knight, 1994; Biggs, 1999). The advantages of using feedback on computer-based activities are direct since they can provide an instant response for each student based on their actions. There is little disagreement about the efficacy of incorporating active responding and knowledge of results into computer-based instructional units (Zemke & Armstrong, 1997).

A common type of feedback used on computer-based activities is Formative Assessment. It refers to assessment that is specifically intended to generate feedback on performance to improve and accelerate learning (Sadler, 1998). The main aim of

formative assessment is to increase student knowledge, skills, and understanding in some content area or general skill, and there are multiple types of feedback that may be employed toward this end. Tittle (1994) asserts that assessment must have meaning for students and teachers in relation to teaching and learning'. Nicol (2006) proposes 7 principles for formative feedback to be useful and meaningful for students:

1. Helps clarify what good performance is
2. Facilitates the development of self-assessment (reflection) in learning
3. Delivers high quality information to students about their learning
4. Encourages teacher and peer dialogue around learning
5. Encourages positive motivational beliefs and self-esteem
6. Provides opportunities to close the gap between current and desired performance
7. Provides information to teachers that can be used to help shape the teaching

Benefits from formative assessment are various. It can signal a gap between a current level of performance and some desired level or goal. Resolving this gap can motivate higher levels of effort (Locke, Latham, Smith, Wood, & Bandura, 1990; Song & Keller, 2001). It can also reduce uncertainty about how well (or poorly) the student is performing on a task (Ashford, Blatt, & Walle, 2003). It can effectively reduce the cognitive load of learners, especially novice or struggling students (Paas, Renkl, & Sweller, 2003).

I.1.3 Interpersonal computer based on mouse

Mainframes were the first computers designed on the early 70's. They were designed to be used by a single user sited in front of a single display, a model which is still widely

inherited on laptops and desktop computers. Nowadays, this paradigm has opened to new types of interaction such as touch surfaces (Morris, Fisher, & Wigdor, 2010), mobile devices (Zurita & Nussbaum, 2004), interactive furniture (Dillenbourg, Jeffrey, & Mauro, 2009) or Single Display Groupware (Stewart, Bederson, & Druid, 1999). The later allows multiple users to share a single display. Stewart (1999) shows that this model has several advantages opposed to each user having a display; it enables collaboration by reducing social barriers, creating new types of interactions and encouraging peer-learning and peer-teaching. The author sees the screen size and user navigation as the main drawbacks of this model.

A similar case of the Single Display Groupware is the Interpersonal Computer. This system is defined as a computer which allows multiple users located on the same physical space each with an input device, to interact simultaneously on a shared space (Kaplan et al, 2009). It differs from the SDG by each user having an input device and does not define the shared space as a display, which has been used with other types of elements (Bachour, Dillenbourg, & Kaplan, 2008). Single Display Groupware is usually referred on the literature as collaborative. The Interpersonal Computer is not associated with collaboration, although it may be used for it.

The use of multiple devices has been studied by several authors who have demonstrated the impact of peers working together on the same screen (Paek et al., 2004). In an educational context, results show that students controlling their own input device on a shared display scenario show less signs of boredom, less disruptive actions and are more active during activities. This suggests a greater engagement towards the activity (Scott, Mandryk, & Inkpen, 2003). One of the main advantages of each student having an input device makes them be participants in their own learning (Infante et al, 2009).

In an educational context, the mouse is recognized as one of the more appropriate input devices for children, being widely used in computer related task for education (Donker & Reitsma, 2007; Wood et al, 2004). This device is used by different students in very different context because of its flexibility. It also covers a large range of users, as the mouse can be efficiently used in simple interfaces by children older than 5 years old (Lane & Ziviani, 2010).

The bonding of an interpersonal computer with a mouse has been explored by previous investigations (Amershi et al, 2010). The most relevant related project is the Microsoft Mouse Mischief, which allows up to 32 students to answer, by its own mouse, a set of pre-defined multiple choice questions (Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009). This initiative showed it was possible to generate massive interaction on a classroom by using a mouse-based Shared Display Interpersonal Computer but it lacked the ability to provide individual feedback to each student (Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009). The main difficulty found was the shared screen, the amount of cursors on-screen and the deployment of information, which authors describe as “chaotic” (Moraveji, Kim, Ge, Pawar, & Mulcahy, 2008). This allowed them to provide only group feedback while individual feedback was reduced to color changes on each student’s cursor (Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009).

I.1.4 School integration

Ertmer (1999) proposes a model for ICT integration on the schools. It is defined by first and second order barriers. First-order barriers refer to a lack of proper resources such as equipment, training and support. Second-order barriers are teacher related and are described as inner beliefs of teachers, referring mainly to human variables. Examples of

this beliefs are teaching methods, time management style and assessment types. Infante (2010) adds a third-barrier to the proposed model related to teachers and students need.

The first-barrier in (Ertmer, 1999) model is mainly determined by resources which are normally overcome with money and it is one of the main subjects of discussion for educational policy. This makes acquisition price of technology a relevant matter for low income schools/countries. To overcome this, several projects have tried to reduce the cost of equipment to a minimum. The two main projects of this kind are the Intel World Ahead Program (Intel Corporation, 2006) and the One Laptop per Child (One Laptop per Child Foundation, 2006). Both are based on a common technology model in education which is to provide each student a computer (Weston & Bain, 2010). This model, noted as 1:1, has been adopted widely in multiple countries such as Uruguay, Portugal, and Venezuela. The One Laptop per Child Foundation has set its long term goal to be 100 USD for each laptop. Kraemer et al. (2009) has stated that the acquisition cost is near 200 USD and has not drop down on the past years.

According to Vital Wave Consulting (2008), the true cost of having and implementing a 1:1 model of 100 USD per laptop is 400 USD. This is because the acquisition cost of the equipment does not consider recurrent costs (support, training, etc.) and hidden costs (repair of equipment, planning, etc.). Even if the expenditure was only of a 100 USD, it would still be too expensive for most low-income countries (Trucano M. , 2010). However, it is expected to see a rise on 1:1 computer programs worldwide, mainly because of the versatility of the personal computer (Zucker & Light, 2009).

The implementation of a mouse-based Shared Display Interpersonal Computer comes as an alternative to introducing computers to developing regions due to its relatively cheap implementation. It consists on a laptop, a projector, mice, USB hubs and cables. This

model for a 40 student class cost around 1000 USD, depending on the hardware specifications and seller. Compared to the acquisition cost of 200 USD (Kraemer, Dedrick, & Sharma, 2009) for a 1:1 model the Shared Display Interpersonal Computer costs 87.5% less. If the solution is shared between 10 courses of 45 students over 2 years, it cost around a 1 USD per student (Trucano, 2010).

Although the mouse-based Shared Display Interpersonal Computer seems attractive economically, this is not the only relevant element for an educational purpose. The introduction of innovative technology to a classroom does not necessarily generate a pedagogical innovation. Groff (2008) states that a problem for the correct integration of innovative technology is the incapability of students to adapt efficiently to systems. This is reinforced by Bielaczyc (2006) which says there is a need for better structure of the class and Penuel et al. (2007) shows that the different characteristics of students are key for a correct integration of technology into the classroom. Zhao (2002) defines a framework which involves 11 factors as conditions for a technology innovation to be properly used. They are grouped into 3 main groups; the project (innovation), the teacher (innovator) and the school (context).

1. The project: The technology related problems of integration are divided in two: dependence and distance. Dependence is the needs of the innovation to be implemented and how they are bonded to elements beyond the control of the teacher. Distance is related to how similar to school characteristics is the current innovation. This involves the difference with current practices, technologies and culture. The latter has been studied by several authors and impact on several levels; teachers' reactions to technological innovations are mediated by their cultural perceptions (Watson, 1998) and both the initial

acceptance and future success depend on cultural perceptions toward technologies (Chen, Mashhadi, Ang, & Harkrider, 1999; Loch, Straub, & Kamel, 2003).

2. The teacher: Zhao (2002) describes the teacher as the innovator since he's responsible for the actual pedagogical innovation. This is reinforced by Harris et al. (2009) who states that successful integration of technology for education has to focus pedagogy over technology. Even though, several teacher related factors have to be tackled in order to be successful. Li (2007) determines that an obstacle for the integration is the degree of comfort with teaching itself. Teachers must be comfortable with the tool both technically and pedagogically.
3. The context: The proper integration of technology in education must address availability of resources and constant support for tool usage, among others (Williams, Coles, Wilson, Richardson, & Tuson, 2000). This condition is related to school logistics and it's directly related with the availability of resources described by Ertmer (1999) as first level barriers.

Under this context, there is a lack of evidence to support the correct integration of the mouse-based Shared Display Interpersonal Computer as a true pedagogical innovation rather than a cheaper solution to the 1:1 model.

I.2 Research Hypotheses

To develop the work of this thesis, three hypotheses were constructed as base for the studies implemented:

1. It is possible to generate a model which allows individual learning for each student using the Shared Display Interpersonal Computer.
2. Using an individualized learning system for basic arithmetic content, there is no difference in student's learning outcome between a Shared Display Interpersonal Computer and a personal laptop computer.
3. Using an individualized feedback system for practicing basic arithmetic content, a Shared Display Interpersonal Computer in the classroom is more beneficial than Personal Computers on a Laboratory on student's outcome.

I.3 Research Questions

Three research questions were constructed to validate the previous hypotheses. The work presented on this thesis will be focused on answering the following:

1. Is it possible for all the students in a class to work simultaneously on their individual basic math problems at a shared display on just one computer and still achieve personalized learning with individual feedback?
2. Are there differences in children's learning outcomes and classroom behavior when they interact with an interpersonal computer and a personal device?
3. Are there any differences between interactive learning software on an Interpersonal Computer on a classroom settings opposed to a Computer Laboratory with a 1:1 student-computer ratio?

I.4 Thesis objectives

The aforementioned research questions seek to fulfill the following thesis objectives:

1. Develop a mouse-based model for the Shared Display Interpersonal Computer that's allows learning through individualized feedback for 30 or more students simultaneously.
2. Determine the difference between a mouse-based Shared Display Interpersonal Computer technology compared to a personal computer scenario, considering student's performance and class behavior.
3. Establish the benefits and disadvantages of using a mouse-based Shared Display Interpersonal Computer technology compared to traditional alternatives.

I.5 Research methodology

Design and implementation of new technological activities for learning proposes a series of challenges for researchers, due to the interdisciplinary nature of the activity. Design Research is a methodology that's seeks to study complex problems on real educational settings (Reeves, 2006; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006; The Design-Based Research Collective, 2003). It bonds empirical educational research, theoretical strategy-driven design and instructional tools. It seeks to study problems in their natural context which is normally more challenging compared to a laboratory scenario. Cobb et al. (2003) says that this methodology is commonly used on innovative proposals, probed on limited amount scenarios with interventionist practices and supported by an iterative process design, driven by discovery and validation of hypothesis.

The methodology used for this thesis is based on Design Research Research and consists of 7 steps of development and deployment. Steps are performed one by one, as described:

1. Literature review: Search of knowledge related to the subject of the investigation. According to the findings, objectives for the intervention will be defined.
2. Work model definition: To fulfill the objectives, a model/software is designed associated with experts on the subject. Variables to measure in and out of the software, hypothesis and expected results are defined. The goal is to evaluate the impact of learning and other aspects of teacher and students' behavior, considering the relevance, utility and alignment with the curricular context (Cox & Marshall, 2007; Reeves, 2008).
3. Software development: The previously designed model is implemented.
4. Software's testing: Features validation and performance of the solution is tested on a restricted scenario, which does not involve target users. The aim is to ensure the designed software in step 2 was implemented properly. If any problems arise these will be repaired.
5. Classroom testing: Features validation and performance of the solution is tested on a real scenario, involving similar students to the intended ones for the experimentation. They are not the same to minimize the risk of lowering motivation of students when performing the experiment. The goal of this step is to adjust software usability and non-technical aspects to the target students.

Common problems on this stage are lack of understanding of system interfaces or easy/hard activities.

6. Experimentation: The main goal is to perform and evaluate the work model defined in step 2. The design of the experimentation relies on the conditions imposed by the school normally being quasi-experimental. A test is performed prior and after the experimentation to control for variables defined in step 2. This test must be previously defined and obtain a Cronbach's Alfa higher than 0.7 (Cronbach, 1951). These value shows that the test has an acceptable capability of classifying students according to the contents provided (Bland & Altman, 1997).
7. Result analysis: Experimentation data is collected and analyzed to check hypothesis of step 2. Results and statistical methods depend on each experiment characteristics.

I.6 Research Limitations

This thesis presents several studies regarding the usefulness of an individual feedback model proposed for the mouse-based Shared Display Interpersonal Computer. These experimentations are performed on students in real settings, since they are complex scenarios to emulate elsewhere and thesis goals are related to real life context. This empirical approach, broadly used on this field, has certain limitations regarding its capability to generalize findings based on the evidence found. This implies that studies results may not repeat under different contexts and should serve as a reference to others as they approach the matter.

Designed research approach activities focus the development of a particular object (software) to intervene a certain set (students) and analyze results, through an iterative process. In this thesis, the contexts of research are classrooms which are very complex scenarios. They are a mixture of physical and human variables. From a researcher view, these variables include physical space, furniture and the teacher, besides the students. Although physical variables can be controlled as constraints or minimum requirements, human variables cannot. A common approach to control these variables is to systematically control pedagogical practices by teacher training and standardization on a process called orchestration (Dillenbourg, Nussbaum, Dimitriadis, & Roschelle, 2013). Issues in this particular regard are beyond the scope of the research of this thesis and are discussed on section I.9.2.

Finally, this thesis does not pretend to replace traditional lectures on math or any subject. It is an alternative model of technology which allows 1:1 interactivity by a low cost solution. The application of this model is a decision for teachers and researchers to make regarding classroom usage, physical space limitations and/or software changes to their particular need.

I.7 Thesis Structure

This thesis is structured around 3 research objectives abovementioned: (1) Develop a mouse-based model for the Shared Display Interpersonal Computer that's allows learning through individualized feedback for 30 or more students simultaneously, (2) Determine the difference between a mouse-based Shared Display Interpersonal Computer technology compared to a personal computer scenario, considering student's performance and class behavior and (3) establish the benefits and disadvantages of using

a mouse-based Shared Display Interpersonal Computer technology compared to traditional alternatives.

The thesis' elements are summarized on Table I.1. Elements are encoded by type, which can be hypothesis, questions, objectives, papers and results. The relations between elements are shown in Figure I-1, denoting each element by a circle and an arrow to represent a directed relationship.

Table I.1: General structure of the thesis

Hypotheses	
H1	It is possible to generate a model which allows individual learning for each student using the Shared Display Interpersonal Computer.
H2	Using an individualized learning system for basic arithmetic content, there is no difference in student's learning outcome between a Shared Display Interpersonal Computer and a personal laptop computer.
H3	Using an individualized feedback system for practicing basic arithmetic content, a Shared Display Interpersonal Computer in the classroom is more beneficial than Personal Computers on a Laboratory on student's outcome
Questions	
Q1	Is it possible for all the students in a class to work simultaneously on their individual basic math problems at a shared display on just one computer and still achieve personalized learning with individual feedback?
Q2	Are there differences in children's learning outcomes and classroom behavior when they interact with an interpersonal computer and a personal device?
Q3	Are there any differences between interactive learning software on an Interpersonal Computer on a classroom settings opposed to a Computer Laboratory with a 1:1 student-computer ratio?
Objectives	
O1	Develop a mouse-based model for the Shared Display Interpersonal Computer that's allows learning through individualized feedback for 30 or more students simultaneously.
O2	Determine the difference between a mouse-based Shared Display Interpersonal Computer technology compared to a personal computer scenario, considering student's performance and class behavior.
O3	Establish the benefits and disadvantages of using a mouse-based Shared Display Interpersonal Computer technology compared to traditional alternatives.
Papers	
P1	One Mouse per Child: interpersonal computer for individual arithmetic practice
P2	Interactive learning: a comparison of individual and interpersonal computer technologies with pen-and-paper
P3	A comparative analysis of interactive arithmetic learning in the classroom and computer lab
Results	
R1	A model which allows all students in a class to participate simultaneously at their own pace by providing individualized feedback using a mouse-based Shared Display Interpersonal Computer.
R2	It is possible to implement Shared Display Interpersonal Computer on diverse cultural and infrastructure settings.
R3	The provision of individual feedback can be provided publicly (shared display) and obtain similar results to private (1:1 display) provision.
R4	The provision of instant feedback allows student to be more efficient at learning on technology based activities for arithmetic exercising opposed to pen-and-paper drill.
R5	The usage of a Shared Display Interpersonal Computer in the classroom is more efficient for math exercising compared to personal computers on laboratory settings due to peer-interaction.

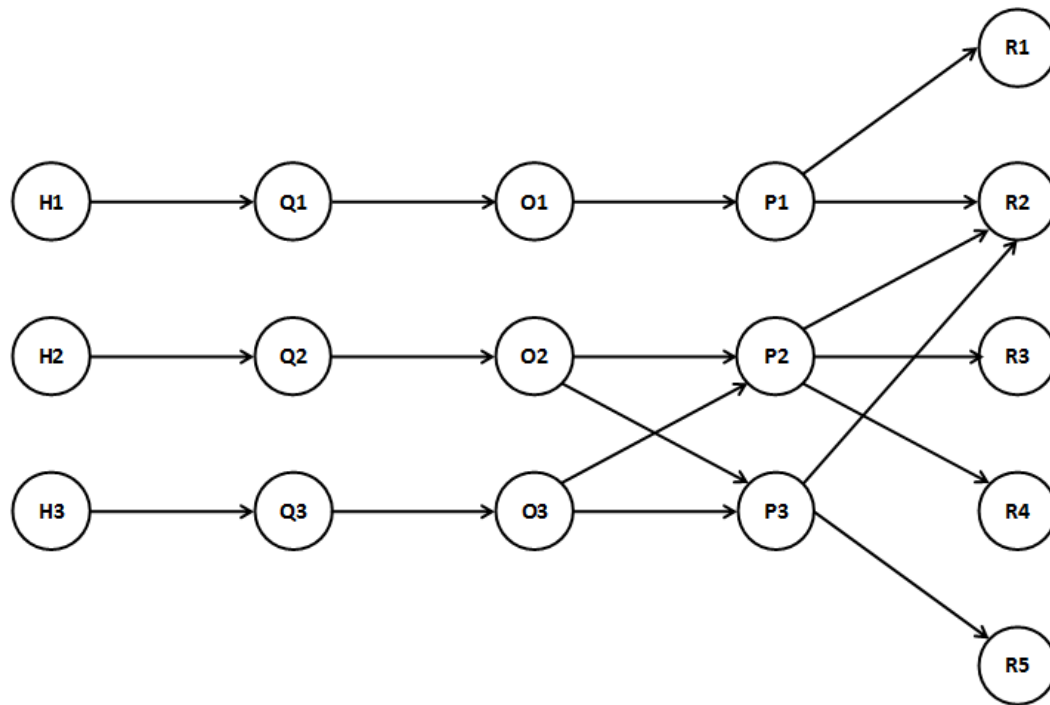


Figure I-1: Association diagram of relationships between Thesis components

Responding to hypothesis H1, i.e., “It is possible to generate a model which allows individual learning for each student using the Shared Display Interpersonal Computer.”, and the related research question Q1 and objective O1, paper P1 proposes R1 which is a model which allows all students in a class to participate simultaneously at their own pace by providing individualized feedback using a mouse-based Shared Display Interpersonal Computer. Paper 1 also leads to R2, which is that *it is possible to implement Shared Display Interpersonal Computer on diverse cultural and infrastructure settings*, through a multi-cultural study of India and Chile. This finding is extended by the works on P2 and P3, validating several other contexts while preserving the characteristics found on R2.

In response to hypothesis H2, i.e., “Using an individualized learning system for basic arithmetic content, there is no difference in student’s learning outcome between a Shared Display Interpersonal Computer and a personal laptop computer.”, and the related research question Q2 and objective O2, paper P2 compares a Shared Display Interpersonal Computer with a Personal Computer over the course of a year leading to the R3, *the provision of individual feedback can be provided publicly (shared display) and obtain similar results to private (1:1 display) provision*. Also linked to P2, Objective 3 seeks to *establish the benefits and disadvantages of using a mouse-based Shared Display Interpersonal Computer technology compared to traditional alternatives*. This objective was analyzed on P2 and several differences were encountered regarding student’s behavior the main leading to R4, *the provision of instant feedback allows student to be more efficient at learning on technology based activities for arithmetic exercising opposed to pen-and-paper drill*.

Finally, hypothesis H3, i.e., “Using an individualized feedback system for practicing basic arithmetic content, a Shared Display Interpersonal Computer in the classroom is more beneficial than Personal Computers on a Laboratory on student’s outcome”, and the associated research question Q3 and objective O3, paper P3 compares the usage of Shared Display Interpersonal Computer in a classroom to a Personal Computer on Laboratory leading to the R5, *the usage of a Shared Display Interpersonal Computer in the classroom is more efficient for math exercising compared to personal computers on laboratory settings due to peer-interaction*. O2 is linked to P3 since it adds new dimensions over the comparison of a mouse-based Shared Display Interpersonal Computer technology compared to a personal computer scenario regarding how the infrastructure affected peer-interaction, thus affecting students learning (R5).

The above described research questions have all been answered through three research papers validating the thesis hypotheses. The results obtained from these studies are related together on the Section I.10. All questions leads to the feasibility of implementing a mouse-based Shared Display Interpersonal Computer solution as a real alternative for educational implementation opposed to 1:1 model due to its capability of providing individualized feedback, the diversity of implementation scenarios and the contrast of results opposed to personal devices.

I.8 System architecture

A detailed description of the system architecture used throughout the experiences described in this thesis is included in Appendix A.

I.9 What else did we learn?

I.9.1 Technical Aspects

The challenge of enabling a 42 student mouse-based simultaneous activity involves several technical solutions in order to be achieved. No investigator or developer has reported to achieve as many students being Moraveji (2009) the closest with 32 mice on the same class. In the previous case, students interacted with the system in small groups so not all of them were working simultaneously, which is much less information to be handled simultaneously. While implementing a 40 students solution, several problems were encountered which has not been addressed before. These difficulties were mainly in 3 aspects of the system; hardware, software and class integration.

I.9.1.1 Hardware

The implementation of the mouse-based Shared Display Interpersonal Computer solution involved several types of hardware component to be integrated together. This included a projector, one computer, mice, USB hub and cables. It was intended that the hardware should be relative inexpensive in order to be attractive as a solution for developing regions

I.9.1.2 Projector

Technically most projectors do not have problems being integrated with a Shared Display system. Its main implication, and constraint, is their resolution. This determines the interaction space for each student, a relevant concern when developing the system because the sizes of elements are determined by the classroom implementation and not the resolution. To clarify, the actual size a student sees is mainly determined by the distance of the projector to the projection and not by the amount of pixels. If the entire screen was populated with rectangle-shaped individual spaces, one for each student, on 800x600 pixel resolution each space would have 114x100 pixels. This space is relatively small for drawing multiple elements in it. In contrast 1024x768 pixels, the next commonly used resolution, provide 63% more area for drawing in each space and it is preferred because it allowed the interface designed for the experiment to fit properly. At the moment of the implementation, the cost of a projector with a 1024x768 pixels was relatively expensive compared to achieving 800x600 pixels. Therefore, this last resolution was used through the experimentation and the proper interface changes had to be addressed.

I.9.1.3 Computer

The only bottle-neck characteristic of an implementation of a mouse-based Shared Display Interpersonal Computer with nowadays technical specifications of computers is the CPU. As is discussed on the software section, on a Windows based solution the power of the CPU to process multiple input is determined by the maximum clock speed of its cores since it's a non-parallel task. The CPU's used on the experiments varied from 1.8 to 2.7 ghz and due to empirical observations it is recommended to use a 2.0 ghz dual core with at least 1 MB L2 cache memory. This specification is normally met by all commercial laptop or desktop computers.

I.9.1.4 Mice

Individually, most USB mice work with the system including corded and wireless solutions. Aligned with the low-cost solution goal of this technology, corded mice were used over wireless since its commercial value is around one fifth of the value. Technical specifications are needed for using wireless mice simultaneously. It is recommended that wireless mice use 2.4 ghz communication with channel hopping which allows the device to use a specific channel and not to be interfered by others.

The maximum range of the device is inversely proportional to the number of devices simultaneously working together. As a reference, we were able to achieve 20 devices with up to 8-9 meters range.

I.9.1.5 USB hub and cables

Theoretically, USB 2.0 imposes several restrictions but mainly 3 are relative to multiple mice usage; (1) the distance between a powered USB source and a device or other source should not be above 5 meters, (2) the hierarchical composition of a USB system

should not have a depth of more than 5 levels and (3) the maximum number of devices connected to a single host is 127. Practically, these restrictions depend on the quality of the devices involved and after extensive usage it is recommended using USB cables with no more than 3.5 meters length, only 4 levels of depth in the hierarchal composition and the total number of devices is relative to the OS, as will be discussed on the software section. Finally, for a good overall performance, it is important that the the USB be connected to an electric supply.

I.9.1.6 Software

The software used for this mouse-based Shared Display Interpersonal Computer implementation was the MultiPointSDK which is a Microsoft technology; therefore software related restrictions and advices are on a Windows based environment. The SDK promoted that it could handle up to 250 mouse devices simultaneously but several test conducted on the original system showed that with more than 15-20 devoces the system would freeze. Microsoft provided us the source code of the SDK in order to solve this problem.

USB mouse devices input messages interrupt CPU normal processing as they will be processed on arrival. The refresh rate for a normal USB mouse is 60Hz which in a 40 mice environment means 2400 messages for the CPU to process. Windows does not support input processing parallelizing, so a single core must handle all the messages. A stress test with real mouse was performed in order to analyze CPU behavior. This showed that pre-processing mouse messages, functions done before handling the incoming message, was consuming a significant amount of processing time. This was analyzed and changed in order for the system to allow more devices. A time-based filter

was created in order to prevent the method from being called and consume CPU's resources. This means that the system would dispose incoming system messages and considered them as handled when the time between messages was less than a customizable value. By doing this, mouse latency could be reduced without any modification of the USB port and up to 43 devices could work simultaneously correctly on a laptop with characteristics discussed on the hardware section.

Another encountered problem was that in a Windows environment it is not possible to recognize more than 43 devices to a single USB host. This number may vary depending on the amount of USB hubs used to connect the devices. Several ideas were tested to solve this problem considering hub connection strategies, Windows USB driver controller replacement and different models of USB cards (including USB 3.0). None of the test successfully solved the device restriction. The hypothesis to explain this difficulty is that Windows has set a maximum number of USB devices per host. Since Windows is not open source this hypothesis cannot be proved. Therefore, even though 42 students and 1 teacher have been achieved to work simultaneously, it is not recommended. We conclude by experimental observations than 40 students and 1 teacher is stable and, with proper hardware, should work in most situations.

I.9.2 Individual feedback for multiple-choice systems

This experiment was designed as part of the main thesis but it was not able to answer its research question. Audience responses systems or clickers allow teacher to collect answers from their students and provide them feedback according to their results. The main objective of this investigation was to show a model that would allow students to provide individual formative assessment in a clicker scenario within the classroom. This

objective was founded on the hypothesis that by introducing individual formative assessment, there would be a better understanding from the student of the current subject because it would be working at their own pace. No evidence was found to statistically sustain the hypothesis which did not allow the research question to be answered. This section contains a brief description of the experiment and an analysis of the results found

I.9.2.1 Motivation

One of the most popular Interpersonal Computers within education is clickers. These systems allow each student to respond to a common question by its own input device, normally a remote controller. Their main advantages in pedagogy are their ability to retain attention (Trees & Jackson, 2007), higher participation due to anonymity (Martyn, 2007) and their capabilities of building knowledge on groups or individually (Crouch & Mazur, 2001). According to Barber & Njus (2007), due to their popularity, which clicker system to use will be a debate over future years.

One of the main disadvantages is that the feedback occurs on a group level, and each student is only provided with which answer was correct. It is the teacher's responsibility to provide feedback, therefore keeping the same pace for the whole class. Considering the relevance of clicker systems on education and the limitations regarding it, arises the research question: Which are the differences between a multiple-choice Shared Display Interpersonal Computer with group feedback opposed to an individual version?

I.9.2.2 Technology

To answer the research question, 2 softwares were designed. Both were based on a Shared Display Interpersonal Computer and used a similar interface with the same content. Each student had its own space within the shared display in which he can

answer what the system asked them. A list with the results from previous answers of all students is shown on the right side of the screen using a color system to show if the question was correctly answered or not (Figure I.2-D). The detail of each system will be shown on the next Section.

I.9.2.2.1 Group multiple-choice feedback

This software allows teacher's to ask questions to students as they normally would on an audience response system, with the difference that the input device is a mouse. Figure I.2 shows the software's interface. The system shows a question to all students (Figure I.2-A), which have an individual space to answer (Figure I.2-B) by selecting the proper answer to the current question (Figure I.2-C). Each student must select its own answer by clicking its own symbol, after which the system hides the selected answer to minimize cheating.

The teacher can reveal the correct answer at any given time. By doing this, each student will be shown its answer with added information showing whether it was correct or not. Information about percentage of students which answered correctly will appear on the screen (Figure I.2-C). The teacher has as much time as he wants to provide feedback to his students. When the group feedback is done, the teacher will proceed to the next question starting the process again. The progress of all students is shown by a ranked grid, showing students with higher number of right answers first (Figure I.2-D). Corrects answers are shown in green, wrong in red and non-submitted answers are white.



Figure I.2: Group multiple-choice feedback system interface

I.9.2.2.2 Individual multiple-choice feedback

The Individual multiple-choice feedback software additionally uses 2 paper-based guides. First, a guide which has all questions and answers. It also has relevant information for the lecture, such as text and/or pictures. A second guide contains feedback for each incorrect answer of the first guide. Each feedback is a small text intended for students to understand the reason why their answer was wrong.

