PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
SCHOOL OF ENGINEERING

TECHNOLOGY-SUPPORTED LEARNING STRATEGIES WITH SELF-PACED LEARNING AND FORMATIVE ASSESSMENT

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

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Santiago, Chile, September 2016

PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE

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To my parents, Sebastian, and Gabriel for their constant love and encouragement.

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ABSTRACT

Formative assessment refers to a set of practices used in the teaching-learning process. These practices take into account the quality of work produced by a student in order to hone and improve their skills. The results of this strategy is not always optimal as defining and implementing formative assessment in the classroom is a complex process that must respect the conditions of the classroom.

One of the classroom condition that must be taken into consideration is the use of technology. Technology is not neutral and can be better suited to certain task than to others. Understanding the impact of different technologies on specific teaching practices is therefore critically important. The most predominant form of technology within education is currently the Tablet PC. An alternative technology is the Interpersonal Computer (IPC), which allows multiple users located in the same physical space to interact simultaneously.

The aim of this thesis is to study how the technology used to support formative assessment impacts the learning of Spanish spelling in primary school, by following an Integrative Learning Design methodology.

The results reveal that a self-paced formative assessment strategy supported by technology promotes learning among the students targeted by the formative component. The data reveal the importance of the contents of the review class and to start the self-paced exercises from a level consistent with each student's prior knowledge. This is consistent with the literature review regarding the need to differentiate the class and contents in order to adapt to a heterogeneous classroom

Finally, it is important to note that the strategy must be assisted by a technology platform that fosters student behavior that is well-aligned with the objective of the teaching strategy. Given the formative assessment strategy designed for this thesis, for this particular case it was observed that Tablet PC promoted significant learning.

Keywords: Formative assessment, self-paced learning, spelling teaching, Tablet PC, Interpersonal Computer.

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ESCUELA DE INGENIERIA

SOPORTE TECNOLÓGICO PARA ESTRATEGIAS DE APRENDIZAJE AUTO-GESTIONADO CON EVALUACIÓN FORMATIVA

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

ANDREA FERNANDA VÁSQUEZ GUERRA

RESUMEN

La evaluación formativa es un conjunto de prácticas usadas en el proceso de enseñanza-aprendizaje, que toman en cuenta la calidad el trabajo producido por los alumnos para modelar y mejorar sus habilidades. Esta estrategia no siempre reporta niveles óptimos de aprendizaje, porque definir e implementar evaluación formativa en la sala de clases es un proceso complejo que debe respetar las condiciones propias del aula.

Una de esas condiciones es el uso de tecnología. La tecnología no es neutral, y por ello es crítico entender cómo diferentes tecnologías influyen en prácticas pedagógicas específicas. Dentro de las tecnologías disponibles, los Tablet PCs actualmente tienen el nivel más alto de penetración en educación. Una tecnología alternativa es el Computador Interpersonal (Interpersonal Computer, IPC), que permite tener múltiples usuarios localizados en el mismo espacio físico interactuando en forma simultánea usando un solo computador.

En este trabajo se estudió cómo la tecnología usada para dar soporte a la implementación de evaluación formativa afecta el aprendizaje de ortografía en enseñanza básica siguiendo la metodología "Integrative Learning Design".

Los resultados obtenidos muestran que una estrategia que considera aprendizaje a su propio ritmo y evaluación formativa con soporte tecnológico promueve el aprendizaje entre los estudiantes a quienes va dirigida la componente formativa. Los datos revelan la importancia de los contenidos de la clase de repaso, y de comenzar la ejercitación en el software considerando el nivel de conocimiento previo de los estudiantes. Esto es consistente con lo reportado en la literatura respecto a la necesidad de diferenciar los contenidos de la clase para adaptarse a un aula heterogénea.

Por otra parte, ciertas características de las plataformas tecnológicas las hacen más adecuadas para ciertas estrategias de aprendizaje. Dada la estrategia de evaluación formativa diseñada para este estudio, en este caso particular se observa que las Tablets promovieron aprendizaje significativo.

Palabras claves: Evaluación formativa, aprendizaje al propio ritmo, enseñanza de ortografía, Tablet PC, Computador Interpersonal.

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1. INTRODUCTION

A curriculum is the program of activities that teachers and students follow so that the latter, as far as possible, can reach certain educational goals (Barrow, 2015). These goals are worked towards over time, giving priority to covering as much knowledge as possible over increasing complexity and depth. This knowledge is expressed in terms of higher and lower-level cognitive domains, where the higher levels should be taught before the lower levels (Leaton Gray, Scott, & Auld, 2014).

In order to ensure the development and continuity established in the curriculum, students are organized into classes according to their age. This type of organization is backed by the conjecture that classroom contents and objectives should be equal for all students, given that their ages are the same (Eisner, 1998). That is to say, structuring classes according to age assumes that all students learn at the same rate (Levine & Levine, 2012).

Despite this, results from different international tests show that students are not learning in the way that their teachers expect them to (Krajcik, Sutherland, Drago, & Merritt, 2012). In the United States, the completion rate in secondary education has decreased when compared to previous decades (Muller, 2015). In Chile, the majority of students do not satisfy the minimum requirements of the class they are in. In fact, in 2014, the performance of 64% of eighth-grade students was equivalent to that of fourth-grade students (Salazar, 2014).

This is explained by the fact that students in the same classroom are spread over a wide spectrum of knowledge, interests, and cultural capital, factors that influence the way in which they learn (Tomlinson, 2014). In this varied context, it is possible to classify the answer of school systems to academic heterogeneity into two models: the separation model and the extensive model (Dupriez, Dumay, & Vause, 2008). In the separation model, students are divided and placed into different educational tracks depending on their academic achievement. The extensive model, in contrast, employs a minimum curriculum that is used by every student until they reach secondary education .

Evidence shows that the separation model favors more advantaged students, who view a change to a higher track as an incentive (Koerselman, 2013). In contrast, students who face greater difficulties tend to perform worse under this system, increasing the academic gap between them and their peers with better grades (Burris, 2014).

In the extensive model, educational systems manage the needs of learners in different ways: by using grade repetition (Chile), grouping by skill (United States), and using personalized work (Finland). The latter form is known as the individualized integration model and has been used to ensure that every student masters the same course content at a similar pace. That is to say, given that some students manage to access the contents of the curriculum better than others, differentiation achieved through the individualized integration model is an effective way to satisfy the needs of all learners (Scott, 2016).

Differentiation requires that the teacher modify his or her teaching method in order to respond to the needs of students with regards to class content, how this content is taught, and the way in which students respond to this content (Dixon, Yssel, McConnell, & Hardin, 2014). Given that this is a difficult process for teachers, an alternative way of supporting them in the implementation of curricular differentiation is computer-assisted learning (Ganimian & Murnane, 2016).

The use of information technology (IT) to support the learning process has been an area of interest of researchers and teachers for at least 20 years (Nickerson, 2013). In recent years, the spread of "one device, one student" initiatives, the increased prevalence of mobile devices, and the ubiquity of the Internet have greatly popularized teaching using technological support (Johnson, Adams Becker, Estrada, & Freeman, 2015). Nevertheless, despite these favorable conditions, the use of these new resources has had disparate effects on learning (Organisation for Economic Co-operation and Development, 2015; Ping Lim, Zhao, Tondeur, Sing Chai, & Tsai, 2013). Given this, the focus of this thesis is to study how the chosen technological support affects the impact of learning strategies.

1.1. Theoretical framework

In order to integrate technology into the classroom, it must be incorporated into day-to-day school activity (Guzman & Nussbaum, 2009). However, the use of technology is often forced onto curricula without considering the needs of students, the goals of teachers, or if it is appropriate to the disciplinary context (Glover, Hepplestone, Parkin, Rodger, & Irwin, 2016).

The following section will analyze the interaction between technology and the school context through a definition of the instructional model, the role of feedback in learning, and how the use of IT can support both these elements in the classroom.

1.1.1. Instructional model

The educational context must constantly adapt to the goals that society places upon it that arise from technological advances, which means that teachers must always be ready to adapt their practice (Toetenel & Rienties, 2016). There are several instructional models that can help achieve this, establishing the design, implementation, evaluation, and administration of processes and resources that aim to improve learning and achievement of students in different scenarios (Reiser, 2001).

Instructional models allow educational theory to enter the classroom by translating the ideas within to concrete concepts that can be applied by teachers. Educational theory is a source of instructional strategies that are effective under certain conditions and for certain students (Ertmer & Newby, 2013). Education is sustained by this source of knowledge, outlining the necessary characteristics of specific teacher-student interactions that enable them to develop their skills and knowledge (Branch & Kopcha, 2014).

In the different scenarios where learning takes place, instructional designs for K–12 teaching should adhere to three principal limitations: the limited time of the school year, a predefined curriculum established by local authorities, and the use of graded assessment procedures (A. H. Brown & Green, 2015). These limitations define the specific shape of and speed with which the content established in education is taught. Nevertheless, the pace of all students (and teachers) cannot be presumed to be the same, as diverse interactions in the classroom are shaped by the individual experience, identity, and culture of each classroom (Schweisfurth, 2015). Additionally, different instructional models display different levels of effectiveness depending on the population of students in which they are applied (Koedinger, Booth, & Klahr, 2013).

The necessity of respecting these paces is not recognized by the currently predominant instructional model, whose focus lies in assessing the quality of pedagogy according to quantifiable indicators (Schweisfurth, 2015). This focus limits students' learning opportunities to a curriculum centered on the content of standardized tests, primarily affecting the students who are the most disadvantaged (Tienken & Zhao, 2013). Furthermore, due to this forced pace of learning, many students develop low self-esteem with regards to their form of learning, as they constantly fail in what is taught to them without respecting their speed of learning (Reigeluth, 2013).

Despite this, teachers have a tacit awareness about their students and their environment, allowing them to design effective methods for reaching educational goals (Mor, Ferguson, & Wasson, 2015). Nevertheless, teachers require support in order to be able to design and implement instructional models, particularly with regards to detecting their students' difficulties in understanding content (Huizinga, Handelzalts, Nieveen, & Voogt, 2013). Technology can help systematize this knowledge through data gathering, by providing tools that allow teachers to capture, analyze, and interpret information on their students (Mor et al., 2015). This is to say, technology can promote learning by helping teachers to provide accurate feedback on their students' performance.

1.1.2. Feedback for teaching

Feedback is the information that students receive on how they are currently developing, in order to improve the quality of future submissions (Boud & Molloy, 2013). This process is modeled as a five-step cycle (Bangert-Drowns, Kulik, Kulik, & Morgan, 1991): the initial state of the student; the search and gathering of information triggered by a question; the student's answer to the question; the assessment of the question on the basis of feedback; and the adjustment of previous knowledge as a result of the assessment. This cycle can be repeated several times if necessary in order to resolve conceptual doubts, monitor the progress of students, and optimize the learning process (Van Lehn, 2011).

There is no consensus as to which is the most effective way of delivering feedback (Shute, 2008). In some cases, detailed feedback can be appropriate (Timmers, Braber-van den Broek, & van den Berg, 2013), while in others it is unclear as to whether or not this has an effect on learning (Goodman, Wood, & Hendrickx, 2004;

Wiliam, 2011). In general, in order for feedback to be effective, it should focus on aspects that can be improved, be specific, and be applied immediately (Chan, Konrad, Gonzalez, Peters, & Ressa, 2014). Obtaining this level of detail of information can be an additional workload for the teacher; nevertheless, it is important to note that feedback does not necessarily have to be given on a one-to-one basis (Lipnevich, McCallen, Miles, & Smith, 2013).

Interactive systems can be powerful tools to provide feedback in school settings, as feedback is an inherent catalyst in all self-regulated activities like computer-assisted learning (Butler & Winne, 1995; Nicol & Macfarlane-Dick, 2007). This is because the multimedia capacities of interactive systems can provide feedback more effectively than traditional systems (West & Turner, 2015), especially to primary education students (Van der Kleij, Feskens, & Eggen, 2015). Examples of this type of system include the Intelligent Tutoring System (Van Lehn, 2011) and Automatic Essay Evaluation software (Shermis & Burstein, 2013). Nevertheless, in areas such as writing, feedback from a teacher has a greater effect than feedback from a peer, self-feedback, or feedback provided by automated systems (Graham, Harris, & Santangelo, 2015). Therefore, when working with technology as a mechanism for feedback support it is essential to properly combine feedback provided by the technological tool with the formative role of the teacher.

A particular type of feedback that takes into account the role of the teacher is formative assessment or assessment for learning, which is using and interpreting evidence of students' progress to guide the teaching process (Black & Wiliam, 2009). Spector, Ifenthaler, Sampson, & Yang (2016) point that technology has the potential to improve the positive effect of formative assessment in learning for two reasons. Firstly, technology allows to capture every learning interaction and allows to provide immediate feedback. Secondly, when combining formative assessment and self-paced learning, students keep interest and motivation for a longer period of time. Technology also facilitates the changes in the teaching instruction that arises from using formative assessment (Boston 2012; Black, 2015). Specifically, it allows to timely devise instructional interventions, align learning milestones to actual students' progress and incorporate scaffolds to better address students' needs (Matuk, Linn, & Eylon, 2015).

1.1.3. Technology in the classroom and the teacher's role

For a technological innovation in the classroom to be leveraged to its fullest, the teacher must manage two aspects: the disciplinary content and how to use the technology in order to achieve deep learning (Glover et al., 2016). The interaction between these aspects is what determines the quality of the integration of the technology, as it is what defines its possibilities and limitations. For example, technological developments have created new perspectives for understanding the world, even changing the nature of some disciplines. Given this, the choice of technology support can facilitate or restrict the way in which content can be represented (Koehler & Mishra, 2009).

One way of directing the integration of IT in the classroom is through the orchestration model. Orchestration is the design and real-time management of multiple activities in the classroom, including the learning process and the teacher's behavior, taking into account the inherent restrictions of the educational context (Dillenbourg & Jermann, 2010). This model achieves the integration of digital and traditional resources through the specification of each aspect of the lesson, giving the structure necessary in order for the teacher to adopt a given technology and to use it beyond the limits of the training they have received (Nussbaum & Diaz, 2013). Using this structure has been shown to aid teachers in combining traditional activities with new, digital activities in a way that fosters learning (Dimitriadis, Prieto, & Asensio-Pérez, 2013).

The orchestration model defines five types of activity that take place continually during a lesson (Dillenbourg, 2013): central activities, emergent activities, routine activities, unrelated events, and infra-activities. The first two correspond to actions that the teacher takes in order to foster learning; they are those actions that educational software typically can take. For example, there are learning systems that respect each student's individual pace of learning (Sheard & Chambers, 2011). These systems allow for each student to receive questions and feedback appropriate to their level of knowledge, irrespective of the level of the rest of the class. That is to say, by using a self-paced learning system it is possible to adapt content to students' behavior and monitor their comprehension, two actions that correspond to central and emergent activities respectively.

The three latter types of activities correspond to situations that are part of classroom interaction but do not directly contribute to learning, such as a student not being present during group work. Usually educational software does not consider these situations in their design, making it difficult to incorporate them into routine classroom activities (Dillenbourg, 2013). Moreover, the teacher is the only person who can adapt learning experiences in order to take advantage of these unforeseen situations (Mor et al., 2015).

When the use of self-paced learning systems is combined with the active presence of the teacher, it is possible to implement an IT integration experiment that takes into account activities both intrinsic and extrinsic to learning, thus making it effective. On one hand, the software allows each student to work and receive feedback according to their own needs, making it possible to follow and assess the progress of individual students in a heterogeneous classroom (Tomlinson, 2015). On the other hand, providing the teacher with detailed information about the progress of his or her students gives rise to mediation instances that promote learning and help manage unexpected events. This makes it possible to cover the aspects that technology itself cannot encompass. That is to say, by giving the teacher a clear role during the intervention (Urhahne, Schanze, Bell, Man sfield, & Holmes, 2010), it is possible to amplify the pedagogical effect of technology.

1.1.4. Technology for learning

One Laptop Per Child was one of the better-known education technology initiatives of the last decade. It proposed giving each child a multimedia computer with an Internet connection for 100 USD (“One laptop per child,” 2005). Its design and implementation were based on the idea that learning takes place in informal social spaces, where the individual can create computerized representations of their cognitive processes, promoting a “learning without teachers” model (Selwyn, 2013). However, what was observed in practice was that both teachers and students used the devices in order to access music, videos, and games, at odds with the “educationally productive” use that researchers expected (Ames, 2016).

A Latin American implementation of OLPC is the Uruguayan Plan CEIBAL. Since 2007, the Uruguayan government has provided computers and tablets for personal use to more than 530 thousand students and 42 thousand teachers, hoping to eliminate the digital gap and promote access to information available online (Vaillant, 2013). Despite having 99% coverage in Uruguayan schools, the implementation of the Plan CEIBAL has not achieved significant progress in language or math learning (De Melo, Machado, Miranda, & Viera, 2013). These results can be explained by the fact that students did not spontaneously develop educational activities (Grompone, Riva, & Bottinelli, 2007).

Besides computers and tablets, there are two technological advances that have been firmly established in the field of educational hardware, these being interactive blackboards and clickers. Interactive blackboards combine a computer, a projector, and a touchscreen that allow easily manipulating multimedia resources (DeSantis, 2011). The use of this technology has increased students' motivation and involvement with their learning, but only when students and teachers share the operation of the blackboard (Beauchamp & Kennewell, 2012). However, the related literature shows that interactive blackboards are underused in practice, as teachers are not able to modify their practice in order to make use of this new resource (Kennewell, Tanner, Jones, & Beauchamp, 2007). Clickers, on the other hand, are small, wireless keyboards that are used to register students' answers in real time (Caldwell, 2007). Clickers provide immediate feedback on the learning process, promotes teacher-student interaction, and increase involvement with class content (Blasco-Arcas, Buil, Hernández-Ortega, & Sese, 2013).

Though these devices represent an important investment for schools, they are often not used as teachers do not have the operational competency or the teaching resources needed in order to take advantage of these new technologies (Firmin & Genesi, 2013). Additionally, in the case of personal hardware, developing countries cannot always count on having one device available per student (Nye, 2014). These examples demonstrate that technology integration needs to address both the teacher and the classroom context, as discussed in the previous sections.

With regards to software, a strategy used in the incorporation of technology in classrooms is intelligent tutors. This type of software provides personalized instruction and precise feedback to students, without the need for outside intervention (Sharma, Ghorpade, Sahni, & Saluja, 2014). Interaction is done primarily through the exchange of information, where the student solves a problem and the system responds with rapid feedback, marking, or aid (Nye, Graesser, & Hu, 2014). This is a cycle designed for independent work, which has been shown to be beneficial only to students that are able to self-regulate their learning (Kelly & Heffernan, 2015). Additionally, intelligent tutors are not yet capable of instructional methods other than immediate feedback. For example, these systems cannot correctly determine when to remove and when to re-establish scaffolding when working with Vygotsky's zone of proximal development (Holden & Sinatra, 2014).

Previous approaches have required using one device per student, which makes technological intervention expensive. One way of lowering costs is to divide students into small groups, whose members share devices. Initially, it was thought that this way of working, as well as lowering costs, would promote collaboration. However, it was observed that small groups do not automatically generate collaboration or interaction between peers (Lou, Abrami, & d'Apollonia, 2001). For this to take place and satisfactory performance be reached, both students and teachers need to be trained in ways of working collaboratively (J. Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010; Lou et al., 2001).

Another low-cost technology that has made a large impact on the educational context is massive open online courses (MOOC). MOOCs are courses given through the

Internet, having a global reach and being free to enter, with few or no prerequisites for joining (Perna et al., 2014). This instructional model particularly speaks to the needs of developing countries that have a scarcity of teachers, but where students can easily access the Internet, primarily through mobile devices (Nye, 2014). Despite the ease of access, MOOCs are completed by around 10% of enrolled students; the lack of interaction with the teacher being one of the most influential factors in low student completion rates (Hone & El Said, 2016).

By way of response, the flipped classroom model combines the long-distance video lessons of MOOCs with face-to-face training workshops and problem solving in groups (Bishop & Verleger, 2013). By shifting the time when information is transmitted to outside of class hours, face-to-face time can be taken advantage of for interactive activities that promote active learning (Abeysekera & Dawson, 2015). By pre-recording lesson material, students can also work at their own pace and use the learning strategy that suits them best (Uzunboylu & Karagozlu, 2015). Nevertheless, as is the case with intelligent tutors, the students that derive the most advantage from this form of learning are those that self-regulate their work and have an intrinsic motivation for learning (McClelland, 2015). These favorable results may even be due to the use of active learning methodologies and not to flipping the classroom (Jensen, Kummer, & Godoy, 2015).

The instructional models discussed above show that technology on its own is not enough to see gains in learning. The classroom is an environment where different factors are in play, among them the needs of each individual student (Tomlinson, 2014), the school dynamics, and culture (Ping Lim et al., 2013). The previous examples show how experiments with using IT in education can fail if these classroom conditions are not considered in their implementation (Rodríguez, Nussbaum, & Dombrovskaia, 2012).

1.2. Research hypotheses

The previous literature review showed the importance of considering the relationship between technological support, formative feedback and individual learning paces in the classroom to promote learning. Thus, the following hypotheses guided the work on this thesis:

1) A self-paced learning strategy using formative assessment, where the teacher plans customized review sessions based on information regarding student performance, produces significant learning gains when compared to a self-paced learning strategy with review sessions that follow the pre-defined order of the curriculum, as established by the local authority.

2) When teaching spelling, a formative assessment strategy with self-paced learning that considers the students' starting level significantly improves learning among the students that are targeted by the teacher's feedback.

3) There is a low-cost software and hardware architecture for Single Display Groupware (SDG) systems, permitting technological support for an entire classroom simultaneously.

4) Different technological platforms have a different impact on learning when following a strategy of self-paced learning using formative assessment.

1.3. Research questions

The following research questions were developed from the hypotheses:

1) What is the impact on learning when a teacher uses objective information about student knowledge to teach a review lesson on spelling?

2) To improve spelling among native Spanish speakers in primary school, how can a formative assessment strategy with self-paced learning be implemented?

3) What software and hardware architecture allow a Shared Worskpaces implementation for co-located SDG in classroom settings?

4) What impact do different technologies have on student learning when using formative assessment to teach spelling?

1.4. Research objectives

The objectives of this thesis are as follows:

1) To propose an instructional strategy that promotes learning based on objective information about students' knowledge and learning pace.

2) To explore the effect on learning of this strategy compared to traditional lessons that follow the order of the curriculum established by the local authority.

3) To implement a software and hardware architecture that allows giving SDG support to an entire class.

4) To compare the effect of two different technologies (tablets and SDG) on the same instructional strategy.

1.5. Methodology

This research was conducted following the design-based research (DBR) methodology (The Design-Based Research Collective, 2003). DBR was chosen as a research methodology because it blends design, educational research, and practice, with the goal of creating a product that can be used by both teachers and students. To this end, DBR makes explicit and integrates into the research the variables inherent in the classroom context, unlike other methodologies that assume interventions to be conducted in laboratories (F. Wang & Hannafin, 2005).

This methodology is funded on five core ideas: that the design of learning environments and educational theories are intertwined; that development and research occur in iterative cycles that translate to constant redesign; that the research should have relevant implications for those who do research and those who work in education; that how the theoretical design works in practical contexts should be explained; and that the relationship between the intervention process and the relevant results should be documented.

Integrative learning design (ILD) is a framework that provides structure to DBR ideas (Bannan-Ritland, 2003). It is designed specifically for interventions in education that incorporate technology, as it takes into account the implementation of various iterative experimental cycles where the product is refined according the results of literature search, the previous cycles, and the feedback from teachers and students (Yutdhana, 2005). ILD integrates processes from instructional design, software engineering, and product design, as well as the principles of quantitative and qualitative educational methodologies. The above is articulated as four steps (Bannan-Ritland, 2007):

1) Informed exploration: Literature review, work with experts, and initial research allowing for outlining different research paths.

2) Enactment: The information obtained during informed exploration is converted into a product or model, which is tested and validated by real users.

3) Local impact: Qualitative and/or quantitative methods are used in order to assess the impact of the product or model on users. These results allow refining the product in future iterations.

4) Broad impact: The dissemination of results and lessons learned.