The software serves as a mediator between both guides, telling students which part of each guide to read. Students are asked questions which they have to answer. If they answer correctly, another question is asked. If the answer is wrong, the system tells the student the reason why the selected option was wrong by telling which feedback to read.

The interface is similar as presented for the group version, except it does not have sections A and C, since it is an asynchronous system where each student advances at

their own pace. Each student individual space is shown on Figure I.3-A. Attached to it, a smaller circle shows which action should the student perform; confirmation or respond.

1. “C” notates that the student should confirm which item of the guide they are reading, denoted by its id (Figure I.3-B). In order to confirm an item, they must select the first two letters of the text.
2. “R” notates that the student should respond the current question by entering the letter they think is correct.

Whenever a student desires to confirm or respond, it must select it from a list of options (Figure I.3-C) and confirm it by clicking its symbol (Figure I.3-D). The system then provides feedback whether the answer was correct or incorrect (Figure I.3-E).

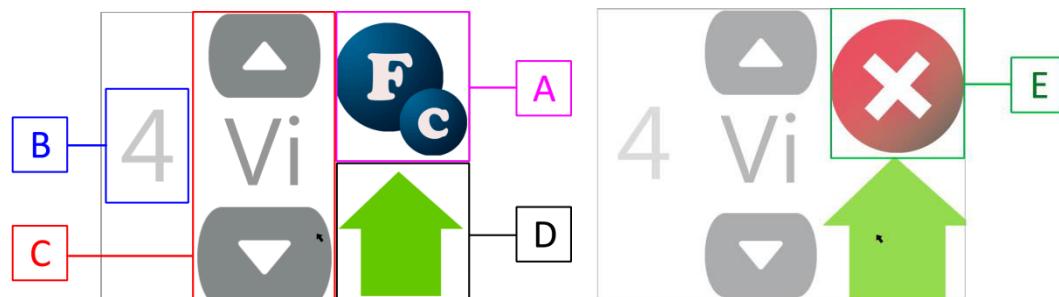


Figure I.3: Students work interface for individual multiple choice feedback.

I.9.2.3 Experimental design

The study was performed with 43 students from 7th grade course, aging between 11 and 12 years old. The school includes primary and secondary education and is partially subsidized. It is located on the capital of Chile and its students come from low-medium socioeconomic level.

Students were divided randomly into 2 groups of similar size. The intervention was designed for Language and Communication subject according to the instructional goal of

“Analyzing comprehensively literary and non-literary text”. This objective corresponds to the curriculum defined by the Ministry of Education and students were facing it for the first time. A standardized test was conducted prior and after the intervention. The instrument used was the “Reading Comprehension Progressive Complexity Test” and it is used to measure reading skills on students. It has specific test for each school level, but for this experience only the 7th graders version was used. The test obtained a Cronbach’s alpha (Cronbach, 1951) of 0.76 and 0.75 on the pre and post-test respectively.

The study consisted in 8 sessions each lengthens 90 minutes for each group. Each session was designed by an expert in the subject, being the same content and questions for each technology. Sessions were divided into 2 parts. First, a PowerPoint based class where students were exposed to a literary or non-literary text and several questions were exemplified by the teacher. Finally, students performed 20 questions according to the technology they were assigned.

Each group was observed throughout each activity by the same person. The objective was to understand what happens within each class through time. This was done by looking for several students’ behavior or attitudes and pointing them on specialized software, which also kept record of the time of each event. Each observed variable as well as its explanation is presented on Table I-2. Observers could write freely at the end of each session to record information outside of the standardized data.

Table I-2: Observed variables for Individual feedback for multiple-choice systems

Objective	Variable	Description
Student's Behaviour	Satisfaction	Comments and gestures which express motivation and/or commitment with work development.
	Disruption	Non-constructive comments and gestures for the his/her work development or a peer
	Random work	Students which develop the activity without the working guide. Applies only to the individual group.
	Boredom	Comments and gestures that show tiredness and/or
	Competitiveness	Comments and gestures related to perform better than a peer.
	Collaboration	Comments and gestures between peers
System Usability	Teacher	The teacher explains to all the students software related questions.
	Students	One or more students ask the teacher software related questions.
Content Knowledge	Teacher	Number of times in which the teacher refers to the students on activity related issues.
	Students	Number of times in which the students ask the teacher for help on activity related issues.

Teachers were introduced to the system in a preliminary meeting and a real session was conducted previous to the experiment. Material used on each class was given to teachers 1 week before each session as well as a detailed guide with each question and answer with the proper explanation. Teachers were rotated between groups each session, to prevent the impact of teaching quality and style. Two school rooms were used during the experiment, which also was rotated as students were motivated more by one room over the other.

I.9.2.4 Results

Students' performance on the pre and post tests can be seen on Table I.3. It shows no significant difference between pre and post-test within each. Due to the lack of evidence

on effective learning no further results can be presented over pre post results. In the analysis section, an extended discussion over this problem is presented.

Table I.3: Experimental results for group and individual feedback groups.

Type of feedback	No. of students	Pre-Test		Post-Test		t	Significance	Cohen's d (Cohen, 1938)
		\bar{X}	s	\bar{X}	S			
Group	21	18.38	6.50	18.33	5.13	0.03	<i>0.51</i>	0.01
Individual	18	19.00	8.09	20.44	6.90	0.52	<i>0.30</i>	0.20

Observations result of boredom throughout each session is detailed by group on Figure I.4. It shows that the Individual feedback group consistently reported less signs of boredom, with a total of 45, compared to the group feedback which reported a total of 145. Also a statically significant correlation between boredom and class interruptions was detected ($r=0.68$; $n=16$; $p=0.004$). This was reinforced with reports given from the observer of the group feedback class which explained that sessions were “often disrupted” and “students were constantly asking the teacher to let them go out of the class”. We attribute this difference due to the synchronous work performed on the group system, which inevitable leads to students following the same pace of the class. Although this is one of the main concerns for teachers (Kennedy, 2005; Mitchell, Bailey, & Monroe, 2007), it follows a teacher-centered approach which does not respect each students need and therefore generates more boredom. Students find the work rhythm not suited for them, usually depending on the pace of the teacher and other student.

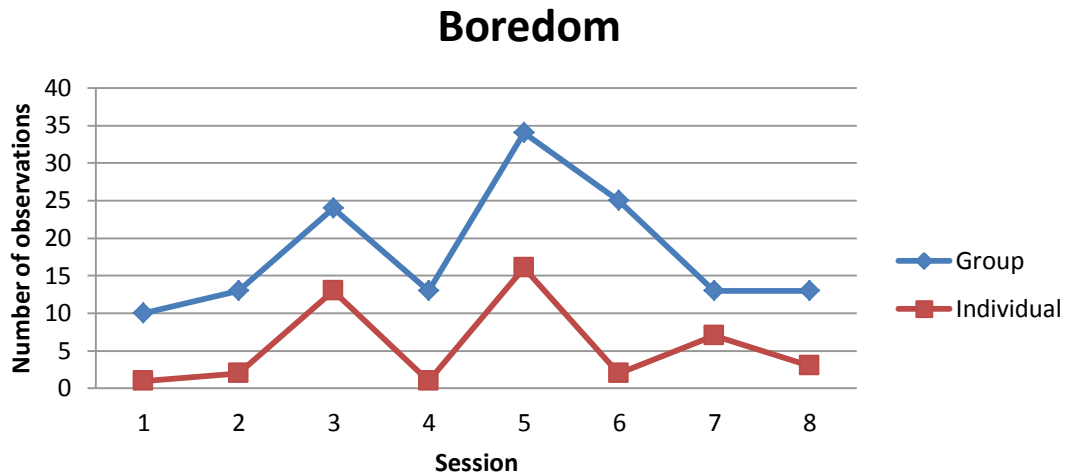


Figure I.4: Comparison graph of boredom observations per session

I.9.2.5 Analysis

The lack of significant evidence in the experimental results does not sustain the experiment hypothesis and therefore the research question could not be answered. A wide range of reasons may explain the encountered experimental results. Statistically, a lack of evidence is the incapability to sustain a given hypothesis. This implies that its validity cannot be determined. Therefore the analysis will be focused in the experimental flaws detected and how they would have affected the global outcome. The factors which may have led to a lack of evidence are described below.

Experimental sample: The total number of students involved in the experimentation was 40, which is relatively low for achieving statistically significant results ($\alpha=0.05$). It was part of the restrictions imposed by the school where the experiment was conducted. Table I.4 resumes the statistical factors of experimental design for each expected effect size difference between the groups. The activity performed on this experimental designed would have only showed statically difference if the impact of reading

comprehension was large according to Cohen's D. If the sample it's quadruplicated the effect size needed for statistically significant results is reduced to half, resulting on a medium effect. Still, this effect size is very difficult to achieve on a complex skill such as reading comprehension in few sessions if even possible.

Table I.4: Experimental design factors for expected effect size

Scenario	Sample Size	Error (α)	Power (β)	Expected effect size
Implemented	40	0.05	0.80	0.80
Ideal	160	0.05	0.80	0.39

Teacher factor: Although several measures were considered to prevent teachers from having a direct impact in the experiments results, observers reported that one of them performed badly over the experimentation. They stated that the professor lacked motivation and did not prepare classes as was originally agreed. It did not manage class situations, such as distracted students, and "*did not react to students talking loudly or not working*" as the observer stated. Even teacher understanding of the subject was questioned through the report as it follows:

"During part of the activity, the teacher doubted in front of the class the correct answer the software was giving. "It is reiteration not a metaphor" - she stated publicly. This answer was correct and teacher misleads all her students."

The problem encountered is inherently hard, since it involves several human aspects being teacher training the main related factor. This variable is outside the scope of this thesis. Lawless & Pellegrino (2007) consider teacher training processes fundamental to effectively accessing new resources and strategies which strengthen the teaching process through digital component integration. Russell (2003) also states that one of the factors

generating this distance is that teachers initially approach these resources as an add-on to the established curriculum, rather than integrating them into their existing activities.

Guzmán (2009) suggests that teacher training processes aimed at strengthening technology integration in the classroom should cover six areas or domains: instrumental, pedagogical, didactic, evaluative, communicational and personal. The first of these skills consist of the effective use of specific hardware and software within a teaching context. This component of teacher training is considered to be extremely important (Markauskaite, 2007) given that it provides the technical abilities and confidence required by trainee teachers to work autonomously in their own classes. Prieto et al. (2011) note, however, that although research projects simultaneously treating pedagogy and the development of technical skills do exist, most professional development programs concentrate mainly on the technical potential of these new tools in a way quite divorced from actual teaching practice (Jung, 2005).

Considering that teachers' responsibilities include preparing lesson plans, adapting official curricula and ensuring discipline and safety in the classroom (Kennedy, 2005), (Dillenbourg, Nussbaum, Dimitriadis, & Roschelle, 2013) suggest adding an orchestration to the technology, defined as the coordination of different classroom activities using different resources for different social levels and contexts (Fischer, 2006). This approach focus on relieving teachers from technological issues allowing them to focus on pedagogy, by dictating exactly what to do on specifics times during the activity. This investigation line is currently being studied by Miguel Nussbaum's doctoral student Anita Díaz.

I.9.3 Collaborative meeting project

This work was a result of an internship in topics related to the main aspects of the thesis. It is intended to serve as a reference to other Shared Display Interpersonal Computer use context and related aspects such as the design, usability and other human-interface device such as the keyboard.

I.9.3.1 Background

Meetings are an essential part of life and they have been throughout human history. People meet for different purposes; fun, work, discussion and many others motives. In the work meeting scenario, people usually gather around a table and discuss about a certain topic or subject, in order to achieve a goal. This has been the traditional meeting format since a long time, but sometimes it would be useful to use computers in them because of the richness of contents and media that it provides.

Computers have been usually been designed with one mouse, one keyboard and a single visual display, which comes from 70's mainframes, which assumed a single user sited in front of them. Therefore, computer interactivity in face to face meeting is not a simple issue. Single Display Groupware (Benjamin Bederson, 1998), referred as SDG, is a type of development which breaks the single user paradigm but keeps only one display. It started because people tend to gather around computers to discuss and collaborate.

In this context there's a need for interaction and collaboration between users in a single room environment. 'Collaborative Meeting Project' is a software developed to enhance that interaction, by sharing a common screen and each participant having its

own mouse and keyboard allowing them to interact as they would usually do with the computer.

I.9.3.2 Motivation

The work described here is parallel to the work of this thesis and it was performed during an internship on École Polytechnique Fédérale de Lausanne, Switzerland. The work done was intended to be a first stage of development in the thesis of Himanshu Verma, a doctoral student of Professor Pierre Dillenbourg. The main objective was to enhance the interaction during meetings by providing computer aid while preserving face to face interaction.

The role of the computer during a meeting is normally to serve as an information tool to expose certain information. This usually implies everyone's attention to a screen or display, not allowing everyone on the meeting to interact actively. This is opposite to meetings objectives, which are normally to share and discuss a certain topic or subject. The idea of the system is to enhance user interaction by bringing collaboration among users through a keyboard and mouse per user sharing the information on a Shared Display. The design of the system had to include the space and furniture to use it, in order to preserve face to face interaction. The system was intended to support people for collaboration and sharing, with features to allow them to use drawings, annotations, multimedia, documents and web resources.

This work expands the thesis perspective of Interpersonal Computer usage and interaction since it is intended for a different objective. It is interesting to see another perspective since it opens the possibilities for the Interpersonal Computer. Several distinguishing elements are discussed below:

1. Users: The exploration of adult users for the Interpersonal Computer opens new scenarios. Opposed to children, adults have more reliable skills allowing for a more complex on-screen interaction. More elements can be displayed simultaneously and user interaction can be thought deeper.
2. Usage context: A non-educational scenario does not imply classroom usage and logistics. This allows designing freely the user physical space. Also, there is no need for a special role such as the teacher since adults may decide who takes the role in which scenario.
3. Input devices: The addition of a keyboard to the mouse-based solution opens many interaction possibilities. Typing, shortcuts and focus switching are examples of this. With both peripherals users have more input tools, similar to normal computers. This allows for interaction to be more complex, opening the possibility of software development opportunities. Other input devices such as headphones or microphones may be added in order to achieve all input/output of a regular computer.
4. Interface and usability: The model proposed on this thesis restricts user interaction space allowing a structure for individual feedback to be provided. This normally implies a grid-based disposition. By removing this limitation, several on-screen opportunities are available such as complex controls, shared user space and bigger elements. Due to only having 4-8 users on the system, individual feedback can be preserved. Details on the usability will be discussed further on.

The work here described served as the basis for a paper called “Complementarity of Input Devices to Achieve Knowledge Sharing in Meetings” presented on the conference of Computer supported cooperative work, San Antonio, USA.

I.9.3.3 Design and Usability

The philosophy behind the construction of the ‘Collaborative Meeting Project’ (colmet) is that computers should be as unobtrusive as they can be, without interfering human interaction but aiding it. To fulfill this, not only software and hardware concerns should be considered but other factors surrounding the user experience.

The success of software that creates collaboration between users depends directly on the user physical layout and disposition (Stanton, 2001). For this intention there were mainly two key elements to provide face to face interaction; the first is to allow users to see all of them at the same time as they were on a meeting and the second is to allow them to see the projection without difficulties whenever they wanted. The goal of the system is to have a supportive role through meetings.

In order to fulfill the needs, several tests were conducted with test users to create a user layout where they could be comfortable and see the screen without difficulties. The result of this test was the construction of a prototype for the colmet project. The design was built by a manufacturing company and the result can be seen on Figure I.5.



Figure I.5: Collaborative Meeting Table

For common applications, software do not have to handle on screen recognition since they single-user based, but when it comes to multi-user paradigm this is a key matter. Each user must be aware of on-screen information such as the cursor position, keyboard focus, elements selected and more. Because the screen is a shared space for users, there is a trade-off between how much screen it is used for recognition and feedback against how much that space interferes with other user recognition.

A first conceptual approach was developed during the internship which can be seen in Figure I.6. The idea was to divide the screen in two different areas, shared and individual space. The common space would contain everything that is shared throughout the meeting such as notes, drawings and documents. This information could be altered and handled by all participants simultaneously. The individual space is essentially used for user recognition allowing them to see the selected commands

as well as their display color. This space was not included in the final version since it takes away user interaction space.

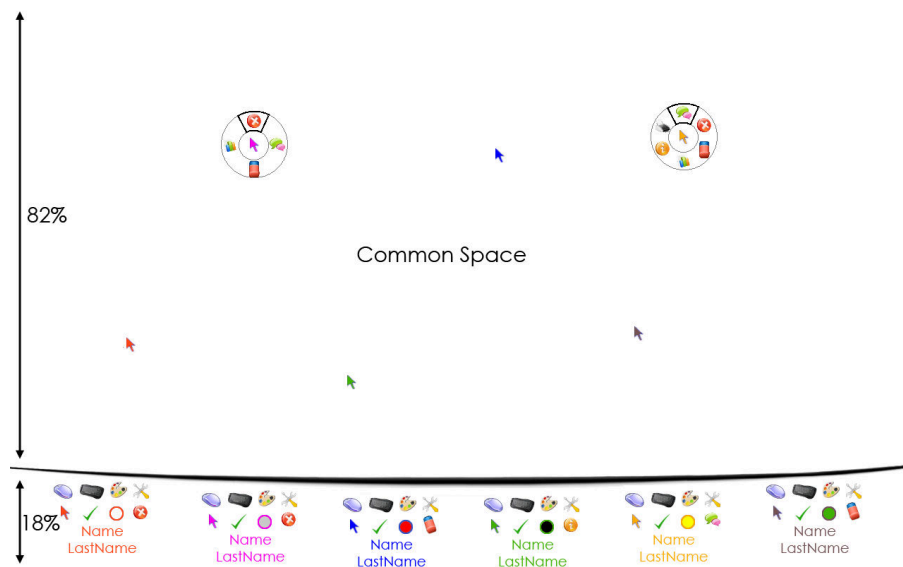


Figure I.6: Preliminary user interface design

Regardless of not using an individual space, each user needs to recognize certain information on-screen. A color notation was used for each user similar to the Shared Display Interpersonal Computer symbol notation. By having a color of its own, users can easily check who is doing what which allows traceability. To aid this concept it was decided to introduce recognition of the actions using each users color. By doing this, users can see who has focus or control over objects in screen and allowed them to interact with them based on their actions. It was intended that input devices should have color distinctness as well, but it was not included in this version.

In every application, there are certain functions that can change the way a cursor or keyboard are interpreted. As an example, clicking over 'copy format' button in Microsoft Word the next click will change the format instead of selecting text. This form of selecting the function consumes part of the screen statically, meaning that it

stays in a certain position of the screen for the user to use it as needed. With intention of maximizing the use of space, a circular shape around the cursor was proposed which could appear/disappear with a user command. The shape would contain all the possible tools and the user could rotate it using its scroll wheel to select the desired tool. This idea was called the Context Menu.

The problem of the original conception of the context menu was that it was too much information displayed and that it could allow no more than 8 tools because of its shape. To solve this, the menu was redesigned so it could hold infinite number of tools but only displaying up to 5 at the same time by cutting the circular shape into half and creating a fade out/in effect whenever a tool goes out of the visible area. To preserve the visibility of the tool, the user cursor changes after selecting a tool, reflecting it on the current cursor. The final context menu and some icon examples can be seen in Figure I.7.



Figure I.7 Context menu

The functionality of reverting actions in software is crucial nowadays. It is considered one of the bases of modern usability. In the case of colmet, the action of a user could be changed by other participant, affecting the possibility of undoing certain actions. As an example if user A moves a note and afterwards user B moves it to another place, A's action is before B's action and if A undoes that action it will change B's action and therefore affect that user's decision.

The solution of this problem needs to cover all scenarios and also be comprehensible for users, so they could use it. The reverting of actions was developed over the idea of ownership of elements. Users only owned at most one element at a time which was the last element they interacted with. If a user revert an action, it will take place on its current owned element. After it, user will automatically own the last element they interacted with before the undone action except another user would have done an action meanwhile. This was also aided with a color border around elements in order for each user to know which element they owned.

I.9.3.4 System architecture

A detailed description of the system architecture used for the collaborative meeting project is included in Appendix B.

I.10 Conclusions

Shared Display Interpersonal Computers are an alternative solution for classroom technology integration. Particularly, a mouse-based approach is an attractive alternative for developing countries and low-income regions due to its very low-cost. Although the economic viability of the technology, it has been used on few pedagogical scenarios mostly regarding multiple-choice systems. This thesis proposes a model for individual feedback provision on a mouse-based Shared Display Interpersonal Computer. This model enables Shared Display technology to achieve 1:1 student interaction within a 1:N system, allowing each student to interact personally. Individualized feedback can be given to each student through this method. The model defines two main actors; students and the teacher, both having a space of interaction. Students have a common space for interaction while preserving

each user a single zone to which they are bounded. Teachers have a zone where they can see information on students' performance and tools for controlling the system. Teachers can use performance information to actively help students on their classroom.

The usage of a mouse-based Shared Display Interpersonal Computer has been shown to be usable and possible to implement using the model proposed for individualized learning. The implementation on different cultural and environmental conditions reinforces this notion. However, conditions for an innovative technology to be introduced effectively into a classroom or school need to be met. Although some of these restrictions have been proven to work on the side of technology several others rely on schools and teachers. For the presented system to be an effective tool on a larger scale, this barriers need to be addressed.

Through experimentation, it was shown the viability of using the mouse-based Shared Display Interpersonal Computer for individualized learning. The system reported to be more beneficial for students with lower initial results due to its capability of allowing each student to work at their own pace. A comparison was performed to compare the learning outcomes of the Interpersonal Computer opposed to several technologies. This included solutions such as pen-and-paper, laptop computers and school laboratory desktop computers. Experimental results showed that the learning outcome was not directly related to specific technologies but with characteristics enabled by them. There were two relevant characteristics distinguished; (1) the provision of instant feedback, which allow students to mediate and understand their own learning process and (2) peer-interaction, through which

students share information on task related topics. Both characteristics were founded to be on both the presented model and the laptop computer technology. Both systems have the capability to provide instant feedback. Peer-interaction is enabled by each by different factor. Laptop technologies allow students to freely move on the classroom, allowing group working and face to face interaction. On the Interpersonal Computer, the shared display shows students all the information constantly. Since peers' work is completely on-screen it allows students to easily interact and communicate.

Finally, the mouse-based Shared Display Interpersonal Computer is an attractive solution for achieving interaction within the classroom at a low-cost. This thesis expands the idea by introducing and validating a model that allows individualized interaction for each student. The model was proven through exercising within the arithmetic context but it can be extended to other subjects and topics. This task is needed for the Interpersonal Computer system to become widely adopted pedagogical tool in educational technology.

I.11 Future work

The validation of the individual feedback model, described in this thesis, was done under specific experimental conditions. This was limited by the scope of the study with a constrained number of students, teachers and schools. Future work may involve other usage scenarios, not only regarding cultural and physical settings, but also new classrooms dynamics and models for individual feedback provision.

The work of this thesis has been subscribed to the usage of a mouse as a basis for human-computer interaction. This has been the traditional approach for investigators

when seeking for classroom usage of an Interpersonal Computer (Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009; Amershi, Ringel Morris, Moraveji, Balakrishnan, & Toyama, 2010), mainly to the wide adoption of the device on educational software. The introduction of other input/outputs such as keyboards, microphones and earphones devices may open several pedagogical alternatives. Exploring these possibilities is recommended as future work.

The proposed model of the thesis is intended to deliver individual feedback to each student while preserving general usability. This is done under the curricular context of basic arithmetic for third grade, which is very suitable for the context since it is based on drill-and-practice activities. Exploring other curricular subjects with a variety of students' age for the Interpersonal Computer is needed for it to become a real tool on curricular teaching. Considering the space restrictions described in this thesis, mixed models of group and individual work may be suitable for other subjects.

The introduction of educational technology in the classroom demands teachers' preparation for their usage additionally to other responsibilities which include preparing lesson plans, adapting official curricula and ensuring discipline and safety in the classroom (Kennedy, 2005). The integration process of innovative technology involves several aspects regarding the context of usage, the technological tool and teacher's related variables (Zhao, Pugh, Sheldon, & Byers, 2002). Orchestration (Dillenbourg, Nussbaum, Dimitriadis, & Roschelle, 2013) seek to relieve teachers from technological issues allowing them to focus on pedagogy, by dictating exactly what to do on specifics times during the activity. This trend should be explored

further since technology's successful integration depends directly on the teacher usage of it.

II. One Mouse per Child: Interpersonal Computer for Individual Arithmetic Practice

II.1 Abstract

Single Display Groupware (SDG) allows multiple people, in the same physical space, to interact simultaneously over a single communal display, through individual input devices that work on the same machine. The aim of this paper is to show how SDG can be used to improve the way resources are used in schools, allowing students to work simultaneously on individual problems at a shared display and achieve personalized learning with individual feedback, within different cultural contexts. We used computational fluency to apply our concept of “One Mouse per Child”. It consists of a participatory approach that makes use of personal feedback on an interpersonal computer for the whole classroom. This allows for N simultaneous Intelligent Tutoring Systems, where each child advances at his own pace, both within a lecture and throughout the curricular units. Each student must solve a series of mathematical exercises, generated according to his performance, through a set of pedagogical rules incorporated into the system. In this process, the teacher has an active mediating role, intervening when students require attention. Two exploratory studies were performed. The first study was a multicultural experience between two such distanced socioeconomic realities as Chile and India. It showed us that, even in different environmental conditions, it is possible to implement this technology with minimal equipment, i.e., a computer, a projector, and one mouse per child.. The second study was carried out in a 3rd grade class, in a low income school in Santiago de Chile. The students were asked to solve mainly addition exercises. We established

statistically relevant results and observed that the software proved most beneficial for the students with the lowest initial results. This happens because the system adapts to the students' needs, reinforcing the content they most need to work on, thus generating a personalized learning process.

II.2 Introduction

II.2.1 Interpersonal Computers

Today's computers are designed under the assumption that a single person interacts with the display at any given moment, manipulating the input device exclusively. Single Display Groupware (SDG) allows multiple people to share the same space and interact simultaneously over a single communal display, on the same machine, each with his own input device (Stewart et al., 1998). A solution is to provide each child with a mouse and cursor that controls his own objects on the screen, thus effectively multiplying the amount of interaction per student, per PC for the cost of a few extra mice (Pal et al., 2006, Pawar et al., 2007). This is highly attractive for schools in developing countries where high student-computer ratios are a common problem. One version of this idea has been implemented to allow 20-30 students in a single class to respond to multiple-choice questions designed by a teacher (Moraveji et al., 2009).

As in Single Display Groupware, where a large display is used by several people at the same time, in Interpersonal Computers the display of information is shared by a group of users, where the control is distributed by multiple inputs; this allows several people to interact at the same time, in the same place (Kaplan et al., 2009). When information is shared, Cao et al (2008) introduce the notion of a crossmodal display

as a proposal for enhancing the privacy of public information displays. The presentation must allow multiple users simultaneously accessing the information - which contains public and personal elements- to interact on a communal display. When small groups (3 to 5 peers) share a screen so that each user has his own work space, the activities can be synchronous, e.g., turn taking (Moed, 2009), or asynchronous, defined by the students' role in the activity (Infante, 2010).

The use of multiple inputs has been studied by a number of researchers who have sought to demonstrate the effects when peers work with a single screen (Paek, Agrawala, Basu, Drucker, Kristjansson, Logan et al., 2004). It is fundamental in favoring interactivity among students, as well as motivation levels, that the activity make each student work with objects that are solely his; each student controls his own input device, which forces him to participate and become the protagonist of his own learning process (Infante et al 2009). Infante et al., (2010) indicate that students focus their attention on the common screen where individual resources are shared, transforming it into a learning place in which students discuss, collaborate and negotiate.

Given that research in Interpersonal Computers has been performed in different countries, as for example in India (Amershi et al., 2010) , Moraveji et al., 2009), China (Moraveji et al., 2008) and Chile ((Infante et al 2009), addressing specific functional and usability issues, our first research question is: considering that Interpersonal Computers are an alternative for maximizing resource utilization in schools, how do different cultures influence the usability of this technology, taking into account differences in knowledge and technological abilities?

II.2.2 Active Participation

Experience and active participation in the educational process are two elements that have revolutionized the traditional concept of teaching and learning over the course of the 20th century. The writings of Dewey, Vygotsky, Piaget and others have taken on renewed relevance for specialists attempting to explain and improve the quality of learning. Participatory interaction is the focal point for organizing the experiences of those who take part in the learning process (Cooper et al., 1991).

Most pedagogical propositions that involve computer support share an interactive concept of the learning process (Panitz, 1999). Interaction presupposes active, flexible and experiential pedagogical processes in which the instructor's pedagogical action effectively manages the inherent uncertainty (Shulman, 2005).

Regardless of the theoretical approach, educators and specialists consider that student participation generates better conditions for learning (Lim, 2008; Ahles & Contento, 2006). The quality of that participation is one of the foci of study of current pedagogical propositions (Shulman, 2005). Studies have demonstrated the importance of active participation by students in the learning process for phenomena such as achieving better results -both with technological support (Zurita & Nussbaum, 2004) and without it (Boaler and Staples, 2008); improving students' perceptions of self-efficacy (Hamman, Fives & Olivarez, 2007); and developing metacognitive reflexive practices and student commitment to the learning process (Dede, 2009).

Active participation can be achieved through interactive learning environments that provide feedback to the students' actions. Feedback can be delivered through the

evaluation of activities, and can be seen as an instance that promotes learning, as opposed to a specific event with the sole purpose of assigning grades, specially considering that when children become involved in the evaluation process, it is viewed as learning, rather than a measuring process (Davies, 2000).

When a shared screen is present, as with an Interpersonal Computer, it is possible to provide personal feedback to each of the students. Given that the screen is seen by all the students, they can see each other's progress, introducing an element of competition between them, while the teacher can observe all students' work knowing which children need their support. This form of group display introduces various technical challenges as well as benefits that are discussed in this work.