The work conducted during this research was structured in two stages, each of which followed the ILD cycles as shown in the following subsections. It is important to note that the participating schools in every stage of this research were Government-subsidized and belonged to low-income communes in Santiago, Chile. Even tough students were at high risk according to the school vulnerability index of the Chilean Ministry of Education, the institutions usually scored above-average in the national standardized tests compared to similar schools.

1.5.1. Development of the formative assessment model

The formative assessment model proposed in this thesis was developed in two ILD cycles. In the first of these, a literature search was conducted and work was done with language teachers in order to generate a proposal, from which the reach of the research was defined. This iteration provided the two central elements of the model:

a tablet-based self-paced learning software for practicing spelling for 1st to 6th grade students and a schedule for review lessons, where the teacher revises the material that the software reports the students are underperforming in. Spelling was chosen as the content of the software due to the favorable results that have been obtained in teaching spelling using formative assessment (Graham, Hebert, & Harris, 2015) and due to the relevance of developing writing skills for improving academic performance (Graham, Gillespie, & McKeown, 2013; Graham & Santangelo, 2014). The model was tested on second-year primary students and the implementation details and results can be found in the chapter 2.

It was observed, based on the results of this cycle, that the model could be refined in order to achieve a higher impact on learning. To this end, two differences in the method of instruction were implemented: making the students begin to work with the self-paced software based on their previous knowledge and adjusting the content of the review lessons into two levels, one for students with better performance and one for those with difficulties. This model was again tested on second-year students; the implementation details and results can be found in chapter 3.

In both cycles, session with students were carried out for 20 minutes each. Depending on the schedule, students worked using technology at their own pace or had a lecture-style review lesson. These lessons were prepared by the researchers and led by the class teacher, as it is detailed in the respective chapters.

1.5.2. Hardware development

Two types of hardware were used in this thesis: tablets and interpersonal computers (IPC) (Kaplan, DoLenh, & Bachour, 2009). Although the same self-paced learning software was implemented on both platforms (see previous subsection), the necessary development for providing technological support for this software was done independently.

In the case of tablets, the informed exploration showed that there are two main ways of developing applications for this device. One way is to develop programs native to a certain operating system. The other way is to develop a web application that emulates a native application but is run through a browser and are not dependent on the tablet's operating system. Due to the technological conditions of classrooms, this work opted instead for using an intermediate (hybrid) model such as is shown in Figure 1.1. In this intermediate model, each tablet maintains an internal database and backups are sent periodically to a central server through a local network. Additionally, the logic of the application is executed locally on each tablet.

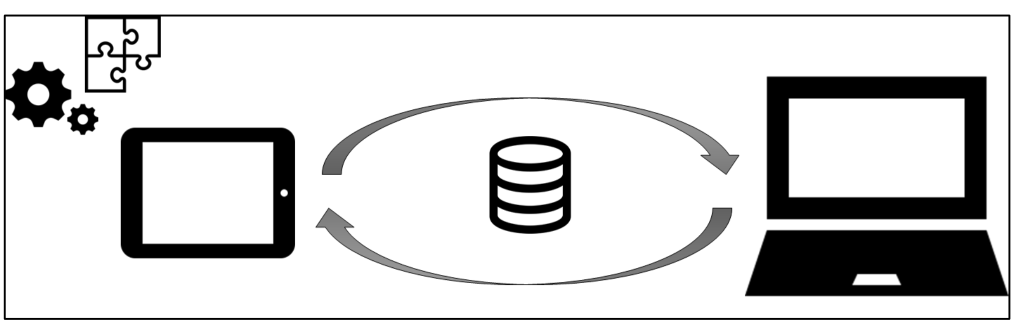

Figure 1.1 Hybrid mobile development model

This development model was chosen because network reliability in schools is low, which means that connectivity cannot be assured at all times (Nye, 2014). This rules out using a web application model. On the other hand, native design is costly and developing native applications is more time-consuming than using the web model (Litayem, Dhupia, & Rubab, 2015). This in an important restriction when working with iterative cycles, such as ILD, as the product goes through constant changes that must be rapidly implemented in order to continue on to the next iteration.

The tablet development model was tested on two occasions, both of which are discussed in detail in chapters 2 and 3.

The IPC development was carried out in three ILD cycles. The first two were dedicated to implementing and testing the architecture for giving technological support to single-display groupware for a classroom. The justification for the necessity of this type of platform, the iterative development of the system, and the results of tests with students can be found in chapter 4. The third cycle corresponded to a classroom experiment, where the proposed architecture was kept but the software was adapted in order to permit collaborative work in the classrooms. This work is detailed in chapter 5.

Finally, the impact on learning of the two types of hardware used was studied. In order to do this, the formative assessment model (see previous subsection) was implemented for tablets and IPC and a comparative study with second-year students was carried out. This experiment is presented in chapter 6.

1.6. Results

The various research cycles carried out during this thesis produced the following series of results:

1) In order to achieve significant learning gains, formative assessment should be incorporated as a component of orchestration using technological resources.

2) The students facing the greatest difficulties are benefitted when a review lesson focusing on the weaknesses of the entire class is conducted.

3) In order to achieve significant learning gains when using a formative assessment model with technological support, instruction should be differentiated both when working with the software as well as when reviewing content.

4) There is a software and hardware architecture that allows providing SDG technological support to an entire classroom.

5) In order to improve the performance of SDG systems for an entire classroom, audio output delivery should be distributed.

6) Collaborative work mediated by technology has effects on learning even when the technological support is unstable.

7) It is possible to develop a software architecture that is common for both collaborative and individual work.

8) The choice of technological platform for the classroom has an impact on student learning.

9) The complexity of the hardware is a factor that affects the impact of technology on learning.

1.7. Research limitations

It is important to highlight the limitations of this research in order to interpret its results in the light of its context and to project possibilities of future work.

- The different studies that this thesis is composed of were conducted in a limited scope. Work was done only on language teaching in primary education in subsidized private schools in Chile. Assessing the impact of formative assessment strategies with technological support in other school subjects and in secondary and higher education is of interest. On the other hand, it is important to assess if the familiarity of students with technology affects the impact that it has on their learning. Thus, one aspect of future work is to conduct this type of intervention with students from other socioeconomic backgrounds and/or countries where technology in the classroom is already commonplace.
- Another limitation of the experimental design is the short duration of the intervention. The school experiments were conducted over 8 or 10 sessions, of which two corresponded to pre and post-testing. Although favorable results were obtained in that timeframe, the effect of these interventions on at least two aspects remains to be studied: if further gains can be made with additional technological and review sessions and the long-term impact of this model on learning.
- The work in this thesis was done using two types of hardware, tablets and IPC, while leaving out smartphones. Tablets were chosen as they were the devices

having the largest spread in schools when interventions began. However, smartphones are today the device that sees the most use in classrooms, which means future work includes assessing their impact on learning.

- Today, large screens are commonplace in both public and private spaces (Rusňák, Ručka, & Holub, 2016), which indicates that shared workspaces are already forming a part of everyday life. This technology was in its inception when this research began; thus, its performance was unreliable. As today development for shared workspaces has matured, an alternative possibility is replicating a study using the available new, more stable technology.
- IPC as a platform has three important advantages compared to other shared-screen devices: their low cost, their low support requirements compared to a computer lab due to requiring only one computer per class, and not requiring hardware that is developed specifically for its implementation. Nevertheless, it is unrealistic to think that the educational system can incorporate into its practice setting up this platform before every use. Thus, any gains in learning proceeding from the implementation of this system in schools need to be measured in order to assess whether they compensate for this effort.

1.8. Thesis outline

The work presented in this thesis is structured in various studies, which have been embodied in two types of documents: a Master’s thesis and several articles. Of these articles, one of them has been accepted for publication and the rest have been submitted for review.

The following section describes these studies, including how they correspond to the chapters of this thesis and the authors and themes with which they deal:

Chapter 2: Corresponds to the article “Using Formative Assessment as a Teaching Tool to Assist with Self-Paced Learning” written by Andrea Vásquez, Miguel Nussbaum, Enzo Sciarresi, and Macarena Oteo in 2014, which is about to be submitted. The study describes the formative assessment model with technological support that was developed in the context of this thesis, presenting the results obtained the first time this model was tested with students and teachers.

Chapter 3: The title of the article included in this chapter is “Self-paced Learning and Formative Assessment for Teaching Spelling” written by Andrea Vásquez, Miguel Nussbaum, and Camila Barahona. It was submitted to the journal Educational Technology and Society (impact factor 1.376) in April 2016 and is currently under review. This article presents the results obtained when incorporating two elements into the formative assessment model with technological support presented in chapter 2: self-paced work on a level appropriate to previous knowledge and performance-based review lessons.

Chapter 4: This chapter discusses the software and hardware architecture developed in order to provide technological support for an entire class through single display groupware. It describes the experiment conducted and the results of the two research cycles in the development of software and hardware for SDG of up to 36 users. This work is found in the paper "Towards a Reference Implementation of SDG Applications to Support Co-located Multiple Users in Classroom Settings" written by Andrea Vásquez, Andrés Neyem, Miguel Nussbaum and Gabriel Vidal. It was submitted to the Journal of Educational Computing Research (impact factor 0.670) in July 2016.

Chapter 5: This chapter includes the results of the work done for the Master's thesis by Tomás Martínez, which is an integral part of this research. It involves the use of SDG architecture (characterized in chapter 4) for collaborative work in small groups. This work observes the importance of the fact that the hardware used in the classroom can be adapted to unpredictable technological contexts and that, even when facing implementation difficulties, collaborative work mediated by technology has a favorable influence on learning.

Chapter 6: The title of the article discussed in this chapter is "The Impact of the Technology Used in Formative Assessment: the Case of Spelling", written by Andrea Vásquez, Miguel Nussbaum, Enzo Sciarresi, Tomás Martínez, Camila Barahona, and Katherine Strasser. This article, which reveals the importance of the choice of technology for use in the classroom, was accepted in 2016 to the Journal of Educational Computing Research (impact factor 0.670). The results obtained show that, given the same educational software, different results can be obtained depending on its implementation on tablets or on IPC.

1.9. Thesis structure

This subsection presents two diagrams that show the structure of this thesis. Table 1-1 summarizes the objectives, hypotheses, research questions, articles, and results obtained of this work. Figure 1.2 is a model that links all of these elements.

Table 1.1 Summary of the thesis structure

Hypothesis	
H1	A self-paced learning strategy using formative assessment, where the teacher plans customized review sessions based on information regarding student performance, produces significant learning gains when compared to a self-paced learning strategy with review sessions that follow the pre-defined order of the curriculum, as established by the local authority.
H2	When teaching spelling, a formative assessment strategy with self-paced learning that considers the students' starting level significantly improves learning among the students that are targeted by the teacher's feedback.
H3	There is a low-cost software and hardware architecture for Shared Device Groupware systems, permitting technological support for an entire classroom simultaneously.
H4	Different technological platforms have a different impact on learning when following a strategy of self-paced learning using formative assessment.
Research questions	
Q1	What is the impact on learning when a teacher uses objective information about student knowledge to teach a review lesson on

	spelling?
Q2	To improve spelling among native Spanish speakers in primary school, how can a formative assessment strategy with self-paced learning be implemented?
Q3	What software and hardware architecture allow a Shared Worskpaces implementation for co-located SDG in classroom settings?
Q4	What impact do different technologies have on student learning when using formative assessment to teach spelling?
Objectives	
O1	To propose an instructional strategy that promotes learning based on objective information about students' knowledge and learning pace.
O2	To explore the effect on learning of this strategy compared to traditional lessons that follow the order of the curriculum established by the local authority.
O3	To implement a software and hardware architecture that allows giving SDG support to an entire class.
O4	To compare the effect of two different technologies (tablets and SDG) on the same instructional strategy.
Thesis and articles	
P1	"Using Formative Assessment as a Teaching Tool to Assit with Self-Paced Learning"
P2	"Self-paced Learning and Formative Assessment for Teaching Spelling"
P3	"Towards a Reference Implementation of SDG Applications to Support Co-located Multiple Users in Classroom Settings"
P4	Results of the Master's thesis by Tomás Martínez
P5	"The Impact of the Technology Used in Formative Assessment: the Case of Spelling"
Results	

R1	In order to achieve significant learning gains, formative assessment should be incorporated as a component of orchestration using technological resources.
R2	The students facing the greatest difficulties are benefitted when a review lesson focusing on the weaknesses of the entire class is conducted.
R3	In order to achieve significant learning gains when using a formative assessment model with technological support, instruction should be differentiated both when working with the software as well when reviewing content.
R4	There is a software and hardware architecture that allows providing SDG technological support to an entire classroom.
R5	In order to improve the performance of SDG systems for an entire classroom, audio output delivery should be distributed.
R6	Collaborative work mediated by technology has effects on learning even when the technological support is unstable.
R7	It is possible to develop a software architecture that is common for both collaborative and individual work.
R8	The choice of technological platform for the classroom has an impact on student learning.
R9	The complexity of the hardware is a factor that affects the impact of technology on learning.

Figure 1.2 shows the relationship between the hypotheses, research questions, and objectives derived from these, as well as the articles and results obtained from these objectives. In several cases one can see how a result is used as evidence in order to generate a new hypothesis.

Hypothesis 1 (H1), “a self-paced learning strategy using formative assessment, where the teacher plans customized review sessions based on information regarding student performance, produces significant learning gains when compared to a self-paced learning strategy with review sessions that follow the pre-defined order of the curriculum, as established by the local authority”, is linked to research question 1 (Q1), “what is the impact on learning when a teacher uses objective information about student knowledge to teach a review lesson on spelling?” and objective 1 (O1), “to propose an instructional strategy that promotes learning based on objective information about students’ knowledge and learning pace”. The article “Using Formative Assessment as a Teaching Tool to Assist with Self-Paced Learning” (P1) was based on these results, which in turn led to results 1 (R1), “in order to achieve significant learning gains, formative assessment should be incorporated as a component of orchestration using technological resources” and 2 (R2), “the students facing the greatest difficulties are benefitted when a review lesson focusing on the weaknesses of the entire class is conducted”.

Hypothesis 2 (H2), “when teaching spelling, a formative assessment strategy with self-paced learning that considers the students’ starting level significantly improves learning among the students that are targeted by the teacher’s feedback”, was based on results R1 and R2. H2 in turn led to the definition of research question 2 (Q2), “to improve spelling among native Spanish speakers in primary school, how can a formative assessment strategy with self-paced learning be implemented?” and objective 2 (O2), “to explore the effect on learning of this strategy compared to traditional lessons that follow the order of the curriculum established by the local authority”. This thesis’ first research paper (P2), “Self-paced Learning and Formative Assessment for Teaching Spelling” was developed from the result obtained in this iteration (R3), “in order to achieve significant learning gains when using a formative assessment model with technological support, instruction should be differentiated both when working with the software as well when reviewing content”.

After these results were obtained, a hypothesis surrounding the hardware used in classrooms was explored (H3), “there is a low-cost software and hardware architecture for Shared Device Groupware systems, permitting technological support for an entire classroom simultaneously”. The research question linked to this hypothesis is (Q3), “what software and hardware architecture allow a Shared Workspace implementation for co-located SDG in classroom settings?” and the related objective is (O3), “to implement a software and hardware architecture that allows giving SDG support to an entire class”. Based on these, two documents were created: the article “Towards a Reference Implementation of SDG Applications to Support Co-located Multiple Users in Classroom Settings” (P3) and the results of the Master’s thesis by Tomás Martínez (P4). The former was based on two results: (R4), “there is a software and hardware architecture that allows providing SDG technological support to an entire classroom” and (R5), “in order to improve the performance of SDG systems for an entire classroom, audio output delivery should be distributed”. Tomás Martínez’ thesis describes the results (R6), “collaborative work mediated by technology has effects on learning even when the technological support is unstable" and (R7), "it is possible to develop a software architecture that is common for both collaborative and individual work".

As it was possible to develop an architecture for providing SDG technological support for an entire class, and using what was previously learnt when developing a learning strategy using formative assessment and self-paced software, the final hypothesis of this work emerged (H4): "different technological platforms have a different impact on learning when following a strategy of self-paced learning using formative assessment". This hypothesis was used to outline research question (Q4), "what impact do different technologies have on student learning when using formative assessment to teach spelling?" and objective (O4), "to compare the effect of two different technologies (tablets and SDG) on the same instructional strategy". The article (P5), "The Impact of the Technology Used in Formative Assessment: The Case of Spelling" discusses the results obtained in this intervention: (R8), "the choice of technological platform for the classroom has an impact on student learning" and (R9), "the complexity of the hardware is a factor that affects the impact of technology on learning". This work provided an opportunity to improve the results obtained in Chapter 2 by retesting its hypothesis with a higher number of students and more sessions.

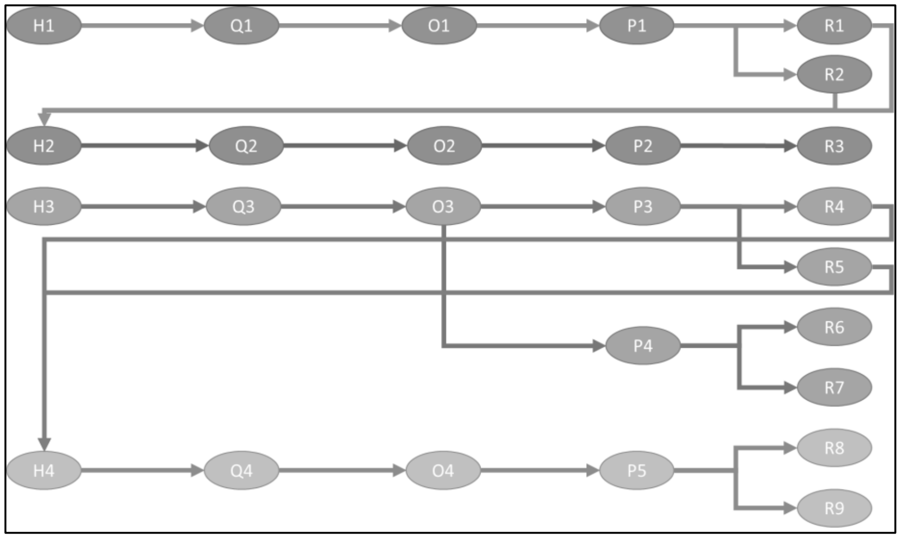

Figure 1.2 Links between the hypotheses, research questions, objectives, papers and results

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2. FORMATIVE ASSESSMENT AS A TEACHING TOOL TO SUPPORT SELF-PACED LEARNING

2.1. Abstract

Evidence shows that the use of technology-assisted, formative assessment in student classroom work leads to significant increases in learning. The question which stems from this is how teachers can use information from their students' interactive work to improve their own teaching. The aim of this research is to show how formative assessment can be used as a tool for teachers to assist with self-paced learning. An application for tablets was developed to help teach writing, where each student works individually and at their own pace. At the end of each session, the teacher receives a report on each student's progress. This information is then used to plan and deliver a review lesson focusing on the students' specific needs, based on the results of the students' work. This strategy was compared with a class where the teacher planned the activities without having access to such feedback. The results show an increase in learning for lower-level students when they can work at their own pace and are assisted by a teacher who focuses their lessons on the students' specific weaknesses.

2.2. Introduction

One of the most complex elements to master when learning how to write in Spanish is spelling. In order to address this issue, a specific teaching approach is required (Sotomayor, Molina, Bedwell, & Hernández, 2013). However, a significant percentage of teachers instead choose to focus their efforts on reading (Medina, Valdivia, & Gaete, 2012). A study carried out by Atorresi (2010) regarding writing skills in Latin American countries shows that, on average, 3rd grade students make 0.2 lexical errors in a written text of between 1 and 10 words. More errors are made when students have a smaller vocabulary, related to a lack of exposure to writing exercises. In the case of the United States, around 54% of 8th grade students make spelling mistakes which, in some cases, can hinder the reader's comprehension of the text (National Center for Education Statistics, 2012).

Feedback can be seen as a tool to empower self-regulated learning (Nicol & Macfarlane-Dick, 2007). However, there is no consensus as to which is the most effective way of delivering such learning (Shute, 2008). In some cases, detailed feedback can be appropriate (Timmers et al., 2013), while in others it is unclear as to whether or not this has an effect on learning (Goodman et al., 2004; Wiliam, 2011). Considering that feedback is an inherent catalyst in all self-regulated activities (e.g. an interactive system) (Butler & Winne, 1995), it is essential to adequately link the tool's feedback with the formative role of the teacher.

An educational practice is considered to be formative when evidence of a student's achievements is interpreted and used by teachers, learners, or their peers to make a decision regarding the next step in the teaching process (Black & Wiliam, 2009). Formative assessment is the set of activities used to help students learn (K. H. Wang, Wang, Wang, & Huang, 2006). More than being an instrument, formative assessment is a process which gives a qualitative insight into the student's understanding (R. E. Bennett, 2011).

According to Black & William, there is evidence to suggest that learning gains made in the classroom using formative assessment can be significant; in some cases up to a full standard deviation increase on the students' original level (as cited in Phelan, Choi, Vendlinski, Baker, & Herman, 2011). A report by Carnegie Corporation on teaching spelling shows that two characteristics of formative assessment have a positive impact on learning: teacher feedback on the level of development of a particular writing skill and monitoring student progress (Graham, Harris, & Hebert, 2011). While these are indeed key stages, there is little evidence to show how capable teachers are of adapting their teaching based on an assessment of the students' comprehension and progress at a given moment in time (Heritage, Kim, Vendlinski, & Herman, 2009). This could be due partly to the fact that the majority of teaching approaches which use technology do not make the teacher's role clear, especially when this role differs from being in front of the class (Urhahne et al., 2010).

Interaction is one attribute of the learning environment which enhances the quality of the educational materials and can facilitate learning (Domagk, Schwartz, & Plass, 2010). An interactive learning system allows the student to be involved in significant learning activities (Sabry & Barker, 2009), by reacting to their actions, either individually or in a group, with different levels of application and comprehension of the concepts and processes (Beauchamp & Kennewell, 2010). In line with what has been expressed in constructivism, interaction allows for learning by prompting a cognitive process through a visible exchange between the student and the learning environment (Atkinson & Renkl, 2007).

Self-paced learning is a strategy which is usually assisted by technology and allows students to work at their own pace and receive immediate feedback on their performance (Sheard & Chambers, 2011). In general, and according to Tatum & Lenel (2012), a self-paced learning system is composed of small instructional units, established criteria which indicate when a unit has successfully been completed, frequent testing of the content, immediate feedback on performance, written material to meet the learning objectives, as well as classes and guided discussions to enrich the process.

In this study we consider the value of using formative assessment as a tool for teachers so as to integrate their teaching tasks with an interactive, self-paced learning system. More specifically, our research question is “what is the impact on learning when a teacher uses objective information about student knowledge to teach a review lesson on spelling?”

2.3. Instruments used

In order to answer our research question, a piece of software was developed to teach spelling rules in Spanish using the curricular contents established by the Chilean Ministry of Education for 1st to 6th grade (MINEDUC, 2012). The topics covered are shown in Table A.1 in the appendix A.

Each of the 41 aforementioned topics was incorporated as a separate level on the software, following the same sequence as they are introduced to students during their primary education. The number of exercises to be completed by a student at each level depends on how well they master the relevant skill, progressing to the next level if they successfully complete 10 exercises from a total of 15, without making any mistakes in the last five exercises, as suggested in Alcoholado et al., (2012).

A session begins with the student identifying themselves. The software includes a system which saves the student's progress from the previous session. This allows the student to pick up from where they left off, thus working at their own pace and according to their own needs.

Depending on the topic being covered, the questions can be delivered in audio or as a text. Table A.1 in appendix A shows the question format for each topic. Once the instructions have been given, a student can then answer the question by typing in or selecting a response depending on the type of exercise. The exercises can be written (Figure 2.1, left), or multiple choice (Figure 2.1, right), where the student must choose the correct answer from the 2 or 3 options that are presented. The type of exercise to be completed is determined by the topic that is being covered, as indicated in Table A.1 in the appendix A.

Figure 2.1 Screenshots taken from the software for written (left) and multiple choice exercises (right).