II.2.3 Math Teaching

Understanding numbers and their representation is a fundamental goal when teaching mathematics (NCTM, 2009). This requires understanding mathematical operations, considering the actions they represent, as well as the possibility of discovering unknown numerical information, from known numerical information. According to Berch (2005), processing the meaning of the numbers allows students to solve problems, by understanding everything from the meaning of a single number to development strategies; from creating numerical comparisons to creating procedures for numeric operations; and integrating their knowledge in order to interpret information. In this sense, computational fluency in whole-number arithmetic is vital; the corresponding procedures are so basic and have such wide application that Ball et al., (2005), suggest that they should be practiced to the point of automaticity through efficiency and accuracy. To this end, progress in learning calculating

procedures should be closely linked to the process of learning numbers, so as to support it. In order to achieve this, it is necessary to carefully plan the sequence of numbers to be included when practicing operations.

When teaching math, it is important to establish bases for knowledge, in order to progress onto learning more complex operations. We must therefore make sure that all students acquire said bases. If the work is too easy or too difficult, students won't get involved, and learning math will be a constant struggle throughout their education. When faced with an entire class, where each student is different, teaching with consideration to individual rhythms can be a great challenge. However, it is crucial that each student feel constantly challenged in order to achieve success. This can be achieved by incorporating gradual rhythms into each task, so the student won't become frustrated and abandon the challenge (Sangster, 2006).

Our second research question is: is it possible for all the students in a class to work simultaneously on their individual basic math problems at a shared display on just one computer, and still achieve personalized learning with individual feedback? The aim of this research question is to explore how an Interpersonal Computer supports personalized learning in a given curricular context, thereby understanding how students and their teacher respond to this technology.

Therefore, the purpose of this work is to show how a participatory approach that makes use of an interpersonal computer for the whole classroom can be implemented for teaching basic math. This is done through a sequence of 'drill and practice' exercises, with feedback for each student and the teacher, which allows the latter to address misconceptions and do some formative teaching as appropriate. The One

Mouse per Child (OMPC) application that follows the previous aims is described in Section 0. Two exploratory studies were performed as shown in Table II.5. In the first, described in Section II.4, we show a usability analysis of the technology based on a comparative study of the use of the tool in two different cultures: India and Chile, and in the second, Section II.5 we show the experimental work performed to carry out a qualitative and quantitative assessment of achievement and conduct.. The paper finishes with conclusions. There is an Appendix with the rules of the system used in this experience.

Table II.5: Exploratory studies performed using the same type of technology for one classroom: shared display, one computer, and one mouse per child for teaching basic math.

Section	Country	Age	Number of students	Number of sessions (time per session)	Purpose
3	India	9-10	30	4 (90 min)	Usability analysis
3	Chile	9-10	20	4 (30 min)	Usability analysis
4	Chile	8-10	40	7 (30 min)	Achievement and Conduct assessment (qualitative and quantitative)

II.3 One mouse per child for Basic Math

One mouse per child for Basic Math is an application for teaching arithmetic, oriented towards working simultaneously with an entire class, using an interpersonal computer. In our case, for one classroom this consists of one PC, one projector, one mouse for the teacher, and one mouse for each child participating in the activity. Each student must solve a series of arithmetic exercises, which will be generated according to his

performance, through a set of pedagogical rules incorporated into the system. In this process, the teacher has an active mediating role, as the system's protagonist. His mouse has special abilities that enable him to intervene in his students' learning process, according to what he considers to be pedagogically convenient.

II.3.12.1 General description

Once the teacher accesses the system and is assigned his cursor, the children must identify themselves, with their respective mice. It is necessary to go through an identification process, because the mice don't have unique identifiers to recognize them. Once all the children have selected their name, the teacher begins the activity. Each child has a cell, where he will work individually. No child can exit his cell, or enter another classmate's (Figure II.8). All the individual spaces are displayed as a grid, with size varying according to the number of mice connected to the system, because the idea is to maximize each child's individual space. According to experimental observations, the maximum viable number of individual work spaces, on a 1024 X 768 pixel projection on a conventional 1,5 mt. x 1,5 mt. screen, is 49, which means 49 children could work simultaneously in a classroom.



Figure II.8: 36 students working simultaneously on One Mouse per Child for Basic Math

Most classroom-based Interpersonal Computers with individual mouse input are mainly constrained to point-and click activities, like true-false or multiple choice based activities (Amershi et al., 2010). We added a scrolling technique (Hinckley, 2002) that makes use of the mouse to avoid incorporating a more expensive and less versatile device, such as the keyboard.

Each student's work space is composed of the five elements shown in Figure II.9.

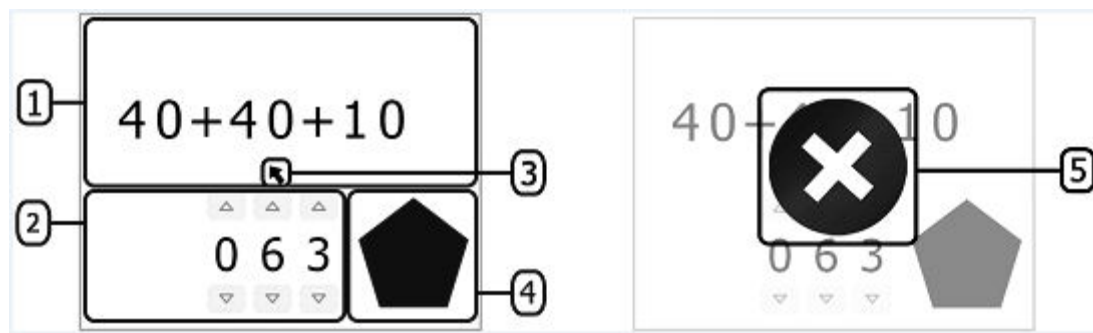


Figure II.9: Each child's work space

1. Equation: In zone 1, Figure II.9, a mathematical equation is displayed, for the child to solve. This equation can be written vertically or horizontally (as shown).
2. Answer zone: In zone 2, Figure II.9, the child must enter the answer to the equation (zone 1). The number of digits in this area depends on the length of the correct answer.
3. Player's pointer: This represents each child's cursor, which can only move within the cell formed by zones 1, 2, and 4.
4. Player's identifying symbol: The icon in zone 4 (Figure II.9) serves two purposes: it identifies the child's work area, and at the same time works as a button that must be pressed to enter the answer.
5. Feedback zone: Once the child enters his answer, feedback to his actions is displayed in the middle of his cell. There are four types of feedback : correct answer (Figure II.9, column 2, row 4); incorrect answer (Figure II.9, column 1, row 2); correct answer, and pass to the next level (Figure II.9, column 3, row 5); and, if the child doesn't move his mouse for 60 seconds, a sleeping symbol is displayed (Figure II.9, column 2, row 1). If inactivity persists after 120 seconds,

the background of his cell becomes the same color as the sleeping symbol (Figure II.9, column 2, row 3).

II.3.2 Pedagogic rules

Each child is shown an equation determined by the teacher, or according to the student's level, which in turn corresponds to a specific pedagogic rule. The child must solve said equation and enter the answer in the specified zone. If the answer is correct, a new equation will appear, according to the pedagogic rule system; if it is incorrect, the same equation will be displayed, until the child solves it correctly.

This application is designed to support the teaching of math in the classroom, which is why it has a set of rules that increase in difficulty. These rules are aligned with the math contents set out by Chile's Ministry of Education (MINEDUC), for grades 1 to 4. In the appendix, we show the rules used in this experience, i.e., for addition (18, Table 5) and subtraction (18, Table 6). The total number of rules for the system is 65; the 36 addition and subtraction levels we already mentioned, plus 13 for multiplication and 16 for division.

For each level, children must carry out at least 10 exercises, which are randomly generated according to the rule. If the student correctly answers all 10 exercises, he moves on to the next level. If he makes a mistake in the first 10 exercises, he must solve 5 more in order to pass. If at the end of these 15 exercises he has solved at least 8 with no mistakes, he may move on to the next level. If he hasn't, the system will keep generating a new exercise from the same level, until the above criterion is met. The objective in having a variable number of exercises is for children to reinforce the levels

where their performance is insufficient, as well as showing certain abilities in managing the mathematical activity they were exposed to, when they pass a level.

II.3.3 The teacher's role

In Figure II.8, a ranking is displayed outside of the students' work space, (on the right side) which graphically sums up each child's information, listing them according to their placement in the application, in terms of level achieved, number of exercises solved, and progress. This is shown as feedback for the students, so they can know how they are doing with regard to their classmates. Because the list is in order of results, it adds a competitive-ludic element among participants. This ranking, along with the icons regarding inactivity, allow the teacher to see the groups' progress, as well as knowing which students are lagging behind or have low results and need his attention and mediation.

Once the teacher ends the session, the students' data is saved so the child can work on the same level during the next session. The data corresponding to each session can be displayed at the teacher's request.

The teacher's cursor is different from the student's because it is red and the only one not limited in its movement. It can freely move throughout the screen, to intervene in a student's work if he so wishes. The teacher can identify any student's name and go into a given child's work space to work with him inside his area.

When the teacher wishes to explain something in greater detail to the entire class, he can go from practice mode to teaching mode (Figure II.10), where only the teacher interacts with the system. In teaching mode, he has his own work space (component 3, Figure II.10), which will help him choose and show the pedagogic rule he needs (component 1,

Figure 3), with a short description (component 2, Figure II.10). The teachers' work space (component 3, Figure II.10) works exactly the same as the students', except feedback is displayed at the right side (component 4, Figure II.10). Within the work space (component 3, Figure II.10), the teacher can write, and underline.



Figure II.10: Teaching mode

II.4 Comparative analysis in different cultures: Usability Analysis:

II.4.1 Objective

A multicultural exploratory study was performed to prove whether students could adequately use the technology, regardless of differences in knowledge and technological abilities, considering they came from such distanced socioeconomic realities as Chile and India. It did not seek to measure the pedagogic value of the system (analysis performed in Section II.5), but its usability.

The two schools studied in Chile and India are representative of government run or supported schools in each country. Yet, both countries have wide variation in the quality of their schools' infrastructure; teaching style, teacher qualifications, and student

backgrounds vary significantly from school to school. Specific results may have differed had the assessment been carried out in different schools from the same countries. Thus, in the ensuing analysis, while the schools are referred as being in Chile or India, this should not be taken as a generalized expectation across the two countries, just as an illustration of the variation that can occur when using the analyzed tool.

II.4.2 Experimental design

The tests in India were carried out in an average school in Bangalore, financed with state support as well as voluntary donations. The students come from a low socioeconomic background, where most fathers are employed as laborers, and most mothers are domestic workers. The school gives out two meals a day, which is one of the main factors for parents to send their children to school instead of making them do field work. The school has a computer lab with 9 computers, one of which has internet access. Teachers normally take their classes to the computers because they value the importance of learning to use them, especially learning to type. The computers are open for students to use freely, but access to them is difficult, as they are in the principal's office. Most students don't have a computer at home, and have limited access to them in general.

In Chile, the tests were carried out in a school corresponding to the middle socioeconomic class, with state subsidy. Most parents have 14 or 15 years of schooling. The school has a computer lab with about 10 computers, all of them with internet access. They also have technology such as projectors, and a screen. The computers are open for students and teachers to use, as wanted and needed. Their primary use is for work assigned in class. Most students have access to a computer at home, or at a neighbor's house.

In India, the tests were carried out with a sample of 30 students, ranging between 9 and 10 years of age, in a multipurpose room (smaller classroom), with the students sitting on the floor, in rows of 7. In Chile, the experience was carried out with 20 students from the same age group, in the computer lab. In both groups, the equipment was similar: a laptop, a projector, plus the necessary mice and hubs.

In both cases, 4 experimental sessions were carried out, each lasting approximately 90 minutes in India, and 30 in Chile due to time restrictions imposed by the school. During that time, the students carried out the exercises indicated by the system.

At the beginning of the sessions, we explained how to use the system, with slides. This introduction was sometimes omitted, according to the students' requirements.

In India, the teachers in charge of the participating students were present at the intervention, as well as some other teachers who expressed interest, while in Chile only the research team was present during most of the sessions, because the teacher had to take care of the students who weren't participating in the experience. In India, teachers and those in charge of the experiment took note of students' questions, so they could help with language issues. Videos were recorded in both countries, in order to document the qualitative study. Additionally, surveys were carried out amongst students and teachers.

The system described in Section 2 already considers some of the usability findings of this study. Therefore, for the intercultural usability study we used an earlier version of that system. The differences include minor changes in the graphics and the teacher's tools. Data was not saved between sessions. Two or three-digit addition exercises were randomly generated (at the teacher's discretion).

II.4.3 Comparative Analysis

Table II.6 reports the statistics of use of the experience performed in Chile and India, for the first and last sessions, to illustrate the corresponding evolution. In each case we define the parameter and also report the differences observed. This data, plus the qualitative observations are used as input for the usability analysis of Section 0.

Table II.6: Comparative analysis

	INDIA		CHILE	
	Initial session	Final session	Initial session	Final session
<u>Initiation time.</u> Time it took the children to settle in their seats and be ready to begin (shows the logistic challenges to starting a session). Differences are due to the number of children in each group, and the different physical infrastructure	7 Min.	7 Min.	5 Min.	4 Min.
<u>Session length.</u> The available time in India was much longer.	90 Min.	90 Min.	30 Min.	30 Min.
<u>Introduction.</u> Necessity of explanation at the beginning of the session. In both countries, this was only so at first.	YES	NO	YES	NO
<u>Number of activities completed in the session.</u> In Chile activities were completed within the first session, which was not possible in India, due to the children's distance from the use of technology. During the last session in India the activities carried out were twice as many as in Chile, since much more time was available.	0	6	1	3
<u>Type of addition.</u> Number of digits (2 or 3) involved. In Chile, because of initial knowledge, it began and ended with three digits.	2 digits	3digits	3 digits	3 digits
<u>Mean number of total answers.</u> Sum of all correct and incorrect answers, normalized by the number of participating children. Similar at the beginning in both countries, but increased more in India than in Chile.	7.96	11.53	7.5	9.05
<u>Mean number of correct answers.</u> Sum of all correct answers, normalized by the number of participating children. The initial state of correct answers in Chile was much greater than in India, which showed a notable increase, less visible in Chile.	0.59	5.55	7.05	7.63
<u>Mean number of incorrect answers.</u> Sum of all incorrect answers, normalized by the number of participating children. The initial low number of correct answers in India was due not only to lack of knowledge, but also to poor handling of the technology	8.25	6.38	1.76	1.89
<u>Mean number of questions regarding position on screen.</u> The average student's difficulty in identifying his personal work space on the screen. Similar values can be observed in both countries	0.4	0	0.2	0.05

<u>Mean number of questions regarding use of the mouse.</u> The average of how many times children asked how to use the mouse, or how to use it to enter their answer correctly. Initial difficulties were greater in India than in Chile, but at the end both were similar.	1.56	0.13	0.2	0.45
<u>Mean number of conceptual questions.</u> The average number of questions about the exercise being presented to the student. Similar values can be observed in both cases.	0.43	0.8	0.65	0.45
<u>Mean number of recognition comments.</u> Students raised their hands as if they had a question, but when the teacher approached, the student was actually expecting recognition for the solved exercise. Similar behavior in time in India. This aspect was not observed in Chile.	0.7	0.56	0	0
<u>Student interest.</u> Before, during and after the activity, students were questioned about their interest in the activity and if they would like to play it again. Interest was always lower in Chile than in India, in fact decreasing over time, as the activity was always the same because there wasn't a self-regulated system of rules	100%	100%	>90%	> 80%
<u>Teacher interest.</u> Before, during and after the activity, teachers were asked if they were interested in the OMPC concept and the software itself, and if they would use it in other subjects; interest was very high in both countries.	100%	100%	100%	100%

II.4.4 Usability study

System usability is characterized by learnability, memorability, efficiency, errors and satisfaction (Nielsen, 1994).

II.4.4.1 Learnability

Regarding learnability, we observed that the number of activities carried out per session was very different between the first and final sessions in India, where students went from not completing any activities, to completing six. In Chile, on the other hand, we can see an increase in the number of completed activities, from one to three. However, the available time was greater in India (90 minutes, against 30 minutes in Chile). This shows that students managed to overcome the technical and system-related difficulties they had at the beginning of the experience in both countries.

A second observation regarding learnability is the analysis of the mean of correct answers during the experience. In India, between the first and second sessions, it

increases considerably (from 0.59 to 5.00), stabilizing itself from then on, until reaching an average of 5.55 correct answers. This indicates that students reached the techno-educational threshold as early as the second session. The techno-educational threshold is the point where the results of the mathematical exercises stabilize between sessions (average of correct and incorrect answers). This shows that the difficulties in improving no longer have to do with using the technology, but rather with the complexity of the mathematical exercise. The mean of incorrect answers also maintains a slight decrease, which corresponds to an increase in the number of correct and total answers, showing an improvement in learning, mainly in the technological aspect. In the Chilean experience there isn't a significant increase in the mean of correct answers (7.05 to 7.63), which indicates students had little technological difficulty at the beginning, reaching a quick balance when faced with the difficulty of the mathematical exercises. The mean of incorrect answers increases slightly between the first and last sessions (1.76 to 1.89), but it is less than the increase in the mean number of total answers (7.5 to 9.05), due to better use of the technology.

A final aspect of learnability was observing the need for culture-independent graphic elements. This made us rethink the feedback and symbol systems, originating the version seen in Section 2.

II.4.4.2 Memorability

Concerning memorability we observed that, both in India and Chile, students didn't need an introduction to the activity as of the third session. In both countries, many students expressed not needing an introduction as early as the second session.

II.4.4.3 Efficiency

Regarding efficiency, on-site observations, as well as the audiovisual material, indicate that students in Chile had minimal problems in understanding how to use the technology, specifically the mice. In India, many of the students had never used a mouse before, and couldn't handle it properly in the beginning, presenting problems with movement sensibility (they couldn't click where they wanted to, and thus got many wrong answers by mistake), or clicking the right button (when the activity required clicking the left button). However, we can see from the number of questions regarding the use of the mouse (which decreased progressively between sessions), that most of the students developed the ability to use the mouse. Likewise, their ability to identify themselves, based on the symbol on screen also progressed as they dominated the technology and understood the activity.

A second aspect pertaining to efficiency is the initiation time for the activity. When there is a reduced available time, as in Chile (just half an hour), initiation time can be a considerable 15% of the session. This is mainly due to the complexity of managing a massive number of mice with cables. This problem can be solved in a lab wired to meet these needs. Another solution is the use of wireless mice; however this is much more expensive.

II.4.4.4 Errors

Concerning errors, we observed that the superior technological abilities shown by the students in Chile also meant more demands towards the system and its proper functioning. When there was a problem (involuntary disconnection of one or more mice), the students showed explicit dissatisfaction, and their motivation towards the

activity decreased. A clear example could be observed during the third session in Chile, where we had a major technical problem, which notably diminished enthusiasm not only during that session, but also during the one that followed. In contrast, Indian students showed great tolerance towards software errors that interrupted the normal flow of the activity. In spite of the fact that said tolerance decreased as the sessions went on, enthusiasm towards using the technology was always absolute. In addition to possible cultural differences, we believe that because of greater previous exposure to PC use, the Chilean students were more sophisticated in their expectations and therefore demanded better software; the Indian students were perhaps more forgiving because they had little other experience for comparison.

II.4.4.5 Satisfaction

We observed that students in India constantly showed great satisfaction in using the technology, with most of them wanting to keep using it past the duration of the session. Teachers had no problem with carrying on with the work, considering the students' enthusiasm. This also happened in Chile, where some students used the free time they had between classes to take advantage of the activity, though that was a small group. We concluded that the technology generated great interest in both countries, both in students and in teachers, because of the opportunity it presented to the students. This was especially so in India. We hypothesize that the novelty of interacting with a computing system explains the different responses. The Chilean students were accustomed to using PCs; the Indian students were enthralled by the interaction. It is not clear that this difference would continue after sustained use.

II.5 Achievement and Conduct Assessment in a second study in Chile

II.5.1 Design of the intervention

As indicated at the end of Section II.4.2, a second version of the Software, the one shown in Section 0, was used to do a qualitative and quantitative assessment of achievement and conduct.

An exploratory study was designed, to be carried out in a state-subsidized school located in a low-income neighborhood of Santiago de Chile. The school was next to land illegally occupied by families with lightly constructed housing, without adequate living conditions. According to official data, 57.51% to 82.5% of these students are socially vulnerable, which means both their wellbeing and quality of life is at risk. The children only went to school in the afternoon.

The sample was taken from the 3rd grade (boys and girls, ranging between the ages of 8 and 10). The class was made up of 43 students, 40 of which actually participated. The school has a computer lab with 20 computers, which is used regularly by different classes. Because of the characteristics of this intervention, the activity was carried out in two regular, adjoining classrooms, randomly dividing the children into two groups of 20. Each room was equipped with a notebook, a projector and the number of mice required for the children present. Each room was led by a person from the research team, and the class' teacher alternated between both classrooms.

Seven 30-minute sessions were carried out, twice a week. The first and last were dedicated to pre and post tests, to assess abilities in solving basic equations, similar to those featured in the studied system. Therefore, the children were exposed to the system 5 times. . The children only worked with addition and subtraction, because of their

school level. The exercises were automatically generated by the system. In order to evaluate the experience, the following aspects were considered:

1. Management of the system, by the students and the teacher.
2. Children's explicit conduct (verbal comments), as well as implicit conduct (gestures, body language) towards working with the system.
3. Achievement in solving exercises similar to those included in the system.

Aspects 1 and 2 were observed by applying an open ended observation checklist, designed by the research team. Students were observed during 3 sessions (sessions 2, 3 and 5). Aspect 3 was evaluated with a written open-answer test, made up of exercises with the same structure as those found in the software. Exercises were chosen from the system, so they would correspond to a 3rd grade level, as far as the numeric aspect, abilities, and difficulty. The test was applied twice: before and after the intervention. Each correct answer was assigned 1 point, while each incorrect answer got 0 points; the entire test had 16 points. The software log was also considered to analyze each student's achieved level and performance. We report only the results for addition exercises since these accounts for 96.3% of the exercises performed.

II.5.2 Qualitative observations

Students had few requests in the technological aspect of the intervention, although they initially had difficulties identifying themselves on the screen and, to a lesser degree, using the mouse.

As far as the pedagogic aspects of the exercise, during the first session with the system, students asked for help on solving equations, because many of them had deficiencies in

basic addition and subtraction operations. In spite of the fact that these weaknesses were present throughout the remaining classes, the students progressively asked for less help.

Disruptions were observed on the second and fifth session with the system. In general, there were always some students who said they didn't want to participate, showing lack of concentration and restlessness. For instance, they asked to go to the bathroom, or got distracted and played with their adjacent peers. This was due to a number of factors, mainly disruptive conducts present in some students prior to the intervention, difficulty in understanding and carrying out the exercises, frustration, and fatigue. The teacher reported that the children that showed low level of engagement in the activity recurrently showed a lack of motivation in other subjects too. On the third session with the system disruptions increased significantly since there were technical problems at the beginning of the session; this caused annoyance among the students, and lack of motivation, which resulted in more fatigue conducts being observed in this session.

Both competitive and cooperative behaviors were observed, though competition was slightly greater. We observed that the children that were more engaged with the activity were more interested in reaching a new level than interacting with their peers.

II.5.3 Quantitative analysis

The quantitative design was quasi-experimental, with pre and post tests. The obtained data was subjected to frequency analysis, difference of means tests (repeated measures ANOVA) and effect size tests (Cohen's d).

There is a 17.86% of improvement ($p < 0.001$) between the pre and post test in the addition exercises, achieving a medium effect size (Cohen's $d = 0.768$). If we analyze the software's log we discover that the percentage of correct answers obtained by the

students when solving exercises with the system between the first and last session, increases in 14.75% ($p < 0.001$), with a large effect size (Cohen's $d = 0.855$). This shows us that, though the exercises' difficulty increases, the quality of the work improves.

In order to analyze the impact of the work according to the children's achievement, the class was split into two groups, according to their achievement on the initial test. Achievement was measured by obtaining the maximum level each child reached at the end of the experience and then, in the pre and post tests, only considering questions up to that level. The results of both groups on the test were compared (Table II.7), observing greater improvement (25.53%) in the students with the lowest initial results. This progress is statistically significant, with a medium effect size.

Table II.7: Achievement percentage on the test, separating the class according to their results on the initial evaluation.

Achievement percentage on the test	Initial	Final	Improvement	Significance	Cohen's d
Group with the highest results on the initial test	66.52	69.64	4.69%	0.457	0.255
Group with the lowest results on the initial test	39.17	49.17	25.53%	0.008*	0.775

When comparing the percentage of correct answers obtained by students when solving exercises with the system, there is also greater improvement (20.96%) for students who had the lowest initial results (Table II.8). This progress is statistically significant with a large effect size for both groups.

Table II.8: Achievement percentage in the SW, separating the class according to their results on the initial evaluation.

Achievement percentage in the SW	Initial	Final	Improvement	Significance	Cohen's d
Group with the highest results on the initial test	87,23	95,21	9.15%	0,044*	0,960
Group with the lowest results on the initial test	73,25	88,60	20.96%	0,004*	0,940

We can conclude, from the results in Table II.7 and Table II.8, that the software proved most beneficial for the students with the lowest initial results. However, both groups improved their learning level, when we consider individual advancement with the software. This happens because the system adapts to the students' needs, reinforcing the content they most need to work on, thus generating a personalized learning process, adapted to the needs of each student. This was also observed with the software's log data. For example, in levels 12 and 13 –which are the final levels reached by close to 40% of the class- there are differences of up to 122 exercises between the student who solved the most and the one who solved the least exercises, on a single level (where both students had the same number of sessions with the system). This illustrates the difference in difficulty that a single level can represent for different children.

II.6 Conclusions

Our first research question was if Interpersonal Computers, which are an alternative that maximizes resource utilization in schools, can be used in different cultural classroom settings.

We showed how, with minimal equipment, i.e., a computer, a projector, and one mouse per student we can allow all students in a class to participate simultaneously at their own

pace. If we take into consideration that this equipment is used daily by the students, that up to 10 different groups can share it per day, and that the equipment has a useful life of at least two years, the cost per student –considering a class of 45 - is close to one dollar per student per year (Trucano, 2010). This technology relies on just one computer for a whole classroom, which makes it a critical resource in case it fails; although in a similar way, all technical support can focus on just one device. We followed standard design principles for Single Display Groupware applications including goal-based progression, personal reinforcement and scoring, and color and shape-coded mouse pointers (Jain et al. 2009).

The very different environmental conditions where the activity was carried out, in India and Chile (students sitting on the floor, or at desks, lighting conditions and quality of the technical equipment), showed us that it is possible to implement massive interactive technology in very diverse conditions. We empirically showed that the children in both cultures had no problem in identifying their personal work space on the common display. We also showed that the Indian children, who – in contrast to the Chileans- had no previous computer knowledge, were able to control the mouse much like the Chilean students in just a few sessions. The software was mastered at a similar pace in both countries, even though for the Indian children this was their first encounter with a computer program. The Indian students showed more interest which was reflected in the mean number of exercises answered, enormously increasing their rate of correct answers between the four sessions, but not reaching the rate attained in Chile.

Teacher enthusiasm in both countries was due to the fact that teachers feel that technology has an important role in the general context, and they see in it an economically viable opportunity to support their students' learning. Additionally,

bringing participatory activities into the classroom is seen as an attractive incentive to come to class. Regarding the software itself, teachers valued its ability to effectively develop mental calculations.

Our second research question was if it is possible for all the students in a class to work simultaneously on their individual basic math problems at a shared display on just one computer, and still achieve personalized learning with individual feedback.

We have to understand that the benefits of technology can be realized only through an effective learning and teaching strategy; the problem to focus on is not technological, but pedagogical. We don't see the OMPC approach as a general tool but a curriculum oriented one, in the sense that the presented application covers basic math; we are working on a second application on Fractions, and a third on Reading/Writing. Our application can be compared to Mischief (Moraveji et al 2009) which is a Single Display Groupware general tool for up to 30 kids; however, it has a different pedagogical approach, characterized by collective feedback. In our application, feedback is individual since we manage the identity of each child. This allows us to have N simultaneous Intelligent Tutoring Systems, where each child advances at his own pace in a lecture and throughout curricular units. While in Mischief reports are focused on classroom behavior, our approach is student oriented, providing the teacher with tools to mediate the different kids that need it.

We established statistically relevant results, with medium and large effect sizes in the mean individual performance, in learning addition. We also empirically observed that though the exercises' difficulty increased between levels, the quality of the work improved (percentage of correct answers in a level). An especially interesting result is the greater improvement in achievement (pre and post test) and quality of the work of

students who began the intervention with lower results. The presented system adapts to the needs of the students, reinforcing the contents they most need to work on, thus generating personalized learning.

Future work considers introducing collaboration within a Single Display Groupware environment. Open questions are the collaborative mechanisms that have to be developed in such environments where students are not necessarily adjacent, and the working models that support it. We are also working on how to introduce ludic language to the OMPC method, to improve children's appropriation and involvement. The key research question is how to achieve immersion and challenge in such an environment.