The software's display is composed of 3 sections (Figure 2.2):

- Question section (area 1): Space where the exercise appears, or left blank if it is an audio question. Clicking on the speaker icon (Figure 2.2, area 5) plays an audio file with the instructions for the question.
- Answer section (area 2): Space where the student types in or selects their answer. The circle is used to submit the answer and is blocked off when the audio file is being played (area 4) so as to avoid the student answering without listening to the whole exercise.
- Feedback section (area 3): A progress bar where each block represents the status of the exercise. The system shows exercises which have not yet been completed in grey, with green for exercises completed correctly at the first attempt, yellow for exercises completed correctly at the second attempt and red for exercises that were not completed correctly.

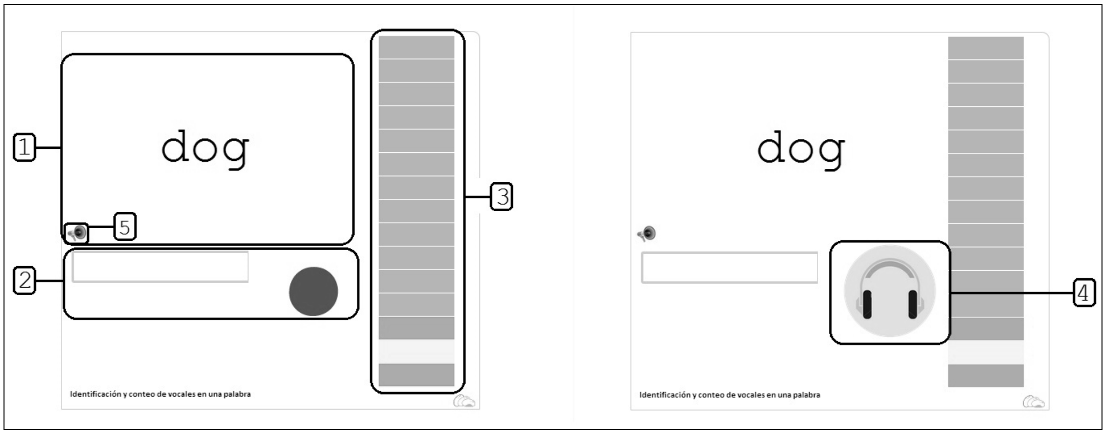


Figure 2.2 Software display screen

Figure 2.3 shows the system's response when a student completes an exercise correctly (Figure 2.3, left) and incorrectly (Figure 2.3, middle). The final icon (Figure 2.3, right) appears when a student has successfully completed all of the exercises for a given level and thus met the curricular objective.

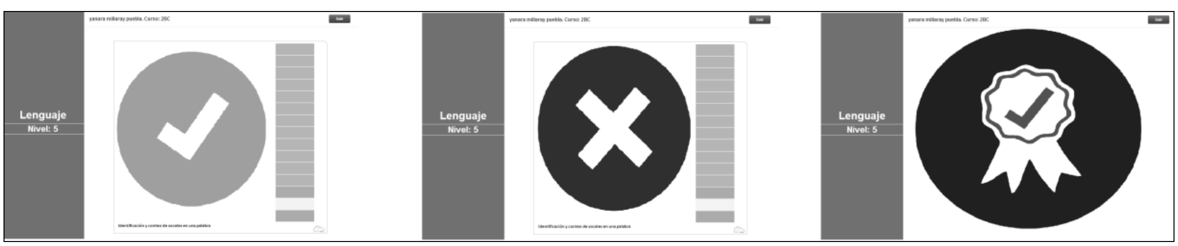


Figure 2.3 Software display screen for correct answers (left), incorrect answers (middle) and level completed (right)

At the end of the activity, the software sends the teacher a progress report on the work carried out by students. This report shows the level reached by each student by the end of the session and the answers which they gave (both correct and incorrect). Furthermore, for each question that was answered the report shows how many students answered that question, detailing whether it was answered correctly or incorrectly and expressed as both a number and percentage. Table 2.1 gives an example of the report, showing the question's ID number, the text displayed by the software for that question, the instructions given to the students for each question, the number of students that answered the question incorrectly, the total number of students that answered the question, and the percentage of incorrect answers for that question.

Table 2.1 Example of report generated by the software

ID	Text	Instructions	Students who answered incorrectly	Total number of students who answered	Percentage of incorrect answers
494	Friends	How many consonants are there in the following word?	12	13	92.30
588	Snails feed on lovely *leaves*	Choose the correct part of speech for the highlighted word.	12	13	92.30
744	Opo__um	Choose the correct way of spelling the word.	12	13	92.30
530	pet	How many consonants are there in the following word?	11	12	91.66

Figure 2.4 shows a summary of the report sent to the teacher. On the left-hand side of Figure 2.4, there is a graph to show the level reached by each student at the end of the session, demonstrating how the software allows students to work at their own pace. On the right-hand side of Figure 2.4, there is a graph which shows the percentage of errors in the answers given by the students, broken down by level. This summary is then used by the teacher to plan review sessions as it shows each student's progress and the areas where most mistakes are made.

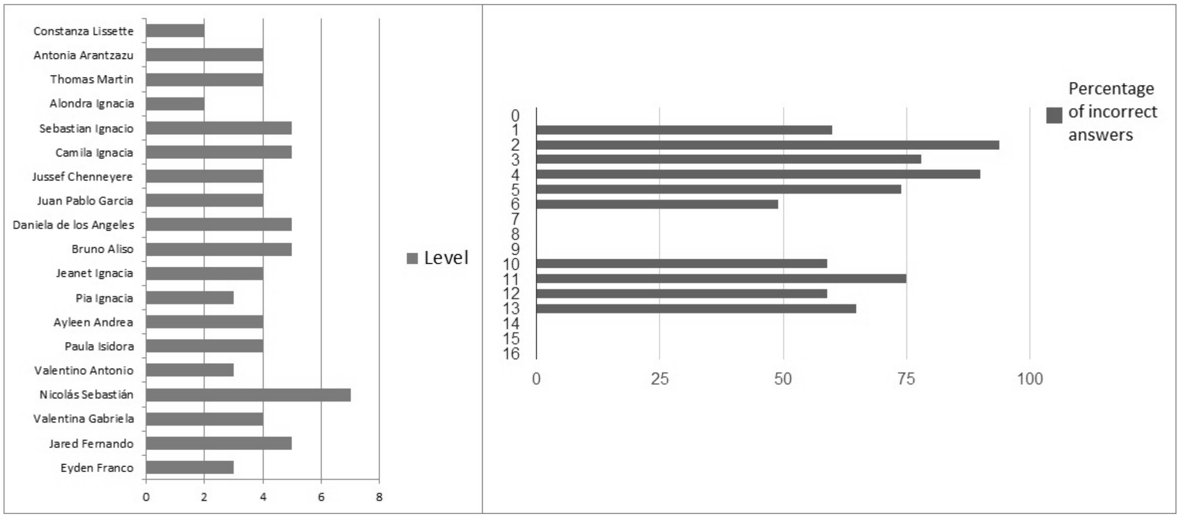


Figure 2.4 Summary of the report generated by the software

2.4. Methodology

To investigate how a teacher using objective information on the work carried out by students during the drill and practice process impacts learning, a study was conducted in a government-subsidized school in Santiago, Chile, with 2nd grade students aged between 8 and 9 practicing spelling. The teacher had lessons scheduled in the timetable to review reading and writing, with the final 6 writing lessons of the year dedicated to this study. The children were divided into two groups: an experimental group and a control group. In the experimental group, 18 students (8 girls and 10 boys) attended the sessions using the software, as well as the pre- and post-tests. In the control group, this number was 27 (22 girls and 5 boys). There was a significant decrease in attendance towards the end of the study as this coincided with the end of the school year.

It is worth noting that this is a quasi-experimental design, as work was only done with a single class from a school that was not randomly selected and therefore is not necessarily representative of the wider population.

6 experimental sessions, each of 20 minutes' duration, were carried out over a five-week period. Both groups had 3 sessions in the computer lab, each of which was followed by a review session in the classroom. The sessions in the computer lab featured interactive work where the students completed spelling exercises using a tablet and the software described in the previous section, as can be seen in Figure 2.5.

Figure 2.5 Student using the software

The only difference between the control group and the experimental group was in the review session that was conducted in the classroom following each lab session, as shown in Figure 2.6. The control group had a general review of second grade content, split across the 3 classroom sessions. The experimental group, on the other hand, had a review which was based on the progress report generated for each child after each session in the computer lab, Figure 2.6. In both cases, the review lessons were taught by the researcher, who acted as the teacher throughout the study with direct support from the classroom teacher.

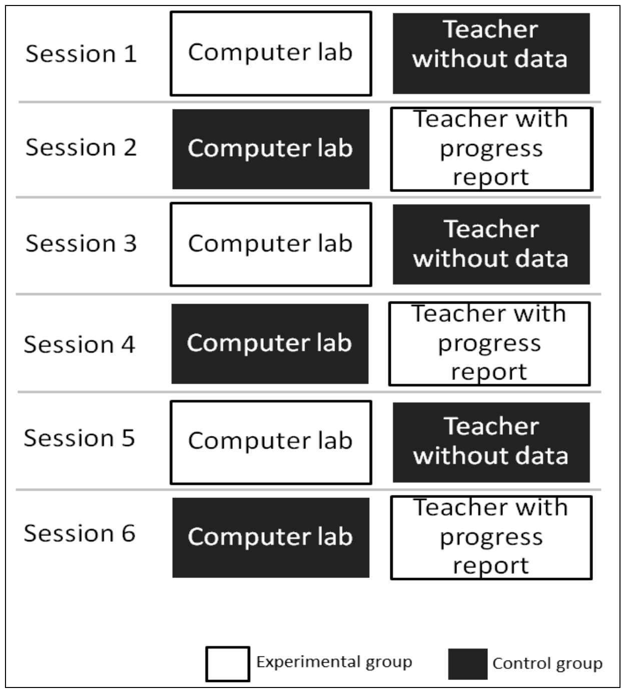


Figure 2.6 Distribution of students between experimental group and control group, as well as the activities carried out

A diagnostic test was conducted with the aim of measuring the students' level of knowledge in spelling before and after the activity. This test consisted of 36 exercises, spread evenly between the two types of exercise included in Table A.1 in appendix A. Cronbach's Alpha was 0.7525 for the pre-test and 0.7962 for the post-test.

2.5. Results

The results were taken from the information provided by the pre- and post-tests, as well as the data taken from the software after each lab session regarding the students' progress. Table 2.2 shows the descriptive statistics for both tests and for both the control group and experimental group.

Table 2.2 Descriptive statistics for pre- and post-test for both control and experimental groups

	CONTROL GROUP			EXPERIMENTAL GROUP		
	Pre-test total	**Post-test total**	**Difference between pre- and post-test**	**Pre-test total**	**Post-test total**	**Difference between pre- and post-test**
N	27			18		
Median	25.93	28.63	2.7	27.56	30.61	3.06
Std. Dev.	4.632	5.644	5.090	5.338	4.146	3.654
Range	17	23	19	19	13	14
Minimum	20	19	-4	19	24	-6
Maximum	37	42	15	38	37	8

Table 2-3 shows an analysis of variance (ANOVA) for the difference between the pre- and post-test results for both groups. This shows the near-significant increases in learning for both groups.

Table 2.3 ANOVA for the difference between pre- and post-test

	d.f.	F	Sig.
Control group	1	3.927	0.053
Experimental group	1	3.676	0.064

However, the ANOVA for the difference in results between the experimental group and control group (Table 2.4) reveals that there is no evidence to suggest that the difference between the two groups is significant.

Table 2.4 ANOVA for the pre- and post-test difference between the experimental and control groups

	Sum of squares	d.f.	Root mean square	F	Sig.
Intergroup difference between pre- and post-test	1.337	1	1.337	0.064	0.802

To analyze this result in greater depth, Table 2.5 shows the ANOVA for the difference between pre- and post-test results broken down into quintiles of students for the experimental and control groups. The first quintile corresponds to the students with the smallest difference between pre- and post-test scores, while the fifth quintile corresponds to the students with the greatest difference. Here it can be seen that the difference is significant in the final two quintiles, suggesting that the students from the two quintiles which learnt the most, learned significantly more in the experimental group than in the control group.

Table 2.5 ANOVA for the difference between pre- and post-test, by quintiles of students un the experimental and control groups

Quintile	Sum of the squares	Root mean square	F	Sig.
1	0.4091	0.4091	1.385	0.36
2	0.5	0,5	3	0.333
3	6	3	0	1
4	0.6944	0.6944	25	0.03777
5	56.25	56.25	225	0.00442

Table 2.6 shows the Pearson correlation between the pre-test and the pre-post difference, and between the post-test and the pre-post difference. A significant, negative correlation can be observed for the experimental group for the pre-test and pre-post difference. This suggests that the students from the experimental group with the lower pre-test scores managed a greater difference between pre- and post-test scores. Therefore, the greatest increase in learning within the experimental group was achieved by students who started with a lower level of knowledge.

Table 2.6 Pearson’s correlation between pre-test score and pre-post difference.

	Pre-test and pre-post difference		Post-test and pre-post difference	
	Control group	**Experimental group**	**Control group**	**Experimental group**
Pearson’s correlation	-0.329	-0.632	0.632	0.068
Significance	0.094	0.005	0.0001	0.790

Furthermore, there is a positive correlation between the post-test and the pre-post difference in the control group that is not present in the experimental group. This suggests that the students from the control group who performed better on the post-test managed a greater increase in learning by the end of the study. Therefore, students in the control group with a higher level of knowledge of the topics covered in the study benefited more from the traditional review method.

Finally, Table 2.7 shows a positive correlation between the number of levels advanced and the post-test score for both groups. This means that in both the experimental and the control group, the students who advanced the most on the software achieved a better score on the post-test. This suggests that the software developed for this study allowed the students who advanced the most to work on skills that come later in the curriculum (Table A.1), something which is reflected in a better level of performance on the post-test.

Table 2.7 Correlation between post-test score and number of levels advanced for both groups.

	Control group	Experimental group
Pearson's correlation	0.510	0.534
Significance	0.007	0.022

2.6. Discussion

In Kolb & Kolb (2005), they suggest that in order to enhance student learning, feedback must be provided. Similarly, our results show that facilitating individual work, while carrying out group review sessions that focus on the class' most common mistakes, benefits lower-level students (Table 2.6). This also allows other students to continue making progress in their own learning (Table 2.7).

In the case of traditional review, higher-level students make more progress in their learning (Table 2.6). This could be explained by the fact that these students have the ability to learn in the traditional classroom setting, something which is not the case for their lower-performing peers.

By allowing each student to work at their own pace, a gap emerged in the topics covered by the students, reflected in the different number of levels worked on by each student. For example, in the final session the most advanced student reached level 20, while the student who had made least progress only reached level 4. This corresponds to a whole school year of difference, a difference which cannot be managed adequately in a traditional classroom in which the teacher must follow a previously-established scope and sequence.

Both during the lab sessions as well as the review sessions, the students showed signs of tiredness and lack of concentration after 20 minutes. It was therefore decided not to conduct longer sessions. Before the 20 minute limit, only minimal disruption was experienced and there were even signs of spontaneous collaboration between students.

With regards to logistics, the set up for each session was done by the researchers in charge of the study. However, this could have been done by the teacher as the software is accessible online, without requiring any further configuration. While it was not done for this study, it is possible to automate the process of analyzing the activity log for each session and therefore facilitate the teacher's role.

2.7. Conclusions

In this study we asked the research question "what is the impact on learning when a teacher uses objective information about student knowledge to teach a review lesson on spelling?" The results show that having students work at their own pace, assisted by a teacher who focuses on the students' specific weaknesses leads to improved learning for lower-level students.

Considering that spontaneous collaboration between peers was observed during this study, it remains as future work to repeat this intervention using a collaborative format. The objective of this would be to study the impact of working collaboratively on learning how to spell, and compare it with the learning that was achieved by working individually. Furthermore, it is necessary to repeat this investigation across a whole school year and apply it to other areas of the curriculum so as to analyze whether focused review allows progress in learning relating to other subjects and whether the impact of focused review is greater over a more prolonged period.

3. SELF-PACED LEARNING AND FORMATIVE ASSESSMENT FOR TEACHING SPELING

3.1. Abstract

Self-paced learning is an instructional strategy that takes into account the pace at which students learn. It is usually considered a stand-alone strategy. When used with technology, it also allows student progress to be monitored. Self-paced learning can therefore support formative assessment as it provides evidence of the students' achievements, allowing the teacher to adjust their instruction in response. The objective of this exploratory study is to determine the value of a self-paced learning and formative assessment strategy for teaching spelling in Spanish to native speakers in primary school. A strategy is proposed, in which technology-based, self-paced learning sessions are interspersed with targeted review sessions. Before starting the intervention, a placement test is used to determine the students' starting level for the self-paced work, in line with their academic needs. During the review sessions, the teacher uses a report generated at the end of each session with the software; the report details the topics covered by the students and the difficulties they encountered. Significant learning is achieved when students receive feedback that caters to their specific academic needs and when they can work at their own pace, taking into account their prior knowledge from the beginning of the activity.

3.2. Introduction

Self-paced learning is an instructional strategy that takes into account the pace at which students learn. It features frequent testing and provides immediate feedback (Tatum &

Lenel, 2012). It is usually considered a stand-alone strategy, where the learner has complete control of the learning process and thus the teacher plays a minimal role, or no role at all (Lakshmisri & Nirmal, 2012). When using this strategy students work through short units, each with its own mastery criteria. Technology can increase the effect on learning enjoyed by self-paced learning, by allowing student progress to be monitored and controlling the time spent on each exercise (Tullis & Benjamin, 2011). It is important to note that, when working with educational software, motivation and engagement are negatively affected if the students' starting level is not in line with their level of ability (Azadegan et al., 2014). Self-paced learning is currently used by massive open online courses (MOOCs) (Chang, Hung, & Lin, 2015) and flipped classrooms (Virginia, Franqueira, & Tunnicliffe, 2015).

Self-paced learning systems can help with the implementation of formative assessment. An educational practice is considered to be formative when evidence of a student's achievement is interpreted and used by teachers, learners, or their peers to make a decision regarding the next step in the teaching process (Black & Wiliam, 2009). Some aspects of formative assessment can be supported by technology. For example, the creation of moments of contingency, which guide the flow of instruction according to students' response, and thus cannot be pre-determined (Pachler, Daly, Mor, & Mellar, 2010). This individualized work can be achieved using self-paced learning, allowing students to work at their own pace and receive immediate feedback on their performance (Sheard & Chambers, 2014).

Different studies have shown that using software with self-paced learning and formative assessment leads to gains in learning. For example, when teaching social studies, Chen and Huang (2012) showed that a system that is capable of constantly assessing the students and providing them with suitably challenging material increases their level of motivation and the effectiveness of the learning. Tempelaar, Heck, Cuypers, van der Kooij, and van de Vrie (2013) observed that providing students with information on their performance by using a test-directed learning environment, together with whole-group, lecture-style classes, benefits students who reach the highest levels on their platform when studying mathematics and statistics. Yang, Chuang, Li, and Tseng (2013) proposed a model with a Learning Management System and regular tests to provide personalized instruction, showing that both components boosted critical thinking skills. Gitsaki and Robby (2015) used a self-paced, web-based software to teach mathematics to a remedial class. The authors found that small, independent mastery units help build student's skills and self-efficacy, as well as closing the gap between struggling and advanced students.

It is worth noting that the focus of the aforementioned systems is on providing the students with information of their performance. In addition to this, both Black and Wiliam (2009) and Shute and Kim (2014) suggest that a system supporting formative assessment should also take the role of the teacher into account. By doing so, it should help them to gather information on their students, make sense of this information and adjust their teaching accordingly.

Learning the rules of spelling for any given language is essential for overall literacy development (Hutcheon, Campbell, & Stewart, 2012). Nevertheless, 250 million children are not learning basic literacy skills (Schweisfurth, 2015). Given this, teaching spelling in the first years of school becomes increasingly important.

Improvements in learning have been reported when teaching spelling using formative assessment (Graham et al., 2011; Horstmanshof & Brownie, 2013; Little & Akin-Little, 2014). Two characteristics of formative assessment have a positive impact on instruction: teacher feedback on the level of development of a particular writing skill and monitoring student progress (Graham et al., 2011). These act as the reviewing phase of the writing process, providing an opportunity for students to understand and apply criteria regarding the quality of a text to their own work (Lipnevich et al., 2013). For teachers, using formative assessment for writing instruction allows them to focus on the student's current level, facilitating progress in content and language learning while using their preferred teaching strategy (Bailey & Heritage, 2014).

From the literature review, the following hypothesis arises: When teaching spelling, a formative assessment strategy with self-paced learning that considers the students' starting level significantly improves learning among the students that are targeted by the teacher's feedback. Therefore, the research question guiding this study is the following: "To improve spelling among native Spanish speakers in primary school, how can a formative assessment strategy with self-paced learning be implemented?".

3.3. Material and methods

To answer our research question, a formative assessment and self-paced learning strategy was developed to teach spelling in Spanish to native speakers in primary school.

A piece of software was designed to support the self-paced learning with formative assessment strategy. As mentioned in the introduction, the software starting level should be on line with the student level of ability. Better results have been obtained when using a placement test to determine which level the students should start from (Buckingham, Beaman-Wheldall, Wheldall, & Yates, 2014). For these reasons, the pre-test (see next section) was used to determine each student's starting level on the software. As well as the software, this strategy included review sessions conducted by a teacher following the self-paced work.

An exploratory study was conducted with second grade students from a state-subsidized school in Santiago, Chile. This type of school was chosen as they boast the highest enrolment figures in the country (MINEDUC, 2015). The participating school and classes were chosen randomly.

3.3.1. Assessment instruments

In order to answer the research question, improvements had to be measured in spelling. Therefore, the variables of interest for this study were the student's initial level of knowledge, their final level of knowledge and the difference between the two.

A written tests was produced in order to gather data for these variables. The test consisted of 48 questions, with a Cronbach's alpha of 0.874. All of the questions only required short responses and were answered individually by the students (without the teacher's help). The students had 45 minutes to complete the test. The instrument was used as both a pre- and post-test.

To ensure the content validity of the test, each of the questions was related to a topic from the Chilean Ministry of Education's curriculum for spelling, from 1st to 6th grade (MINEDUC, 2012), detailed in Appendix A. Its contents were also validated by Language Arts experts. Before its application, the test was piloted with 30 second grade students from a school that did not participate in this study.

3.3.2. Software used

Our methodology features the use of a Tablet-based application that allows self-paced learning, Figure 3.1. It should be noted that while Figure 3.1 is in English to aid comprehension for the reader, the software used was in Spanish.

Once an instruction is given either by audio or text, the student answers the question by typing in or selecting a response, depending on the type of exercise. Both the type of input and output is determined by the topic being covered.

The design of the display includes the following areas:

- Question section (area 1): Space where the exercise appears, or is left blank if it is an audio question. Clicking on the speaker icon plays an audio file with the corresponding instructions.
- Answer section (area 2): Space where the student types in or selects their answer. When selecting their answers (such as in Figure 3.1), the alternatives appear in a different order with every attempt. The circle is used to submit the answer and is blocked off when the audio file is being played. This is done so as to avoid the student answering without listening to the whole exercise.
- Feedback section (area 3): A progress bar where each block represents the status of the exercise. The system shows exercises which have not yet been completed in grey, with green for exercises completed correctly at the first attempt, yellow for exercises completed correctly at the second attempt and red for exercises that were not completed correctly.
- Topic (area 4): The bottom of the screen shows which topic is being covered. This is a guide for the teachers to see what the students are working on.