II.7 Acknowledgements

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II.8 Appendix: System rules

Table II.9: Pedagogic rules for addition

Addition		
Level	Description	Examples
1	Additions with 2 addends, without carrying	$3+4$
2	Additions with 3 or more addends, without carrying	$2+3+2$
3	Additions with 2 addends, without carrying, up to the tens	$20+7$
4	Additions with 3 or more addends, with tens in each one, without carrying	$30+40+20$
5	Additions with 2 addends, each one with two digits, without carrying	$25+33$
6	Additions with 2 identical addends, one digit each, with or without carrying	$4+4, 6+6$
7	Additions with 2 addends, without carrying	$3+4, 30+40, 300+400$
8	Additions with 3 addends, without carrying	$200+50+10$
9	Additions with 2 identical addends, one and two digits, with or without carrying in the ones	$32+32$
10	Additions with 3 identical addends, one and two digits, with or without carrying in the ones	$450+30, 354 + 231$
11	Additions with 2 addends, and carrying in the ones	$14+18, 135+325$
12	Additions with 2 addends, multiples of 10, and carrying in the tens	$80+30, 140+270$
13	Additions with 2 addends and carrying in the tens and ones	$38+73, 156+266$
14	Additions with 2 addends, without carrying	$3.200+54, 3.271+2716$
15	Additions with 2 addends, carrying only once, in one position (tens or ones)	$28.146+37, 26.734 + 139$
16	Additions with 2 addends, carrying only once, in one position, except in the tens of thousands	$28.146+1.337, 37.235 + 51.337$
17	Combined addition and subtraction exercises, with parentheses	$(36+24)-15, (364+24)-15$
18	Combined addition and subtraction exercises, without parentheses with numbers	$36+24-15, 364+24-15$

Table II.10: Pedagogic rules for subtraction

Subtraction		
Level	Description	Examples
1	Additions with 2 addends, where an addend is missing, without carrying	$6+_=9$, $63+_=96$
2	Simple subtraction, without carrying	$6-3$, $60-30$
3	Intermediate subtraction, without carrying	$63-20$, $63-23$
4	Successive subtractions with 3 terms, with only one digit	$9-2-1$
5	Advanced subtractions, without carrying	$7-3$, $70-30$, $700-300$
6	Subtractions with carrying in the units, and one-digit subtrahend	$50-2$, $150-2$
7	Subtractions with carrying in the units, and one-digit results	$45-36$, $345-338$
8	Subtractions with carrying in the units, and two-digit results	$45-18$
9	Subtractions with carrying in the tens	$451-61$, $451-161$
10	Subtractions with carrying in the units and the tens, and one-digit subtrahend	$500-2$, $700-9$
11	Open numeric subtraction phrases that involve adding or subtracting, without carrying, to be solved	$__-5=43$, $___-215=143$
12	Subtractions with carrying in the units and the tens, and two-digit subtrahend	$451-62$, $374-96$
13	Subtractions with carrying in the units in the tens, and three-digit subtrahend	$451-162$, $374-196$
14	Subtractions with 5-digit minuend, without carrying	$13.427-426$, $13.437-13.426$
15	Subtractions with carrying in only one position	$28.146-147$, $24.257-9.023$
16	Subtractions that require carrying twice, in any position	$28.146-17.247$, $2.678-1.849$
17	Open numeric subtraction and addition phrases, that involve adding or subtracting, to be solved. Operations may or may not require carrying	$___-145=1.893$, $5.806-___=522$
18	Combined addition and subtraction exercises, without parentheses with numbers	$(36+24)-15$, $364+24-15$

III. Interactive learning: a comparison of individual and interpersonal computer technologies with pen-and-paper

III.1 Abstract

Among the education technology projects that have been adopted by developing country governments, the project that has garnered the most attention is the One Laptop per Child initiative, which aims to provide 1:1 educational computing to students in emerging economies. This solution, however, is still too expensive for many countries. A more affordable option is the interpersonal computer, which can achieve interactive learning with a group of students using just a single computer, a projector, and a mouse for each child. The research question of this study is to determine the differences in children's learning outcomes and classroom behaviour when they interact with an interpersonal computer, a personal device and pen-and-paper. A multi-session experiment conducted at a Chilean primary school to compare the two technologies and conventional pen-and-paper methods found that even though the children using pen and paper completed more exercises, those working with the technologies actually learned more (though the difference was only statistically significant for those using the interpersonal computer). The lack of a significant difference in learning between the two technologies suggests that the difference observed between them and pen-and-paper methods is the ability of the former to provide instant feedback, whether on an individual or a shared display. Additionally, instant feedback can be provided "publicly" (on an interpersonal computer) and obtain similar results to "private" provision (personal computer).

III.2 Introduction

The introduction of technology into the classroom has enabled interactive learning, which in turn allows students to deepen their participation and engage in more reflective action (Beauchamp & Kennewell, 2010). One of the most common technology models is to provide each student with their own personal computer (Weston & Bain, 2010). This model, known as 1:1, has been adopted in many countries like Uruguay, Portugal, Peru, Rwanda, among others. The two major projects of this type are the Intel World Ahead Program (Intel Corporation, 2006) and the One Laptop per Child (One Laptop per Child Foundation, 2006). The latter hopes to minimize the cost of implementing such technology per student, with the goal of lowering prices to US\$100 per computer. As of now, the cost of acquiring such computers is close to US\$200 (Kraemer, Dedrick, & Sharma, 2009). Even at just US\$100 per device, the One Laptop per Child solution is still much too expensive to be implemented in most developing communities around the world (Trucano, 2010).

A more affordable option has proven to be the interpersonal computer (Moraveji, Kim, Ge, Pawar, & Mulcahy, 2008), a model that implements Single Display Groupware (Stewart, Bederson, & Druid, 1999) which allows multiples user located in the same physical space to interact simultaneously on a single display. The interpersonal computer consists of a shared display, and an input device per user (Kaplan et al., 2009). It has proven to achieve interactive learning with a group of students at a cost of one dollar per child per year using a single computer, a projector and a mouse for each student (Alcoholado et al., 2012). This alternative is the motivation for the research question addressed in the present study: Are there differences in children's learning

outcomes and classroom behaviour when they interact with an interpersonal computer, a personal device and pen-and-paper?

In Alcoholado et al., 2012 we showed how an interpersonal computer can be used to teach arithmetic; here, we attempt to answer our research question by comparing it with a personal computer using the same underlying intelligent tutoring system as its software. The objective of this paper is thus to study how two different technologies, a personal computer (netbook) and an interpersonal computer, influence the learning achieved through arithmetic drills. We examine not only their impacts on learning but also how they affect student behaviour. The system used with both platforms is described in Section 2. The design of the experiment is presented in Section 3 and the results are set out in Section 4, which are discussed in Section 5. Finally, our conclusions are presented in Section 6.

III.3 Interactive arithmetic

The development of the intelligent tutoring system (ITS) for arithmetic practice drills used on the technology platforms is based on the arithmetic curriculum for the first four school years set by the Chilean Ministry of Education (MINEDUC, 2011). The system is built around 65 levels, of which 18 relate to addition, 18 to subtraction, 13 to multiplication and 16 to division (Alcoholado et al., 2012). The levels follow a sequence defined by the curriculum framework, and the number of exercises assigned for each level depends on the student's proficiency. Students advance from one level to the next once they successfully solve either 10 exercises with no mistakes or 8 of at least 15. Exercises were generated randomly in real time according to the level of the student.

Both the netbook and the interpersonal computer use the same intelligent tutoring system and user interface. The interface has four display states as shown in panels A through D of Figure III.11. The state depicted in 1A is the display of an exercise generated by the intelligent tutoring system depending on the student's progress. The states in 1B and 1C show the system's respective responses to an incorrect and a correct answer. To solve an exercise, the student must construct his/her answer by incrementing or decrementing each digit in the answer row (the three 0's in 1A). This method ensures the answer cannot be just guessed. Once the answer has been entered, the student clicks on the symbol, which in this case is a star. On the interpersonal computer this symbol also serves as the individual student's identifier. The fourth and final display state (1D) appears when a student has answered all the exercises for a level, thus completing a curricular objective.

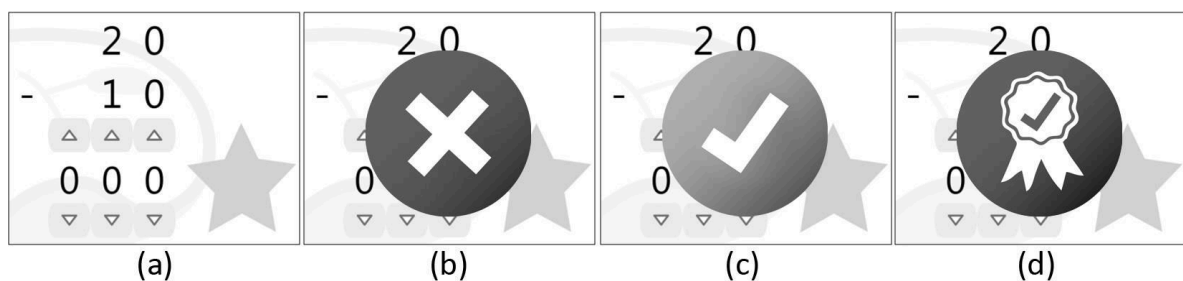


Figure III.11: ITS interface display states

On the interpersonal computer, each student has a box containing their current activity and their identifier. The various boxes are all displayed simultaneously in a grid as shown in Figure III.12. A column on the far right of the figure shows each student's current state by means of a string of squares that represents the last 15 exercises for the level they are working on. The strings are identified by the identifier symbols, which display the corresponding student's name once the symbol is clicked by the teacher. The

squares are color-coded to show the outcome of the students' efforts on each exercise: green for a correct answer on the first attempt, yellow for a correct answer on the second attempt and red for a correct answer on the third or further attempt. These indicator strings are grouped in the column by the curricular level of the students' current level (4 to 9 in Figure III.12). The teacher thus monitors the students' progress, providing assistance and reinforcement to those that need it.

On the personal computer (netbook) system, instead of showing the whole classroom information, each student's individual screen (Figure III.13) displays the information in Figure III.11-A plus the same state information displayed on the interpersonal computer, that is, the current curricular level the student is working on and the outcomes of their attempts to solve last 15 exercises.

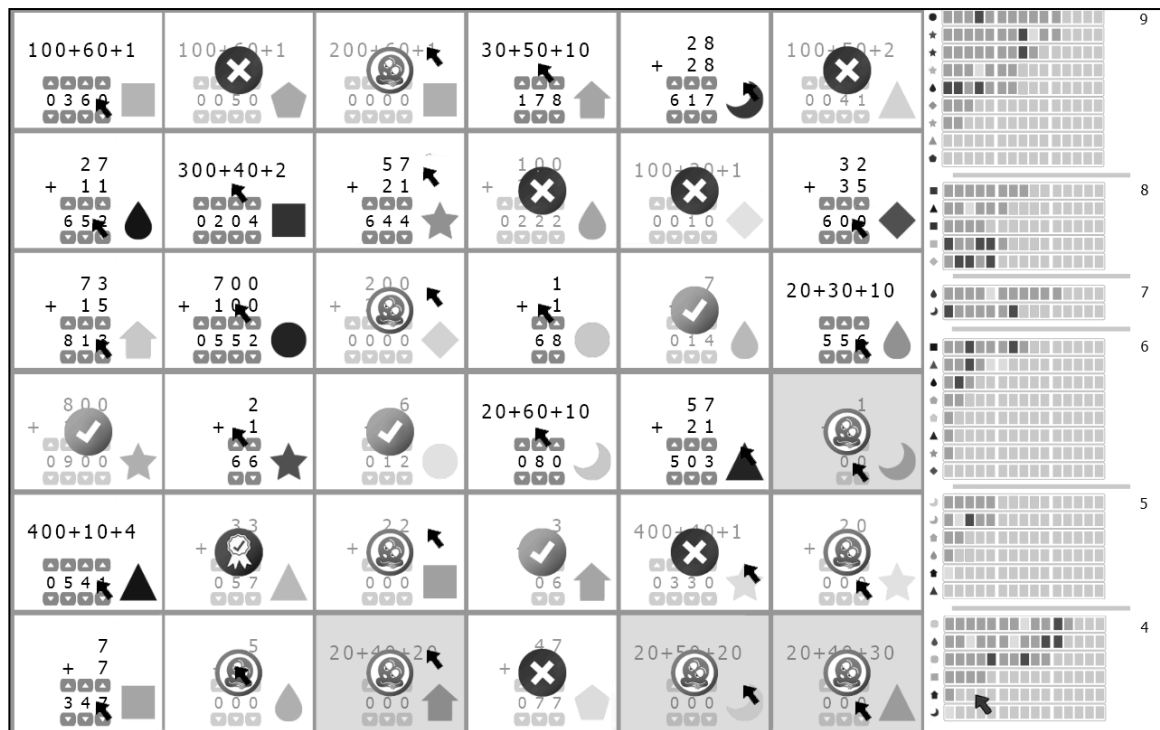


Figure III.12: Interpersonal computer information display

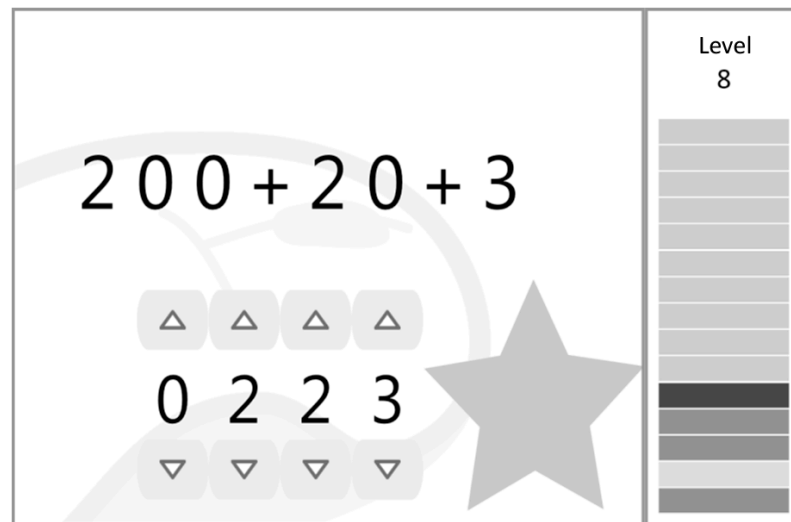


Figure III.13: Netbook information display

The students' activities are essentially the same on the two technological platforms since on either one, the children work at their own pace. The only major difference is that those with netbooks begin working on their exercises immediately while those using the interpersonal computer must first complete the identification step in which they recognize their identifier symbols using their respective mice (Alcoholado et al., 2012). This initial task took the students about 8 minutes in the early sessions but once they were familiar with it this dropped to about 3 minutes.

III.4 Experimental design

A multi-session experiment was conducted with three groups of schoolchildren. One group worked with an Interpersonal Computer, a second with a Personal Computer and a third with pen-and-paper. The three groups performed the same exercises used in the intelligent tutoring system; only the first two had technological support. Two booklets were distributed to the third group, one a workbook with the exercises and the other containing the answers. The main difference between the third group and the other two

was in the immediacy of the feedback. Whereas the groups using the technologies received immediate feedback and could not advance to the following exercise until they had answered the current one correctly, the group working with pen and paper had to complete all the exercises at a given curricular level before finding out which ones were answered correctly, and did not necessarily have to redo the wrong answers since the teacher did not always supervise them directly. A real-life class scene of each group is shown in Figure III.14.



Figure III.14: Real-life class scene for; (a) Interpersonal Computer, (b) Personal Computer and (c) Pen-and-paper

A comparison of the three systems is set out in Table 1. Note that for students using pen and paper, the number of exercises to be practiced at each level is fixed at 15, whereas for those using either of the two computer technologies, the number is variable and will depend on the individual student's performance. The total cost of netbooks for a classroom of 35 children (the standard size for a Chilean classroom) is £7700, which corresponds to 35 computers at £220 each (Atom 1.6GHz processor, 1GB RAM, 320GB HDD and 10.1" display), while the cost of IPC is £822, which corresponds to one £300 laptop (i3-2330M processor, 4GB RAM, 500GB HDD and 15.6" display), one £215

projector (800x600 pixels, 2500 lumens) 35 USB mice at £5 each, 6 USB hubs at £16 each and 6 USB extension cords at £6 each (cost estimates from Amazon UK).

Table III.11: Comparison of systems

	Interpersonal computer	Netbook	Pen and Paper
Type of feedback	Immediate		Upon completion of all 15 exercises in a curricular level
Display of information	Public	Private	Private
Display of score	Public (ranked by progress)	Private	(no display)
Exercises to be completed before advancing to next level	10 exercises, all answered correctly, or 15 or more exercises, of which at least 8 must be answered correctly.		15 exercises
Acquisition cost for 35 students	£7700	£822	Cost of photocopies

The multi-session experiment was conducted at a government-subsidized private school in Santiago, Chile attended by children from low-income families in which 60% of the parents did not finish grade school. The majority of students do not have access to computers at home; however, they regularly work with computers in the laboratories at school, starting in 1st grade. The 81 participants were all in third grade and included 44 boys and 37 girls between the ages of 8 and 10. They were divided randomly into three groups of 27, one group for each system, which were maintained throughout the study. The final analysis was based on the results of 54 students who performed both the pre-test and the post-test, 19 of which were from the interpersonal computer group, 17 from the netbook group and 18 from the pen-and-paper group. We decided to consider only

students that performed both tests since other data was not complete for statistical analysis. This is a quasi-experimental design because we worked in just one school which was not randomly chosen and is not necessarily representative of the whole population.

The sessions began in May and ended in November, shortly before the end of the Chilean school year. It was originally intended that a 40-minute activity would be performed each week simultaneously by all three groups. However, there were a number of weeks in which no sessions could be conducted due to extra-curricular events and legal holidays. In the end, the pen-and-paper and netbook groups each held a total of 14 sessions while the interpersonal computer group held only 12, the other 2 being cancelled due to technical problems with the software. Two additional sessions were needed with all three groups to administer the pre-test and post-test. These activities were above the regular 8 hours per week of 40-minute mathematics classes.

Each group held all of its sessions in the same room and was assigned a mathematics teacher from the school. To minimize the possible effects of differences in the quality of support given to the students, the teachers were rotated twice so that every group had the same three teachers for equal periods during the experiment. The two groups using computers also had support staff to supervise the activities and handle any technology-related problems.

The pre-test and post-test consisted of a pen-and-paper exam with 45 questions based on the various curricular levels worked on during the sessions. The questions were chosen by teachers at the school from among a set generated at random according to the 65 ITS levels discussed in Section 2 and were based on the knowledge they expected students to have by the end of third grade. Before applying this instrument it was validated on 76

fourth grade pupils at the same school, the results displaying a Cronbach's alpha of 0.8901. Thirty minutes were allowed for answering the exam questions, the students' scores being simply the number of correct answers.

To analyse the children's behaviour, observation data was recorded during the entire period of the experiment. To standardize the results, a single observer was rotated from week to week between the three groups. The observer recorded events by following an observation guideline throughout the duration of the class, with no direct interaction with the children. Since 11 observations (or more precisely, sets of observations) were taken, the first and last were eliminated, thus leaving an equal number (3) for each group. The data was collected whenever the observer noticed that a student within the classroom showed one of the following attributes:

1. Fatigue - (1) Boredom: comments suggesting the children did not want to continue the activity or were not enjoying it; (2) Tiredness: physical or verbal indications; (3) Interruptions: any act by a student whose objective or actual effect was to interrupt the flow of the activity.
2. Interaction - (1) Collaboration: helpful comments or actual assistance between two pupils; (2) Competition: comments between two or more children.
3. System: Teacher's explanations of the use of the system to a particular student.
4. Pedagogy - (1) Explanations: Teacher's explanations of a particular exercise to a particular student; (2) Interventions: Teacher interrupts the students' work in order to explain either the system or particular exercises to the whole classroom.

These behavioural data were entered in a Tablet PC that had an interactive observation guideline which contained the previously defined elements. The time the event was recorded was automatically registered so that the evolution in these attribute variables could be tracked as the experiment progressed. For the analysis, the score was taken as the number of events recorded for each attribute.

III.5 Results

III.5.1 Quantitative results

The progress made by the three groups, as demonstrated by the difference between their pre-test and post-test results, was in all cases significant and with a large effect size. As can be seen in Table 2, the students using the two computer technologies displayed similar advances even though the interpersonal computer (IPC) group had two fewer sessions. Indeed, the difference between their results was shown by a t test not to be significant ($p < .37$). The difference between the netbook and pen-and-paper (P&P) groups was also not significant ($p < .10$), but the IPC's superior performance compared to the P&P group was significant ($p < .03$).

Table III.12: Pre-test and post-test results (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

	No. of students	Pre-Test		Post-Test		$\Delta\%$	t	Significance	Cohen's d (Cohen, 1938)
		\bar{X}	s	\bar{X}	s				
IPC	19	18.95	8.09	29.26	9.94	54.44%	9.29	$p < .01$	1.17
Netbook	17	19.06	6.56	28.71	6.88	50.62%	5.74	$p < .01$	1.48
P&P	18	25.50	5.97	32.44	6.59	27.23%	5.51	$p < .01$	1.14

III.5.2 Length of sessions

The students' actual working time on the interpersonal computer increased from 11 minutes in the first 40- minute session to almost 38 by the last. Students' assigned netbooks showed little change in their working time, which was 31 minutes in the first session and averaged 33 over the entire period of the experimental.

This working time difference between the two group's trends was due mainly to the different adaptation times for the two technologies. The interpersonal computer in particular included an identification phase in which the students had to recognize their names with their mice for data traceability (Alcoholado et al., 2012). Also, 29 minutes of the first session with the interpersonal computer was devoted to explaining how it worked while for the netbook only 9 minutes of the first session were needed to explain its functioning.

As for the pen-and-paper group, the students began working on the exercises almost immediately, the only delay being the time taken to hand out the paper notebooks.

III.5.3 Exercises completed

The students completed an average of 26.71 exercises per session on the interpersonal computer, 32.80 on the netbook and 52.50 using pen and paper. Figure III.15 shows the average number of exercises completed per student per session for each work group (netbook, interpersonal computer, and pen-and-paper), clearly demonstrating how the interpersonal computer group steadily increased its total over the first three sessions as the children mastered the software, a process the netbook group evidently did not require. From that point forward, however, all three groups exhibited a decline as the

exercises' level of difficulty increased. In the final sessions, exercises completed by the interpersonal group overtook that of the netbook group.

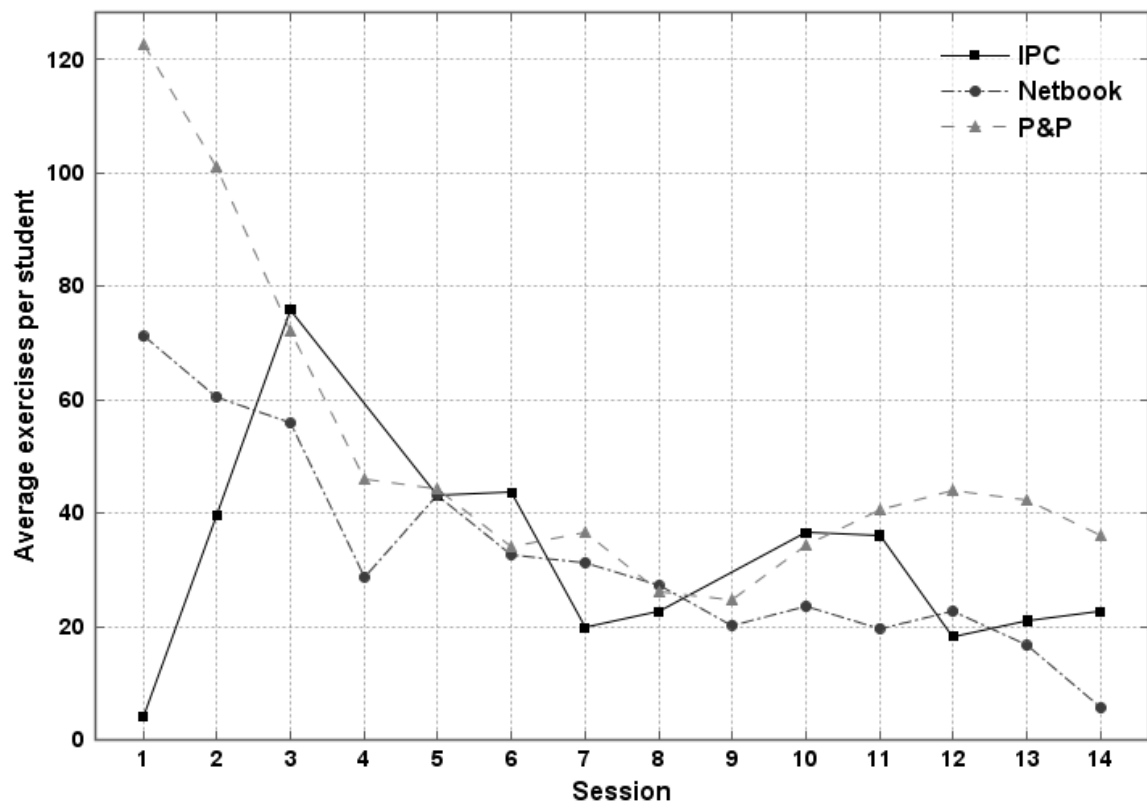


Figure III.15: Number of completed exercises per student by session and technology group (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

Figure III.16 shows the percentage of students who completed their respective curriculum levels by the end of the experiment. The results show that the pen-and-paper group advanced considerably further given that it was not slowed down by the automatic feedback system. However, as we saw in Table 2, this did not translate into greater learning compared to the two technology groups. Also clear from the graph is that the notebook group's progress was similar to that of the interpersonal computer group.

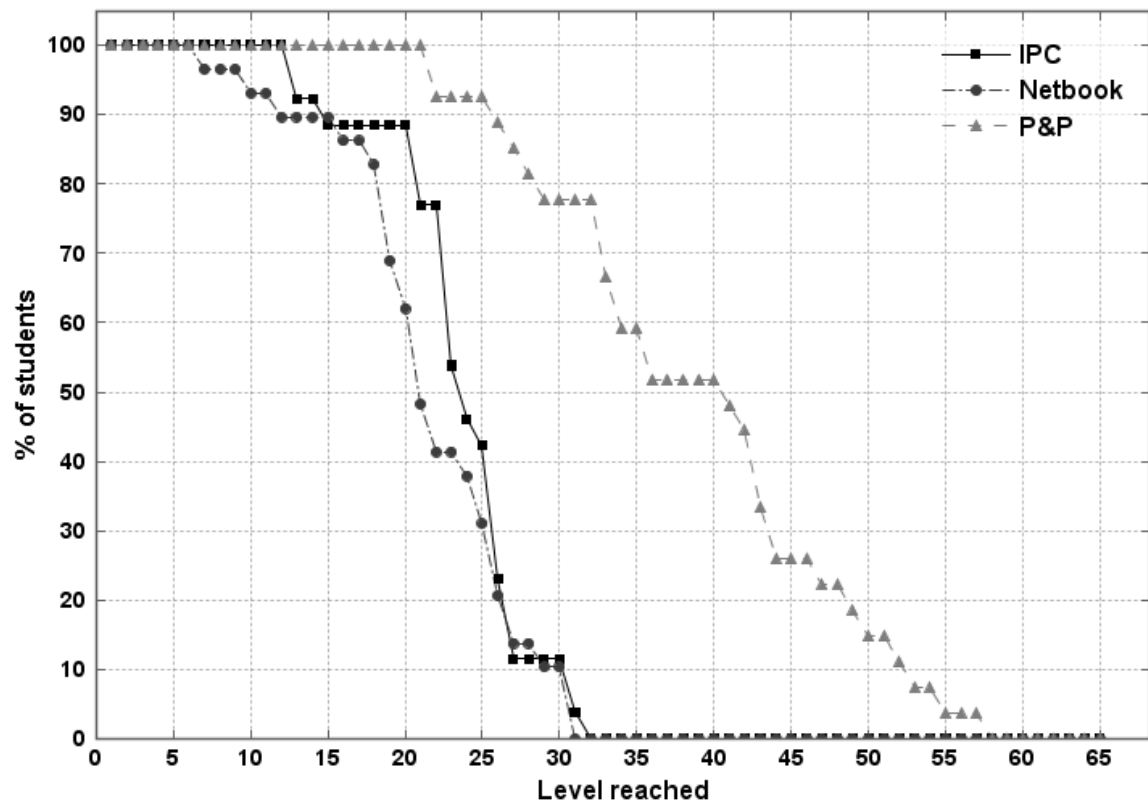


Figure III.16: Level reached by end of experiment (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

III.5.4 Observations results

Table III.13: Number of observations by attribute (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

Attribute	Observation	Netbook	IPC	P&P
Fatigue	Student shows signs of boredom	34	54	54
	Student shows signs of tiredness	4	13	6
	Student interrupts flow of activity	85	91	64
Interaction	Student shows signs of collaborative behaviour	63	48	11
	Student shows signs of competitive behaviour	6	8	10
System	Student requests help with the system	17	3	-
Pedagogy	Student requests help with the exercises	55	47	27
	Teacher interventions	3	11	0

The behavioral observations for the three groups are summarized in Table 3 where we report the number of observations obtained for each of the variables of the attributes defined in Section 3. They show that the two technology groups generated a more collaborative environment than did the pen-and-paper group even though such was not the intention of the design. As for competitive behavior, even though they could see each other's ranking at every moment, the children working on the interpersonal computer exhibited no real difference in this attribute from the other two groups. According to the teachers, the children tended to be very focused on their own individual boxes, leaving only the teacher to keep an eye on their ranking from moment to moment. Also revealed by Table 3 is that the netbook group had more difficulties with their system than did the interpersonal computer group. Whereas in the netbook case the problems generally involved charging batteries and dealing with system popups, the problems arising with the interpersonal computer system had mainly to do with setting up the equipment at the beginning and end of each session.

There were relatively few signs of tiredness, with the interpersonal computer group accounting for more than half of the cases observed. This was because children in the group with poor vision struggled to read the display projected on the classroom wall. After considering the seating arrangements, the problem was minimized by seating the children with vision problems closer to the screen.

The collaboration observed in each group is illustrated in Figure III.17 for each group's three observed sessions. The netbook and pen-and-paper groups both showed a downward trend over the course of the sessions, the latter group by the last session showing no signs of collaborative behavior at all. By contrast, requests for help with the

exercises increased steadily in the interpersonal group between the first and the last sessions, as demonstrated in Figure III.18.