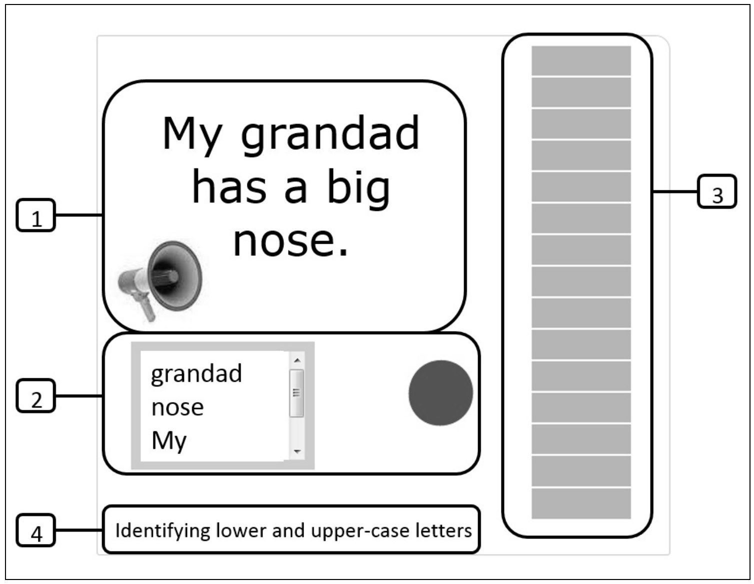


Figure 3.1 Software display design

The topics covered by the software were taken from the Chilean Ministry of Education's program for primary school Spanish Language Arts (MINEDUC, 2012). Each topic is a different level in the software, with each level containing between 50 and 100 different exercises. In order to advance to the next level, the student must have successfully completed at least 10 of the previous 15 exercises. Students' progress is saved after each session, so that they can advance through the software at their own pace.

Table 3.1 shows spelling principles so as to improve learning and transfer of knowledge and how these were applied on the software. The software allows for personalized instruction, featuring the elements of self-paced learning suggested by Tatum and Lenel (2012). Furthermore, the software also adopts the teaching principles described by Merrill (2002) and techniques for lowering the cognitive load suggested by De Jong (2010) in order to enhance learning. These principles and techniques are complemented by ideas on how to present information in order to minimize distractions (Fisher, Godwin, & Seltman, 2014) and maximize motivation (Sandberg, Maris, & Hoogendoorn, 2014). The concepts described by Karemaker, Pitchford, and O'Malley (2008) were taken as a guide.

Table 3.1 Design logic of the self-paced software

Principle (reference)	**Inclusion in the software**
Elements for self-paced learning: frequent testing (Tatum & Lenel, 2012).	Each software session tests the student's mastery of the topic through multiple-choice and short answer questions.
Elements for self-paced learning: immediate feedback on test results (Tatum & Lenel, 2012).	The system lets the student know if their answer is correct or incorrect as soon as they have answered a question.
Learning is facilitated when the student can apply the newly acquired knowledge (Merrill, 2002).	The software presents a set of exercises that are completed using self-paced learning. The student cannot advance to the next level until they have mastered the current level (Alcoholado et al., 2012).
Elements for self-paced learning: small instructional units (Tatum & Lenel, 2012).	The curricular content to be covered is presented atomically, i.e., each topic can be studied independently.
Learning can be boosted by lowering the intrinsic cognitive load (De Jong, 2010).	The topics are introduced in order of difficulty (easiest to most difficult).
Learning can be boosted by lowering the extraneous cognitive load (De Jong, 2010).	In the software, the exercises and feedback are displayed on the same screen, minimizing the split-attention effect (De Jong, 2010). Visual resources (the text in the exercises) and sound (instructions, feedback) are used simultaneously, in line with the modality principle (De Jong, 2010).

Principle (reference)	Inclusion in the software
To keep students motivated over a long period of time, the contents must adapt to the level of knowledge and skills being developed by the student (Sandberg et al., 2014). Elements for self-paced learning: mastery of units to an established criterion (Tatum & Lenel, 2012).	The platform is based on pedagogical rules to determine when the student should advance to the next level.
Visual distractions affect the students' attention during teaching (Fisher et al., 2014).	The activities contained in the software display only the necessary elements (Figure 3.1).
"Children's word recognition, fluency and comprehension have been shown to improve more when a small set of words are repeated within sentences and passages of text than when sentences and passages contain mainly different words" (Karemaker et al., 2008, p. 33).	The software presents the exercises in sentences of between 8 and 10 words. The same word is used in different exercises.

3.3.3. Formative assessment strategy

The element of formative assessment considered in the proposed strategy is provided by the targeted review sessions. These are based on a report of the students' performance of the self-paced sessions. At the end of these sessions, the software provides a report with the topics that the students struggled with the most. This report is given to the teacher so that they can prepare and deliver a review class focusing on the students' main areas of weakness. As each review session is based on the topics that caused most problems, they must be taught before the following technology session. By doing so, the students work on these unsettled topics before continuing to work on their own. The technology therefore meets the demands of a heterogeneous classroom by allowing the students to work individually and advising the teacher on the difficulties faced by each student (Tomlinson, 2014).

An example of the report can be found in Table B.1 and Figures B.1 and B.2 (Appendix B). The report of Table B.1, shows which questions were answered incorrectly by the majority of students, as well as their respective (incorrect) answers. Furthermore, the report indicates each individual student's progress by showing the level they have reached on the software (Figure B.1) and the percentage of incorrect answers they gave by level (Figure B.2).

The differentiating element of this methodology with regards to those described in the introduction is the fact that the review session is conducted in person and led by the teacher. The teacher acts as a mediator during the reflection and discussion that is prompted during the review session. As the teacher knows the students' previous level of knowledge, the teacher can guide the process of integrating the next subject with the topics that the system considers have been mastered the least. In doing so, the teacher follows Merrill's (2002) suggestion that learning is facilitated when the student integrates new knowledge into their prior knowledge.

The format of the review session is defined by following the proposal by Proske, Roscoe, and McNamara (2014). In their study, the authors suggest that practice based on models (i.e., studying correct examples) and on completing exercises has a positive impact on the students' ability to transfer the acquired knowledge. In our proposal, in the review session the teacher models how to deal with the new content. In order to do so, they teach a lecture-style class, showing the students how to solve exercises that are similar to those covered during the sessions using technology. Furthermore, the teacher provides new exercises so that the students can practice during the class. These exercises are focused on the topics that the students master the least when using the software.

3.4. Procedure

3.4.1. Context

The participating school had obtained above-average scores on the national standardized test for Language Arts, when compared with similar establishments. However, according to statistics from the Chilean Ministry of Education, almost 75% of the students at this school are at risk of dropping out of school.

3.4.2. Experimental design

The intervention was designed according to the framework proposed by Antoniou and James (2014) to analyze formative assessment methodologies. It comprises the following steps:

- Elicitation and collection of information: In terms of gathering evidence on student learning, which is normally difficult to do in the classroom, the self-paced learning system that was implemented in this study automatically records the level achieved by the students, as well as the difficulties they experienced at each level.

- Interpretation of information/judgement: This refers to how the teacher interprets the information that is gathered. The strategy proposed in this study includes providing the teacher with a report generated by the software, so that they can properly determine what the students most need to review.
- Regulation of learning: This refers to the decisions made and actions taken by the teacher in order to adapt the teaching-learning process. In the proposed strategy, this takes place in the review sessions that follow the work with the software.

When planning and teaching a class, the teacher must take into account that the students within the classroom will be at different levels in terms of their academic formation (Tomlinson, 2015). One of the obstacles teachers face when teaching writing skills relates to the lack of opportunities to differentiate the work based on the students’ level of academic development (Harward et al., 2014). The strategy proposed in this study explicitly considers opportunities for review based on the student’s specific needs, according to their level of skill development. The students were divided into two halves, based on their performance on the pre-test (higher and lower performers). Given that each group was (relatively) homogenous, the most common mistakes that were made by students when using the software were representative of the majority of students within the group. As students within a group had similar needs, the teacher could therefore focus their efforts more effectively during the review sessions.

Care must be taken when using differentiated instruction, as the quality of the materials and of the teaching itself must be the same for every group of students (Maloch & Worthy, 2013). To ensure this, in the strategy proposed in this study, the same teacher delivers the review session to all of the students in the class. Furthermore, the format of the sessions is the same for both groups of students; it is only the content that changes, in response to the report generated by the software.

The students worked with their classroom teacher for a total of 8 sessions, split between the software and review sessions, plus 2 additional sessions to administer the pre- and post-test. The students alternated between sessions using the software and review sessions, with a total of 4 sessions of each. The sessions using the software and the review sessions lasted 20 minutes each, while the pre- and post-test lasted 45 minutes.

3.4.3. Participants

Eighty-three second grade students participated in this study, as well as their Language Arts teachers. The study lasted for 4 weeks. The students were divided into two groups, according to their performance on the pre-test. The higher-performing group featured 42 students (15 boys and 27 girls), while the lower-performing group featured 41 students (26 boys and 15 girls). The groups comprised students from different classes, so as to control for the effect of the teacher on the students' performance (Sanders & Rivers, 1996).

3.4.4. Data analysis plan

As the groups were chosen based on their prior knowledge, and not randomly, the two groups were not equivalent. Given this, the following statistics were used to analyze the data:

- Descriptive statistics for the results from the pre- and post-test.
- Levene's test and a t-test: To confirm that both groups were indeed different; an ANOVA was therefore not possible.
- T-test within each group: To study the difference between the average scores on the pre- and post-test.
- Cohen's d for the difference in the results between the pre- and post-test for each group: To calculate the effect size

3.5. Results

Table 3.2 shows the descriptive statistics for the intervention. For the results on the pre-test, the variance in scores is similar for the higher-performing and lower-performing groups, $F = 0.011$, $p = .915$. However, the average scores are significantly different, $T(80.53) = 10.878$, $p < .001$. The groups are therefore not comparable, which is an outcome of the experimental design as the groups were not chosen at random.

The difference between the pre- and post-test scores is statistically significant for the higher-performing group, $T(41) = 5.953$, $p < .001$, Cohen's $d = 0.870$, as well as the lower-performing group, $T(40) = 5.302$, $p < .001$, Cohen's $d = 0.895$.

Table 3.2 Descriptive statistics for the higher-performing and lower-performing students

	Higher-performing group			Lower-performing group		
	Pre-test total	**Post-test total**	**Pre-/Post-difference**	**Pre-test total**	**Post-test total**	**Pre-/Post-difference**
N		42			41	
Mean	68.69	75.04	6.71	44.76	53.05	8.29
Std. Dev.	9.76	9.30	7.31	10.28	14.39	10.02
Minimum	50	51	-9	11	14	-18
Maximum	92	91	20	60	75	27

Table 3.3 compares the different topics that were reviewed by the two groups of students. Each number corresponds to a different topic, as detailed in Appendix A. Topics number 15, 16, 18, 20, 21, 22, 25 and 26 were only reviewed by the higher-performing group (highlighted in bold in Table 3.3). The higher-performing group reviewed twice as many different topics as the lower-performing group; the review sessions with the lower-performing group focused on fewer topics.

Table 3.3 Topics reviewed by higher-performing group and lower-performing group

Session	**Topics reviewed by the higher-performing group**	**Topics reviewed by the lower-performing group**
1	5-6-7-8-10-11-14**-15-25-26**	5-6-7-8-10-11
2	10-14-**16-**17-**26**	10-14
3	10-**12**-14-17-**18-20-21-26**	10-11-14
4	10-14-**16**-17-18-**21-22**-24-**25-26**	14-17-24
Total	33 topics (18 different topics)	14 topics (9 different topics)

3.6. Discussion, limitations and future work

This study revealed significant learning gains and a large effect size for both groups of students (higher performers and lower performers). The experimental design included individual work, using the self-paced software starting from a specific level based on each student's pre-test score, as well as review sessions targeting the needs of each group, as defined by the results of the work using the software. This allowed the students to take full advantage of the sessions using the software, as well as the review sessions.

Our results reveal the importance of personalizing both the interactive drill work, as well as the work with the teacher. On the one hand, the drill work was personalized by having the students start from a level of the software that was in line with their prior knowledge, using the pre-test as a placement test. On the other hand, the review sessions were adapted to meet the students' real needs by taking into account that there are different levels of skill development within a class. This was reflected in targeted review sessions that were different for each group.

The higher-performing students covered twice as many topics in the review sessions as the lower-performing students. This shows the difference in the pace at which students learn within a class, something which is hard to accommodate in a traditional classroom. In fact, the curriculum sequence established by the Chilean Ministry of Education did not satisfy the pedagogical needs of the higher-performing students, nor the lower-performing students. For both groups, some of the topics had to be repeated, while the higher-performing group even reviewed a topic from a higher grade level.

The model presented in this study fulfils the three conditions of effective instruction proposed by Matuk, Linn, and Eylon (2015): (1) keep a record of the students' actions, which is achieved transparently when self-paced learning is supported by the use of technology; (2) providing tools for carrying out formative assessment, which is achieved through the reports generated at the end of the self-paced learning sessions, as well as including a regular and explicit space for talking about the difficulties that were encountered (i.e., the review sessions); and (3) providing room to redesign the pedagogical activities, which is achieved by the teacher when deciding which topics to cover during the review session based on the information in the reports.

The role of the teacher must be clearly defined when working with technology in the classroom (Urhahne et al., 2010). During the review sessions, the teacher uses a report generated by the software at the end of each technology session; the report details the topics covered by the students and the difficulties they encountered. The importance of defining the teacher's role has already been observed by Van Lehn (2011), who suggests that the effect of a technology-assisted, self-paced learning system on learning can be increased when the teacher actively interacts with the students, guiding their reasoning by providing them with feedback and scaffolding.

The limitations of this study have to do with the way in which the students' starting level was determined and the way in which the groups were formed. The teacher's experience of their students' performance levels was not considered, even though they knew their students. This may have improved the personalization of the teaching when making the groups (Tomlinson & Moon, 2013) and thus remains for future work.

Only Tablet PCs were used in this study, as these devices are recommended for teaching early literacy (Neumann & Neumann, 2013). The results of this study therefore need to be validated using other technologies, such as smartphones, which have proven to be effective tools for fostering language learning (P. Lee, 2014).

Another limitation of this study stem from the experimental design. The fact that this study was conducted towards the end of the school year had an impact on the number of sessions that were carried out (10). A study on several schools, different subjects, and during a whole school year should be performed in the future.

3.7. Conclusions

Our research question asked: "To improve spelling among native Spanish speakers in primary school, how can a formative assessment strategy with self-paced learning be implemented?" We showed that interspersing technology-based, self-paced learning sessions (where the students start working from the topics which they most need to cover) with targeted review sessions, statistically improves learning among low-performing and high-performing students. In other words, there was evidence to reject the null hypothesis. We learned that significant learning gains are achieved when students receive feedback that caters to their specific academic needs and when they can work at their own pace, taking into account their prior knowledge of the subject when starting the activity.

However, the literature suggests that separating students into different groups based on their ability (tracking) is not advisable as it perpetuates inequalities by creating differences, and only benefits a privileged few (L. Anderson & Oakes, 2014; Wilkinson & Penney, 2013). Nevertheless, by providing learners with adequate, targeted support (as proposed in this study), designing challenging activities for more advanced students and providing support to a wide range of students, it is possible to manage the heterogeneity present in a classroom (Tomlinson, 2015). The flipped classroom (Bishop & Verleger, 2013; Staker & Horn, 2012; Virginia et al., 2015), which moves away from a lecture-based classroom, leaving the content to pre-class videos and focusing classroom time on targeted activities for the students (Thibaut, Curwood, Carvalho, & Simpson, 2015), provides an opportunity for strategies such as the one presented in this study. More research is needed to show that strategies such as the one described here, where face-to-face sessions are focused on formative assessment and based on information generated by self-paced learning, do not lead to social discrimination from tracking.

4. TOWARDS A REFERENCE IMPLEMENTATION OF SHARED WORKSPACE APPLICATIONS TO SUPPORT MULTI-USER CO-LOCATED INTERACTION IN A CLASSROOM SETTING

4.1. Abstract

In today's workplace, the focus has shifted from individual to cooperative/collaborative tasks. This is particularly relevant in a school setting, where the learning process benefits from the whole class being able to work at the same time. However, the computer systems that are currently present in the classroom are not designed for whole-class interactivity and are not equipped with devices for collaborative or cooperative work. This study presents a Shared Workspace system based on Single Display Groupware architecture, designed to allow up to 36 simultaneous users on a single computer using personal input/output devices and a shared screen. Following a design-based research approach, the implementation of this system highlights the importance of managing the output, as well as the configuration of the hardware, in order to achieve a smooth user experience.

4.2. Introduction

The ubiquitous presence of computers has shifted the focus in the workplace from individual tasks to increased social interactions (Divoli, Potena, Diamantini, & Smari, 2014). Multiple, co-located users can create and explore information simultaneously using a range of devices and displays (Jetter, Zöllner, Gerken, & Reiterer, 2012). However, traditional methods of interaction do not suffice when it comes to working in settings with more than one user at a time. New software and hardware structures are therefore required in order to support mass interaction in an everyday setting (Jagodic, Renambot, Johnson, Leigh, & Deshpande, 2011; Zeng & Zhang, 2014).

Shared Workspaces allow users to share information and therefore facilitate collaborative and cooperative tasks (Whittaker, Geelhoed, & Robinson, 1993). Providing a shared view of a task's status and the interaction between participants allows cooperative/collaborative objectives to be met more effectively (Lim, Ahn, Kang, Suh, & Lee, 2014). Such systems have been implemented using shared screens in a range of settings. Examples of these include systems for learning (Beserra, Nussbaum, Oteo, & Martin, 2014), systems for decision making in logistics (Ploskas, Athanasiadis, Papathanasiou, & Samaras, 2015) and systems for managing natural disasters (Sakuraba, Ishida, Ebara, & Shibata, 2015).

One example of a Shared Workspace is Single Display Groupware (SDG) (Stewart, Bederson, & Druin, 1999), which allows for interaction between synchronous, co-located users by using a shared screen and individual input devices. Previous uses of SDG include social media (Maresh-Fuehrer & Smith, 2016), medical monitoring and diagnosis (Madni, Nayan, Sulaiman, & Tahir, 2015), and group discussions (Verma, 2015).

When carrying out tasks of varying levels of complexity, user performance is improved through the use of SDG with a large display, in comparison to other, smaller displays (Bradel, Endert, Koch, Andrews, & North, 2013). The shared setting provided by SDG through the use of a single screen allows users to view the current status of a task and the interaction between participants. This leads to objectives being met quicker and more efficiently (Lim et al., 2014). Furthermore, SDG provide each user with an individual and familiar input device. This allows the users to quickly learn how to use the system, as well as giving everyone the opportunity to participate (Chung, Lee, & Liu, 2013; Jeong, Ji, Suma, Yu, & Chang, 2015). Additionally, this type of system increases the user's awareness of the other participants' activities within the task itself (Dourish & Bellotti, 1992), something which occurs naturally in synchronous and co-located settings (Gutwin & Greenberg, 2002). This can therefore lead to improved efficiency when dealing with group work (Romero, Mendoza, & Sanchez, 2013).

SDG are especially useful in educational settings as they can be adapted to overcome the barriers that can hinder the introduction of ICT in the classroom (Rodríguez et al., 2012), such as the need to support a whole class (Di Blas, Paolini, & Sabiescu, 2010) and the school's infrastructure cost.

Whole-class, interactive instruction allows for the co-creation of knowledge by all of the students in a classroom. In this sense, the students have to explain and demonstrate their solutions to others, while the teacher acts as a mediator (Caballero et al., 2014; Reynolds & Farrell, 1996). This type of instruction exposes the students not only to the ideas of nearby students, but also to the ideas of the rest of the class. This allows even the less participative students to internalize the content of a lesson (Smetana & Bell, 2013). Furthermore, given their role as mediator, whole-class group work allows the teacher to dedicate more time to the key concepts and difficulties being faced by the students, when compared with small-group work (Stephens & Clement, 2015).

In terms of the infrastructure cost for the school, when using a projector as a shared screen, a single computer and one mouse per student, the cost of SDG can be as low as one dollar per user per year for an entire classroom (Alcoholado, Diaz, Tagle, Nussbaum, & Infante, 2016). SDG has previously been used to support topics such as geometry (Caballero et al., 2014), arithmetic (Beserra, Nussbaum, Zeni, Rodriguez, & Wurman, 2014) and grammar (Rosen, Nussbaum, Alario-Hoyos, Readi, & Hernandez, 2014). However, in the aforementioned examples the system was implemented using only a mouse and therefore the options for interaction were somewhat limited.

Other examples of Shared Workspace systems based on the SDG architecture in a classroom setting are interactive whiteboards (IWB) and interactive tabletops. Even though these technologies have led to improvements in learning, their ability to support whole-class interactivity is limited (Evans & Rick, 2014). For example, IWB can only manage one input device, while interactive tabletops, which can support multiple, concurrent users, are too small for a whole class. Furthermore, the majority of commercially available IWB and interactive tabletops cannot track who the owner of the input device is. This can hinder collaboration as it is not possible to distribute tasks and roles individually.

SDG systems can be used with a range of different input devices, although some of these devices promote cooperation/collaboration between users more than others. For example, individual audio output improves participant awareness of private and shared work (Gutwin, Schneider, Xiao, & Brewster, 2011). On the other hand, physical keyboards are a useful addition to SDG systems as they make it easier to input information (Hwang & Su, 2012). Previous studies have described different implementations of SDG using these devices, such as Zhou, Mori, and Kita (2012) and Calderón, Nussbaum, Carmach, Díaz, and Villalta (2014). However, in each case they can only handle up to 4 users. This is clearly a limitation for settings where there are a greater number of participants (such as in a classroom). This is because in order to promote participation each user must be provided with an individual input device (Chung et al., 2013).

These examples therefore reveal a trade-off between the hardware and the number of users supported by the SDG when it comes to implementing ICT in an educational setting. Given this, our research question asks the following: what software and hardware architecture will allow a Shared Workspace to be implemented using co-located SDG in a classroom setting?

4.3. Methodology

4.3.1. Addressing current research issues in education through Design-Based Research

Design-Based Research is a paradigm for educational inquiry that promotes continuous cycles of exploration in authentic settings to refine our understanding of learning (The Design-Based Research Collective, 2003). Design-Based Research allows for its methods to vary as new needs arise and the focus of the research evolves, thus facilitating in-situ research (F. Wang & Hannafin, 2005). The objective of this study is to define an SDG architecture to support whole-class interaction in a classroom setting. This is achieved through an iterative process, thus allowing for continuous product improvement (Ries, 2011). Given this objective, the Design-Based Research approach was adopted as it was considered to be the most appropriate methodology for this research.

The Integrative Learning Design Framework for Design-Based Research (Bannan-Ritland, 2003) was used as it articulates a series of steps for constructing learning environments that are likely to be used in practice. These steps include informed exploration, enactment, local evaluation and broader evaluation, each of which may be iterated upon in cycles or phases. By doing so, the framework integrates instructional and product design, software engineering and diffusion of innovations, with particular emphasis placed on the lessons learned during each step (Bannan-Ritland, 2007).

This study was conducted in three cycles (Figure 4.1) following the Integrative Learning Design Framework. This process started with an informed exploration (section 4.2) and ended with a broad evaluation of the results (section 4.7). In Cycle 1 (section 4.4), a Shared Workspace system of hardware and software based on SDG architecture was developed and tested using first and second year university students. The purpose of doing so was to determine whether or not the proposed solution could be used in a classroom setting. This system was improved during Cycle 2 (section 4.5), based on the results from Cycle 1. As such, modifications were made to the SDG in Cycle 2 and the improved system was then tested using schoolchildren. The observations from the first two cycles then led to the need for a new experiment. Cycle 3 (section 4.6) was therefore a controlled assessment in order to test the modifications to the proposed system and enhance its performance.

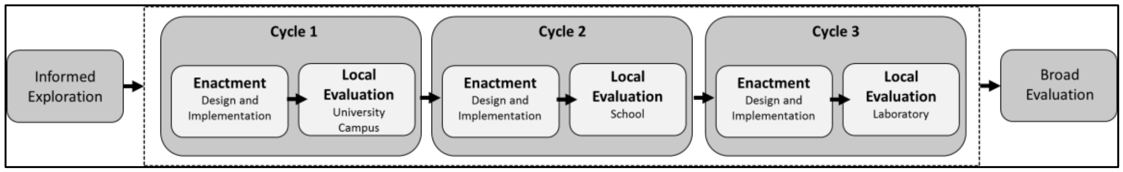


Figure 4.1 Implementation of the ILDF for this study.

4.3.2. The proposed architecture

System architectures are defined based on certain attributes and constraints (Aleti, Buhnova, Grunske, Koziolek, & Meedeniya, 2013). For this study, a Shared Workspace system was developed to allow for whole-class interactivity and cooperative/collaborative work. This system uses input/output devices that are familiar to the students, as well as keeping deployment costs down.