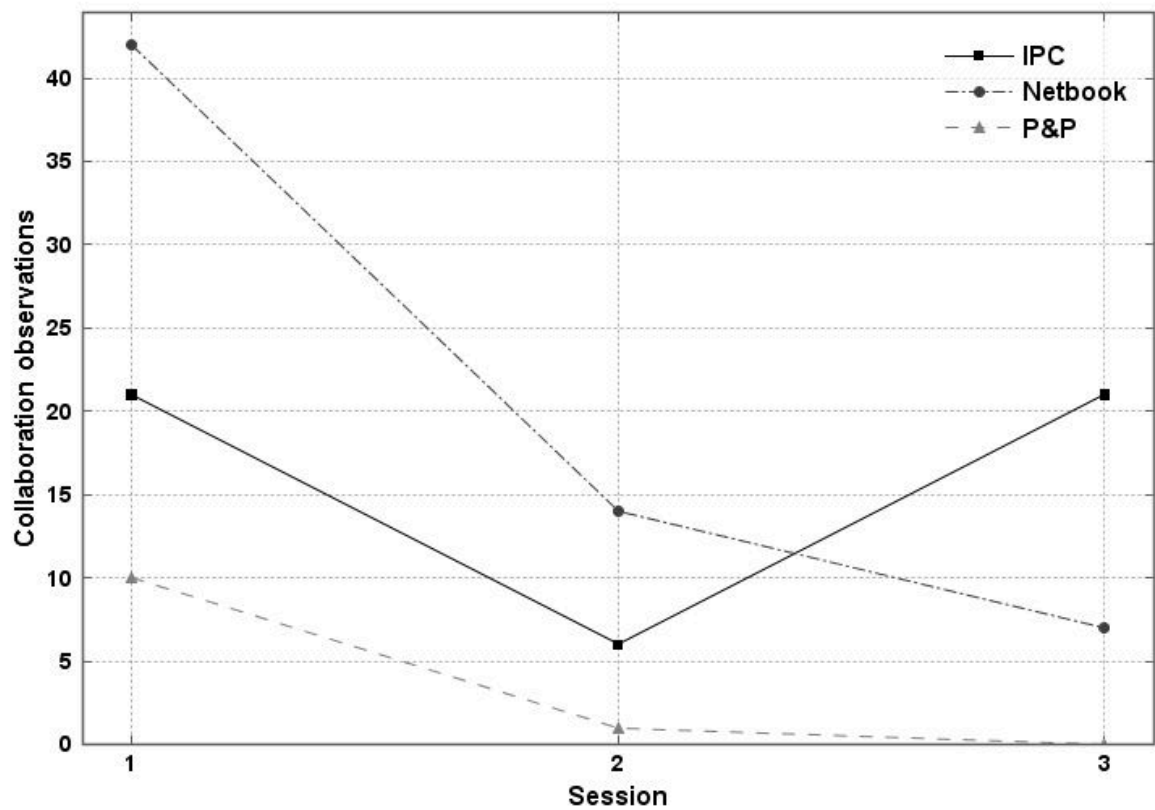


Figure III.17 Observations of collaboration by observed session (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

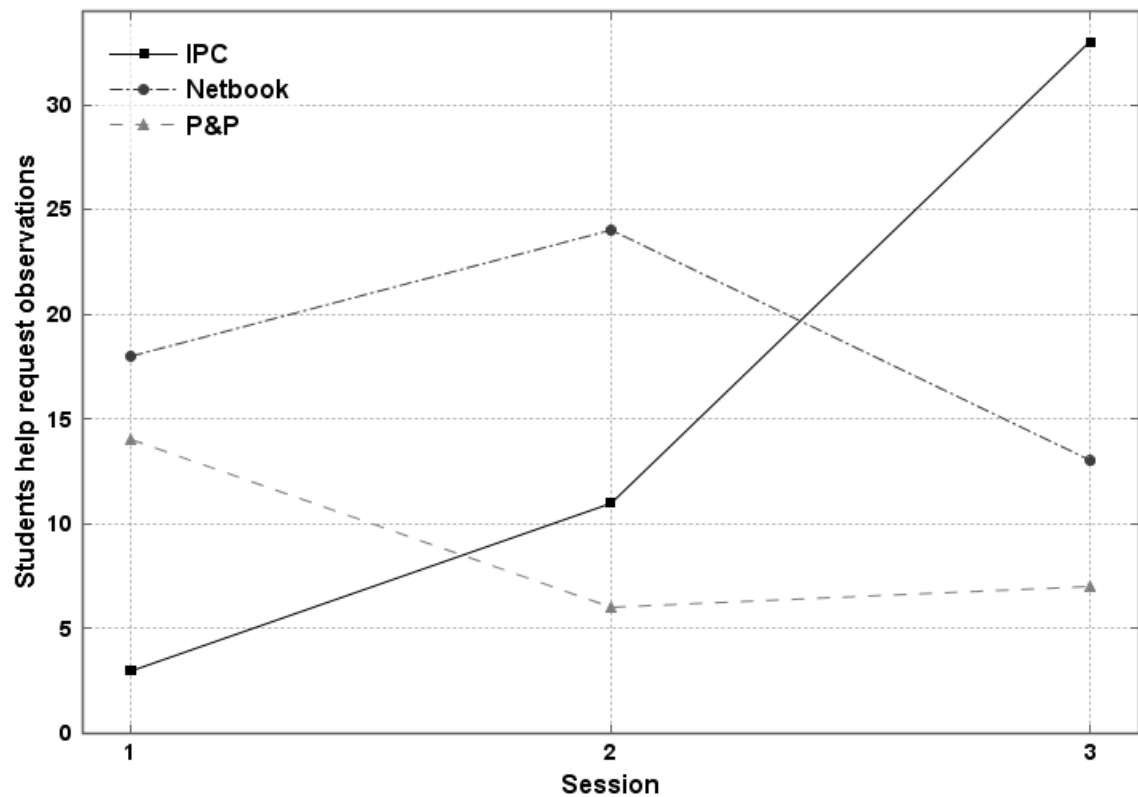


Figure III.18 Observations of exercise help requests by observed session (IPC:

Interpersonal Computer; P&P: Pen-and-Paper)

The correlations between the boredom, collaboration and work interruption observations by group are summarized in Table 4. As can be appreciated, the behaviour of the pen-and-paper group as regards interruptions was completely the opposite of that exhibited by the two technology groups. In all three groups, the correlation between collaboration and interruptions and between boredom and collaboration was high, suggesting that when the students begin to tire of their work they turn to their classmates, whether to collaborate with them or just to interrupt them.

Table III.14: Correlations among boredom, collaboration and interruptions attributes by session (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

	Boredom vs. Collaboration	Boredom vs. Interruptions	Collaboration vs. Interruptions
IPC	0.80	0.67	0.98
Netbook	0.98	0.76	0.87
P&P	1.00	-0.93	-1.00

To further investigate the phenomenon of boredom, a single session was divided into three equal time intervals and the observations recorded and graphed. Figure III.19 illustrates the observations of boredom during all the sessions based on the intervals of time in which the phenomenon was recorded. The results indicate that the pen-and-paper group experienced greater boredom than the other two groups at the beginning. This was likely because of a positive predisposition towards using the technologies, a novelty for many of the children. As the session progressed, however, the boredom level among the technology groups generally grew while that of the pen-and-paper group stayed relatively constant.

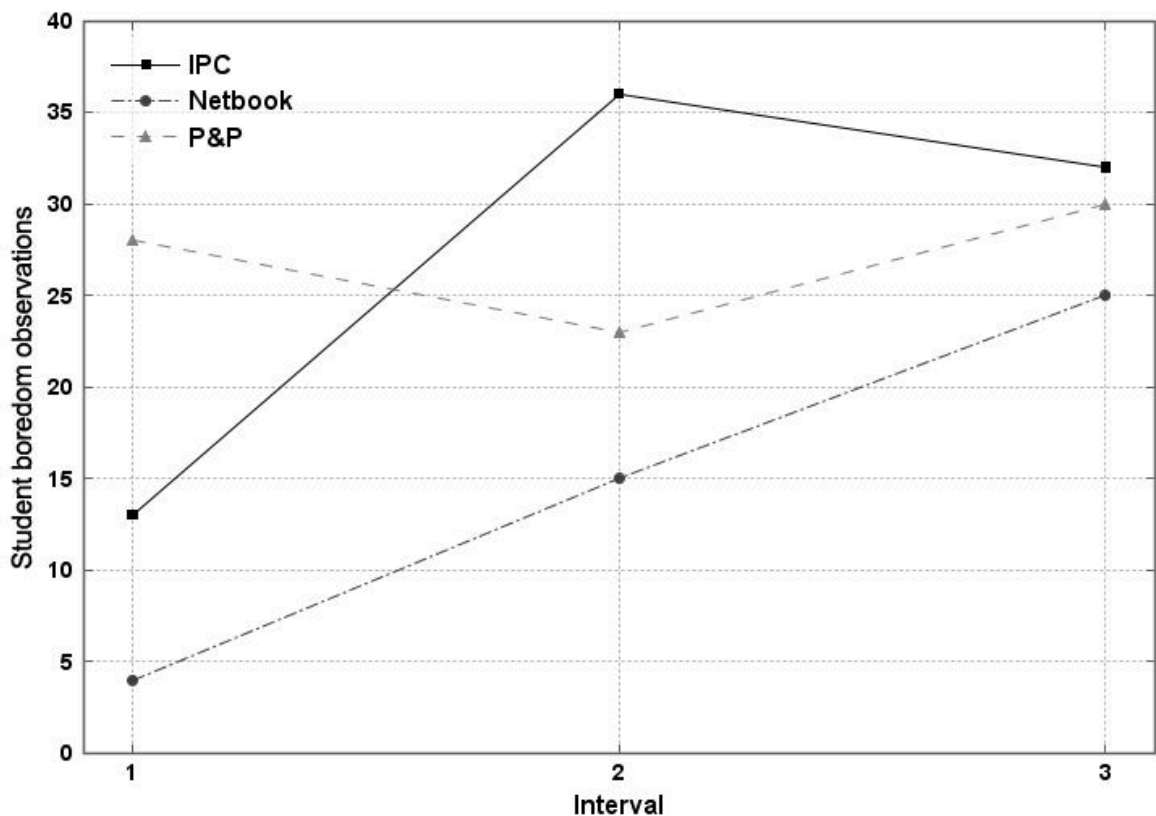


Figure III.19: Boredom by time interval over a single session (IPC: Interpersonal Computer; P&P: Pen-and-Paper)

As for the teacher's role in the activity, they barely intervened during the student's work, as can be seen in Table 3. The pen-and-paper group did not have a single teacher intervention during the observed sessions; this can be ascribed to the teacher acting as supervisor of a regular exercise-based lesson. In the Interpersonal Computer group, the software provided tools for the teacher which encouraged him to make more interventions. However, the overall number of interventions was considerably smaller than expected by the research team. This is addressed in the discussion section.

III.6 Discussion

As Table 2 shows, the two technology groups achieved greater improvement in learning compared to the pen-and-paper group (although the difference was only significant statistically with the interpersonal computer group). In contrast, the pen-and-paper group completed 33% more exercises per session and reached a curricular level on average 60% higher than the two technology groups. The improvements in learning made by the students using the technology systems can be mainly ascribed to the feedback given to them by the system. The pen-and-paper students made quicker progress because they did not necessarily redo an exercise until it was correct, which was the case for the technology groups, as they corrected the exercises themselves by following a printed answer sheet.

By allowing each student to work at their own pace and level, it produced a great disparity in the topics being worked on in each class (Figure III.16). After 14 sessions, we could observe a difference of up to 20 levels between students, equivalent to almost a year's curriculum. This divergence in student learning paces generates an array of pedagogical needs in the classroom, leaving the teacher without a shared context.

In a traditional classroom, the class follows a single pace defined by the teacher. However, in our case the teacher must adapt themselves to the needs of the students in each session, something for which they may not necessarily be pedagogically prepared. This leads to teachers dedicating their time exclusively to responding to their students' specific needs, instead of guiding them in the learning process according to what they observe in the work being done in class. This invites them to look for techniques which offer a harmonious balance between the needs of the teachers and the students (Alavi,

Dillenbourg, & Kaplan, 2009), that allow for orchestration of the teacher's work, guiding them in the integration of digital and non-digital resources in the classroom (Nussbaum, Dillenbourg, Fischer, Looi & Roschelle, 2011).

One way of bridging the gap between different learning paces is to assign homework which are linked to the work being done in class. We are working on a web-based system which communicates with the classroom system and guides the students, under the teacher's supervision, allowing those who are further behind to do extra work in order to reinforce their weaknesses (Nussbaum, Büchi, Alcoholado, Diaz & Infante, 2012).

During the experiment the logistics required for the in-class work was managed by the research team, providing technical support for each session and coordinating the availability of resources for each session with the school. In order to meet these conditions, the establishment must be able to provide the necessary technical support, in line with the work being done by the teacher. If this is not the case, the job of the teacher is made more difficult and leads them to view the technology as more of a problem than an aid.

If the learning impacts of the two technologies were similar, their acquisition and maintenance costs are not. The clear advantage of the interpersonal computer scheme on this fundamental criterion is illustrated by the fact that equipping a classroom would involve an expenditure, depending on the number of students, of around 90% less than that for netbooks; also less technical support is required since it is just one machine and the kids are in direct contact with the system software. The use of the interpersonal computers is thus a highly attractive alternative for personalized learning in developing economies where 1:1 equipment or computer labs are not generally accessible. Further

research should compare the use of individual and interpersonal computer technologies with other type of interactive activities in different curricular topics.

Bearing in mind that the experiment was carried out with third grade mathematics students from just one school, our results cannot be generalized. This is because the sample cannot guarantee that the results would be repeated in other situations. Future research could look at carrying out a large scale comparison and in other school settings, so as to study whether or not the results remain consistent with the results obtained in this experiment.

III.7 Conclusions

Two technology-based methods for conducting arithmetic drills were compared to the traditional pen-and-paper approach as regards both learning impacts and differences in student behaviour. Students participating in a multi-session experiment in which they worked through arithmetic exercises at different curricular levels were divided into three groups, one using personal computers (netbooks), another using an interpersonal computer, and the third using pen and paper.

The results of the experiment showed that the two technology groups achieved higher learning progress compared to the pen and paper group on the pre-/post- test).The lack of a significant difference between the interpersonal computer and netbook groups suggests that the difference between the two technology groups on the one hand and the pen-and-paper group on the other lies principally in the ability of the technologies to give instant individualized feedback, whether on an individual or a shared display. Considering the research question, are there any differences in children's learning outcomes and classroom behaviour when they interact with an interpersonal computer as

opposed to a personal device?, we conclude that instant feedback can be provided “publicly” (on an interpersonal computer) and obtain similar results to “private” provision (personal computer).

Besides the future work described in Section 5, the authors plan to extend the research reported here by studying how personal and interpersonal computers differ in their learning and behavioural impact for school subjects other than arithmetic, such as native language skills and foreign language acquisition, complementing the mice with earphones and keyboards. Another area we to explore is how the type of technology affects the results for whole-class collaborative work (Szewkis et al., 2011).

IV. A COMPARATIVE ANALYSIS OF INTERACTIVE ARITHMETIC LEARNING IN THE CLASSROOM AND COMPUTER LAB

IV.1 Abstract

One of the main benefits of using technology in education is the opportunity it provides for student interactivity. The exact location of where to implement technology for interactive learning in schools has been a topic of debate across the field, with the classroom and the computer lab emerging as the most common options. This paper answers if there is any difference in learning between personalized interactive work carried out in the classroom using a Shared Display Interpersonal Computer, and personalized work done in a computer lab using personal computers. Comparisons were made between classroom work using a Shared Display Interpersonal Computer, work in a computer lab using a personal computer and mixed work using a combination of the two. Both systems performed the same rule based arithmetic system with the same functionality and interface. While in the Shared Display Interpersonal Computer all the children shared the screen in the PCs each child had its own screen. Results of the study show significant differences in learning in favor of the classroom groups. Explanations, which have to be validated in future work, are the interactions between peers observed in the classroom and the teachers support inside the classroom.

IV.2 Introduction

One of the main benefits of using technology in education is the opportunity it provides for student interactivity (Zurita & Nussbaum, 2004). In addition, technology supports reflective thinking (Beauchamp & Kennewell, 2009) and enables students to play a

central role in their own learning (Infante, Hidalgo, Nussbaum, Alarcón, & Gottlieb, 2009). The interactive learning process can be supported using a number of different technologies, such as the 1:1 model (One Laptop per Child Foundation, 2006), multi-touch surfaces (Morris, Fisher, & Wigdor, 2010) and Interpersonal Computers (Kaplan, DoLenh, Bachour, Yi-ing Kao, Gault, & Dillenbourg, 2009), among others.

The Interpersonal Computer allows multiple users located in the same physical space, using their own input device on the same computer, to simultaneously interact (Kaplan, DoLenh, Bachour, Yi-ing Kao, Gault, & Dillenbourg, 2009). A common application of the Interpersonal Computer is the Shared Display (Yang & Lin, 2010). Of the various applications that use the Shared Display Interpersonal Computer, the most well-known are clickers, which aid in the process of asking groups of students multiple choice questions (Trees & Jackson, 2007; Crouch & Mazur, 2001). While clickers only provide group-level feedback to students, there are other Shared Display Interpersonal Computer applications which allow a greater degree of simultaneous student involvement for all students in the classroom (Scott, Mandryk, & Inkpen, 2003; Paek, Drucker, Kristjansson, Logan, & Toyama, 2004). Accordingly, the most common alternative has been to use the mouse as an input device for each student (Pawar, Pal, Gupta, & Toyama, 2007).

The Shared Display Interpersonal Computer is a good alternative, particularly in low income economies, as it allows for personalized interactivity at a cost of approximately US\$1 per child per year (Trucano, 2010). Diverse uses of the mouse as an input device have been developed. Mouse Mischief (Moraveji, Inkpen, Cutrell, & Balakrishnan, 2009) lets different students answer multiple choice questions, and then provides group feedback regarding the class's overall performance. In order to find a way of providing

individual feedback, (Alcoholado et al., 20123) demonstrated how useful this technology is for teaching basic arithmetic. (Szewkis et al., 2011) proposed the use of this technology for achieving collaboration with all students in a classroom. In their analysis, the authors noted that students helped one another, not sitting beside each other, not with words but rather by using the software, in a process they called “silent collaboration”.

The exact location of where to implement technology for interactive learning in schools has been a topic of debate across the field, with the classroom and the computer lab emerging as the most common options. (Davis & Shade, 1994) suggest that integrating technology into the classroom leads to greater appropriation of the curriculum, while (ITL Research, 2011) argues that access to ICT (Information and Communication Technology) in the classroom leads to more innovative ways of teaching. Conversely, some argue that the computer lab is more conducive to developing students’ ICT skills (Rule, Barrera, & Dockstader, 2002). However, the computer lab has been shown to be more intimidating for teachers (Trucano, 2010; Salomon, 1990; Hepp, Hinostroza, Laval, & Rebién, 2004).

Given the opportunities provided by the Shared Display Interpersonal Computer for classroom work, and the predominance of computers in school computer labs, our research question is: Is there any difference in learning between personalized interactive work carried out in the classroom using a Shared Display Interpersonal Computer, and personalized work done in a computer lab using personal computers? The technologies used in this study are outlined in Section IV.3. The experimental design is detailed in Section IV.4 and the results in Section 0. Finally, a discussion of findings, conclusions and future work is presented in Section IV.7.

IV.3 Technologies used in the study

For the interactivity of a particular type of software to be effective it is necessary to take student feedback into account, which some authors consider the foundation of learning (Biggs, 1999; Brown & Knight, 1994). One model that facilitates the implementation of this idea is the Formative Assessment model, which seeks to provide feedback on performance to each student, with the aim of accelerating the learning process (Sadler, 1998). Using this concept, two systems were designed to teach arithmetic.

The first system incorporates a Shared Display Interpersonal Computer, in which all students share the same screen but each child has their own input device: a mouse. This way, all the students in one class can work simultaneously by sharing the same computer and screen (Figure IV.20a), allowing each child to work at their own pace (Alcoholado et al., 2012). The students share a common interface (Figure IV.20b), in which each child possesses an individual work space with an exercise box, described below (Figure IV.21a). In addition, on the right hand side of the screen there is a space which shows the students' performance in real time. This information is intended to help the teacher assist any student who requires help.

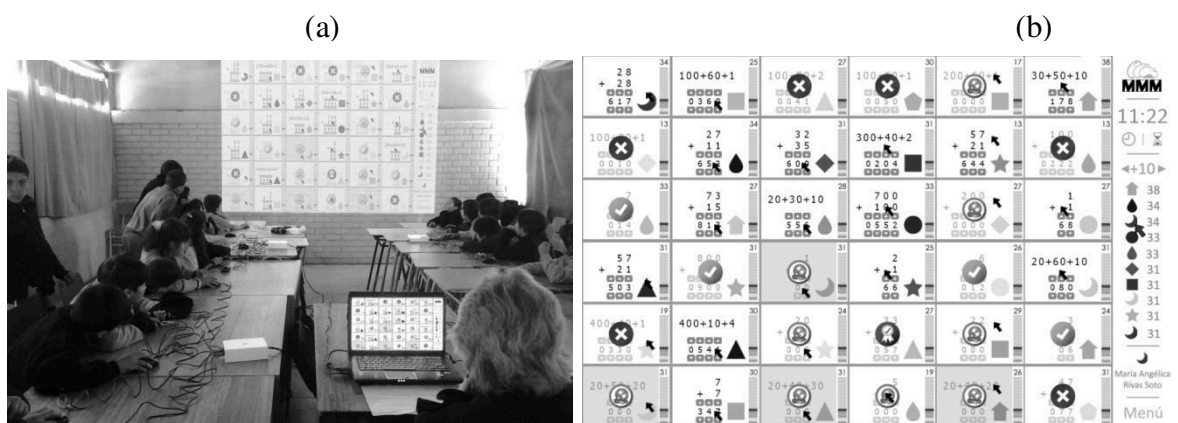


Figure IV.20: Use and interface of the system used for classroom work

The second platform used in this experiment was a web-based system. This remote access system used the same workspace and functionality as the Shared Display Interpersonal Computer (Figure IV.21a). However, with the web-based system each student has their own screen, whereas the Shared Display involves up to 32 students sharing one screen. Another difference between both systems is that the teacher does not have access to information on the group's progress when using the web-based alternative.

Both systems enabled students to save their work at the end of a session and resume it in the following session. In addition, the two systems were mutually compatible, making it possible to synchronize the progress of the students work in the classroom using the Shared Display Interpersonal Computer with the web-based system. This allowed students to continue with their classroom work from any type of computer with an internet connection, and on returning to the classroom, to pick up from where they left off.

Both types of software were built around the same content, in line with the Chilean national curriculum (MINEDUC, 2013). This content is divided into a system of 65 mathematical rules, 18 of which relate to addition, 18 to subtraction, 13 to multiplication and 16 to division (Alcoholado et al., 2012). The rules are presented in order of difficulty and the students must work sequentially. To advance to the next rule, students must correctly answer the first ten questions without making any mistakes. If a mistake is made, they must then answer five additional questions, and have a total of at least eight correct answers, including three from these five extra questions. If they fail to meet these requirements, they must continue to answer questions until the criteria is met.

These rules applied to both systems, which also shared the same functionality and interface (Figure IV.21a). Each student is identified on the screen by a particular symbol (a triangle in this case) and a question which must be answered by formulating a response. The student then receives feedback regarding their answer, indicating whether the answer was incorrect (Figure IV.21b) or correct (Figure IV.21c). As described previously, the student can only advance from one rule to the next by meeting the aforementioned requirements. When a student finishes a rule, the system shows that they have completed the work on that particular rule (Figure IV.21d).

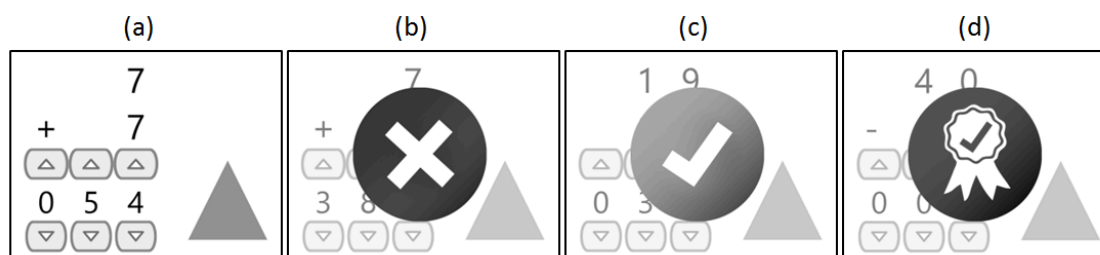


Figure IV.21: System feedback provided to students

IV.4 Experimental Design

To answer our research question, “Is there any difference in learning between personalized interactive work carried out in the classroom using a Shared Display Interpersonal Computer, and personalized work done in a computer lab using personal computers?”, three work groups were devised: (1) in the classroom, using the Shared Display Interpersonal Computer; (2) in the computer lab, using the web-based system; and (3) a mixed model of the two. Groups 1 and 2 worked once per week, while Group 3 worked twice per week, with one weekly session for each type of technology.

The quasi-experimental study was done with 88 third grade students aged between eight and ten years old from a public school in Santiago, Chile. The sample consisted of three

classes, with each assigned one of the aforementioned technologies, as outlined in Table IV.. The experiment was conducted over the course of an academic year, and lasted for a total of 26 weeks. Not all groups worked on a weekly basis as planned (Table IV.), due to various reasons not related to the experiment. All groups worked autonomously with occasional supervision provided by a member of the research team. Each experimental session lasted for an average of approximately 30 minutes.

A pre- and post-test was carried out using the same instrument, which consisted of 45 questions and was previously used in a separate investigation (Tagle, Alcoholado, Nussbaum, & Infante, 2013). These questions, representing the aforementioned mathematical rules, were devised using a set of one question per rule, all of which were deemed appropriate for a third grade student, according to three third grade teachers. Cronbach's Alpha for this instrument in the post-test was 0.915 for the 82 students who took the test.

Table IV.15: Numerical breakdown of sessions and students per group

Group	Technology	No. of students			Sessions	
		Male	Female	Total	Classroom	Computer Lab
1	Classroom	19	13	32	21	-
2	Computer lab	15	12	27	-	15
3	Mixed	10	19	29	19	20

IV.5 Results

Results from the pre- and post-tests are shown in Table IV.16. The statistical significance (p) was measured for each group using a one-tailed t-test, which found significant results for each of the groups. Only students who took both tests were

included in the results so as not to have to make any adjustments and allow students to be compared using their pre- and post-test scores.

Table IV.16: Groups' results in pre- and post-tests

Group	Technology	N	Pre-Test		Post-Test		t	P	Cohen's d
			\bar{X}	s	\bar{X}	s			
1	Classroom	22	16.23	7.74	30.64	7.83	13.51	< 0.001	1.89
2	Computer lab	17	17.76	7.07	27.24	8.37	6.80	< 0.001	1.26
3	Mixed	24	17.79	6.38	31.00	6.09	12.86	< 0.001	2.16

A one-way analysis of covariance (ANCOVA) was conducted to compare the effectiveness of the groups. Preliminary checks were carried out to ensure no ANCOVA assumption was broken. After adjusting for pre-experiment scores, gender and group variables were used as controls for the children's progress. The gender of the student was irrelevant ($F < 0.001$, $p = 0.989$). The group variable was significant for post-test scores ($F = 4.180$, $p = .020$). In order to compare the effect of each group, pair-wise differences among the adjusted means for each group were evaluated using Tukey's post-hoc test to analyze the differences detected by ANCOVA. The Holm multi-step correction procedure was used to control for Type I error across the three pair-wise comparisons. The results of this test are shown in Table IV.17; those marked with an asterisk are statistically significant.

Table IV.17: Results of post-hoc tests for the differences between the means

Group	\bar{X}	$\bar{X}_{adjusted}$	Adjusted Mean Differences [Xi-Xk] (p-value)		
			G1	G2	G3
G1 (Classroom)	30.64	31.42	-	4.588 (p=0.016*)	0.844 (p=0.577)
G2 (Computer lab)	27.24	26.83		-	3.744 (p=0.049*)
G3 (Mixed)	31.00	30.57			-

Table IV.17 shows that the group working exclusively in the computer lab reported a statistically lower difference compared to the other two groups working in the classroom. Conversely, the comparison between the classroom model and the mixed model demonstrated no statistical difference.

The aforementioned information relates to the progress made by students over the year, i.e. it only takes into account the beginning and end of the experiment. Figure IV.22 illustrates the average progress made per student, measured in terms of the number of pedagogical rules completed per minute by each student, for every session of each of the three groups. Group 3 was divided into two sub-groups, Classroom and Computer Lab, as a way of examining the differences separately. Sessions are chronologically consecutive for each group, which means that weeks in which a particular group had no sessions at all were not taken into account. This information was obtained using records taken from the systems.

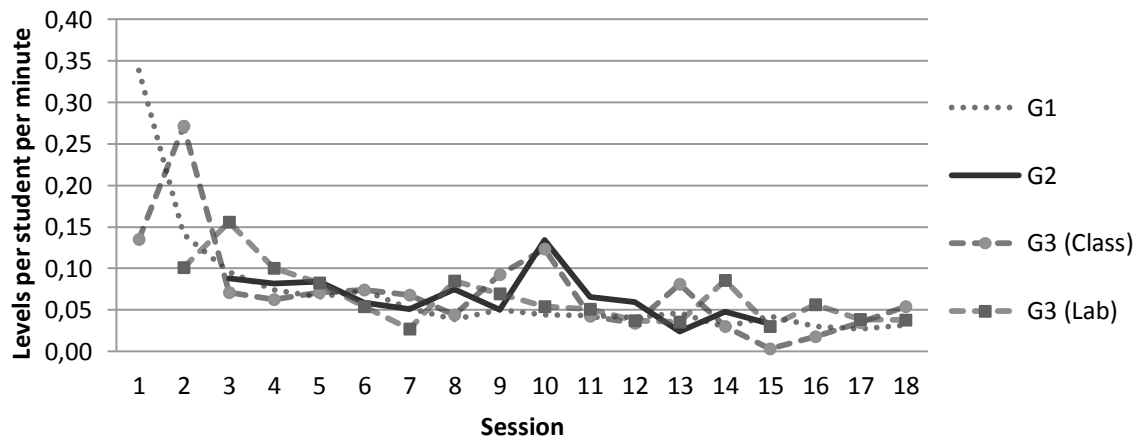


Figure IV.22: Levels progressed per student per minute for each session, by group

Figure IV.22 shows that there were similarities between the groups and that no group stood out in particular, with the exception of the beginning phase of the experiment. In this phase, students start working on basic addition and the pace of progress through the rules is greater until reaching rules which related to knowledge that had not yet been acquired. To gauge whether there were any differences in the averages between the groups, a variance analysis was conducted, excluding sessions in which one of the groups was unable to participate. The test revealed no evidence to suggest any variation in the trends of each group ($F=0.625$; $gl=3.52$; $p=.602$). We therefore conclude that there is no difference in the level of progress between one group and another.

IV.6 Discussion

Table IV.15 shows that there are differences between the number of sessions for each group. This is due to a range of school-related factors, mainly extra-curricular events, as well as the experimental design in the case of Group 3. These differences may have an impact on the ANCOVA results because not all groups received the same level of intervention. The Mixed Group (G3) had two fewer sessions in the classroom and 20

more in the computer lab than the Classroom Group (G1). Given that there were no statistical differences between G1 and G3, but that there was a difference between these two groups and G2, this would seem to indicate that the number of sessions in the computer lab has less of an influence on the learning process than the number of sessions in the classroom.

The results included in Table IV.17 establish significant differences between the groups, while Figure IV.22 shows that there is no difference between the groups in terms of the pace at which students progressed. This leads us to search for other variables which may explain the results.

In (Tagle, Alcoholado, Nussbaum, & Infante, 2013) a comparison of technologies similar to the present study was conducted, using the same software, instruments, and curricular content as described here. The students that participated in that experiment were of the same age range and from comparable schools. The study compared inside a classroom the use of a Shared Display Interpersonal Computer with a group of students using netbooks, as opposed to the desktop PCs used in this study. (Tagle, Alcoholado, Nussbaum, & Infante, 2013) found no difference in curricular progress between the group using the Shared Display Interpersonal Computer and the group using netbooks. However, they did observe that the netbooks provided students with mobility which allowed them to move closer to their classmates and work together. In the present experiment, the computers in the computer lab were immobile, meaning no such interaction between peers was possible. Even though there are differences in terms of experimental conditions between the two cases, we believe the main differentiating factor in both experiments is that students were able to share and collaborate with their peers a characteristic which can have a positive effect on student learning (Crook, 1996).

For the Shared Display Interpersonal Computer, interaction is made possible by sharing the screen and as a result of the classroom layout (Figure IV.20a). Given that effective progress was the same for both technologies used in the study (Figure IV.22), the significant differences lead us to believe that this progress was consolidated when the students could share their reasoning with each other. In future work, it will be necessary to record the number and type of interactions between peers in order to prove this hypothesis.

An important factor of using ICT in education is that technology allows teachers to strengthen their teaching skills and adapt their practices in the classroom (Baggot la Velle, Wishart, McFarlane, Brawn, & John, 2007). Although information relating to the teacher's work with students in the classroom was not recorded, we hypothesize that teacher support provided to students in the classroom was more valuable than in the computer lab, influencing the quality of the students' learning experience. This is because the classroom is a more favorable setting for implementing the curriculum than the computer lab (Davis & Shade, 1994). This hypothesis should be validated by future work which includes as one of its variables teacher adoption and transformation of teaching practices according to the work spaces and environment.

IV.7 Conclusion

To answer our research question, "Is there any difference in learning between personalized interactive work carried out in the classroom using a Shared Display Interpersonal Computer, and personalized work undertaken in a computer lab using personal computers?", comparisons were made between classroom work using a Shared Display Interpersonal Computer, work in a computer lab using a personal computer and

mixed work using a combination of the two. Results of the study show significant differences in learning in favor of the classroom groups working with a Shared Display Interpersonal Computer. One explanation for this is the observed interaction between pairs in the classroom, which allowed them to provide additional feedback to one another, beyond the feedback given by the system. In addition, the value of the classroom's physical space could favor personalized intervention by the teacher for the students who need it the most. These two hypotheses require validation through future work, with two possible alternatives. The first option is orchestration (Dillenbourg, Nussbaum, Dimitriadis, & Roschelle, 2013), which standardizes the teacher's actions during sessions, maximizes the tools' benefits, and seeks to isolate factors relating to the teachers. The second option is to work with another type of software that enables interactivity in the classroom without the use of a Shared Display. In this way, the value of working with the Shared Display could be determined, as well as the value of working in the classroom compared with the computer lab.

REFERENCES

- Ahles, P., & Contento, J. M. (2006). Explaining Helping Behavior in a Cooperative Learning Classroom Setting Using Attribution Theory. *Community College Journal of Research & Practice*, 30(8), 609-626.
- Alavi, H., Dillenbourg, P., & Kaplan, F. (2009). Distributed Awareness for Class Orchestration. In *Learning in the Synergy of Multiple Disciplines* (pp. 211-225). Springer Berlin / Heidelberg.
- Alcoholado, C., Nussbaum, M., Tagle, A., Gomez, F., Denardin, F., Susaeta, H., Villalta, M., & Toyama, K. (2012). One Mouse per Child: Interpersonal computer for individual arithmetic practice. *Journal of Computer Assisted Learning*, 28(4), pp. 295-309.
- Amershi, S., Ringel Morris, M., Moraveji, N., Balakrishnan, R., & Toyama, K. (2010). Multiple mouse text entry for single-display groupware. *Proceedings of the 2010 ACM conference on Computer supported cooperative work* (pp. 169-178). New York: ACM.
- Ashford, S. J., Blatt, R., & Walle, D. V. (2003). Reflections on the looking glass: A review of research on feedback-seeking behavior in organizations. *Journal of Management*, 29(6), 773-799.
- Bachour, K., Dillenbourg, P., & Kaplan, F. (2008). Reflect: An interactive table for regulating face-to-face collaborative learning. *Times of Convergence. Technologies Across Learning Contexts*, 39-48.
- Baggot la Velle, L., Wishart, J., McFarlane, A., Brawn, R., & John, P. (2007). Teaching and learning with ICT within the subject culture of secondary school science. *Research in Science & Technological Education*, 25(3), 339-349.
- Ball, D. Ferrini-Mundy, J., Kilpatrick, J., Milgram, R.J., Schmid, W., and Schaar, R., (2005) Reaching for Common Ground in K-12 Mathematics Education, Notices of the AMS, September 2005, pp 1055-1058
- Barber, M., & Njus, D. (2007). Clicker Evolution: Seeking Intelligent Design. *Life Sciences Education*, 6, 1-20.
- Barr, R. B., & Tagg, J. (1995). From teaching to learning—A new paradigm for undergraduate education. *Change: The magazine of higher learning*, 27(6), 12-26.
- Beauchamp, G., & Kennewell, S. (2009). Interactivity in the classroom and its impact on learning. *Computers and Education*, 759-766.
- Benjamin Bederson, J. S. (1998). Single Display Groupware. *ACM Press*.

- Berch, D. B. (2005) Making sense of number sense: Implications for children with mathematical disabilities. *Journal of Learning Disabilities*, 38, 333-339.
- Bielaczyc, K. (2006). Designing Social Infrastructure: Critical Issues in Creating Learning Environments With Technology. *Journal of the Learning Sciences*, 15(3), 301-329.
- Biggs, J. (1999). *Teaching for quality learning at university*. Buckingham: SHRE.
- Bland, J. M., & Altman, D. G. (1997). Statistics notes: Cronbach's alpha. *BMJ*, 314, 572.
- Boaler, J. & Staples, M. (2008). Creating Mathematical Futures through an Equitable Teaching Approach: The Case of Railside School. *Teachers College Record*, 110(3), 608-645.
- Brown, S., & Knight, P. (1994). *Assessing learners in higher education*. Routledge.
- Cao, H., Olivier, P. & Jackson, D. (2008) Enhancing Privacy in Public Spaces Through Crossmodal Displays. *Social Science Computer Review*, Vol. 26, No. 1, pp 87-102.
- Chen, A., Mashhadi, A., Ang, D., & Harkrider, N. (1999). Cultural issues in the design of technology-enhanced learning environments. *British Journal of Educational Technology*, 217-230.
- Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Research*, 32(1), 9-13.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Cooper, J., & Others, A. (1991). Cooperative/Collaborative Learning: Research and Practice (Primarily) at the Collegiate Level, Parts I and II, *Journal of Staff, Program, & Organization Development*, 79(34), pp 143-148 and pp 239-252.
- Cox, M., & Marshall, G. (2007). Effects of ICT: Do we know what we should know? *Education and Information Technologies*, 12(2), 59-70.
- Cronbach, L. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, 16(3), 297-334.
- Crook, C. (1996). *Computers and the Collaborative Experience of Learning*. International Library of Psychology.
- Crouch, C., & Mazur, E. (2001). Peer Instruction: Ten years experience and results. *American Journal of Physics*, 69(9), 970-977.

- Davies, A. (2000). Making classroom assessment work. Merville, British Columbia, Canada: Connections Publishing.
- Davis, B. C., & Shade, D. (1994). Integrate, don't isolate! Computers in the early childhood curriculum. Urbana, IL: ERIC Clearinghouse on Elementary and Early Childhood Education.
- Deaney, R., Ruthven, K., & Hennessy, S. (2006). Teachers' developing "practical theories" of the contribution of information and communication technologies to subject teaching and learning: An analysis of cases from English secondary schools. *British Journal of Educational Research*, 32(3), 459-480.
- DeCorte, E. (1996). New perspectives on learning and teaching in higher education. In A. Burgen, *Goals and purposes of higher education in the 21st century*. London: Jessica Kingsley Publishers.
- Dede, C. (2009). Immersive Interfaces for Engagement and Learning. *Science*, 323 no. 5910, 66-69.
- Dillenbourg, P., Jeffrey, H., & Mauro, C. (2009). *Interactive artifacts and furniture supporting collaborative work and learning*. Springer.
- Dillenbourg, P., Nussbaum, M., Dimitriadis, Y., & Roschelle, J. (2013). Design for Classroom Orchestration. *Computers & Education*, Accepted for publication.
- Donker, A., & Reitsma, P. (2007). Young children's ability to use a computer mouse. *Computers and Education*, 602-617.
- Ertmer, P. (1999). Addressing first- and second-order barriers to change: strategies for technology integration. *Educational Technology Research and Development*, 47-61.
- Fischer, F. D. (2006). Challenges of orchestrating computer-supported collaborative learning. *87th annual meeting of the American educational research association (AERA)*. San Francisco: USA.
- Groff, J., & Mouza, C. (2008). A framework for addressing challenges to classroom technology use. *AACE Journal*, 16(1), 21-46.
- Guzmán, M. &. (2009). Teaching competencies for technology integration in the classroom. *Journal of Computer of Assisted Learning*, 25(5), 453-469.
- Hamman, D., Fives, H., & Olivarez. (2007). Efficacy and Pedagogical Interaction in Cooperating and Student Teacher Dyads. *The Journal of Classroom Interaction*, 41/42(2/1), 55-63.

Harris, J., Mishra, P., & Koehler, M. (2009). Teachers' Technological Pedagogical Content Knowledge and Learning Activity Types : Curriculum-based Technology Integration Reframed. *Journal of Research on Technology in Education*, 41(3), 393-416.

Hepp, P., Hinostroza, E., Laval, E., & Rebién, L. (2004). Technology in schools: Education, ICT and the knowledge society. Washington: The World Bank.

Hinckley, K., Cutrell, E., Bathiche, S., and Muss, T., (2002), Quantitative analysis of scrolling techniques, Proceedings of CHI 2002, April 20-25, 2002, Minneapolis, Minnesota, USA, pp. 65-72

Infante, C. (2010). Teachers and Students of Collaborative Software Running on Conventional Technology. *Pontificia Universidad Católica de Chile*, Diss.

Infante, C., Weitz, J., Reyes, T., Nussbaum, M., Gómez., F. & Radovic, D. (2010) Co-located Collaborative Learning Video Game with Single Display Groupware. *Interactive Learning Environments*, Vol. 18, No. 2, June 2010, pp 177–195.

Infante, C., Hidalgo, P., Nussbaum, M., Alarcón, R., & Gottlieb, A. (2009). Multiple Mouse Based Collaborative One-to-One Learning. *Computers and Education*, 393-401.

Intel Corporation. (2006). Retrieved December 13, 2011, from Intel World Ahead Program: <http://www.intel.com/content/www/us/en/company-overview/world-ahead.html>

ITL Research. (2011). ITL Research Findings and Implications. Washington.

Jain, M.; Gupta, A.; Samdaria, N.; Shekhar, P.; Pal, J.; (2009), DISHA: Disease and health awareness for children on multiple input devices, *International Conference on Information and Communication Technologies and Development (ICTD)*, Doha, 17-19 April 2009, 482.

Johnson, R. E. (1997, October). Frameworks = (components + patterns). *Communications of the ACM*, 40-42.

Jung, I. (2005). ICT-pedagogy integration in teacher training: application cases worldwide. *Educational Technology & Society*, 5(2), 94–101.

Kaplan, F., DoLenh, S., Bachour, K., Yi-ing Kao, G., Gault, C. & Dillenbourg, P. (2009) Interpersonal Computers for Higher Education. P. Dillenbourg et al. (eds.), *Interactive Artifacts and Furniture Supporting Collaborative Work and Learning*, 10, pp. 1-17.

Kennedy, M. (2005). *Inside Teaching. How classroom Life Undermine Reform*. Estados Unidos: Harvard University Press.

Kraemer, K. L., Dedrick, J., & Sharma, P. (2009). One Laptop Per Child: vision vs. reality. *Communications of the ACM* 8, 8.

- Lane, A., & Ziviani, J. (2010). Factors in fluencing skilled use of the computer mouse by school-aged children. *Computers & Education*.
- Lawless, K., & Pellegrino, J. (n.d.). Professional development in integrating technology into teaching and learning: knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research*, 77(4), 575–614.
- Li, Q. (2007). Student and Teacher Views About Technology: A Tale of Two Cities? *Journal of Research on Technology in Education*, 39(4), 377-397.
- Lim, C. (2008). Global citizenship education, school curriculum and games: Learning Mathematics, English and Science as a global citizen. *Computers & Education*, 51(3), 1073-1093.
- Loch, K., Straub, D., & Kamel, S. (2003). Diffusing the Internet in the Arab Wolrd: the role of social norms and technological culturaltion. *IEEE Transactions on Engineering Management*, 45-63.
- Locke, E., Latham, G., Smith, K., Wood, R., & Bandura, A. (1990). *A theory of goal setting & task performance*. Englewood Cliffs: NJ: Prentice Halls.
- Markauskaite, L. (2007). Exploring the structure of trainee teacher's ICT literacy: the main components of, and relationships between, general cognitive and technical capabilities. *Educational Technology. Research and Development*, 55(6), 547–572.
- Martyn, M. (2007). Clickers in the Classroom: An Active Learning Approach. *Educause Quaterly*, 2, 71-74.
- MINEDUC. (2011). *Programa de Estudio, Primer año Básico, Educacion Matemática*. Retrieved September 27, 2011, from http://curriculumenlinea.MINEDUC.cl/descargar.php?id_doc=201102080047580
- MINEDUC. (2013). MINEDUC: Planes de Estudio. Recuperado el 31 de 3 de 2013, de www.MINEDUC.cl
- Mitchell, B., Bailey, J., & Monroe, E. (2007). Integrating Technology and a Standards-Based Pedagogy in a Geometry Class. *Computers in the Schools*, 24(1), 75-91.
- Moed, A., Otto, O., Pal, J., Pawar U., Kam, M., Toyama, K., (2009), Reducing dominance in multiple-mouse learning activities, *Proceedings of the 9th international conference on Computer supported collaborative learning*, pp 360-364, June 08-13, 2009, Rhodes, Greece
- Moraveji, N., Inkpen, K., Cutrell, E., & Balakrishnan, R. (2009). A Mischief of Mice: Examining Children's Performance in Single Display Groupware Systems with 1 to 32 Mice. *Proceedings of the 27th international conference on Human factors in computing systems* (pp. 2157-2166). Chicago: ACM, New York.

- Moraveji, N., Kim, T., Ge, J., Pawar, U., & Mulcahy, K. (2008). Mischief: supporting remote teaching in developing regions . *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems* (pp. 353-362). Chicago: ACM.
- Morris, M., Fisher, D., & Wigdor, D. (2010). Search on surfaces: Exploring the potential of interactive tabletops for collaborative search tasks. *Information Processing and Management*, 703-717.
- NCTM (2009); National Council of Teachers of Mathematics; Principles & Standards for School Mathematics. <http://standards.nctm.org/>
- Nicol, D., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: a model and seven principles of good feedback practice. *Studies in Higher Education*, 199-218.
- Nielsen, J. Usability Engineering, Morgan Kaufmann, 1994.
- Nussbaum, M., Büchi, T., Alcoholado C., Diaz A., Infante C., (2012) Integration of digital resources to bridge student and teacher needs inside the classroom, EARLI SIG 6&7 Conference, September 2012, Bari, Italy.
- Nussbaum, M., Dillenbourg, P., Fischer, F., Looi, C., & Roschelle, J. (2011). How to Integrate CSCL in Classroom Life. Orchestration Workshop at CSCL, Hong Kong.
- One Laptop per Child Foundation. (2006). *One Laptop per Child*. Retrieved December 13, 2011, from <http://one.laptop.org/>
- Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist*, 38(1), 1-4.
- Paek, T. A., Drucker, S., Kristjansson, T., Logan, R., & Toyama, K. (2004). Toward universal mobile interaction for shared displays. *ACM Conference on Computer Supported Cooperative Work* (pp. 266-269). ACM.
- Pal, J., Pawar, U. S., Brewer, E. A., and Toyama, K. (2006). The case for multi-user design for computer aided learning in developing regions. *Proceedings of the 15th international Conference on World Wide Web*, Edinburgh, Scotland, May 23 - 26, 2006.
- Panitz, T. (1999). The Case for Student Centered Instruction via Collaborative Learning Paradigms. ERIC database No. ED448444, Retrieved February 10, 2011.
- Pawar, U. S., Pal, J., Gupta, R., & Toyama, K. (2007). Multiple mice for retention tasks in disadvantaged schools. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, San Jose, California, USA, April 28 - May 03, 2007 pp. 1581-1590.

- Penuel, W., Boscardin, C. K., Masyn, K., & Crawford, V. (2007). Teaching with student response systems in elementary and secondary education settings: A survey study. *Educational Technology Research and Development*, 55(4), 315-346.
- Pontefracta, C., & Hardman, F. (2005). The discourse of classroom interaction in Kenyan primary schools. *Comparative Education*, 87-106.
- Prieto, L., Villagr , S., Jorr n, A., Mart nez, I., & Dimitriadis, Y. (2011). Recurrent routines: analyzing and supporting orchestration in technology-enhanced primary classrooms. *Computers and Education*, 57(1), 1214-1227.
- Reeves, T. (2006). Design research from a technology perspective. In J. Van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen, *Educational Design Research*. London: Routledge.
- Reeves, T. (2008). Evaluation of the Design and Development of IT Tools in Education. In J. Voogt, & G. Knezek (Eds.), *International Handbook of Information Technology in Primary and Secondary Education* (pp. 1037-1051).
- Robertson, J. (2003). Stepping out of the box: Rethinking the failure of ICT to transform schools. *Journal of Educational Change*, 4(4), 323-344.
- Rule, A., Barrera, T., & Dockstader, C. (2002). Comparing Technology Skill Development in Computer Lab versus Classroom Settings of Two Sixth Grade Classes. *Journal of Interactive Online Learning*, 1(1).
- Russell, M. B., & O'Connor, K. (2003). Examining teacher technology use implications for preservice and inservice teacher preparation. *Journal of Teacher Education*, 54(4), 297-310.
- Sadler, D. (1998). Formative assessment: revisiting the territory. *Assessment in Education*, 5(1), 77-84.
- Salomon, G. (1990). The Computer Lab: A Bad Idea Now Sanctified. *Educational Technology*, 30(10), 50-52.
- Sangster, M (2006). The role of pace within primary mathematics lessons. *Proceedings of the British Society for Research into Learning Mathematics* 26(1).
- Scott, S. D., Mandryk, R. L., & Inkpen, K. M. (2003). Understanding children's collaborative interactions in shared environments. *Journal of Computer Assisted Learning*, 220-228.
- Shechtman, Z., & Leichtentritta, J. (2004). Affective teaching: a method to enhance classroom management. *European Journal of Teacher Education*, 323-333.

Shepard, L.A (2000). The role of assessment in learning culture. *Educational Researcher*, 29(7), pp. 4-14.

Shulman, L. (2005). Pedagogies of Uncertainty. *Liberal Education*, 91(2), 18-25.

Song, S. H., & Keller, J. M. (2001). Effectiveness of motivationally adaptive computer-assisted. *Educational Technology Research and*, 49(2), 5-22.

Stewart, J., Bederson, B., & Druid, A. (1999). Single display groupware: a model for co-present collaboration. *Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit* (pp. 286-293). New York: ACM.

Szewkis, E., Nussbaum, M. D., Rosen, T., Caballero, D., Tagle, A., & Alcoholado, C. (2011). Collaboration between large groups in classroom. *Computer Supported Collaborative Learning* , 6, 561-575.

Tagle, A., Alcoholado, C., Nussbaum, N., & Infante, C. (2013). Interactive learning: a comparison of individual and interpersonal computer technologies with pen-and-paper. *British Journal of Educational Technology*, Sent for publication.

The Design-Based Research Collective. (2003). Design-Based Research: An Emerging Paradigm for Educational Inquiry. *Educational Researcher*, 32(1), 5-8.

Trees, A., & Jackson, M. (2007). The learning environment in clicker classrooms: student processes of learning and involvement in large university-level courses using student response systems. *Learning, Media and Technology*, 32(1), 21-40.

Trucano, M. (2010). *One Mouse Per Child*, *EduTech: A World Bank Blog on ICT use in Education*. Retrieved September 28, 2011, from <http://blogs.worldbank.org/edutech/one-mouse-per-child>

Trucano, M. (2011). School computer labs: A bad idea? Retrieved November 03, 2013 from EduTech: A WorldBank ICT use in Education: <http://blogs.worldbank.org/edutech/computer-labs>

Van den Akker, J., Gravemeijer, K., McKenney, S., & Nieveen, N. (2006). *Educational Design Research*. London: Routledge.

Vital Wave Consulting. (2008). *Affordable Computing for Schools in Developing Countries: A Total Cost of Ownership (TCO) Model for Education Officials*. California: Vital Wave Consulting.

Watson, D. M. (1998). Blame the technocentric artifact! What research tells us about problems inhibiting teacher use of IT. In G. Marshall, & M. Ruohonen, *Capacity Building for IT in Education in Developing Countries* (pp. 185-192). London: Chapman & Hall.

- Weston, M., & Bain, A. (2010). The End of Techno-Critique: The naked truth about 1: 1 laptop initiatives and educational change. *The Journal of Technology, Learning, and Assessment*, 9(6), 4-26.
- Williams, D., Coles, L., Wilson, K., Richardson, A., & Tuson, J. (2000). Teachers and ICT: current use and future needs. *British Journal of Educational Technology*, 31(4), 307-320.
- Wood, D. O., & Malley, C. (1996). Collaborative learning between peers: An overview. *Educational Psychology Practice*, 4-9.
- Wood, E., Willoughby, T., Schmidt, A., Porter, L., Specht, J., & Gilbert, J. (2004). Assessing the use of input devices for teachers and children in early childhood education programs. *Information Technology in Childhood Education Annual*, 261-280.
- Zemke, R., & Armstrong, J. (1997). Timeless Rules for Good Instruction. Training Classics. *Training*, 34(9), 55-58.
- Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. (2002). Conditions for Classroom Technology Innovations. *Teachers College Record*, 482-515.
- Zucker, D., & Light, D. (2009). Laptop Programs for Students. *Science* 2, 82-85.
- Zurita, G., & Nussbaum, N. (2004). Computer Supported Collaborative Learning Using Wirelessly Interconnected Handheld. *Computers & Education*, 3(42), 289-314.

V. APPENDICES

V.1 Appendix A

This appendix is an adapted version of Arturo Tagle's Master Thesis section 1.3, titled "Software". It details the Interpersonal Computer system used in all experiences of this thesis.

V.1.1 Software

For the development of the current thesis, two softwares were developed: an interpersonal computer version and a single computer adapted version. Both programs were developed using C# and .NET 3.5. The main focus of the description will be on the first one, which allows each student to controls mouse as input. This system uses Microsoft Multipoint 1.0 Software Development Kit (SDK) that allows recognizing several mice plugged in to the computer and allows some basic functionality.

V.1.2 Interpersonal Computer software

This software supports up to 43 mice connected at the same time. To achieve this, Multipoint SDK 1.0 developed by Microsoft in 2007 was used. This SDK originally supported up to 10-15 mice depending on the computer's characteristics due to performance problems, but some modification and optimizations were done to reach 43 mice working simultaneously, more details can be seen on Section I.9.1.

Multipoint 1.0 provides basic functionality to develop multiple mouse applications. This library handles the device recognition and it draws cursors in the screen for each. It handles mouse events, such as movement and click, by wrapping them for easier programing.

The software developed is divided in two main components: the framework and the plug-ins or applications. The framework is a common base for all MIPC applications. It

handles common problems such as mouse recognition and provides basic functionality for course management, XML data reading and writing and teacher functions.

The applications are developed as plug-ins for the framework described before. This plug-ins needs to implement IMMPlugin interface that comes in MultipointControl DLL. The interface not only enables the plug-in to implement an application to be used with the framework, but it also gives the ability to extend some of the functionalities provided by it.

V.1.3 Framework

The structure of building a framework was motivated by the idea of developing MIPC applications in a fast and easy way, in order to make a skeleton for applications that can be customized by developers (Johnson, 1997). Like all frameworks, it has non-modifiable code but it can be extended. The controller of the software it's the framework and not the extension (inversion of control) and finally, it has a default behavior is defined by the framework shown in Figure V.23.

As shown in Figure V.24, the framework depends on DLLs MultiPointControl and MMMCommon. Figure V.25 shows the class hierarchy diagram. As it can be seen, it's a very simple class hierarchy, which handles the flow described in Figure V.23. Finally, Table V.18 has a description of the classes described in the class hierarchy diagram.

The application may interact with the framework in three points of the program: In the application configuration process, the main application activity and the application summary. The first one, in case it's defined by the application, it's an opportunity to ask the user for settings before the main activity is initialized. The second one is the main

activity of the application, defined by the application developer, and finally, there is a chance to show a summary of the activity, in case the latter requires it.