Based on the literature review, it was determined that by following an SDG architecture the characteristics that facilitate cooperative/collaborative work in a Shared Workspace (Lim et al., 2014) could be maintained. This is because SDG provide a shared screen and individual input devices, while simultaneously overcoming the barriers that are inherent in a school setting (Di Blas et al., 2010; Rodríguez et al., 2012). This is made possible by only needing a single computer to work with a whole class.

The proposed architecture works as a Shared Workspace because it provides mechanisms for sharing information and allows the users to view the current status of their classmates' work. In specific terms, the system follows a Single Display Groupware architecture based on software components and centralized hardware. This is because users can see each other's work on a shared screen, while every user has their own input device.

In terms of hardware, the proposed architecture features a single Central Hub and a series of Mobile Hubs (Figure 4.2). The Central Hub is a single computer that acts as a server. This computer houses the application logic for every user, including input/output management. This centralized approach reduces the implementation and maintenance costs of the architecture as there is only one computer that acts as a single entry point to the system (Alcoholado et al., 2016). The Mobile Hubs comprise the different hardware components that are needed to support individual interaction through the Central Hub.

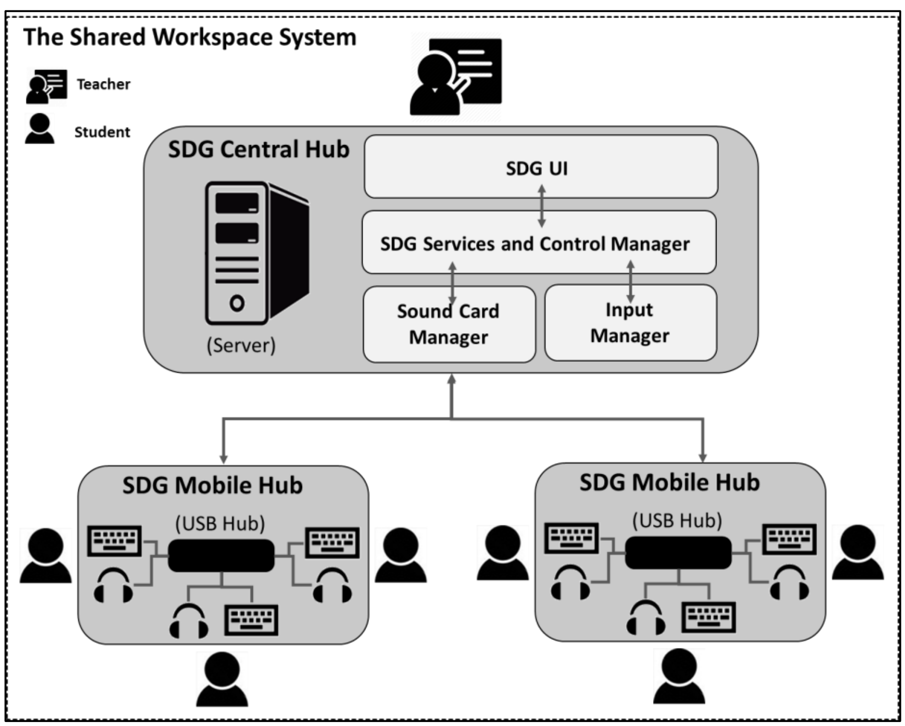


Figure 4.2 The General Architecture for the proposed Shared Workspace System, including supported roles.

Keyboards and headphones were chosen as the devices for the SDG Mobile Hubs in this study. This is because any system that is to be used in a classroom setting must be low-cost and use familiar devices (Starcic, Cotic, & Zajc, 2013). Furthermore, keyboards and headphones are also known to promote cooperative/collaborative work (Duarte, Kim, Kim, & Snow, 2012; Gutwin et al., 2011).

Component-based software-engineering (Crnkovic, 2001) was chosen for the software development as it allows for the design of elements that can be subsequently reused in other applications. The proposed architecture may therefore be used in the future to implement SDG in other domains.

Figure 4.3 shows the software architecture contained in the SDG's Central Hub, which is the only element within the architecture where data is processed. The software comprises the following components:

- Soundcard Manager: This component uses an abstraction to represent the soundcards to which the headphones are connected. This is implemented using the operating system's own audio management interface. Furthermore, it encapsulates the text-to-speech operations by sending an audio file to the corresponding soundcard(s). These audio files are configured by taking into account the appropriate bitrate and buffer size given the hardware that is used.

- Input Manager: The role of this component is to interpret each user's input so that it may be implemented by the application logic. In order to do so, it receives a raw representation of the data from the operating system, which is then translated into characters or coordinates depending on whether the input is from a keyboard, mouse or joystick. Once this is done, the translated input events and an identifier for the device that it came from are made available to the other components. Therefore, the type of input device that is used can be clearly identified by the application.
- SDG Services and Control Manager: This is an extension point for creating different applications based on the proposed system. This component is able to access the abstractions provided by the Input Manager and Soundcard Manager and provides a programming interface that acts as a façade pattern (Gamma, Helm, Johnson, & Vlissides, 1994) for implementing specific hardware. Therefore, the system provides a programming structure that allows for the incorporation of input/output elements into the program's logic, regardless of the type of device that is being used.
- SDG UI: This component provides classes to assist with the development of graphical user interfaces (GUI) on a large shared display. For this study, the UI was extended to provide an individual workspace on the shared screen for each user. Based on the services provided by the SDG Services and Control Manager abstraction layer, the SDG UI graphically represents the individual input controls and directs the personalized output to each user. For the software developed during

this study, the UI component depicted a cursor for each user and any text they entered, as well as sending individual audio feedback to each set of headphones.

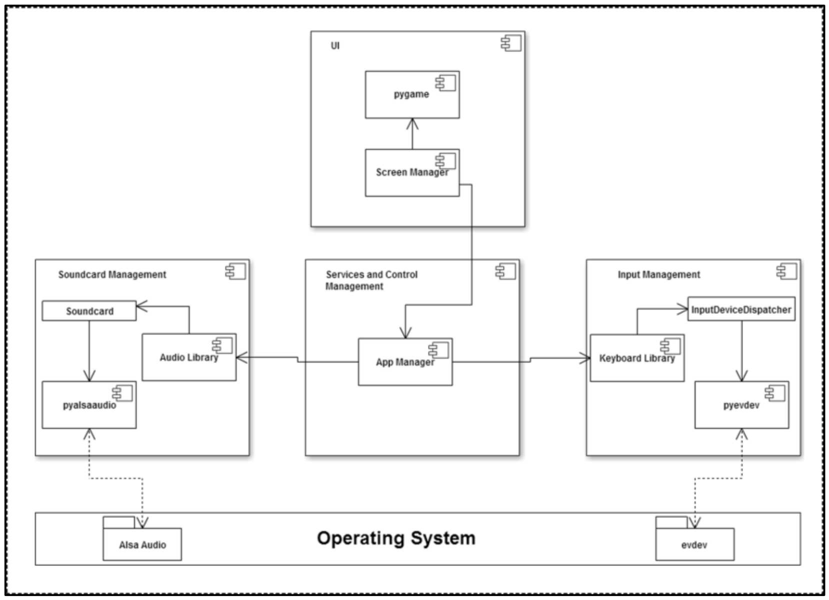


Figure 4.3 Architecture of the SDG Central Hub.

The architecture was developed for a conventional operating system (i.e. not one adapted for SDG systems), so that it may be used with existing computers in a school setting. However, this type of system is not designed for interaction with multiple, simultaneous users (Jetter et al., 2012). Therefore, to allow each user to have their own independent input/output device, by default the Soundcard Management and Input Manager components implement the interfaces provided by the operating system to modify their behaviour.

In the case of the soundcard management component, when implementing the interface a logical flow called an audio process was created. This process features three steps, as shown in Figure 4.4:

- Step (a) - Create audio: the application logic requests an audio file. This request is received by the soundcard management module, where the audio file is created and placed in an independent queue for each card.
- Step (b) - Waiting time: this refers to the polling time, i.e. the time it takes for the card to be ready able to send the audio file.
- Step (c) - Reproduce: the audio file is sent to the user through the soundcard.

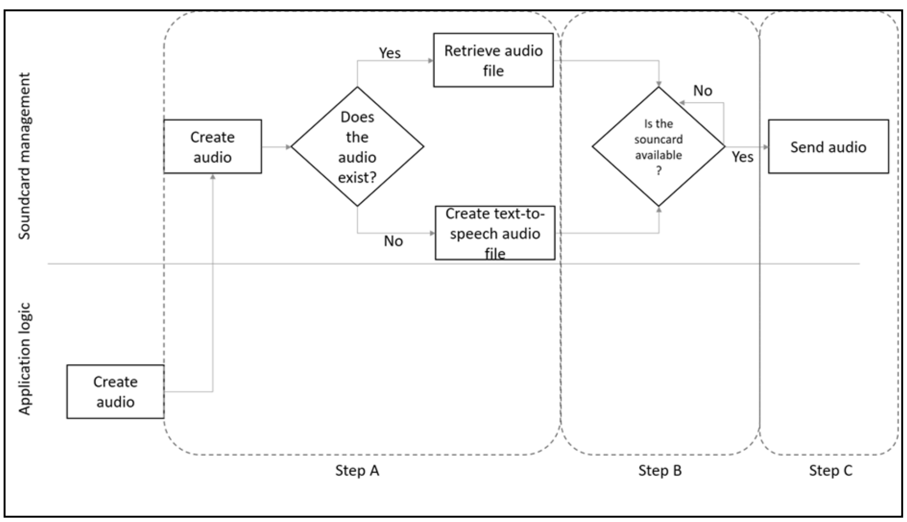


Figure 4.4 Diagram of the audio process.

Even though the operating system natively supports input from multiple keyboards, it does so by joining every input in a single output stream. Therefore, the Input Manager component has to be extended so as to give every keyboard its own output stream and allow each user to write independently.

Firstly, the component searches for all connected keyboards and creates objects to display the keystroke events for each one. This is done by accessing the device file system for each keyboard, provided by the OS through its generic interface evdev (Pavlik, 2001). As this is an I/O bound process, the asyncore library (Python Software Foundation, 2016) was used to handle the files from the different input devices simultaneously. When reading these files, the event codes triggered for each keyboard are translated into the corresponding character and sent to the Services and Control Manager component.

4.3.3. Hardware specifications

The objective of the hardware configuration chosen for this architecture is to facilitate its implementation in schools by using readily available devices and keeping its costs as low as possible. Given this, the system was implemented using consumer-level hardware (Figure 4.5).

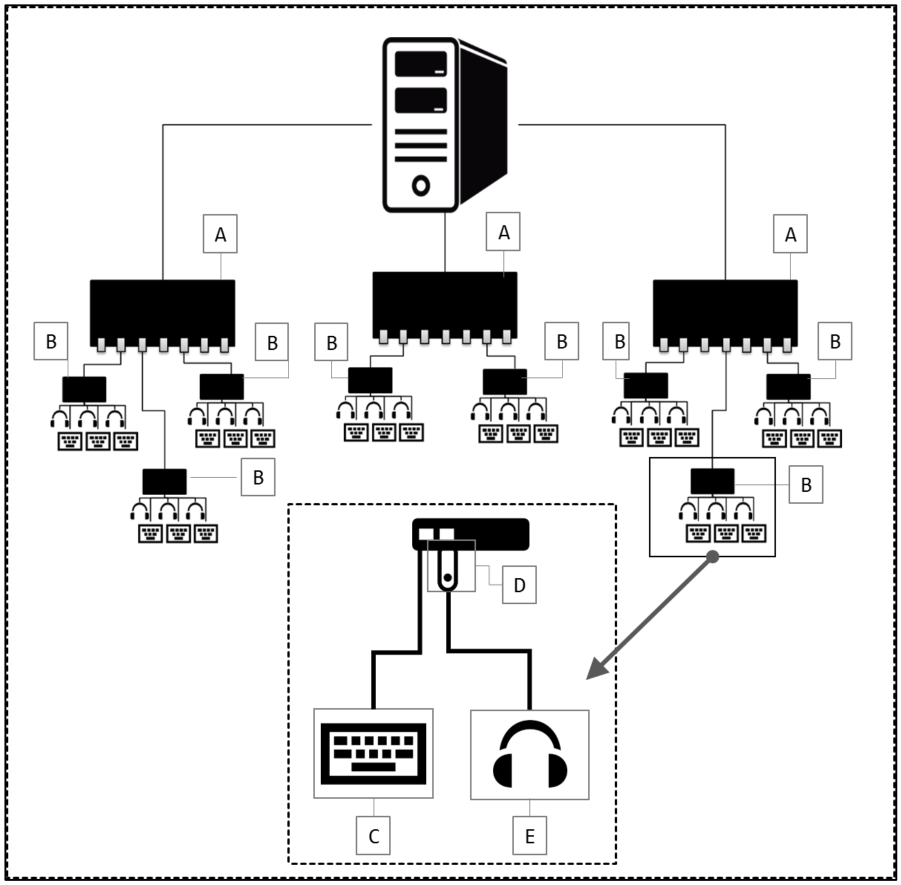


Figure 4.5 Hardware configuration for the proposed Shared Workspace.

The SDG Central Hub was implemented using a 2.4 GHz quad-core Intel Core i7-3770 computer, with a 500 GB, 7,200 RPM SATA hard drive and 6GB of 1,800 MHz DDR3 RAM. An ASUS P8Z68-V mother board with an Intel 268 chipset was also used. These specifications correspond to a mid-level home computer (Bastounis, 2016).

In order to provide enough USB ports to connect every user in the class, a series of D-Link DUB-H7, 7-port USB 2.0 hubs were used. When choosing a USB hub to support the SDG Mobile Hubs, it is important to note that the connectivity rules for the USB hubs indicate that up to 5 hubs can be connected in a series and that the hubs can be connected to one another using cables of up to 5 meters.

For the input, each user had a USB 2.0 keyboard. For transmitting individual audio, external USB 2.0 soundcards with 5.1 channels were connected to each hub. A set of headphones was then connected to each soundcard. The soundcards meet the specifications for full-speed transmission and can therefore transfer data at up to 12 Mbps.

The devices were arranged as shown in Figure 4.5. Two 7-port USB hubs were connected directly to the PC (“root” hubs, Figure 4.5, Section A). Further hubs were then connected to each of these hubs (“leaf” hubs, Figure 4.5, Section B), with 3 keyboards (Figure 4.5, Section C), 3 soundcards (Figure 4.5, Section D) and a set of headphones for each soundcard (Figure 4.5, Section E) then connected to each of these hubs. Therefore, each leaf hub could accommodate up to three users.

The shared output was achieved by projecting the workspace into a screen. It was decided to use a projector for this study as they are widely used in the classroom (Smetana & Bell, 2013).

4.3.4. Data analysis plan

Cycle 1 looked to determine whether the proposed architecture would allow for a smooth user experience when used with multiple, simultaneous users for whole-class interactivity.

In order to do so, the system's performance was measured from the user's point of view, as well as the usage of the computer's resources.

User experience is mainly measured using the system response time (Shneiderman, 1984). In the case of the proposed Shared Workspace, personalized interaction with the user comes from input from the keyboard (and the graphical representation on the shared screen) and the audio output. Therefore, the response time was studied using the following indicators:

- Length of audio processes: this refers to the time from when the application sends the instruction to create the audio file to when the audio is sent to the corresponding soundcard. This is relevant to the user experience because it is this process which determines the perceivable response time for the output provided by the system.
- Time from keystroke to feedback (as audio or text): this is related to the response time that is perceived by the user for the input received by the system.

To understand the relationship between the perceivable response time for the user and the system's resources, the number of operations per second performed by the CPU and RAM was also recorded (Raju & Govindarajulu, 2014). To verify whether or not the use of resources was related to the number of simultaneous users, the events which suggested that there was user interaction with the system were also recorded. This included the number of keystrokes per user and the number of audio processes that were open every 0.5 seconds

(Singhal, Kulkarni, Chand, & Bhattacharjee, 2014). Using this, the following indicators were obtained:

- Relationship between the number of keystrokes, open audio processes and CPU & RAM usage over time: this indicator looks to explain how the input and output loads affect the system's performance.
- Length of waiting time for the audio processes: this corresponds to the time from when the audio is ready to be reproduced to when it begins to be transmitted via the user's headphones. This is the only step in the audio process where the duration does not depend on the length of the text that needs to be reproduced and can therefore be adjusted in order to achieve a faster response from the system.

Based on the results from Cycle 1, it was necessary to analyze the audio processes again in Cycle 2. In order to do so, descriptors were obtained for the total duration of the audio processes, as well as for the time it took to create the audio, and the waiting time before the audio was reproduced. Finally, in Cycle 3, only the waiting time for the audio processes was measured for different hardware configurations.

4.4. Cycle 1: collaborative story-telling

This section describes the details of the experiment that was conducted in order to study the performance of the proposed software and hardware.

4.4.1. Experimental design

To test this cycle, an SDG program was developed for collaborative story-telling. Each user started by typing a sentence to begin their story. This sentence appeared on the shared screen (and could therefore be viewed by everyone) and was then sent privately via audio to another user at random. This user then had to continue the story by adding their own sentence. This flow therefore allowed for the constant generation of input from the keyboard (by typing sentences) and audio output (from the sentences that were received). Doing so allowed the system to continually serve all of the users and provided a high-intensity environment in which to measure the performance of the proposed Shared Workspace system. Given the above, the variables time from keystroke to feedback and length of audio processes were measured in this cycle.

The hardware configuration that was used matches the specifications included in Section 4.3.3, while Figure 4.6 shows the view screen with 36 simultaneous users.

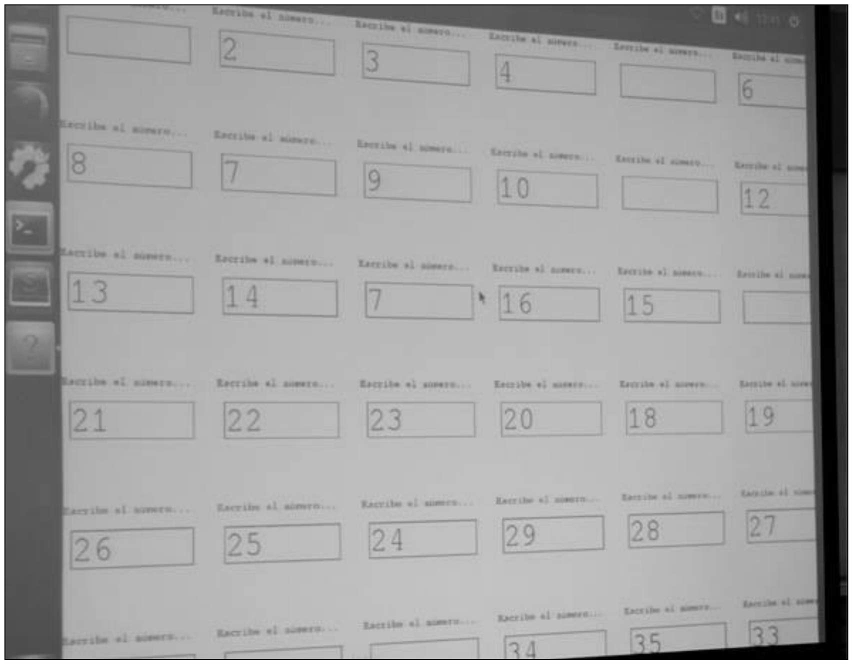


Figure 4.6 View of the screen for the proposed Shared Workspace system with 36 simultaneous users.

4.4.2. Participants and procedures

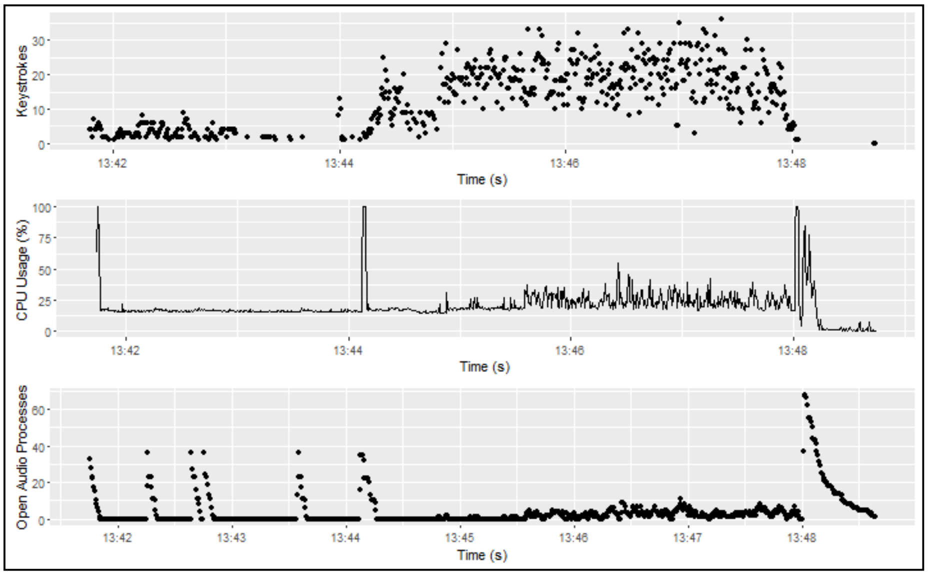
First and second year engineering students, aged between 18 and 20, were invited to test the system (Figure 4.7). These students participated voluntarily and were told that they needed to be familiar with the use of a keyboard and that they could not participate if they had any difficulties with their sight or hearing.

Figure 4.7 Testing of the Shared Workspace system (Cycle 1).

4.4.3. Results

Initially, 39 students were ready to take part in this stage of the study. However, the system was only able to recognize and connect 36 sets of devices. Upon connecting the 37th soundcard, the system logs indicated a loss of devices due to exceeded bandwidth.

Graph 4.1 shows the relationship between the number of keystrokes (keystrokes registered by the system), the percentage of CPU usage and the number of open audio processes, over time.



Graph 4.1: Keystrokes, CPU usage and open audio processes, over time.

Table 4.1 shows the length of the audio processes, from the moment the software logic requests the creation of the audio file to the moment it begins to be reproduced. The table reveals that 419 of the 621 processes last between 0 and 2 seconds, while 168 of the processes last for more than 2.5 seconds.

Table 4.1 Distribution of the length of the audio processes (Cycle 1)

Time (s)	**Number of processes**
0-0.5	277
0.5-1	48
1-1.5	38
1.5-2	56
2-2-5	34
> 2.5	168

Table 4.2 shows the average duration for Steps A and B of the audio processes (Figure 4.4) before the audio was reproduced.

Table 4.2 Descriptive statistics for the audio process (Cycle 1)

Step of the process	**Mean (s)**	**Max (s)**	**Min (s)**	**SD**
Create audio (A)	0.804	11.815	0.0003	1.77
Waiting time (B)	1.519	26.416	0.00004	3.116

Table 4.3 shows the descriptive statistics for the waiting time (Step B) of the audio process, for each hub of 3 soundcards. This corresponds to the polling time for each soundcard in seconds, from the time that the audio reaches the hub to when it begins to be reproduced.

Table 4.3 Descriptive statistics for the polling time for each hub (Cycle 1).

Hub	Mean (s)	Max (s)	Min (s)	SD
1	1.0724	7.423	0.000050	1.582
2	1.5059	22.814	0.000050	3.228
3	1.8277	10.908	0.000050	2.447
4	1.5402	8.844	0.000050	2.068
5	1.2300	13.560	0.000050	2.285
6	1.8466	26.416	0.000050	4.011
7	1.7429	7.683	0.000050	2.113
8	1.6179	13.325	0.000050	2.313
9	0.8905	10.614	0.000050	2.047
10	1.9181	26.276	0.000050	4.420
11	1.4734	25.864	0.000050	3.680
12	1.9616	24.753	0.000050	4.399

Table 4.4 shows the descriptive statistics for time from when the user presses a key to when they receive feedback from the system, i.e. the response time associated with a keystroke event.

Table 4.4 Descriptive statistics for response time (keyboards) (Cycle 1)

Descriptor	Time (s)
Mean	0.046
SD	0.085
Maximum	1.534
Minimum	0.0003

4.4.4. Discussion and limitations of Cycle 1

Graph 4.1 reveals a direct relationship between CPU usage and the number of open audio processes. No relationship is observed between the number of keystrokes and CPU usage. In other words, for a Shared Workspace based on SDG architecture with personalized audio, the audio output load affects the system's performance. Furthermore, RAM usage did not exceed 18% of the system's capacity throughout the test.

There are 3 peaks in the number of open audio processes that are directly related with the peaks in CPU usage (Graph 4.1). These peaks correspond to audio that was created at run time and simultaneously sent to all of the users. Furthermore, there are 4 peaks in the number of open audio processes that do not correlate with CPU usage (between 13:42 and 13:44 in Graph 4.1). These peaks correspond to times in the study when all of the users were playing audio that had been created beforehand. In other words, the audio processes affect the computer's performance when all of the users receive audio that is created on-demand. Pre-recorded audio files do not produce peaks in CPU usage (Böttcher, 2013). Therefore, for systems with large numbers of users, pre-recorded audio files produce a system load that does not affect the usability of the Shared Workspace system.

The delay in responding to the user is due to the fact that when there are a number of open processes the CPU usage increases (Graph 4.1). In particular, Table 4.1 reveals that there are audio processes which last for more than 2.5 seconds. Therefore, one way to improve performance is to ensure that there are fewer open processes per unit of time. Given that not all of the processes start at the same time, this can be achieved by shortening the length of the audio processes in general.

The behaviour of the time it takes to create the audio and to reproduce the audio file depends on the user’s input. If the user enters new text, the time it takes to create the audio increases as the file has to be created; the longer the file, the longer it will take. The waiting time (Step B in the audio process in Figure 4.4) is the only step that does not depend on user input. Table 4.2 reveals that waiting time has a greater maximum (26.42s) than the other steps in the audio process. Therefore, it is the waiting time that must be reduced in order to shorten the overall length of the audio processes in general.

Table 4.3 shows the polling times for the audio processes, per hub. It can be observed that the maximum times exceed 7 seconds, and that the minimum times are consistent (0.0005 s.). Using the software log, it was determined that the maximum times occurred towards the end of the study, when very long audio files were simultaneously sent to all of the participants. Given the hardware configuration used in this cycle (Section 4.4.1), in order to send the audio files to all of the users at the same time, the three soundcards that are connected to the same hub receive the data simultaneously. This is when the maximum waiting times were produced. Furthermore, the minimum waiting times occurred when only one of the soundcards connected to the hub was reproducing the audio. Therefore, the number of soundcards per hub has an effect on the polling time, which in turn has an effect on the user experience.

Table 4.4 shows that, on average, the system's response to keystroke events occurred in under 0.05 seconds, i.e. an acceptable amount of time for the user (Dabrowski & Munson, 2011). Furthermore, the log suggests that response times of almost 1 second occurred at the start of the experiment, when all of the students were simultaneously receiving instructions (via audio) and refreshing the screen to start the activity. When reviewed in conjunction with the data on CPU usage from Graph 4.1, it can be concluded that simultaneous keystrokes do not overload the proposed system.

In conclusion, during this cycle it was observed that the system's main bottle neck is the waiting time from the queue that is formed for individual audio output. This prompted the need to carry out a second research cycle.

4.5. Cycle 2: software for practicing spelling

This section describes the experiment that was conducted in order to answer the research questions that arose from the results from Cycle 1: what type of audio output decreases the perceivable response time for users of a Shared Workspace system based on an SDG architecture? For such systems, what impact does the hardware configuration that is used to support personalized audio have on response time?

4.5.1. Experimental design

The experimental design for this Cycle was based on two hypotheses: pre-recorded audio leads to a shorter perceivable response time for the user, in comparison with audio that is created on-demand; and response time decreases when there are fewer users connected to each Mobile Hub.

The results from Cycle 1 (Section 4.4.3) show that polling time is the main factor in determining the system's response time. Changes were therefore made to the software and hardware for Cycle 2 in order to reduce polling time.

A new piece of software was developed for the proposed Shared Workspace. The literature review (Böttcher, 2013) showed that pre-recorded audio files do not affect system performance. The software to be developed in this Cycle therefore has to consider a domain where the audio output can be pre-established. One such domain is drill-and-practice software as feedback can be produced ahead of time based on the questions and expected answers. Spelling was chosen as the topic for this software as it allows the interaction to mainly take place by means of text input. As the results from the previous cycle showed, this type of input did not affect the system's performance.

This new software was developed based on the software architecture used in Cycle 1 (Section 4.3.2). In this architecture, the soundcard management component was extended to use memory-mapping (mmap) for storing the audio files, so as to avoid I/O calls each time the audio is needed (Hellmann, 2015).

The software used in this cycle allowed for self-paced learning of spelling and covered topics from the 1st to 6th grade curriculum. These topics were adapted to create multiple choice and short answer exercises. In both cases, the instructions and feedback were delivered through audio, while the answer had to be selected or written using the keyboard. Given the hypotheses of this cycle, the variable to be measured during this experiment was the length of the audio process, considering the time it took to create the audio, and the waiting time before the audio was reproduced.

From the results of Cycle 1, fewer users were assigned to each Mobile Hub to decrease the polling time of the audio output. To achieve this, in terms of the hardware used in this Cycle, 3 USB hubs were connected directly to the computer ("root" hubs) so as to arrange the students in three rows. Two of these devices had 3 USB hubs connected to them, while the third had 2 USB hubs connected to it. Three keyboards and soundcards were then connected to each of these hubs. This corresponds to an adaptation of the configuration shown in Figure 4.5, Section 4.3.3, leaving more free USB ports per hub than in the configuration used in Cycle 1.

4.5.2. Participants and procedures

For this cycle, 24 students from a 2nd grade class used the proposed Shared Workspace system for 30 minutes (Figure 4.8). All of the participants had used a computer before and so they knew how to use a keyboard. None of the students had hearing impairments, although two of the students wore glasses and were therefore seated at the front of the class.

Figure 4.8 Schoolchildren using the proposed Shared Workspace system (Cycle 2).

4.5.3. Results

Table 4.5 shows the distribution of the length of the audio processes, from the time the application logic requests an audio file to just before it starts to be reproduced over the user's headphones. This corresponds to Steps A and B of the audio process (Figure 4.4).

Table 4.5 Distribution of the length of the audio processes (Cycle 2).

Time (s)	**Number of processes**
0-0.5	1270
0.5-1	42
1-1.5	313
1.5-2	206
2-2-5	192
> 2.5	102

Table 4.6 presents the descriptive statistics for the audio processes that occurred in Cycle 2. It reveals that, on average, the step for creating the audio took longer than any other step in the audio process.

Table 4.6 Descriptive statistics for the audio processes (Cycle 2).

Step of the process	**Mean (s)**	**Max (s)**	**Min (s)**	**SD**
Create audio (A)	0.179	5.279	0.0002	0.509
Waiting time (B)	0.0001	0.002	0.00004	0.00006

4.5.4. Discussion and limitations of Cycle 2

The results from this cycle show that it is possible to improve the user experience when using the proposed Shared Workspace system based on an SDG architecture. This is done by reducing the length of the audio processes by modifying both the software and hardware, i.e. the results confirm the hypotheses that were set out at the beginning of this cycle.

In terms of the software, it was possible to use short audio files as it was a drill-and-practice activity and therefore the questions and feedback could be defined beforehand. Given this, the audio output files were created once for each user. If an audio file had to be repeated it was retrieved from memory (Section 4.5.1), thus bypassing the create audio step of process.

With regards to the hardware, leaving ports free in the USB root hubs (section 4.5.1) shortened the waiting time for each audio output that was created (step B of the audio process in Figure 4.4), therefore reducing polling time.

By reviewing the system log, it was possible to determine which conditions led to the maximum time for creating the audio, as reported in Table 4.6. As explained in Section 4.3.2, each soundcard had a queue where the audio files were placed before being reproduced. When the application logic requests an audio file that has not been played before, the audio manager produces the file and places it in the queue. If during this time the user performs an action that requires a new audio file, this cannot be created until the previous file has been placed in the queue. This is done in order to avoid losing the older file, although it is done so at the expense of delaying the creation of the new file.

4.6. Cycle 3: Lab Experiment

Based on the results from Cycle 2, this third research cycle looks to answer the following research question: when using pre-recorded audio, which hardware configuration can reduce the perceived response time for users of a Shared Workspace based on an SDG architecture for whole-class interactivity?

4.6.1. Experimental design

A lab experiment was conducted in order to answer the aforementioned research question. This experiment was guided by the following hypothesis: a hardware configuration with fewer users per Mobile Hub reduces the polling time for the audio that is created, regardless of the number of simultaneous users working on the system.

Using the proposed Shared Workspace system, a new piece of software was developed which simultaneously sent pre-recorded phrases to each soundcard. By doing so, the system was consistently able to reproduce audio on all of the hubs and soundcards.

Two hardware configurations were used for this experiment. The first configuration, which was the same as the configuration used in Cycle 1, featured 3 users per leaf hub (Section 4.3.3). In order to test the hypothesis for this third cycle, the second configuration featured only 1 user per leaf hub. Three root hubs were used in this configuration, with 6 leaf hubs connected to each. A soundcard and keyboard was then connected to each leaf hub.

This experiment was conducted for both hardware configurations, and each configuration was tested 3 times: first with 6 soundcards, then with 12 and finally with 18. The aim of this was to verify whether or not the number of soundcards being used affected the computer's performance. In each case, the same number of keyboards and soundcards were connected so that the allocation of internal USBs on the operating system would be similar to when used by real participants. For both configurations, the variable to be measured was the polling time for the audio processes.

4.6.2. Participants and procedures

This experiment was carried out using simulated users generated by software so as to control the exact load of the audio output. The experiment was conducted in three stages, with 6, 12 and 18 virtual users, where each user was represented by a soundcard and keyboard connected to a hub.

4.6.3. Results

Table 4.7 shows the polling time (Step B of the audio process in Figure 4.4) for the pre-recorded audio files, for both hardware configurations used in this cycle, with 6, 12 and 18 simulated users.

Table 4.7 Descriptive statistics for polling time in Cycle 3.

Number of virtual users	Statistic	Polling time (s) in configuration 1	Polling time (s) in configuration 2
6	**Mean**	3.125	0.00005
	Maximum	4.076	0.00009
	Minimum	0.00006	0.00004
	SD	0.844	0.000008
12	**Mean**	3.112	0.00005
	Maximum	4.076	0.00013
	Minimum	0.0005	0.00004
	SD	0.841	0.00001
18	**Mean**	3.135	0.00005
	Maximum	4.076	0.00014
	Minimum	0.00005	0.00004
	SD	0.842	0.00001

4.6.4. Discussion and limitations of Cycle 3

The results showed that having fewer users connected to each Mobile Hub reduced the audio polling time, therefore confirming the hypothesis for this cycle. By having 1 soundcard per hub, the polling times were 4 to 6 times lower than when there are 3 soundcards per hub. The polling time also remained relatively constant, regardless of the number of virtual users (i.e. the number of sets of keyboards and soundcards that were connected to the system). The configuration of one user per Mobile Hub therefore effectively eliminates the waiting time for the soundcards, with the increased cost of needing one hub per user.

The differences in waiting time between the two configurations can be explained by the structure of the USB hubs. Each hub provides an upstream port (Brownell, 2003), from which the system sends instructions to the connected devices. Only one instruction can pass through this port at any one time. For the configuration used in Cycles 1 and 2, the three soundcards connected to a hub share the only upstream port. This port is only freed up by each soundcard once it has finished reproducing the audio file. Until then, the hub cannot receive any more data. Therefore, the three soundcards connected to the same hub cannot operate simultaneously. With the new configuration used in Cycle 3, however, each soundcard is given its own upstream port as only one soundcard is connected to each hub. The upstream port is located in the hub repeater (D. Anderson & Dzatko, 2001) and it would therefore be possible to only use this component instead of a complete hub to support the soundcards. In general, these results show that waiting time can be reduced by distributing the audio transmission across several devices.

4.7. Synthesis and discussion

The results obtained in this study show that whole-class interactivity can be achieved using a Shared Workspace based on an SDG architecture. The results from the three research cycles show that the perceivable response time for users decreases when there are fewer users per Mobile Hub. In particular, and given the centralized nature of the hardware, the hardware configuration for the Mobile Hubs is a determining factor in achieving a smooth user experience with the proposed system. In this sense, having fewer nested hubs leads to shorter response times from the system.

Table 4.8 shows a comparison of the three cycles included in this study:

Table 4.8 Summary of the research cycles included in this study

Criteria	Cycle 1	Cycle 2	Cycle 2
Objective	To determine the software and hardware architecture that is required to support whole-class interactivity in a shared workspace system.	To determine the type of audio output and hardware configuration that minimizes response times in the proposed architecture.	To determine which hardware configuration can minimize polling time for personalized, pre-recorded audio output.
Experimental design	36 first and second year university students using the proposed system for collaborative story-telling for a period of 9 minutes.	24 schoolchildren simultaneously using the proposed system for spelling practice, for a period of 30 minutes.	6, 12 and 18 virtual users, each represented by a soundcard and keyboard.
Variables to be measured	Length of audio processes Time from keystroke to feedback Keystrokes per user. Open audio processes. CPU and RAM usage.	Length of audio processes.	Polling time for audio processes.
Main findings	Personalized audio output affects the system's response time. This is not the case with multiple, personalized input devices such as keyboards.	Saving audio files for repeated use and leaving free ports in the USB "root" hubs improves the Shared Workspace experience.	Having multiple soundcards placed in the same USB hubs increases the polling time for each audio file, increasing the system's response time.

4.8. Conclusions

The results obtained in this study reveal two essential conditions when implementing and using a Shared Workspace system based on an SDG architecture in a classroom setting. In this particular case, the system is powered by a single computer and features up to 36 simultaneous users using keyboards and headphones for personal input and output, as well as a shared screen. The first condition is that the SDG should be used with software that mainly relies on pre-recorded audio files to provide interactivity. The second condition is that the hardware configuration used to support the proposed System Workspace system must take into account the bandwidth demand of the devices used for personalized output.

This is because for multi-user, co-located SDG systems, such as the one used in this study, the main factor that leads the system to overload is creating and sending personal output. The results obtained in this study show that in order to make better use of the computer's resources, the output that is to be used should be created beforehand. This finding is in line with previous findings reported in the literature (Böttcher, 2013). In the case of audio files, this can be achieved in two ways: pre-recording the messages that are transmitted, or storing the audio files that are created so that they can be repeated whenever necessary, without needing to recreate them. If this is not possible due to application constraints, the way in which the personal output is sent must be well distributed. One way of achieving this is to use individual devices (such as hub repeaters in this case) to send the content to the users. Doing so can avoid the USB ports from becoming saturated and dropping devices as the transmission channel is shared with fewer users.

Furthermore, in Cycle 1 it was observed that there is a practical limit of 72 keyboards and USB soundcards that can be connected to a single system, plus the 14 hubs used to connect them. This differs from the theoretical limit of 127 USB devices per host (Leavitt, 2007) and can be explained by the real use of the available bandwidth. In theory, the USB 2.0 protocol allows a maximum speed of 480 Mbps (Ramamurthy & Ashenayi, 2002). Given that the USB sound cards can transmit data at up to 12 Mbps, only 40 of these devices can be connected. However, the operating system reserves 90% of the maximum bandwidth to be used by any device that makes time sensitive information transmission (i.e. isochronous transfers), such as soundcards (Peacock, 2011). Given this, the study revealed that a smooth user experience could be achieved with a maximum of 36 sound cards. However, as keyboards are interrupt-transfer devices they only use up to 64 bytes (Axelson, 2015). Therefore, as they only use a fraction of the total bandwidth, more than 36 devices of this type can be connected to the proposed SDG. USB mice are also interrupt-transfer devices (Ramadoss & Hung, 2008) and therefore may also be added as an input device in this type of system architecture.

As well as using other appropriate input devices with this type of architecture in a school setting (such as mice or joysticks), it remains as future work to test the proposed SDG with USB 3.0 controllers because devices as these are now consumer-level devices (Safford, 2015). USB 3.0 provides 10 times more bandwidth than USB 2.0 (USB Implementers Forum, 2013) and may therefore allow more users to be added to the system, or indeed for the use of interactive devices that consume more bandwidth (such as microphones).

One of the limitations of the proposed architecture for Shared Workspaces is the use of wired devices with the Mobile Hubs. This is because the use of cables makes it harder to set the system up for multiple users. It remains as a future work to implement the proposed architecture using ad-hoc networks to connect both the Mobile Hubs to the central server, as well as the personal devices to the Mobile Hubs, wirelessly. The Mobile Hubs used in this study were USB hubs. However, it is possible to encapsulate other forms of embedded devices in the wireless architecture described above. For example, by using a computer-on-module or an expansion board as a Mobile Hub, it is possible to support Wi-Fi or Bluetooth connections for the input devices (Figure 4.9).

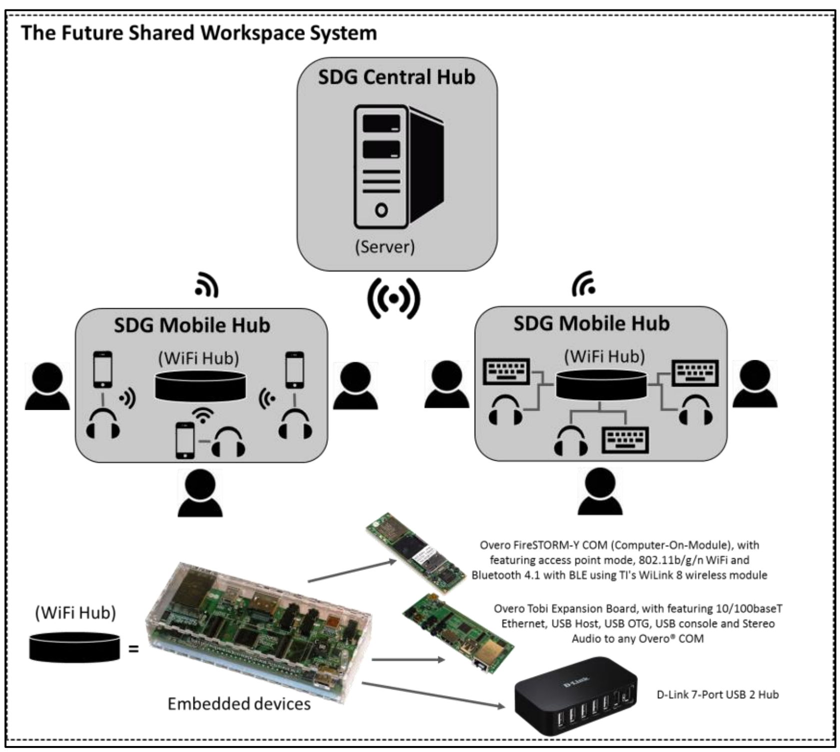


Figure 4.9 Architecture for the future, wireless Shared Workspace system.

A current trend in Shared Workspaces is the use of personal devices for input, wirelessly connected to a public display (Berkhoff et al., 2014; Manathunga et al., 2015). Given this, one application of the future Shared Workspace system described above would be to use the centralized architecture with smartphones acting as Mobile Hubs. By using an ad hoc mobile network, each device acts as a router and distributes the network load (Conti & Giordano, 2014), therefore avoiding network saturation.

5. THE USE OF SHARED DISPLAY AS A TOOL FOR COLLABORATIVE LANGUAGE TEACHING IN THIRD-YEAR STUDENTS

The objective of this chapter is to study how to use interpersonal computers (IPC) with formative assessment for group work. To this end, a collaborative work tool was developed based on the architecture described in chapter 4, adapting the software presented in chapter

The system is designed to be used by several groups of three students simultaneously; this determines how interaction takes place. For example, for individual work, students are immediately assigned to the space they will use throughout the entire session. In contrast, in the collaborative system, the screen should be adapted for various students to work simultaneously on the same portion of the assigned screen. This is achieved by dividing the available space into an amount of sections equal to the number of groups and subsequently dividing each of these new spaces into three parts. Each student is in this way assigned their starting quadrant prior to the configuration of the system.

The group work configuration stage has two steps: the position on screen and the level selection. Each student's name is highlighted in the group's portion of the screen so that he or she can find his or her workspace. Once every student has found their name, the content they will be working with is chosen. In order for every student to be able to take part in the content, the group begins to work starting at the level of the student that, in the previous session, had gone over the least amount of material.

Once the activity begins, the system presents the entire group with a question of the level that corresponds to them. Instructions are given to the students via audio through their headphones. The questions can be multiple-choice questions or contain a short text. Each student then chooses what they believe is the correct answer. In the event that the three students have not given the same answer, the system asks them to reach an agreement. This is done in order to generate discussion surrounding the material and for the students to be able to express and resolve their doubts. Once a consensus is reached, the system compares the response given by the group to the expected response. If the answer given is incorrect, the system invites the students to try again. If it is correct, the system assesses whether the students should go on to more advanced content according to the pedagogic rules established in the software, and then provides the students with the following question.

The development of the collaborative SDG was tested in an experiment conducted in 2014 in a subsidized private school in Santiago, Chile. The participants were four third-year courses and their Language Arts teachers, separated into three groups:

- Control group, given lessons without technological support and given review lessons according to the results of periodic paper tests.
- Individual software group, with self-paced exercises using the software detailed in chapter 2 adapted to IPC, given review lessons according to the content that the system found were the students' weakest

- Collaborative software group, with self-paced exercises using IPC with the collaborative software developed for this experiment, given the same review lessons as the individual software group.

Each class had weekly sessions for a total of 10 weeks. The control group alternated work sessions with review lessons, while the two groups that received technological support undertook self-paced work using the software, followed by a review session. For further details on the software and the intervention, see the Master's thesis by Tomás Martínez.

In order to measure the effect of the experiment on the students' learning, a pre and post-test were given to the participants. The pre-test was taken by 150 students and the post-test by 139; the difference in the number of students is explained by the absence of some students from the post-test session and by changes in class composition throughout the semester. The Cronbach's alpha values for these tests were 0.818 and 0.775 respectively, which is in the range of "good and/or satisfactory" (George & Mallery, 2007) for the internal consistency of the instrument.

Table 5.1 shows the descriptive statistics for the results of the pre and post-tests. It can be observed that the control group, being the group that scored the lowest on the pre-test, had the greatest variance in results. The analysis of variance (ANOVA) does not reveal any significant differences between pre and post-test results for any group. However, Table 5.2 shows that the intervention had a medium effect on learning in the control group and in one of the groups using the software collaboratively.

The unstable behavior of the system during the experiment led to a suboptimal learning environment, but despite this, it was observed that students were capable of working collaboratively.

Table 5.1 Descriptive statistics for the results of the pre and post-tests, by group

	Control group			**Group with individual software**			**Group with collaborative software (A)**			**Group with collaborative software (B)**		
	Pre-test	**Post-test**	**Pre-/Post-difference**	**Pre-test**	**Post-test**	**Pre-/Post-difference**	**Pre-test**	**Post-test**	**Pre-/Post-difference**	**Pre-test**	**Post-test**	**Pre-/Post-difference**
N	23			36			37			35		
Mean	26.47	30.04	3.57	28.50	29.47	0.97	24.16	27.32	3.16	28.49	30.43	1.94
Std. Dev.	4.851	5.022	3.527	4.651	4.185	3.582	5.085	4.785	4.259	5.043	4.053	3.572
Min.	19	21	-2	19	15	-6	15	15	-7	19	23	-5
Max.	36	40	10	37	38	9	33	37	12	37	38	10

Table 5.2 Descriptive statistics for the results of the pre and post-tests, by group.

Group	**Cohen's d**	**Interpretation**
Control	0.72	Medium effect
Individual	0.22	Low effect
Collaborative (A)	0.64	Low effect
Collaborative (B)	0.42	Medium effect

6. THE IMPACT OF THE TECHNOLOGY USED IN FORMATIVE ASSESSMENT: THE CASE OF SPELLING

6.1. Abstract

This study demonstrates how the technology used to assist formative assessment in spelling can have an impact on learning. Formative assessment represents a set of student-centered practices, the results of which are not always optimal. Furthermore, different technologies are better suited to certain tasks than to others. The study follows a Design-Based Research approach and was conducted in Chile in two phases. In the first phase of the study, a formative assessment strategy for teaching spelling is developed. In a subsequent phase, the impact of different technologies on this strategy is analyzed. This is achieved by comparing two different technologies: Tablet PCs and the Interpersonal Computer. The results reveal that a self-paced formative assessment strategy using Tablets is more effective than the same strategy using an Interpersonal Computer when teaching spelling to primary school students. This therefore highlights the impact of technology on learning when adopting a formative assessment strategy.