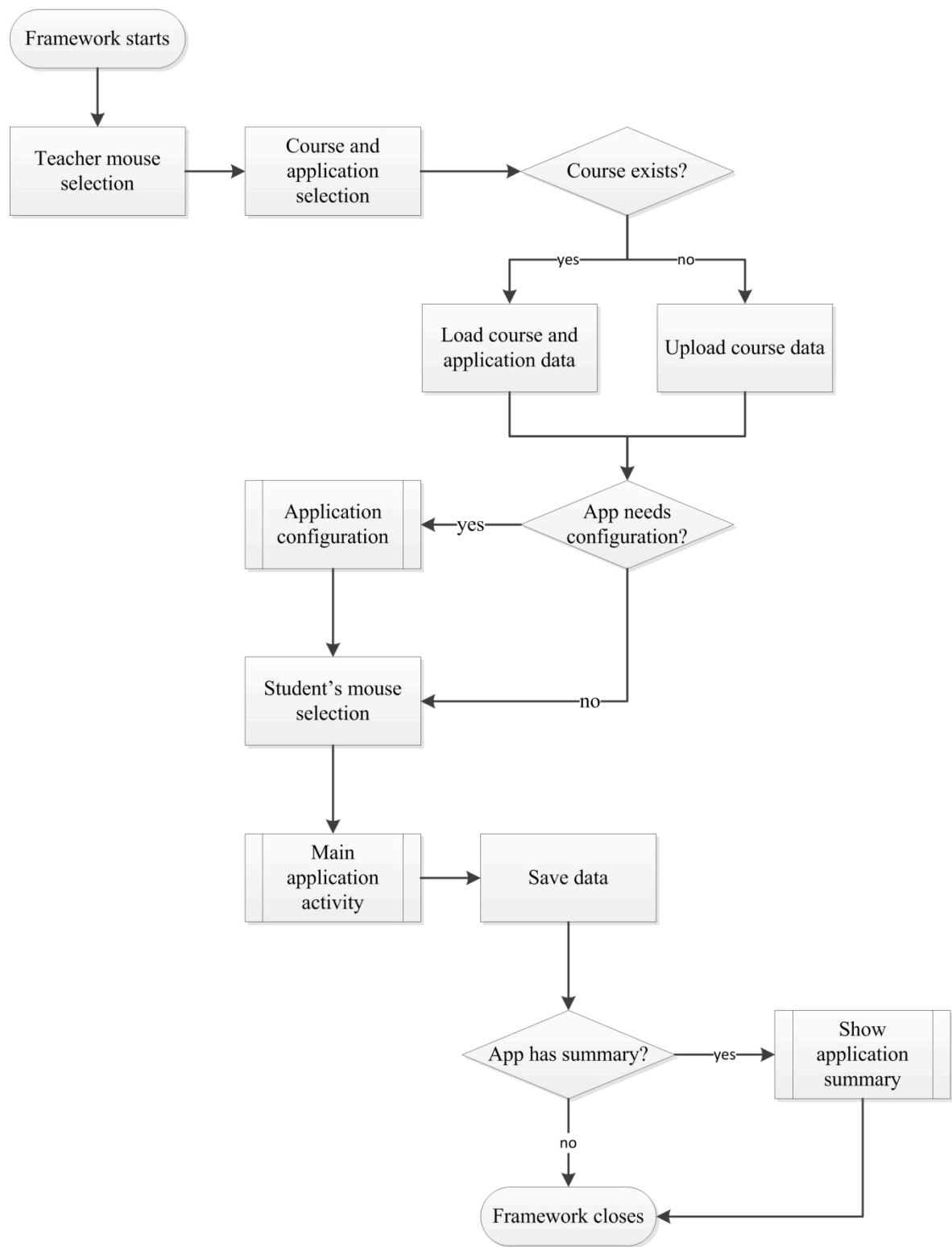


Figure V.23: Framework flow chart

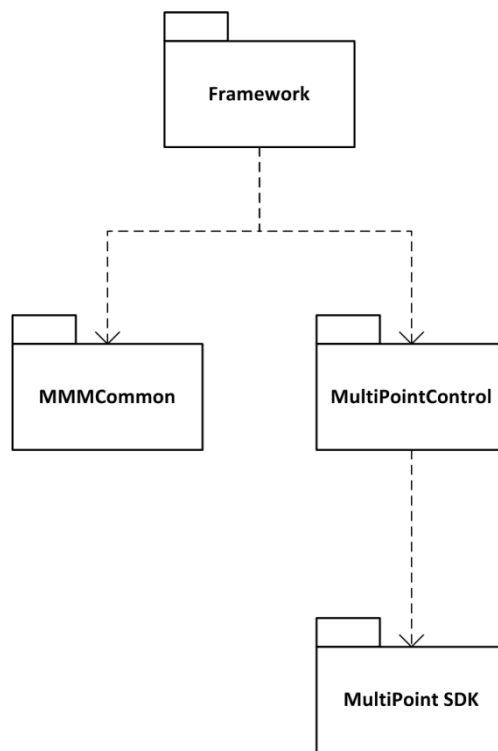


Figure V.24: Framework dependencies

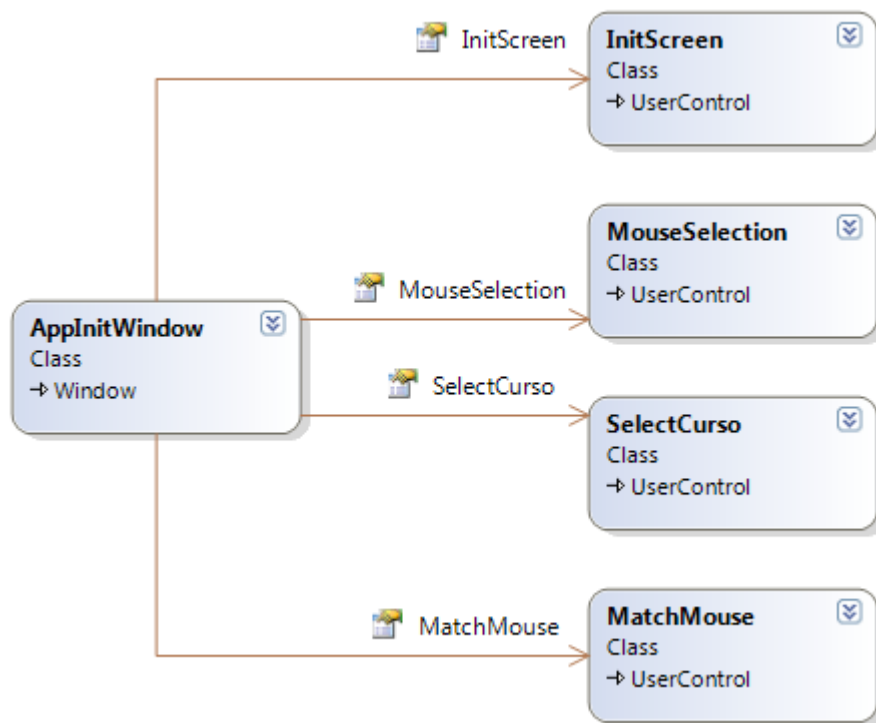


Figure V.25: Framework class hierarchy

Table V.18: Framework class description

Class	Description
AppInitWindow	Main window of the program. Controls the flow of the framework.
InitScreen	Shows the application logo and version number.
MatchMouse	This control allows the students to select their name from the list of the class in order to do the match between mice and students.
MouseSelection	Allows selecting a teacher mouse, by pressing the M key and right clicking. It also gives the chance to reset the selection in case someone else gains control of the teacher mouse by pressing the R key. After the teacher mouse is selected, it turns red to differentiate it from the other mice.
SelectCurso	Control that allows the teacher to select the course and the application that the course will work. After the course and application are selected, the data is obtained from the XML file.

V.1.4 Framework components

V.1.4.1 MMMCommon DLL

This library provides course, students and session management functions. It also provides functionality for reading and writing this data in the correct XML format. Figure V.26 shows the class hierarchy for this DLL and Table V.19 shows a brief description of each class.



Figure V.26: MMMCommon DLL class hierarchy

Table V.19: MMMCommon DLL class description

Class	Description
Alumno	Contains basic information for each student such as id, name, last name and identification symbol.
BasicXMLReader	Provides functionality for reading and writing into the Xml file that stores the course information.
Curso	Contains a list of students and the sessions they have participated. It also has an XMLReader object for writing and reading this data stored in a Xml file.
Sesion	Contains basic information about sessions that students have played such as date and duration.

V.1.4.2 MultipointControl DLL

This library has common controls capable of handling multipoint events, such as multi user Labels and Buttons. This library handles the fact that normal WPF controls don't recognize multipoint events, so they are useless in multipoint environments. In order to make this re-implementation easier, MultiPoint SDK declares an interface that must be implemented in a control in order to make it capable of recognizing multipoint events. Controls in this library implement this interface and some provides further functionality. It's possible to find the DLL's class hierarchy in Figure V.27 and a brief class description in Table V.20.

In this DLL it is also the declaration of IMMPlugin interface. This interface provides the capability to generate the communication between the framework and the plug-ins.

MMPluginInfo class defines some attributes that plug-ins need to declare in order to get basic information about the plug-in during the opening of it. Figure V.28 shows a UML class diagram for these classes.

Finally, it is the BasicMouse class. An UML class diagram can be found in Figure V.29.

This class work as a wrapper for DeviceInfo class from Multipoint SDK in order to make an easier way to interact with this class and to provide new functionalities and properties such as define a teacher mouse, show, hide, enable and disable a mouse, among others.



Figure V.27: MultipointControl DLL class hierarchy

Table V.20: MultiPointControl DLL class description

Class	Description
BasicMouse	Wrapper for Multipoint's DeviceInfo class to facilitate its use and provide new functionality.
IMMMPlugin	Interface that defines the methods and properties that every application needs to define in order to become a plug-in for the framework.
MMMPluginInfo	Inherited from Attribute, defines attributes that are read using reflection when a plug-in is opened.
MultiPointButton	Inherited from Button, this class extends this functionality to work with Multipoint events.
MultiPointCheck	Implements a checkbox that supports multipoint.
MultiPointCheckGroup	Changes the behavior of a group of MultiPointChecks to behave like radiobuttons: only one MultiPointCheck checked at a time.
MultiPointCicleChoice	Shows an element from a list and two controls, up and down, to change it.
MultiPointInkCanvas	Inherited from InkCanvas, this class extends this functionality to work with Multipoint events. It is set to paint with a red line when left button is down and with yellow highlighter when right button is down.
MultiPointLabel	Inherited from Label, this class extends this functionality to work with Multipoint events.
MultiPointListView	Inherited from ListView, this control provides a way to show a list of items, with vertical and horizontal scroll bar.
MultiPointOpenFileDialog	Implements an open file dialog that supports multipoint.

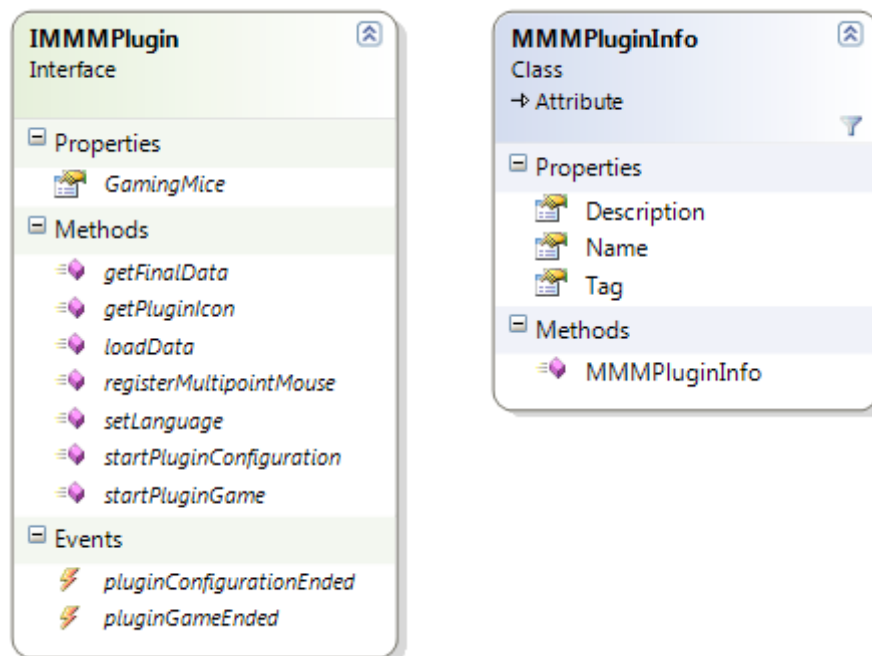


Figure V.28: IMMPlugin interface and MMMPluginInfo class diagram

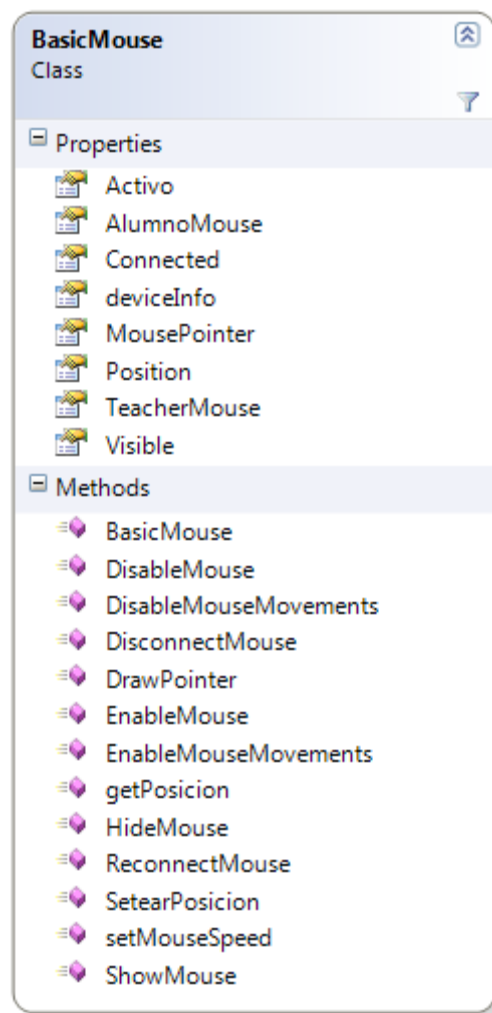


Figure V.29: BasicMouse class diagram

V.1.5 Framework's Plug-in

In order to develop new applications for this framework, it's necessary to make a plug-in. To create one, the developer needs to implement IMMMPugin interface from MultiPointControl DLL. Several plug-ins were developed, but only the one used on this thesis work will be described.

V.1.5.1 Sumas Plugin

The main objective of the software is teaching arithmetic. This is achieved by giving the student an exercise that needs to be solved. The student enters an answer and feedback is given so the student knows if his answer was correct or incorrect. The software adapts to each student controlling the level of the exercise given. There are 66 pedagogic rules implemented based on Chilean Ministry of Education math curriculum (MINEDUC, 2011).

The application was developed in order to use the arithmetic software in a one mouse per child environment using it as a plug-in for the framework described in the previous section.

When this plug-in starts its main activity, the screen is divided in one section for every mouse connected to the computer and one kidbox is drawn for each section. The kidboxes are the space where students can work. Figure V.31 shows a kidbox. The red box is the current exercise display space. The green box is the space where the student has to enter the answer by clicking the arrows of the digits. Finally, in the blue box it's the identification symbol, which in this case it also works as a confirmation button that the student has to click when he student thinks it's ready.

When the student clicks the symbol, a feedback is displayed depending on whether the answer was correct or incorrect. If the answer is wrong, feedback is shown (Figure V.32) and the student must try again. If the answer is correct, feedback is shown (Figure V.33) but there is also a possibility that the student may have passed to the next level and another kind of feedback is shown to let the student know he is in the next level (Figure V.34). The conditions to get to the next level are to answer the first 10 exercises correct or to answer the last 8 exercises out of the last 15 correct. By doing this a student is enforced to learn how to solve an exercise and not doing it by trial and error. Additionally there are two more feedbacks that a student may receive: when he is not working or “sleeping” (Figure V.35) or when he is not working at all or in a “deep sleep” state (Figure V.36).

Figure V.37 shows a screenshot of the main activity of plug-in working with 36 mice at one time. The screen, in addition to the kidbox, shows in the right side the points section, where one point bar is displayed for every mouse that is participating on the activity.

The points bars, detailed in Figure V.38, have 3 main elements: the symbol in the left to indicate which student represents, the number in the right that shows the level of the students, and the points won. Each exercise is represented by a rectangle that may be filled with green if the exercise was answered right by the student in the first attempt, yellow if it was right in the second attempt or red if it was right after three or more attempts.

A basic flow of the plug-in is shown in Figure V.42. Once the Kidboxs are drawn and sorted, in the “kidbox flow” process, the math activity start, following the flow described in Figure V.43. This flow continues until the application is closed or the

teacher enters the Teachmode. When the latter occurs, the application follows the flow described in Figure V.44. Again, this flow continues until the teacher interrupts it.

The Teachmode, as shown in Figure V.39, consist in a special module where the teacher can show how to solve a specific exercise to the whole class. When the program goes to this mode, all mice are hided and only the teacher mouse can interact. The teacher besides the possibility to solve an exercise using the same kidbox that students have, it also has a highlighter tool (blue box in Figure V.37) and a pen tool to write in the screen (red box).

When the Teachmode is closed, the flow continues with the main activity and all the students return to their exercises and continue where they left them.

When the application is closed, the kidbox flow is interrupted and the data of the students is sent back to the framework for saving the file. After the file is saved, the framework shows the plug-in's summary window (Figure V.40).

V.1.5.2 SumasCommon DLL

This library provides specific functions for the generation of exercises according to the rules defined by the Ministry of Education (MINEDUC, 2011). Specifically, the Reglas class contains the logic to generate an exercise of any of the 66 levels implemented in the software.

It also extends the Curso, Alumno and Sesion classes to provide specific functionality regarding the exercises and the arithmetic application. Figure V.30 shows the DLL's class hierarchy and Table V.21 briefly describes the main characteristics of these classes.

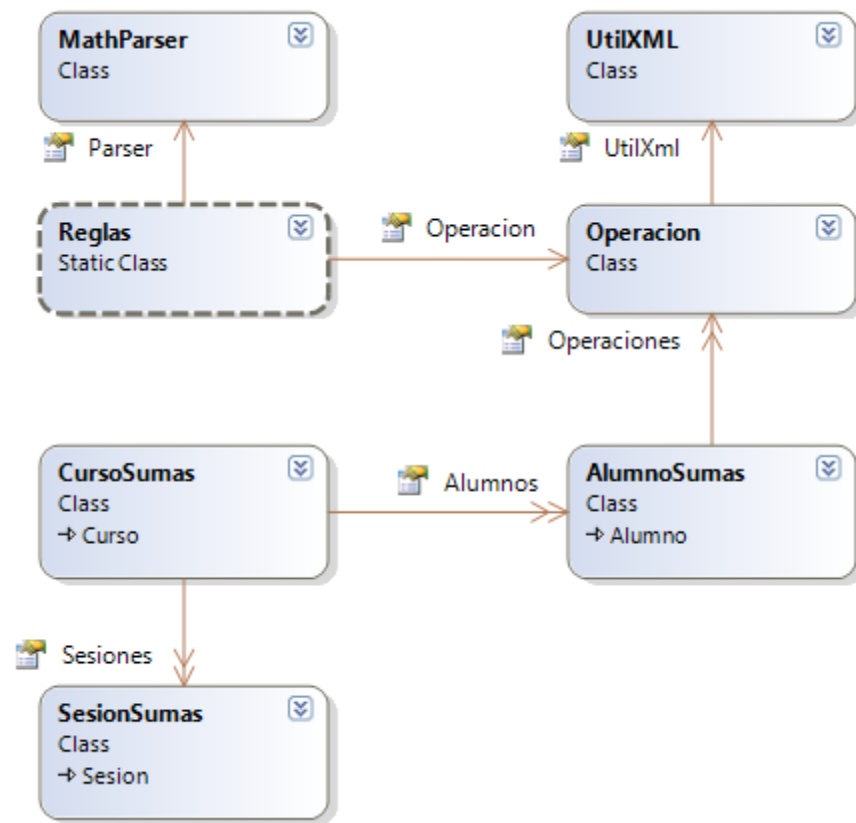


Figure V.30: SumasCommon DLL class hierarchy

Table V.21: SumasCommon DLL class description

Class	Description
AlumnoSumas	Extension of <i>Alumno</i> from MMMCommon that adds the ability to store a list of operations
CursoSumas	Extension of <i>Curso</i> from MMMCommon to provide specific functionality for the arithmetic plug-in
MathParser	This class provides functions that supports the exercise generation.
Operacion	Holds information about the operations generated, such as the exercise, the correct answer and the points obtained.
Reglas	Static class that generates operations for each of the 66 levels of addition, subtraction, multiplication and division developed based on the curriculum proposed by the Ministry of Education.
SesionSumas	Extension of <i>Sesion</i> from MMMCommon that adds the ability to support arithmetic sessions.
UtilXML	Reads and write the operations into the Xml file that stores the course data.

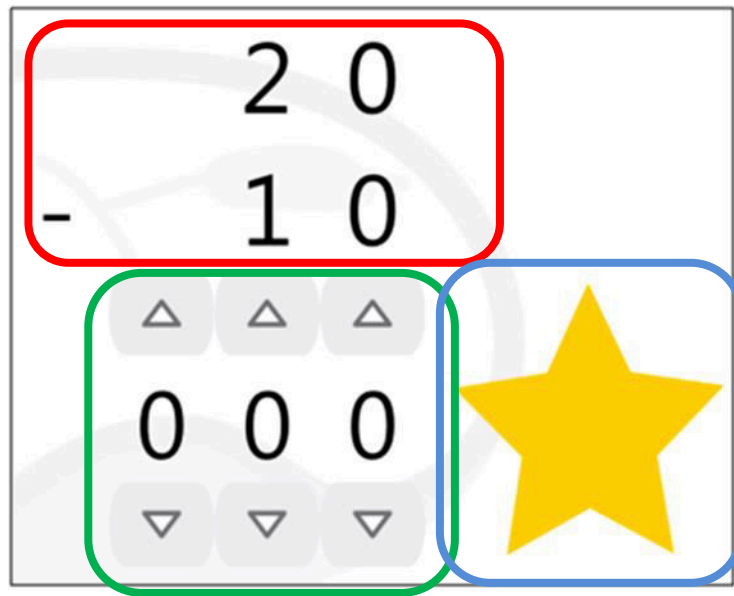


Figure V.31: Kidbox screenshot



Figure V.32: Kidbox displaying wrong feedback

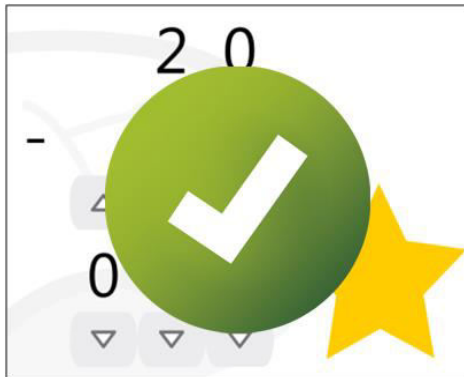


Figure V.33: Kidbox displaying correct feedback

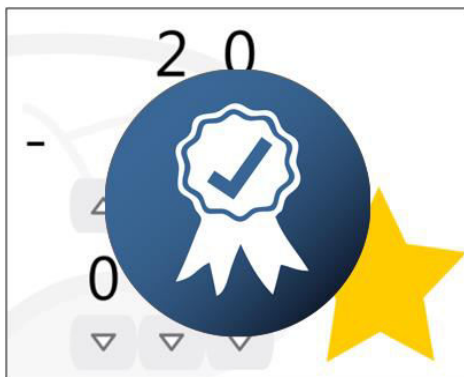


Figure V.34: Kidbox displaying next level feedback



Figure V.35: Kidbox displaying sleep feedback



Figure V.36: Kidbox displaying deep sleep feedback

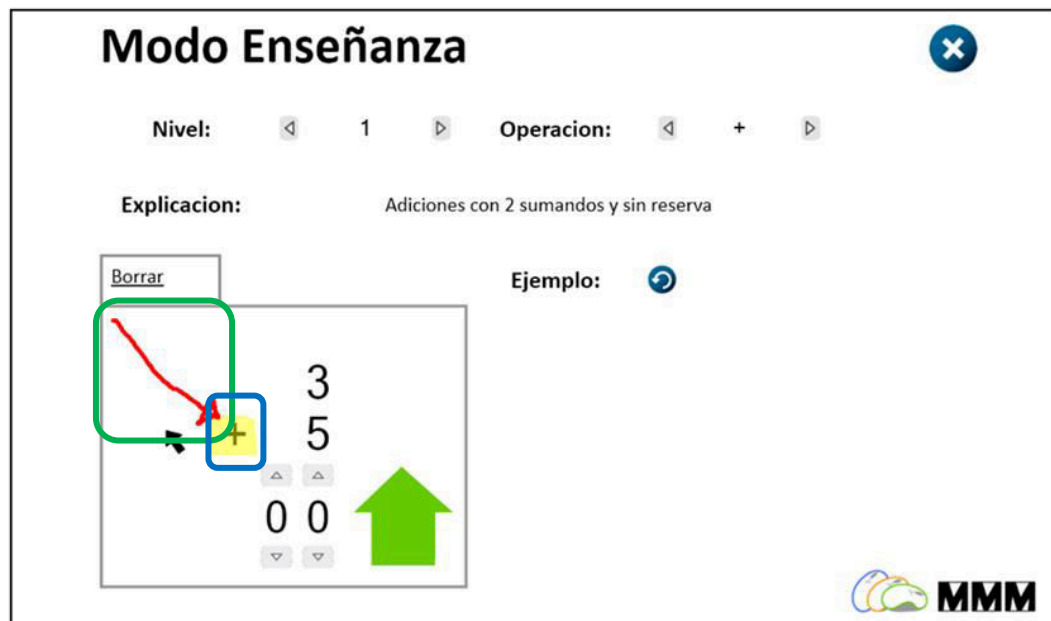


Figure V.39: Teachmode screenshot

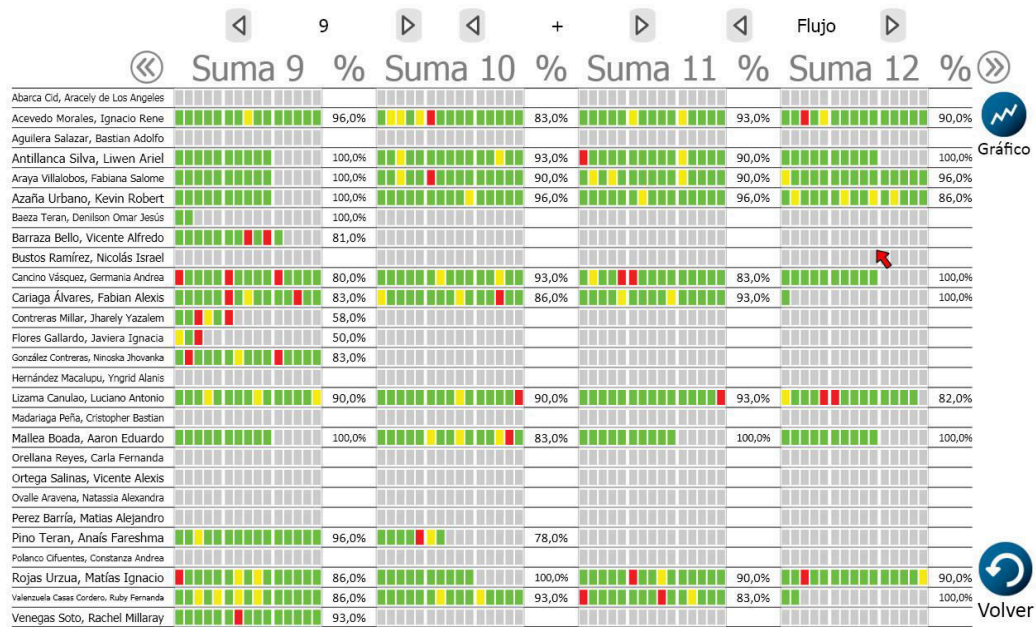


Figure V.40: Summary window screenshot

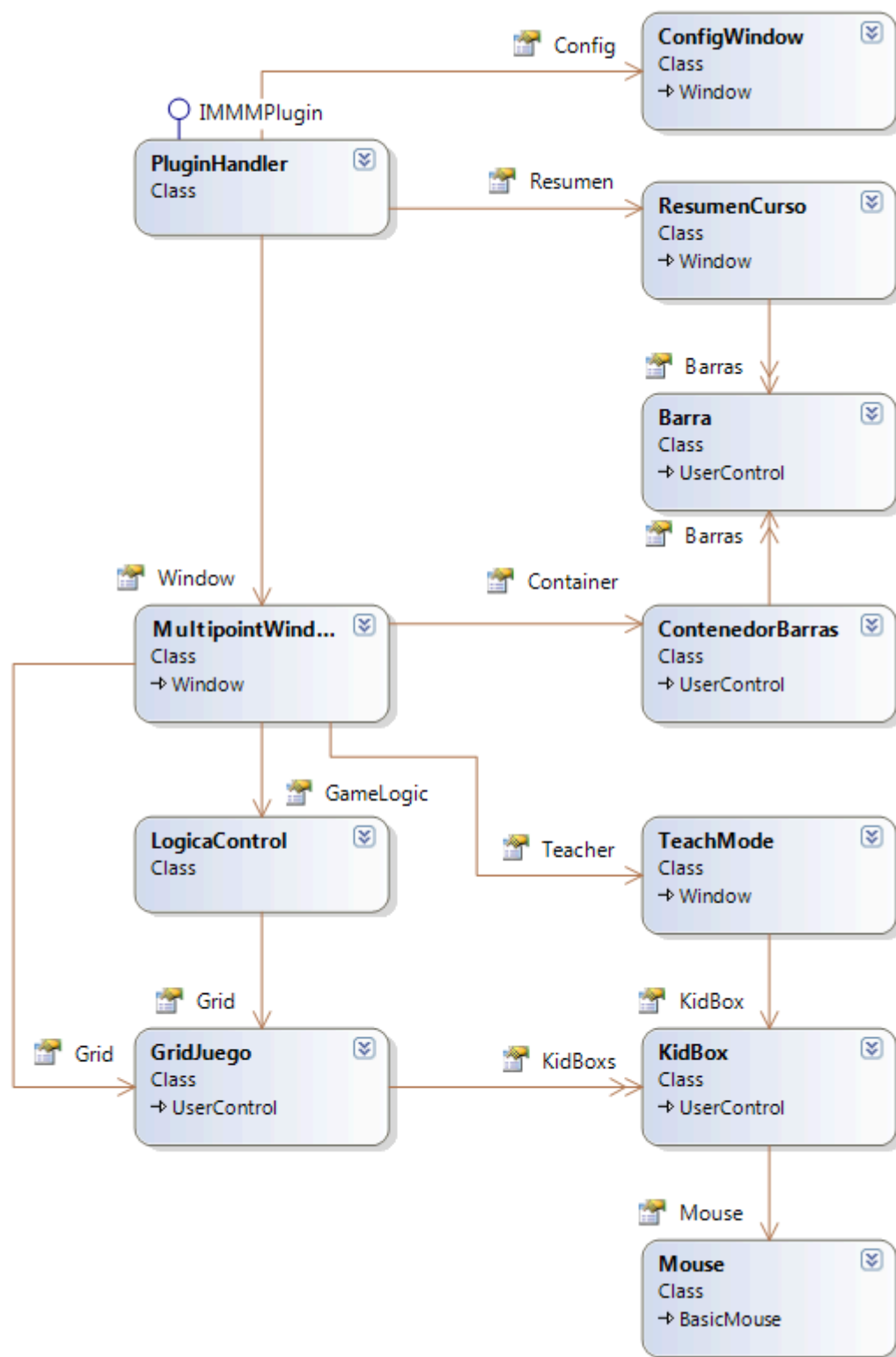


Figure V.41: SumasPlugin class hierarchy

Table V.22: SumasPlugin class description

Class	Description
Barra	Represents a single point bar like the ones shown in Figure V.38 . When an exercise is answered correct, it updates itself to show the point with the corresponding color (green, yellow or red).
ConfigWindow	Window that shows the settings before the main activity begins. The options that can be set are if the students start an activity all over again from a defined level or if they continue the last session.
ContenedorBarras	Contains a group of point bars. It also handles the sorting by points and grouping by level.
GridJuego	Main grid of the game. Contains a group of kidbox and set their position depending on how many mice are connected at the beginning of the activity.
Kidbox	Space where a student can work, as shown in Figure V.32 . It has an exercise (red box), the digits (instances of MultiPointCicleChoice from MultiPointControl DLL) to enter the answer (green box) and the identification symbol (blue box).
LogicaControl	Handles all the exercises. This class determines when an answer is entered if it's correct or not. In case it's correct, this class asks the Reglas class from SumasCommon DLL for the next exercise.
Mouse	Inherited from BasicMouse from MultiPointControl DLL, this class extends the functionality provided by this class in order to incorporate some specific elements from this plug-in.