6.2. Introduction

Formative assessment refers to a set of practices used in the teaching-learning process. These practices take into account the quality of work produced by a student in order to hone and improve their skills (Sadler, 1989). The aim of formative assessment is to identify what the students do (and do not) know, and to subsequently effect significant change in the learning process (Boston, 2002). This can be achieved by following a 5-step model (Black, 2015):

- Step (a): Plan the assessment and establish clear objectives.
- Step (b): Develop activities to meet these objectives.
- Step (c): Implement these activities in the classroom.
- Step (d): Use informal assessment to check the degree to which the objectives have been met.
- Step (e): Take the results of this assessment into account in subsequent teaching.

Formative assessment requires “moments of contingency” in teaching (steps c and d in the above model), allowing the learning process to be regulated (step e). These moments can be synchronous, such as group or class discussions, or asynchronous, such as using information from exercises completed by the students (Black & Wiliam, 2009).

Formative assessment can lead to an improvement in learning within the context of the teaching-learning process. This is because it allows the teacher to provide the necessary support by taking into account the students’ level of skill development (Gikandi, Morrow, & Davis, 2011). This is achieved by providing the teacher with a feedback loop that models and guides student development when pursuing a given learning objective (Roskos & Neuman, 2012). Despite the benefits of formative assessment, its use in the classroom is far from widespread (Shute & Kim, 2014). This is partly due to the fact that formative assessment requires teachers to obtain and analyze information on student learning from several sources and in a short space of time (Ruiz-Primo, 2011). In this sense, teachers are required to radically change the way in which they interact with their students and operate in the classroom (Black, 2015), something which is difficult to achieve in practice.

The literature reports differing results regarding the effect of formative assessment on student achievement in primary and secondary education (R. E. Bennett, 2011; Briggs, Ruiz-Primo, Furtak, Shepard, & Yin, 2012). These differences may be explained by the fact that defining and implementing formative assessment in the classroom is a complex process as it requires teachers to perform different assessment activities (such as observation, judgment and feedback) with varying objectives (Antoniou & James, 2014). These activities must be executed while respecting the conditions of the classroom (Rodríguez et al., 2012).

These conditions include the different pace at which students learn, reflecting their different needs (Santos, Luz, Martins, Dias, & de Paiva Guimarães, 2015). One such need is to incorporate the student's life experiences into the curriculum, while teachers must find comprehension strategies that go beyond the constraints of the curriculum (Hill, 2013). Curriculum pacing is therefore a significant variable when it comes to the scope and quality of student learning (Bossert, 2013). At times, these needs may conflict with the curriculum mapping defined by the local authority (Steadman & Evans, 2013).

Considering the above, the theories that provide the foundation for this research are self-paced learning and formative assessment, which in turn give rise to our first hypothesis, H1: a self-paced learning strategy using formative assessment, where the teacher plans customized review sessions based on information regarding student performance, produces significant learning gains when compared to a self-paced learning strategy with review sessions that follow the pre-defined order of the curriculum, as established by the local authority.

Another classroom condition that must be taken into consideration is the use of technology. Technology is not neutral and can be better suited to certain tasks than to others, depending on the actions it allows to be performed as well as its constrains (Angeli & Valanides, 2009; Koehler & Mishra, 2009). For example, email does not facilitate synchronous communication in the way that a phone call does (Koehler & Mishra, 2008). Understanding the impact of different technologies on specific teaching practices is therefore critically important (Koehler & Mishra, 2009).

Technological platforms are an effective means for the teacher to collect formative evidence (Panero & Aldon, 2016). Nevertheless, the use of technology for supporting formative assessment has produced divergent results (García et al., 2016). For example, H. Lee, Feldman, and Beatty (2011) report that teachers have difficulties understanding their students' thinking based on their answers when using clickers. On the other hand, Kowalski et al. (2015) developed a formative assessment application that uses the handwriting capabilities of the Tablet PC to better capture what the students do and do not know. By using this solution, the students showed grater learning gains than a group following regular lectures. Similarly, Shelton et al. (2016) used formative assessment software with laptops and Tablet PCs, where students could write or draw their answers. However, they found no relation between the score in writing activities and general conceptual understanding. Another example is Chu (2014), who modified a previously validated web-based formative assessment software to be used with mobile devices. With this new setup, the students did not achieve significant learning when compared to a control group that did not receive technological support. These examples show a range of results when working with different software and hardware, thus suggesting that not only the implementation but also the technological platform may determine the results in terms of learning when using formative assessment.

The most predominant form of technology within education is currently the Tablet PC (McEwen & Dubé, 2016). These devices allow for different forms of interaction and are easy to use (Zhu et al., 2014), making them powerful teaching devices (Milman, Carlson-Bancroft, & Boogart, 2014; J.-Y. Wang, Wu, Chien, Hwang, & Hsu, 2015). An alternative technology is the Interpersonal Computer (IPC), which allows multiple users located in the same physical space to interact simultaneously. This interaction is achieved by using individual input devices (such as a mouse or keyboard), a single computer, and a shared display, such as a projector screen (Kaplan et al., 2009). The IPC is particularly attractive in developing countries due to the low entry cost (1 dollar per child per year) (Trucano, 2010). Furthermore, the IPC requires less technological support than a computer lab because there is only one machine and the users do not have direct access to the system's software (Alcoholado et al., 2016).

Considering the disparate effects of formative assessment reported by the literature, as well as the growing use of technology in the learning process, it is important to link the two by studying the impact of technology on formative assessment. Furthermore, given the range of available technologies, a study of two vastly different devices that are focused on two distinct socioeconomic groups may be of particular interest. Our second hypothesis, H2, therefore suggests the following: different technological platforms have a different impact on learning when following a strategy of self-paced learning using formative assessment.

Spelling was chosen as the subject for this study. This is because of the importance of spelling as a linguistic skill (McNeill & Kirk, 2014), as well as the link between spelling skills and achievement in writing (Graham & Harris, 2000). Specifically, proficiency in spelling allows for automatization of the text transcription skills that are required by the writing process (McCutchen, 2008). This frees cognitive resources and allows the generation of longer units of discourse (Ritchey et al., 2015). Furthermore, improvements have previously been achieved in learning using formative assessment to develop writing skills among native speakers (Graham et al., 2011; Horstmanshof & Brownie, 2013). As it is not the purpose of this study to analyze in detail how formative assessment is used for teaching spelling, see Graham, Hebert, et al. (2015) for a more in-depth analysis.

The aim of this study is to therefore, first, to develop a self-paced learning strategy using formative assessment that shows significant learning gains; and then, using the established strategy, show if different platforms have an impact in learning when using this strategy. Consequently, this study answers the following research question: “What impact do different technologies have on student learning when using formative assessment to teach spelling?”.

6.3. Methodology

An Integrative Learning Design framework (ILD) (Bannan-Ritland, 2003) was used in this study to guide a process of Design-Based Research (The Design-Based Research Collective, 2003). As Bannan-Ritland (2007) shows, ILD is a systematic integration of Design-Based Research for instructional design and software engineering. ILD was chosen for two reasons. Firstly, it was developed specifically for technological interventions in an educational setting (Yutdhana, 2005). Secondly, educational design research (such as ILD) provides an effective approach to support evidence-based claims in the field of educational technology (Reeves, 2015).

Based on this framework, the research was structured in two phases. Phase one, the aim of which was to prove the first hypothesis, focused on designing a self-paced learning strategy using formative assessment in order to improve student learning in spelling. Once the first hypothesis had been proven, the second phase was subsequently implemented. Based on the previously-validated self-paced learning strategy, the aim of this phase was to measure the impact on learning of two different technologies.

The students who participated in this study were native Spanish speakers in the first years of primary school. Both phases of the study were conducted in government-subsidized schools in Santiago, Chile. This type of school was chosen because they have the highest student enrolment figures in the country (MINEDUC, 2015) and are therefore more representative of the general population.

The ILD framework highlights the importance of avoiding the practice effect, by using phase-specific “data streams” (Bannan-Ritland, 2003). In order to avoid this effect, different groups of students were therefore used for each phase of the study. Given this, no comparison is made between the students’ scores from the two phases. The two participating schools (one for each phase) were chosen at random, as were the classes within each school.

6.3.1. Variables of study, instruments and data collection

The instruments were developed in three stages. Firstly, a piece of software was designed and developed to support self-paced learning using formative assessment for teaching spelling in Spanish. Subsequently, a set of instruments was developed to measure student learning. Finally, as a result of the iterative process within the ILD framework, the need arose to incorporate another instrument in order to record student behavior during the second phase.

A piece of self-paced learning software was developed to teach spelling in Spanish. Given that the level of knowledge among students can vary significantly (Tomlinson, 2014), the software included the entire contents of the curriculum established by the Chilean Ministry of Education for 1st to 6th grade (MINEDUC, 2012). Each topic was included as a separate level on the software, with the levels following the same sequence in which they are introduced to students during their primary education.

The exercises for each level were short-answer or multiple choice questions and were presented in the same way on both the Tablet PCs and the IPC (see Vasquez et al., 2016, for further details). An example of the IPC display is included in Figure 6.1, showing 20 students working simultaneously on the different types of existing exercises. Each exercise on the Tablet PC used the full 10" screen. In the case of the IPC, the whole class shared the display, with each child allocated a 480 x 216 pixel space (1/20 of the total screen). Even though the software is in Spanish, figures have been translated into English so as to facilitate the reader's comprehension of the exercises.

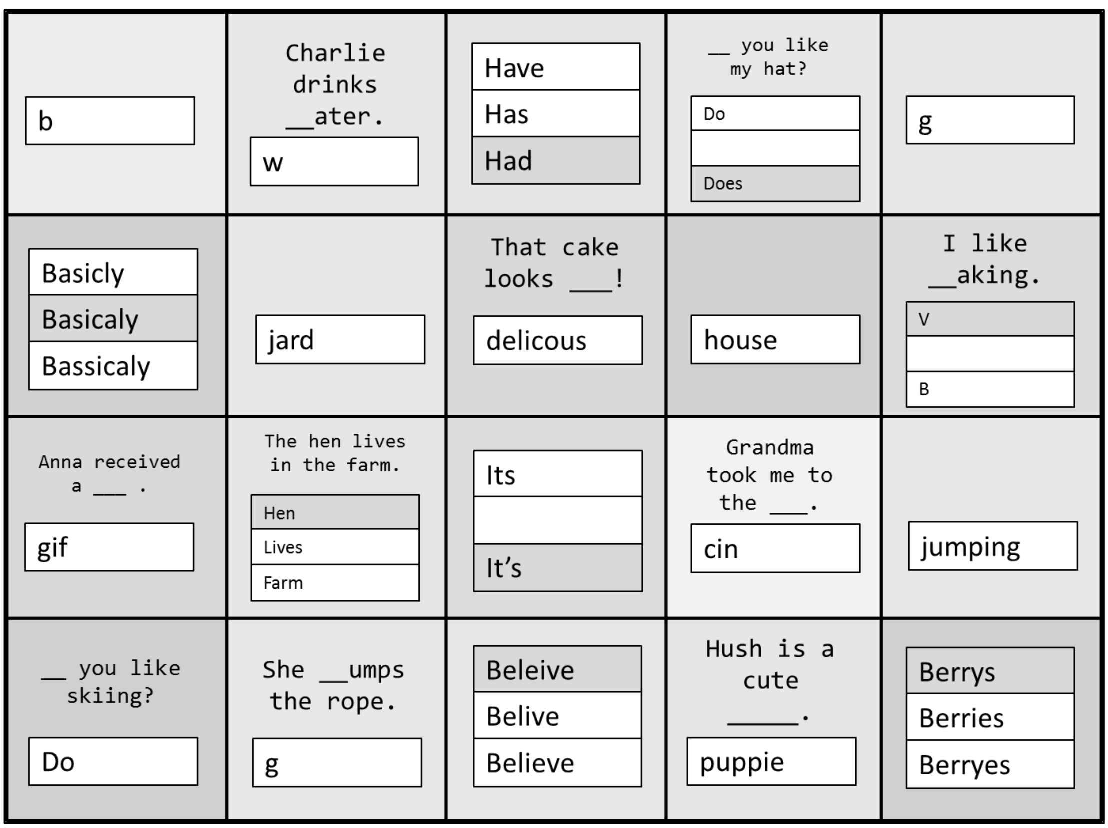


Figure 6.1 Software display (IPC version)

To assist formative assessment, the software generated a student progress report for the teacher at the end of each session. This report showed the level reached by each student by the end of the session and the answers which they gave (both correct and incorrect). Furthermore, for each question that was attempted, the report revealed how many students answered the question, detailing whether it was answered correctly or incorrectly (expressed as both a number and a percentage). With this information, the teacher could then identify the main areas of difficulty for the students and prepare the following class accordingly, focusing on the topics that most needed to be reviewed. Doing so provided the “moments of contingency” that are necessary for learning (Black & Wiliam, 2009), as well as defining the role of the teacher within the intervention (Urhahne et al., 2010).

Once the software was developed, the following variables were defined in order to assess achievement in spelling:

- Student knowledge before the intervention.
- Student knowledge after the intervention.
- Learning gains, i.e. the difference in student knowledge before and after the intervention.

To measure these variables, a written test (pre- and post-) was used to assess the students’ knowledge before and after the intervention (see sections 6.4.2 and 6.5.2 for a discussion of the intervention). Each question on the test was related to one of the levels on the software used in the study. This written test can be found in Vasquez et al. (2016).

Construct validity, content validity and criterion validity were all used to validate this instrument (J. D. Brown, 2000):

- Construct validity: The literature shows that performance in spelling increases with age during the early stages of literacy acquisition, as cognitive skills related to spelling develop during this period (Apel, Wilson-Fowler, Brimo, & Perrin, 2011; Vaessen & Blomert, 2013). Given this, a spelling test with construct validity should present a significant difference in the scores of students of different ages. An ANOVA between the scores of the students in 2nd and 3rd grade who took the test for this study reveals a significant difference in their scores, $F(1,88) = 79.08$, $p < .001$, thus validating the construct.
- Content validity: The test was developed by Language Arts teachers, based on the topics set by the Chilean Ministry of Education for teaching spelling in 1st to 6th grade (MINEDUC, 2012). In order to determine consistency in content validity in relation to the Chilean curriculum, the questions in the test were also analyzed by external Language Arts experts.
- Criterion validity: In Chile, the score obtained by the students on the national standardized test of Language Arts is correlated with their individual grades (Villalobos, Treviño, & Valenzuela, 2013). Similarly, for this study the Pearson product-moment correlation between the test scores and the students' grades was 0.58, thus suggesting a strong correlation (Cohen, 1992).

The same test was used in both phases of this study, with a Cronbach's alpha of 0.753. This reveals the internal consistency of the test in measuring ability in spelling, and demonstrates the reliability of the test.

The variables defined by Beserra, Nussbaum, Zeni, et al. (2014) were used to assess student behavior in the second phase of the study. These variables are divided into distraction indicators and concentration indicators:

- Distraction indicators:
    - Distraction without causing interruptions: the student stops paying attention but does not interrupt the work of others.
    - Interrupting classmates: the student becomes distracted and starts to interrupt their classmates' work.
    - Talking about an unrelated topic: the student stops working and talks with their classmates or the researchers about an unrelated topic.
- Concentration indicators
    - Talking about an unrelated topic: the student stops working and talks with their classmates or the researchers about an unrelated topic.
    - Talking about the software: the student asks for or provides help with the platform, or makes comments about the software.

Classroom observations were included in the second phase in order to measure the aforementioned variables of student behavior. A group of observers recorded student behavior during each of the sessions using technology during phase two. The observations were conducted in accordance with the guidelines established by Beserra et al. (2014). The external observers were paid university students and did not interact with the participants in the study. There was one observer for every 5 students. To standardize the way in which information was gathered, the observers were trained before conducting the observations. Furthermore, the observers were also rotated so as to avoid any bias. Due to an agreement with the participating school, the review sessions were not observed.

6.3.2. Data analysis plan

In phase one, descriptive statistics were first obtained for the results from the pre- and post-test. Following this, Levene's test and a t-test were then used to assess the homogeneity of means and variances for the participating groups. As the tests revealed homogeneity in both groups, an ANOVA was subsequently used to assess the difference between the groups' post-test scores. The learning gains in each group were measured using a t-test to compare pre-test and post-test results. Given the small sample size, a Wilcoxon signed-rank test was used as evidence for the findings obtained using the previous t-test. In order to deduce which students in the group benefited most from the intervention, correlations were made between post-test scores and learning gains. To assess the relationship between the number of exercises completed and learning, an ANCOVA was also made between pre-test scores and the final level reached on the software, as well as between post-test scores and the final level reached.

Descriptive statistics were obtained for the results from the pre- and post-test in phase two. Levene's test and a t-test were also conducted to assess the homogeneity of means and variances. As the conditions were met, an ANOVA was then used between the groups to assess the difference in post-test scores. A t-test was used for two different situations: firstly, within each group to assess learning gains and, subsequently, to measure the difference in the number of levels completed by each of the groups. Behavioural statistics were also recorded and compared for each group in every session.

6.4. Phase one: formative assessment versus traditional review classes

This section describes the details of the experiment that was carried out in order to validate the first hypothesis, H1: "A self-paced learning strategy using formative assessment, where the teacher plans customized review sessions based on information regarding student performance, produces significant learning gains when compared to a self-paced learning strategy with review sessions that follow the pre-defined order of the curriculum, as established by the local authority."

6.4.1. Context

A study was conducted in a government-subsidized school in Santiago de Chile. The study lasted for 6 sessions and spanned a period of 6 weeks. In 2015, 71% of the students enrolled in the school came from a vulnerable background (i.e. they were at risk of dropping out of school). Despite this, the school had been ranked as above-average on national standardized tests for Language Arts, when compared with similar establishments.

6.4.2. Experimental design

The objective of this phase was to study the impact on student learning when using a technology-assisted formative assessment strategy for the self-paced study of spelling.

A review of the literature revealed the following:

- (a) In Chile, there are huge differences between students in the same class, as the curriculum assumes that everyone learns at the same pace (Salazar, 2014). A system to assist learning in this context must therefore cover several years of the curriculum and allow students to progress at their own individual pace.
- (b) The role of the teacher must be clearly established when incorporating technology into the teaching practice (Urhahne et al., 2010).
- (c) Interventions in spelling have a greater effect on student learning when these take place in primary school (Goodwin & Ahn, 2013; Puranik & Alotaiba, 2012).

All of the participating students used the software that was designed for this study. As indicated in section 6.3.1, the software that was developed included topics for 1st to 6th grade spelling. The decision to do so was based on point (a) of the requirements obtained from the literature review for this phase. Following each session using the technology, the students attended a review class with their teacher.

Formative assessment was only used with the experimental group. In this case, the teacher used the information on student performance generated by the software in order to prepare the review class following each session using the technology. The teacher received a report on the topics that caused the students from that group most difficulty. For the control group, on the other hand, the contents of the review sessions were pre-defined at the beginning of the study (see section 6.4.3, for a discussion of the differences between the control and experimental groups in this phase). These sessions did not take into consideration the progress made by the students, nor the topics which they found most difficult when working on the self-paced software. To ensure that the teacher did not use the information from the experimental group with the control group, the class material for the control group was prepared beforehand by the researchers and followed the mapping established by the local authority. In both cases the review sessions were conducted by the regular class teacher, taking into consideration point (b) of the requirements obtained from the literature review for this phase.

In phase one, the software was implemented using Tablet PCs. Tablet PCs were chosen because they are widely used within education (McEwen & Dubé, 2016), as well as being easy to use for primary school students and teachers (Zhu et al., 2014).

6.4.3. Participants and procedures

Phase one featured 44 2nd grade students, aged between 7 and 8, as well as their Spanish teacher. This grade level was chosen because it is the first grade in which spelling is formally studied, while it also takes into consideration point (c) from the literature review for this phase.

The students came from two 2nd grade classes that were chosen from the same school at random. They were randomly divided into two groups: an experimental group of 17 students (8 boys, 9 girls) and a control group of 27 students (5 boys, 22 girls). As this phase took place near the end of the school year, many students did not attend the post-test session and thus had to be removed from the records. This explains the different number of participants in each group.

Both groups were taught by the same teacher, thus controlling for the effect of the teacher on student performance (Kane, Taylor, Tyler, & Wooten, 2011; Sanders & Rivers, 1996).

A 45-minute pre-test was conducted the day before the intervention began. Then, for the first session, the experimental group used the technology and the control group attended the first review class (with pre-defined contents). In the following sessions, the groups alternated between using the technology and attending review classes. In other words, they had three sessions using the self-paced learning software, interspersed with three review sessions. All of the sessions (review and technology-assisted) lasted for 20 minutes each. A 45-minute post-test was administered the day after the final session.

6.4.4. Results from Phase One: Formative Assessment versus Traditional Review Classes

Table 6.1 shows the descriptive statistics for the pre- and post-test results. Levene’s test reveals homogeneity of variances between the two groups, $F(1,42) = 1.87$, $p = .282$. On average, the control group scored 0.7 points higher on the pre-test than the experimental group. However, this difference is not statistically significant, t(39.04) = 0.43, p = .671; and therefore the two groups are comparable. Given this, the conditions for conducting an analysis of variance (ANOVA) are therefore satisfied.

Table 6.1 Descriptive statistics for the pre- and post-test in Phase One Descriptive statistics for the pre- and post-test in Phase One

	Control Group			**Experimental Group**		
	Pre-test	**Post-test**	**Difference between pre- and post-test**	**Pe-test**	**Post-test**	**Difference between pre- and post-test**
N (students)	27			17		
Minimum	20	19	-6	19	24	-1
Maximum	38	42	15	33	37	9
Average	26.814	29.074	2.407	26.176	30.176	4.058
Std. Dev.	5.393	5.737	5.408	4.405	4.202	2.794

The ANOVA for the difference in post-test results between the experimental group and control group reveal that there is no evidence to suggest that this difference is significant, F(1,42) = 0.47, p =.498.

The results of a paired t-test for the difference between the pre- and post-test results reveal a significant increase in learning for both groups: control, t(26) = 2.19, p = .037, and experimental, t(16) = 5.83, p < .001. Nevertheless, the non-parametric Wilcoxon signed-rank test only reveals learning gains for the experimental group, V = 134.5, p = 0.0006, g = 0.907; and not for the control group, V = 197, p = .073, g = 0.399.

A Pearson product-moment correlation analysis reveals a moderate, positive correlation between the post-test scores and the pre-post difference in the control group ($r = .53$, $p = .004$). This correlation is not present in the experimental group ($r = .27$, $p = .303$).

Finally, an ANCOVA analysis shows that the number of levels completed on the software is significantly related to the post-test score, $F(1,38) = 7.52$, $p = .009$. This relationship is not present when considering the number of levels completed on the software and the pre-test score, $F(1,38) = 0.22$, $p = .639$.

6.4.5. Lessons Learned from the Phase One Experiment

The results from this phase suggest that a technology-assisted, self-paced learning strategy using formative assessment produces significant learning gains for students who receive targeted review sessions that cater to their specific needs. As the results from the Wilcoxon signed-rank test show, significant learning gains are not achieved when combining the same technology with traditional review sessions, i.e. where the contents follow the pre-defined order of the curriculum established by the local authority and do not take into account the students' specific needs.

The correlation between the post-test results and learning gains suggests that the students in the control group who performed better on the post-test also achieved a greater improvement in learning by the end of the study. Therefore, the students in the control group with greater knowledge of the topics covered in the study benefited more from the traditional review method.

The ANCOVA for both groups shows that the post-test results were significantly related to the levels completed on the software. Given that the same analysis did not reveal a link between pre-test scores and the numbers of levels completed, this suggests that the skill practice led to improved performance on the post-test.

One of the main limitations of this phase is the scope of the results. There are two factors that may help more students experience significant learning gains. Firstly, the technology (i.e. the self-paced learning software) was only implemented using Tablets. As some technology platforms are better suited than others for certain tasks (Koehler & Mishra, 2009), the effect on learning when using other devices for formative assessment must therefore be explored. Secondly, it is important to consider that students within a classroom are at different levels of development (Tomlinson, 2014). This should be reflected in their work with the self-paced learning software.

Another limitation of this phase is related to the small sample size. Because of this, a non-parametric test had to be used in order to analyze the results. This resulted in a lower confidence level for making quantitative statements about the actual differences between the experimental and control groups.

6.5. Phase two: formative assessment using tablets versus formative assessment using an interpersonal computer

This section describes the details of the experiment that was conducted in order to validate the second hypothesis, H2: “Different technological platforms have a different impact on learning when following a strategy of self-paced learning using formative assessment.”

6.5.1. Context

This second phase was also conducted in a government-subsidized school in Santiago de Chile and lasted for 6 sessions, spanning a period of 6 weeks. The school that participated in the second phase was not the same as the school that participated in the first phase, although their socioeconomic characteristics ensure that they are comparable. In 2015, 75% of the students enrolled in the school came from a vulnerable background (i.e. they were in danger of dropping out of school), while the school had also achieved above-average scores on national standardized tests for Language Arts, when compared to similar establishments.

6.5.2. Experimental design

Given the results from phase one, the objective of the second literature review was to find evidence to guide the development of the previously-validated learning strategy and ensure that all students can experience an improvement in learning. The findings are summarized as follows:

- (a) Different levels of improvement in learning are reported when using formative assessment in primary education (R. E. Bennett, 2011; Briggs et al., 2012; Coffey, Hammer, Levin, & Grant, 2011). Furthermore, it is reported that some technologies are better suited to certain tasks than others (Angeli & Valanides, 2009; Koehler & Mishra, 2009). This may affect learning when implementing different technology-assisted teaching strategies.
- (b) Placements tests can be used to gauge a student's initial level of knowledge (Nielson, 2011; Yang et al., 2013). For technological interventions using self-paced learning, this allows the more advanced students to make better use of the available time by starting at a higher level, in accordance with their prior knowledge.
- (c) Classroom observations are needed to assess integration when using technology in the classroom (Bielefeldt, 2012). One important attribute to note during observations is student engagement.

Considering this, the objective of the second phase was to measure the impact on learning of two different technologies, using the same formative assessment strategy described in phase one.

Given point (a) of the requirements obtained from the literature review for this phase, the study was conducted in two groups; one using Tablet PCs and the other using an IPC, adapting the software accordingly (see section 6.5.3, for details regarding the participants in both groups). The progress reports generated after each session by both technologies were used to prepare the review sessions for each group.

Furthermore, given point (b) of the requirements obtained from the literature review for this phase, the pre-test was used as a placement test (Nielson, 2011; Yang et al., 2013) so that the students started working from a level that was in line with their prior knowledge. In this sense, the students did not necessarily start from the most basic level and were therefore able to make better use of the time that was available.

This phase followed the same procedure as the procedure described for the experimental group in phase one. The differences were that each student was placed at a different starting level depending on their performance on the pre-test, as well as the use of two different technology platforms to assist the self-paced learning software.

Considering point (c) of the second literature review, student behavior was also recorded during the technology sessions in this phase. This information could then be used as evidence to support H2: "Different technological platforms have a different impact on learning when following a strategy of self-paced learning using formative assessment."

6.5.3. Participants and procedures

The study featured 46 students from two 3rd grade classes, aged between 8 and 9. It was decided to work with 3rd grade students in this phase as this is when the participating school began to formally teach spelling.

The children were randomly divided into two groups (Tablet and IPC). To control for any effect that the students' class may have had on the results, students from both classes were included in each group. Both groups comprised 23 students. The Tablet group featured 13 girls and 10 boys, while the IPC group featured 8 girls and 15 boys. As in phase one, both groups of students were taught by the same teacher in order to control for the effect of the teacher on learning (Kane et al., 2011; Sanders & Rivers, 1996).

As in phase one, the students completed a 45-minute pre-test the day before the intervention began. Both groups (Tablet and IPC) participated in three sessions using technology, interspersed with three review sessions based on formative feedback, of 20 minutes each. A 45-minute post-test was taken by both groups the day after the final session.

6.5.4. Results from phase two: formative assessment using tablets versus formative assessment using an interpersonal computer

Based on the data from Table 6.2, Levene's test reveals homogeneity of variances between the groups, $F(1,44) = 0.03$, $p = .856$. This table also shows that the groups started with a similar score on the pre-test, $t(43.99) = 1.72$, $p = .09$, thus making them comparable. These results can therefore be studied using an ANOVA.

By the end of the study, the difference in post-test scores between the Tablet and IPC groups was not significant, $F(1,44) = 0.74$, $p = .394$. However, the difference between the pre- and post-test scores for the students in the Tablet group was statistically significant, t(40.66) = 2.05, p = .047, Cohen's d = 0.603. This was not the case for the students in the IPC group, t(43.88) = 0.84, p = .403.

If all of the students who participated in 2 or more of the sessions (regardless of whether or not they took the pre- and/or post-test) are included in the analysis, there is a significant difference between the number of levels completed by each group, t(59.80) = 2.45, p = .01. In this case, the number of levels completed is taken as the final level reached by a student, minus their starting level. This shows that the group using Tablets managed to make more progress in the software.

Table 6.2 Descriptive statistics for the pre- and post-test in Phase Two

	Tablet Group			**IPC Group**		
	Pre-test	**Post-test**	**Difference between pre- and post-test**	**Pre-test**	**Post-test**	**Difference between pre- and post-test**
N (students)	23			23		
Mínimum	11	15	-2	13	13	-4
Maximum	24	26	9	25	26	8
Average	17.652	20.130	1.826	19.391	19.478	0.826
St. Dev.	3.432	2.833	2.639	3.407	2.936	2.724

According to the observations made during the technology sessions, the students in the Tablet group participated more actively than the IPC students. This is demonstrated by the greater number of positive events recorded by the observers (263.8 observations per session for the Tablet group versus 114 for the IPC group). Although the two groups were selected at random, the class teacher confirmed that each group comprised students with similar characteristics. This therefore suggests that the students' behavior when using the different platforms can be compared.

Table 6.3 reveals the evolution in student behavior for each session. The data is standardized per student (the ratio between the number of observations recorded for each variable and the number of students present). The results show that in both groups the students rarely interrupted one another or talked about unrelated topics. However, the number of such events is slightly lower in the case of the IPC group. The number of distractions without interrupting other students decreases across the sessions in both groups, and is greater for the Tablet group. The number of occasions when the students talk about the topic of the session remains relatively constant for both groups, although it is always greater among the Tablet group. The number of times that the students talk about the software in the Tablet group is greater at the beginning of the study and decreases across the sessions, while the opposite is true for the IPC group.

Table 6.3 Evolution of student behavior (number of observations per student) for each session, for both groups in Phase Two

	Session 1		**Session 2**		**Session 3**	
	Tablet	**IPC**	**Tablet**	**IPC**	**Tablet**	**IPC**
Interrupting	0.47	0.11	0.06	0.03	0.40	0.00
Distraction without causing interruptions	2.63	0.66	1.56	0.23	0.12	0.07
Talking about another topic	0.68	0.05	0.53	0.00	0.64	0.00
Talking about the topic of the session	3.79	0.79	3.39	0.54	4.12	1.13
Talking about the software	2.74	0.39	1.75	0.72	0.76	2.13

6.5.5. Lessons learned from the phase two experiment

Significant improvements in learning were observed among students using Tablet PCs in phase two (Table 6.2). However, this was not the case for students using the Interpersonal Computer. The software records revealed that students in the Tablet group made greater progress on the software by completing more levels than the students in the Interpersonal Computer group. Given this, the students in the Tablet group therefore covered more of the curriculum than the students in the IPC group. It should be noted that the groups' initial level of knowledge was comparable (see Levene's tests and t-test in section 6.5.4) and that both groups received the same type of targeted review sessions. It can therefore be suggested that the technology platform that was used had an effect on the students' progress in the software and, subsequently, on the number of topics that they covered.

It is not possible to use an ANCOVA to analyze the final level reached in the software for this phase. As the pre-test was used to define the students' starting level, the pre-test score cannot be considered as being independent of the final level reached on the software.

The classroom observations conducted during this phase (Table 6.3) showed that students from the Tablet group participated more actively than students from the IPC group, even though the teacher reported that the Tablet and IPC groups comprised students with similar behavioral characteristics. The observations also revealed that students from the Tablet group started to talk less about the software and more about the topic of the session as the sessions progressed. The opposite was true for the IPC group. Given this, it is possible to conclude that the platforms have properties that foster certain behavior among students. Phase two therefore revealed that there are certain features of Tablet PCs that favor learning in this context.

Within the limitations of this phase, it is worth noting that Tablets are aimed at individual work, while the IPC is aimed more at cooperative/collaborative work as it uses a shared display (Nussbaum, Alcoholado, & Büchi, 2015). The impact of the devices on learning may therefore be related to the type of learning strategy that is employed. For this study, the strategy was based on individual work and, therefore, Tablets may have been better suited to the teaching objective. It remains as future work to study the effect of the IPC (or other shared screen technologies) on strategies that feature group work.

6.6. Synthesis and discussion

Table 6.4 shows a summary and compilation of the two phases of this study.

The results of this study are consistent with the findings by Tomlinson (2014) regarding the need to differentiate the class and contents in order to adapt to a heterogeneous classroom. The first phase revealed that significant learning was achieved through a strategy of self-paced learning using formative assessment, where the teacher provides targeted review sessions. This may be explained by the fact that formative assessment identifies what the students do (and do not) know and focuses the teacher's work on the students' specific needs (Luckin et al., 2012; Organisation for Economic Co-operation and Development & Centre for Educational Research and Innovation, 2008). Students with greater knowledge of the topic benefited more from the traditional review sessions in the group that used the self-paced learning software without formative assessment. This may be explained by the fact that the teacher delivered the content at a pace that could be followed by the more advanced students, without focusing on the difficulties faced by the remaining students.

Table 6.4 Summary of the study

Criteria	Phase 1	Phase 2
Objective	Develop and test a self-paced learning strategy with formative assessment that produces significant learning gains in spelling.	Evaluate the effect on learning of using different technological platforms to assist the self-paced learning strategy with formative assessment developed in phase 1.
Experimental design	Control group uses self-paced learning software and receives review classes that follow the order of the curriculum established by the local authority. Experimental group uses self-paced learning software and receives review classes that are prepared based on the information provided by the progress report generated by the software.	All students use the self-paced learning software developed in phase 1 and receive review classes based on the information contained in the progress report. The pre-test is used as a placement test in order to define the starting level in the software. Tablet PCs (personal device) are used by one group and an Interpersonal Computer (shared screen) is used by the other.
Variables to measure	Knowledge of spelling before and after the intervention.	Knowledge of spelling before and after the intervention. Student behavior (distraction and concentration).

Criteria	Phase 1	Phase 2
Instruments used	Pre- and post-test Self-paced learning software	Pre- and post-test Self-paced learning software Observation rubric
Number of sessions	3 sessions using the self-paced learning software interspersed with 3 review sessions.	3 sessions using the self-paced learning software interspersed with 3 review sessions.
Main finding	A self-paced learning strategy using formative assessment encourages learning among the students who are targeted by the review sessions.	Certain characteristics of a technology platform make it better suited than others to assist a particular learning strategy.

The second phase of the study revealed that when following the same strategy, students using self-paced learning with Tablets experienced significant learning gains, which was not the case for students using the Interpersonal Computer (IPC). The fact that the children's interaction with the Tablets is very similar to a physical notepad may have aided the process of teaching spelling when using this platform (Neumann & Neumann, 2013).

Based on this study, a series of guidelines can be developed for designing formative assessment strategies. When teaching spelling to native speakers in primary school, it is recommended doing so in two differentiated stages in order to improve learning. The first stage must feature self-paced exercises, starting from a level that is consistent with each student's prior knowledge. The second stage refers to review classes, which must target the students' specific needs and address the heterogeneity of the classroom (Tomlinson, 2014).

Technology can help with the implementation of formative assessment strategies. It is therefore important to bear in mind the relationship between the two. This result is in line with the evidence collected by García et al. (2016). In this case, the aforementioned authors observed that using technology for supporting formative assessment produces different effects on learning. Similarly, the examples presented in the introduction show divergent results depending on the implementation and the hardware that was used. This study explains these results by demonstrating that the platform that is chosen to support a formative assessment strategy must be in line with the teaching objectives, as certain technologies are better suited than others depending on the type of activity (e.g. cooperative/collaborative or individual work).

6.7. Conclusions

In terms of the study's initial objectives, there was evidence to reject the null hypothesis for Hypothesis 1, i.e., there were differences in learning when employing a self-paced learning strategy using formative assessment, when compared to using the same strategy without formative assessment (targeted review). Also, there was evidence to reject the null hypothesis for Hypothesis 2. This result showed that Tablets produced a significant difference in learning for the formative assessment strategy designed for this study.

In summary, and in response to the research question "What impact do different technologies have on student learning when using formative assessment to teach spelling?", we can conclude that the technology platform that is used as part of a formative assessment strategy has an impact on learning. Two elements must be taken into consideration when designing a technology-assisted, formative assessment strategy. Firstly, the formative component (i.e., the review class and exercises) must respond to the students' specific needs. Secondly, the strategy must be assisted by a technology platform that fosters student behavior that is well-aligned with the objective of the teaching strategy. These results deepen the findings by Tomlinson (2014) and García et al. (2016), showing how instruction differentiation (i.e., self-paced learning and review classes) and technological support determine the impact on learning when using formative assessment.

One of the limitations of this study is its scope. Both phases of the study (phase one and two) were based on the same topic (spelling in Spanish for native Spanish-speaking children aged between 7 and 9); they both lasted for 6 weeks; and they both consisted of 3 sessions using technology, interspersed with 3 review sessions. Even though non-parametric statistics were used, the sample size in both studies may also have affected the confidence level of the results.

These findings also have to be validated by other formative assessment practices. For example, using strategies that foster collaborative work or that consider formative methods other than lecture-based classes. Additional factors that may influence the impact of technology on learning (such as gender or familiarity with the device used) should also be considered.

It remains as future work to conduct a more extensive study covering different topics and a wider range of ages. Furthermore, a larger sample size large would strengthen the conclusions presented in this study and provide new insights into these results. Finally, the way in which other technologies, such as smartphones or laptops, affect our results should also be studied.

7. CONCLUSIONS AND FUTURE WORK

In this work, the following research questions were asked:

1) What is the impact on learning when a teacher uses objective information about student knowledge to teach a review lesson on spelling?
2) To improve spelling among native Spanish speakers in primary school, how can a formative assessment strategy with self-paced learning be implemented?
3) What software and hardware architecture allow a Shared Worskpaces implementation for co-located SDG in classroom settings?
4) What impact do different technologies have on student learning when using formative assessment to teach spelling?

To address these questions, the Design-Based Research methodology guided the implementation of five experiences with primary school students of low-income schools in Santiago, Chile with two main objectives. Firstly, to develop an instructional strategy that takes into account the different paces at which students learn in the classroom. Secondly, to understand how technology can affect learning.

According to these objectives, the results of this work can be summarized as follows:

1) Significant learning gains can be obtained when using self-paced learning software to support formative assessment with differentiated review lessons according to the students' ability. This is particularly beneficial for struggling students.

2) The choice of a technological platform to support a learning strategy is not neutral, and the hardware complexity does affect learning outcomes.

Given this, the work presented in this thesis provides evidence to show that the technology used to support formative assessment impacts learning, when each student can practice at their own pace and receive targeted feedback. It also highlights the relevance of choosing an appropriate starting level for the self-paced study and feedback according to the students' academic needs. Besides, a software and hardware architecture to support whole-class interactivity is proposed, showing the importance of handling the personalized output appropriately so to provide a smooth user experience.

To generalize the results presented in this thesis, it remains as future work to validate these results in a larger scale, in a longer experience and with students from upper grades. It is also important to note that these studies were carried out using formative assessment to teach spelling, and that technology is not neutral and can be better suited to certain tasks than to others (Koehler & Mishra, 2009). It would therefore be important to research how the technological support affects the learning outcomes when using other teaching strategies in different subjects. Regarding the feedback provision, it is of interest to study if splitting the class in halves for the targeted review produces social segregation as pointed by Tomlinson (2015). Finally, giving the evolving nature of technology, it is interesting to implement the proposed SDG architecture using the new devices that are now emerging in the classrooms, like the micro:bit and the Raspberry Pi computers (Ball et al., 2016).

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APPENDICES

APPENDIX 1: TOPICS COVERED BY THE CHILEAN MINISTRY OF EDUCATION FOR SPELLING IN PRIMARY SCHOOL

Table A.1: Curricular contents for 1st to 6th grade spelling and how they are covered by the software

Topic	Type of exercise	Type of question
1. Associating the sound of a letter with the corresponding letter	Written	Audio
2. Recognizing the first letter of a word	Multiple choice	Text
3. Recognizing the sound of a letter within a word	Multiple choice	Text
4. Counting the syllables in a word	Multiple choice	Text
5. Identifying and counting vowels in a word	Written	Text
6. Identifying and counting consonants in a word	Written	Text
7. Identifying and counting words in a sentence	Multiple choice	Text
8. Rhyme	Multiple choice	Audio
9. Subject-verb agreement	Multiple choice	Text
10. Use of c in words with ce, ci, se and si	Multiple choice	Text
11. Use of the letter q	Written	Audio
12. Use of the letter g	Multiple choice	Text
13. Use of the letter r	Multiple choice	Text
14. Identifying the ‘r’ sound in a word	Multiple choice	Audio
15. Classifying nouns	Multiple choice	Text
16. Identifying lower and upper-case letters	Written	Text
17. Use of exclamation and question marks	Multiple choice	Text
18. Dictation of words	Written	Audio
19. Identifying the plural form of words ending in z and not ending in z	Written	Text
20. Use of g and j in words with ge, gi, je and ji	Multiple choice	Text

Topic	Type of exercise	Type of question
21. Identifying the diminutive form of a word	Multiple choice	Text
22. Dictation of phrases	Written	Audio
23. Use of b and v	Written	Text
24. Correct use of mb, mp, nv in a word	Multiple choice	Text
25. Use of mb, mp, nv combinations	Written	Text
26. Use of the letter h	Multiple choice	Text
27. Correct use of *ay*, *hay* and *ahí* in a phrase	Multiple choice	Text
28. Identifying words with aguda (final syllable), grave (penultimate syllable), esdrújula (antepenultimate syllable) and sobreesdrújula (fourth, fifth & sixth from last syllable) accents	Multiple choice	Text
29. Placing accents on aguda, grave, esdrújula and sobreesdrújula words	Multiple choice	Audio
30. Identifying synonyms	Multiple choice	Text
31. Identifying opposites (antonyms)	Multiple choice	Text
32. Dictation of sentences	Multiple choice	Audio
33. Correct use of c, s, z in a word	Multiple choice	Text
34. Identifying the correct use of the accents in written Spanish	Multiple choice	Text
35. Identifying dipthongs	Multiple choice	Text
36. Correct use of commas in explanatory phrases	Multiple choice	Text
37. Dictation of sentences II	Multiple choice	Audio
38. Writing using verbs *haber*, *tener* and *ir*	Multiple choice	Text
39. Correct use of commas with connectors	Multiple choice	Text
40. Placing the accent on pronouns in interrogative and exclamatory phrases	Multiple choice	Text
41. Dictation of sentences III	Multiple choice	Audio

APPENDIX 2: SOFTWARE REPORT EXAMPLE

Table B.1 shows an example of a report generated by the system, which corresponds to a summary of the students' performance for each session. Each field in the table shows the following:

- ID: The ID number used to identify each exercise in the system.
- Text: The text that the system reveals to the student when the exercise is introduced.
- Instruction: The audio provided to the student when the exercise is introduced.
- Students who answered incorrectly: the number of students that answered an exercise incorrectly 3 times in a row.
- Total number of students who answered: the total number of students that attempted the exercise.
- Percentage of incorrect answers: the number of students that answered incorrectly, divided by the total number of students that attempted the exercise, multiplied by 100.
- Incorrect answers: the actual incorrect answers given by the students. This example only includes a few of the answers that were given.

Table B.1. Example report: summary of student's performance

Id	**Text**	**Instructions**	**Students who answered incorrectly**	**Total number of students who answered**	**Percentage of incorrect answers**	**Incorrect answers**
464	Friend	How many consonants are there in the following word?	12	13	92.30	-“Two consonants” - “Six consonants”
588	Snails feed on lovely *leaves*	Choose the correct part of speech for the highlighted word.	12	13	92.30	- “Adjective” - “Verb”
744	Opo__um	Choose the correct way of spelling the word	12	13	92.30	- “Opozum” - “Oposum”
530	Pet	How many consonants are there in the following word?	11	12	91.66	- “One consonant”

Figure B.1 shows the level reached by each student at the end of a self-paced learning session, identifying the students by name (not shown in Figure B.1). This shows the topics covered by each student, as well as indicating their respective levels of progress.

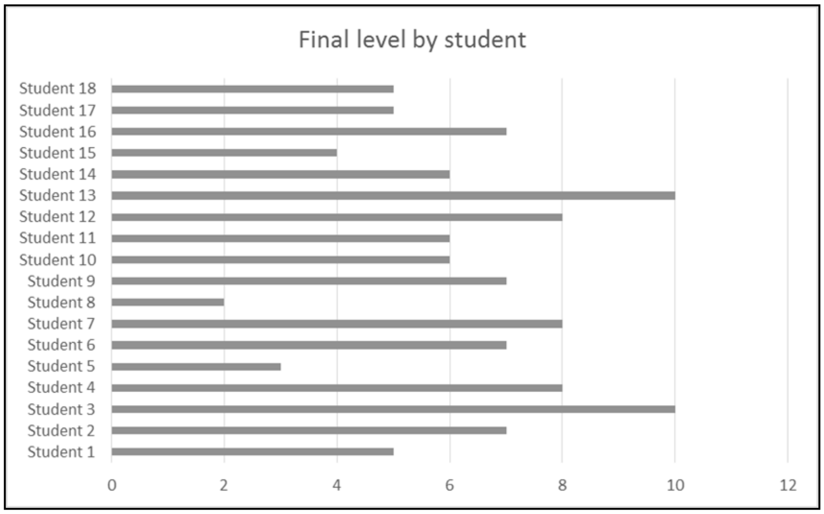

Figure B.1. Example report: level reached by the students

Figure B.2 shows the percentage of incorrect answers given at each level. The teacher can use this information to identify the topics that are causing the students most trouble and focus their review sessions on these topics.

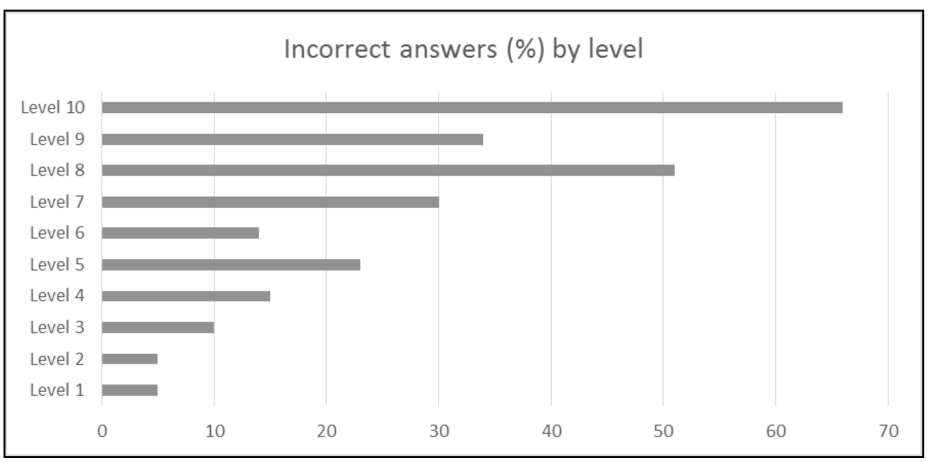

Figure B.2. Example report: percentage of incorrect answers