MultiPointWindow	<p>Main window of the activity. It's launched when the framework calls for the main activity of the plug-in. It also coordinates the interactions between LogicaJuego, the kidboxs and ContenedorBarra.</p> <p>This class implements IMMPlugin interface from MultiPointControl DLL in order to become a plug-in for the framework described in section Section V.1.4.2. It mediates the interactions between the framework and the application.</p>
PluginHandler	
ResumenCurso	<p>Shows a summary of the course work after a session is finalized.</p>
TeachMode	<p>When it's called, stop the class and shows a window with the Teachmode, where a teacher can show how to solve exercises from specified levels.</p>

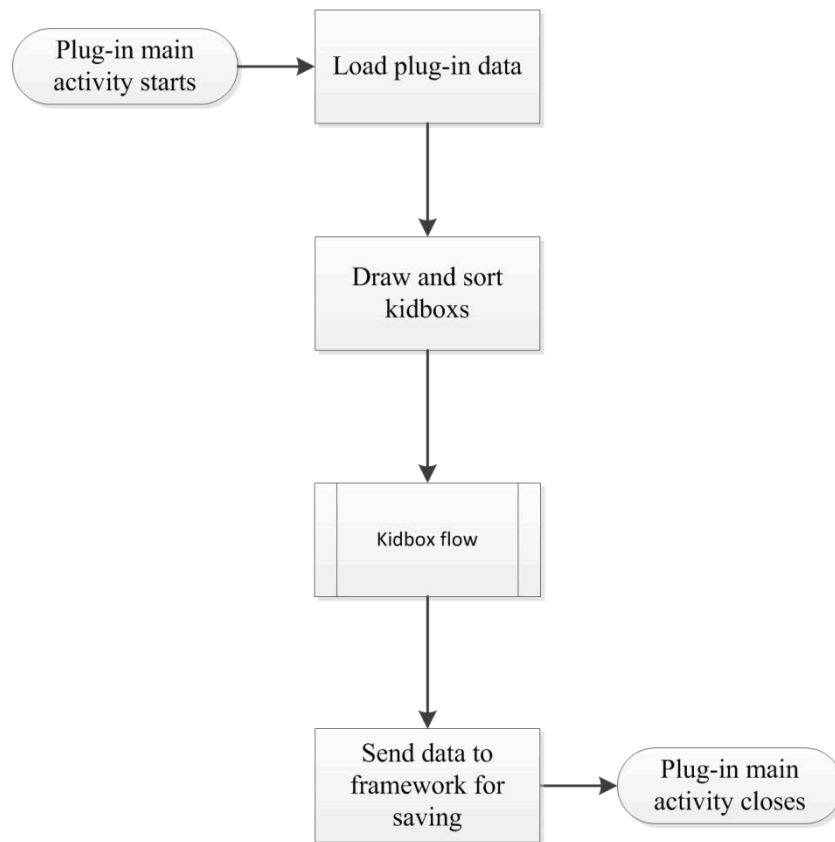


Figure V.42: SumasPlugin basic flow chart

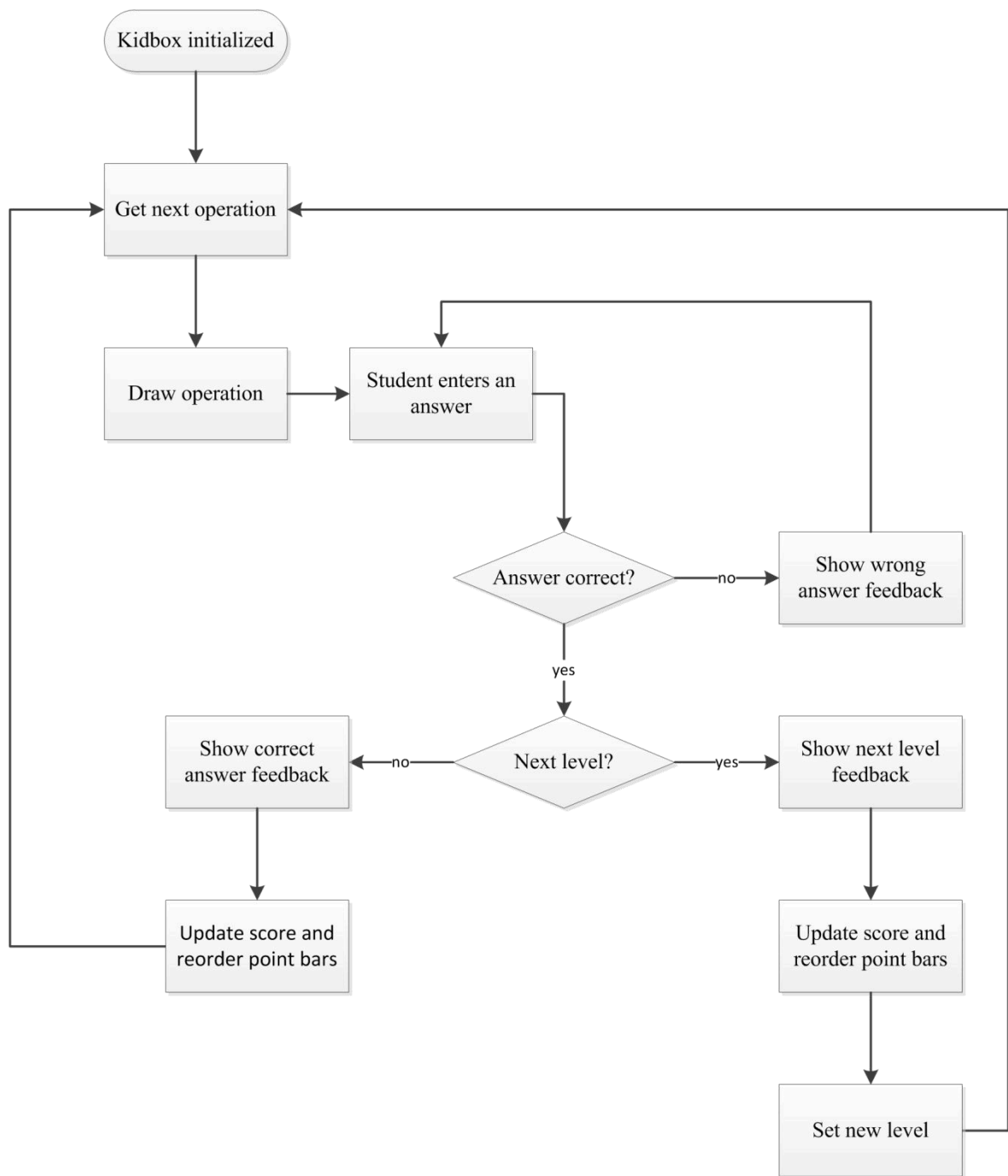


Figure V.43: Kidbox flow chart

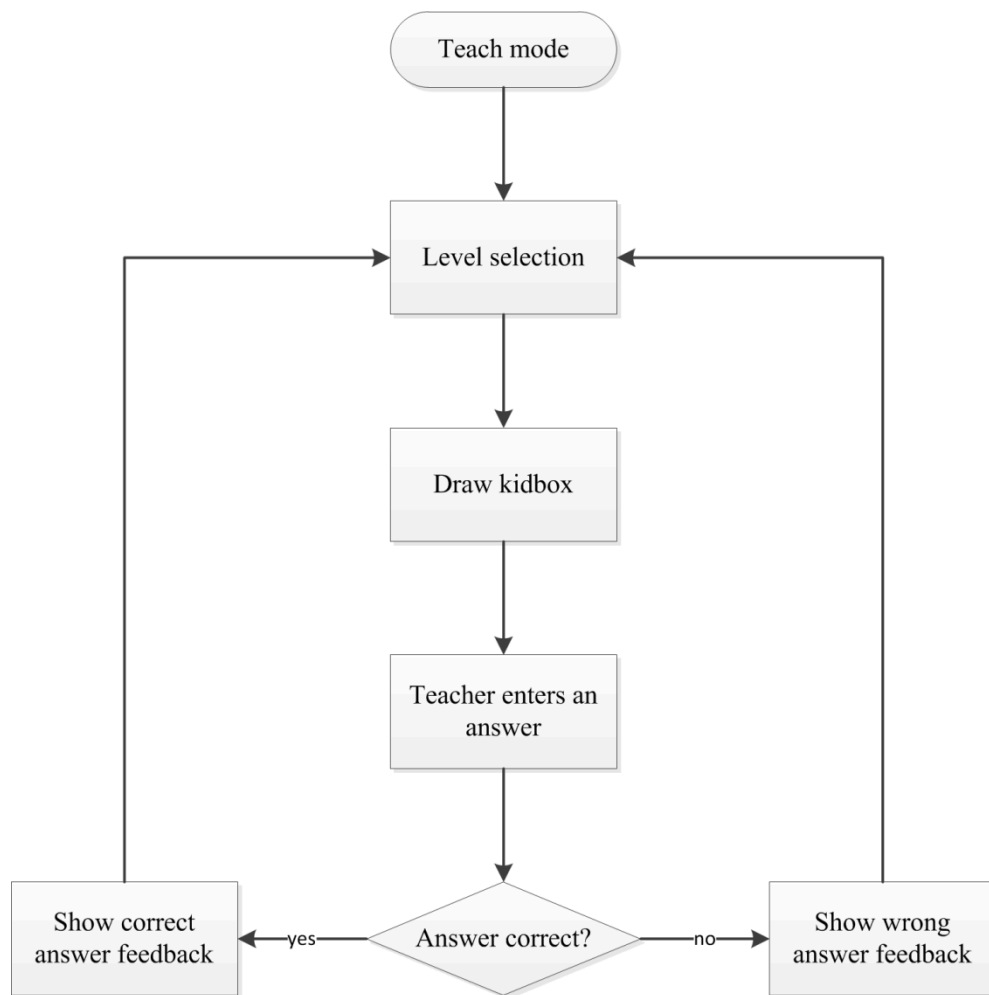


Figure V.44: Teach mode flow chart

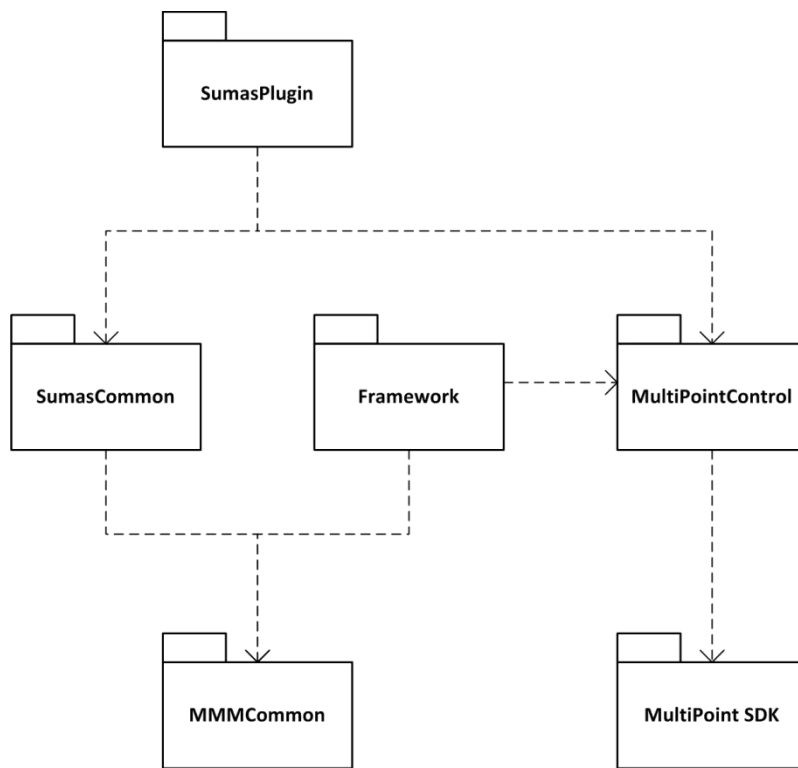


Figure V.45: SumasPlugin dependencies

V.1.6 Personal computer software

This software shared two DLL's (dynamic link library) that provide functionality for common tasks. The first one of this DLL's is MMMCommon and the second is SumasCommon which were described on section V.1.5.2.

This version of the arithmetic software was made to run in a personal computer, using a 1:1 approach. This software was designed to be used in a Classmate PC or a Desktop Laboratory PC running Windows.

Figure V.46 shows a screenshot of the software. Just like the MIPC version, in the red box is the current exercise space. In the green box is the space where the student has to enter the answer by clicking the arrows of the digits. In the blue box is the symbol that the student has to click when he think he has his answer ready. When he does it, a

feedback appears: incorrect feedback (Figure V.32), correct feedback (Figure V.33) and next level feedback (Figure V.34). Finally, in the black box it's the point bar space. It shows the current level of the student and his current score in the activity.

The flow of this software, described in Figure V.47, is very similar to the SumasPlugin flow, described in Figure V.42. The main difference it's that in this case the same software handles the course and student selection, meanwhile in SumasPlugin is handled by the framework. The kidbox flow is exactly the same as the one for SumasPlugin shown in Figure V.31. Other differences are that in this case the Teachmode doesn't exist as well the final summary that is shown at the end of the session. Finally, the main difference between the two systems is that in this one the feedback provided is personal, and in the one mouse per child version is public.

Figure V.48 shows a hierarchy class diagram and Table V.23 shows a description of each class. Just like SumasPlugin, Sumas Single also depends on SumasCommon DLL and MMMCommon DLL, however, because of this version doesn't support Multipoint, all references to the Multipoint SDK and MultiPointControl DLL where eliminated.

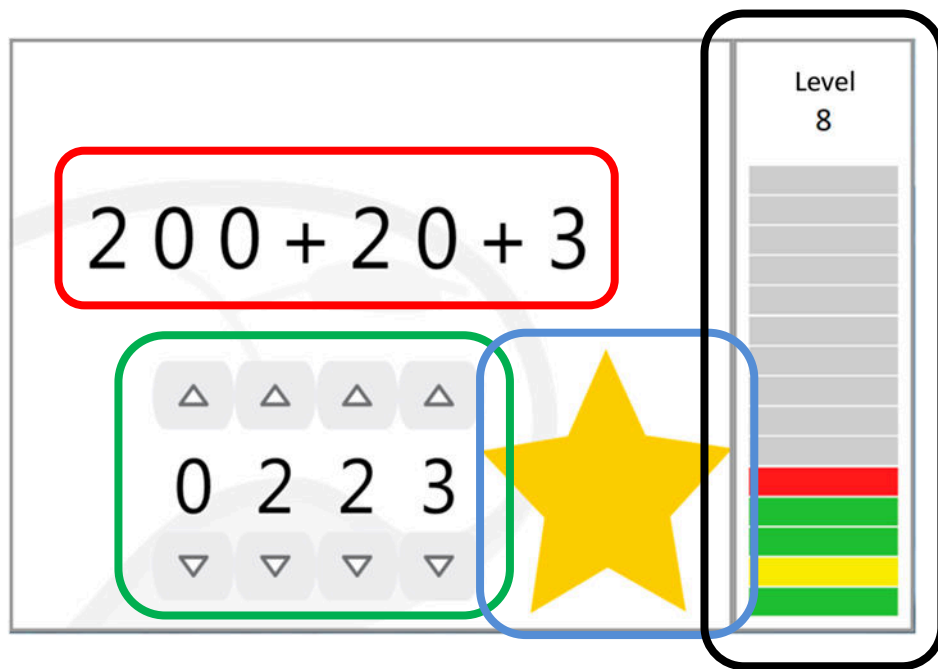


Figure V.46: Sumas Single screenshot

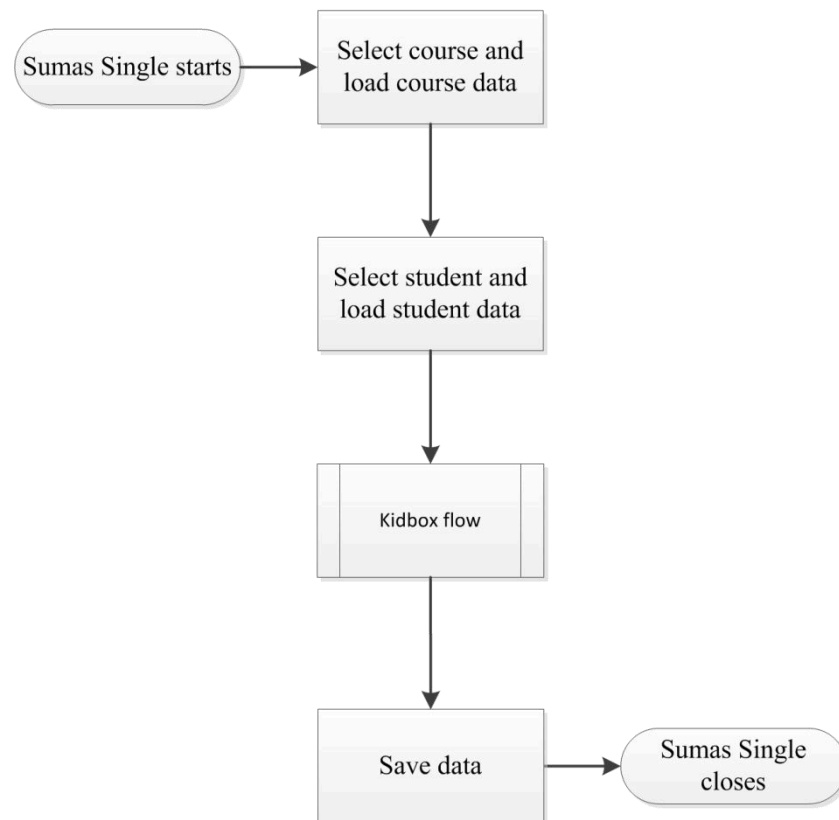


Figure V.47: Sumas Single flow chart

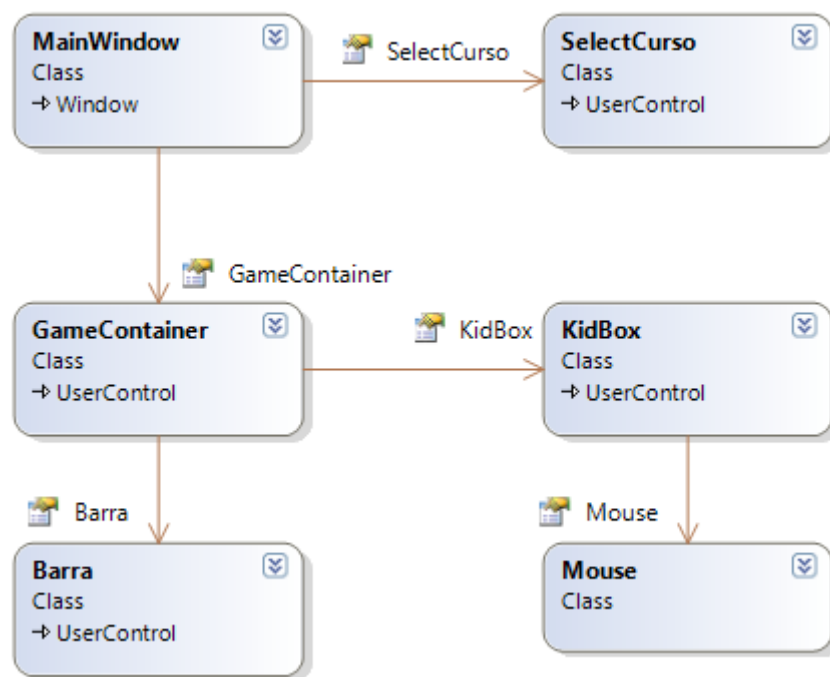


Figure V.48: Sumas Single class hierarchy

Table V.23: Sumas Single class description

Class	Description
MainWindow	Main window of the software. It also controls the main flow of it. It has a SelectCurso and a GameContainer control.
SelectCurso	Control that allows the user to select a course and the name of the student that is working. After, it loads the data necessary for the activity.
GameContainer	Control that contains the KidBox and the point bar.
Barra	Point bar that shows the actual score and level. It works just like the one mouse per child version: Green for answers correct at the first attempt, yellow for answers correct at the second attempt and red for answers correct in the third or higher attempt.
KidBox	Draw the current exercise and it also controls the flow of the set of exercises during a session.
Mouse	Legacy of the one mouse per child version. Stores the data of the session to save it later.

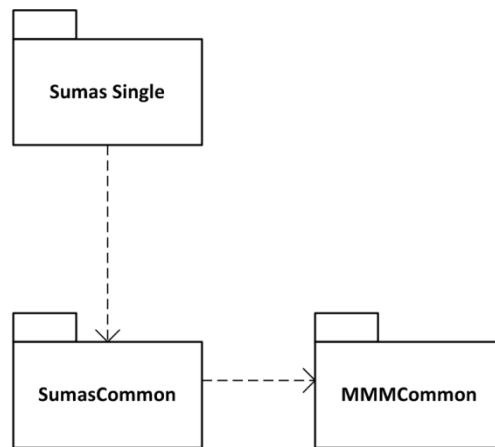


Figure V.49: Sumas Single dependencies

V.2 Appendix B

The software architecture was designed for further reusability. It was divided into 3 packages; the SDG Toolkit, the SDG Control Library and the Collaborative Meeting Project. Each of them will be described later on with detail. In general terms, the SDG Toolkit is a dynamic link library, referred as dll, which handles the multi-user input and the visualization of the multiple mice. This dll is used by the SDG Control Library which contains all SDG-enabled controls as well as some general purpose classes for multi-user input. It is a dll as well and it provides independency of the controls from the main application. Finally, the Collaborative Meeting Project is a Windows based application which uses a specific instance of both the SDG Toolkit and the SDG Control Library. The diagram of the interaction between the packages can be seen in Figure V.50.

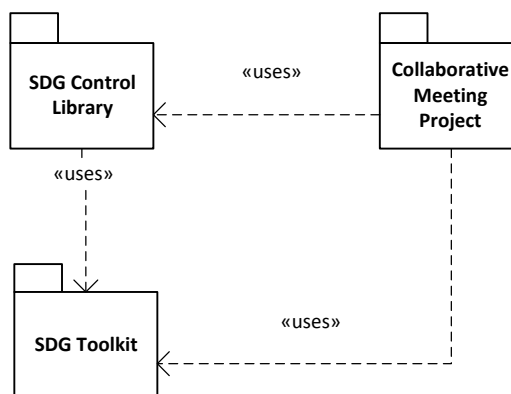


Figure V.50: Top-level package interaction

V.2.1 SDG Toolkit

The SDG Toolkit works as a Service Developer Kit for .NET framework 2.0 applications. It was created in 2004 by Edward Tse as a Master Thesis project. It is an open source Toolkit and can be downloaded from the internet (see references). Windows

applications handle all mice and keyboard information as it was only of each. The SDG Toolkit intercept this messages before they are interpreted by the application and filters them by their source and creating new SDG messages, allowing the possibility of having multiple devices of the same type working separately. This is achieved through the SdgManager class.

The way messages are handled has some drawbacks as well, because the SDG messages do not interact with Windows directly. This means that normal controls do not work with multiple devices over this scenario. Luckily, this can be solved by an interface that the Toolkit provides called ISdgMouseWidget and ISdgKeyboardWidget. The SdgManager handles messages and delivers them to the proper Interface according to the type of message. This is done by checking which controls of the main form are in the event coordinates. This brings some difficulties for developers which are solved by the SdgModifiableControl.

Besides from the input handling, the SDG Toolkit encapsulates all that complexity and represents them as easy-to-use objects. It provides an array of Keyboard and Mices which have information about the devices attached as well as some events associated with user actions.

The student had to alter part of the source code of this Toolkit, in order to achieve things that were not included in it. The drawing of each cursor is done by an invisible Windows Form. As mentioned, it was needed to have a tool selector around the cursor. Doing this from outside the form is not efficient as some test the student did, because it needs to invoke another thread instead of calling it from within. In order to solve this, the student exposed several methods to load tools and afterwards display them in the invisible forms. Another change was the creation of events that were not included such as the

SdgMouseWheelScrollDown, SdgMouseWheelScrollUp, SdgMouseEnter and SdgMouseLeave. As for the keyboard, there was a need to prevent a control from losing focus so two more events were added which are the PreFocusChanged and PostFocusChanged. There were also some bugs that the student solved in the source code of the SDG Toolkit.

V.2.2 SDG Control Library

The SDGControlLibrary is a dll which is intended to be the base of all projects that are SDG-enabled. It is designed around the fact that normal controls do not interact with SDG-input by creating a suite of controls that are enabled for the SDG-toolkit. This is achieved through wrapping normal controls to create a layer before it, handling input in order to make the control work as intended. The main controls designed in it described on Table V.24.

Table V.24: SDG Control Library class description

Control	Description
SdgModifiableControl	This is the base control for every for controls that should run free over the work area. It has the capability of being able to be dragged by users, be resized and stay in the Parents area among others.
SdgPaintableLayer	Contains and enables input for a PaintableLayer object.
PaintableLayer	Allows for basic representations and drawings while providing a transparent background. It also allows for previewing before drawing, erasing them at will and resizing the paintings.
SdgImage	This class is just an image representation allowing users to resize it, draw over and drag it. The load and resize of the image is done by multiple Threads to prevent performance

	issues with big images. It will also show a loading sign while loading images and while resizing (because it will only resize the real image after a time, in order to minimize CPU usage).
SdgStickyNote	This control emulates the behavior of a real life sticky note, so you can write text on it, draw things over it, drag it and stick over other things. This note is not resizable; it will resize itself according to text. It uses an SdgTextBox to handle text.
SdgFreeTextBox	Inherits from the Sticky Note and it only overrides some behaviors. It does not attach to other SdgModifiableControls, it only does to the parent form. It resizes automatically and does not have a minimum size. If it loses focus and no text has been written, it will destroy itself. It uses an SdgTextBox to handle text.
SdgWebBrowser	It is a wrapper class for a Web Browser Control object which is a .NET representation of a web browser. It delivers sdg-enabled input into the web browser, allowing browsing to be controlled by all users.
SdgWordViewer	It is a wrapper class for a Word Viewer Control object which is part of a COM library. It delivers sdg-enabled input into the word viewer, allowing exploring word documents throughout the meeting.

Some other common features were included in this library. The most important of them is the PageTurnControl, which creates an effect of turning a real life paper page using a dll for .NET 2.0 called GDI+. The control could clean the current workspace or loads an old one. Also some PDF saving capabilities were added to that control in order for users to be able to save and print all the notes, drawings and documents they have produced on meetings. Detail of the architecture can be seen in Figure V.51.

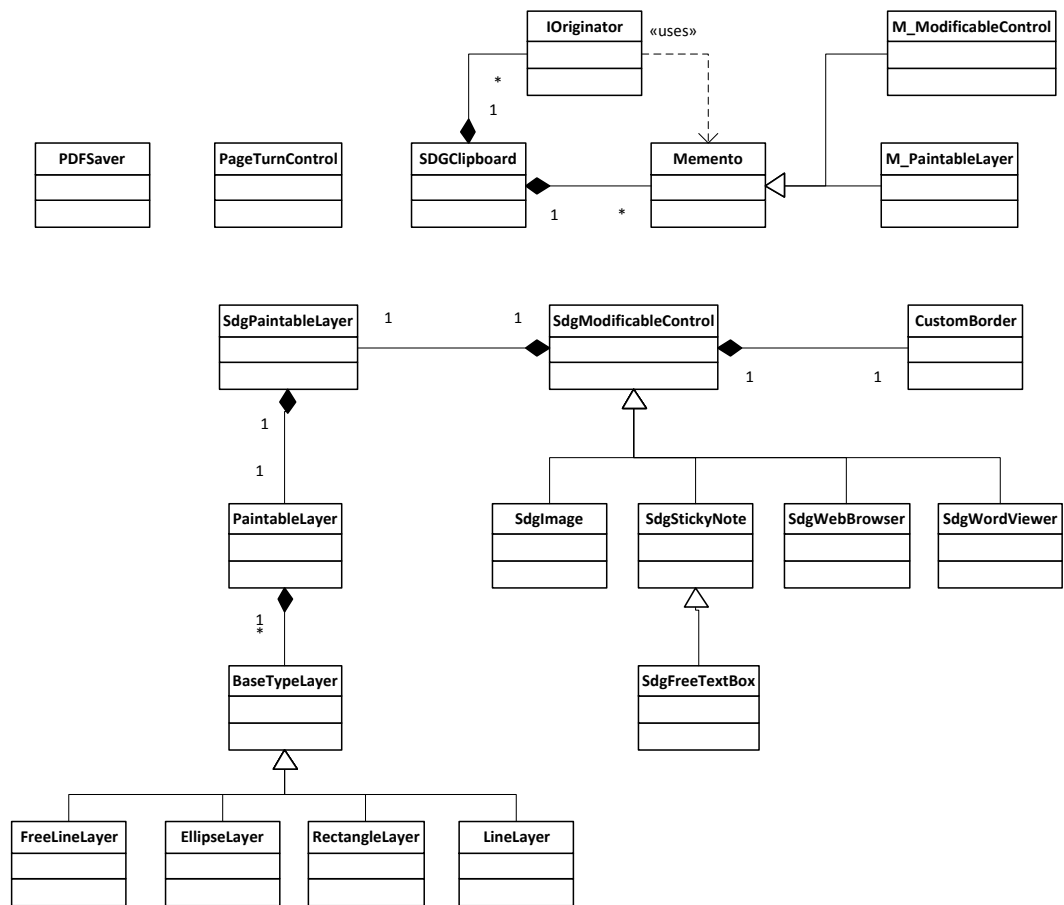


Figure V.51: SDG Control Library software architecture

V.2.3 Collaborative Meeting Project

Main project which orchestrates all the above mentioned. It loads cursors, tools and libraries together and binds several events in order to achieve determined results. It also has the capability of turning pages when desired by the user.