PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
ESCUELA DE INGENIERIA

SPECIFICATION, DESIGN AND FORMALIZATION OF COLLABORATIVE PEDAGOGICAL ACTIVITIES IN THE CLASSROOM: THE CASE OF LANGUAGE LABORATORY

JUAN FELIPE CALDERÓN MAUREIRA

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

Advisor:
MIGUEL NUSSBAUM

Santiago de Chile, January, 2015

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To my wife, parents and children.

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ABSTRACT

Developing learning applications for classroom work must have an adequate pedagogical design, as well as an appropriate technical design that supports learning aspects. In the literature there are many deficiencies in previous research, both in the pedagogical/technical design plan, as well as in its corresponding validation.

Regarding the pedagogical design, in general, studies simplify and idealize application use scenarios, which do not consider the existing dynamism in the classroom. In this dynamism, the teacher's role is crucial because not only is he an expert at teaching, but he also controls the classroom's flow of work, thus verifying the students' learning. Therefore, teachers are simple executors of a learning script without having a control that would allow them, when these scenarios are idealized, e.g. to add or modify in runtime tthe tasks that students must perform. On the same line, another observed aspect is the little use of technical resources already available at educational institutions where the learning scenarios proposed in the literature take place. In general, technically equivalent system resources (e.g. mobile devices with the same technical characteristics) are proposed.

In the field of validating these pedagogical and technical designs, we can also see some deficiencies. From an educational point of view, applications for classroom work are described and analyzed through exploratory studies, without making any studies that can assure their pedagogic validity. From a technical point of view, applications generally have weak and non-analytical specifications, without experimentation or formalization.

Dealing with these problems, in this thesis we propose defining the design and implementation of a learning activity through an incremental work methodology. First, we will deal with the need to create and validate a pedagogic scenario through the design of a collaborative language laboratory using a quasi-experimental methodology. As a result of this study, made on an elementary Chilean school, we observed that a collaborative language laboratory presented better results than an individual one in pronunciation and listening. We also observed the development of specific aspects of collaborative learning, such as communication and coordination among students.

Afterwards, in the following increment, and using the previously validated pedagogic scenario, we propose an architecture that can support a better use of technological resources. This is achieved through mechanisms of resource sharing and with robustness characteristics when facing changes in the environment where the activity is developed. This is validated through a study made in collaboration with international researchers from Sweden and Chile, using possible real execution scenario simulations. With this we proved that it is possible to build this type of architecture, attending to the requisites with which it was designed through a multi-agent system, and a self-adaptation system.

Finally, in the last increment, the dynamic changes in-classroom problem is incorporated under a formal approach. This approach allows specifying a flexible pedagogic scenario, where the teacher can make changes in execution time, which are validated in real time using specifications based on flexible workflows and petri-nets concepts. As a result, we obtained the formal modeling of the problem, the creation of a methodology that allows designing this type of learning activity, as well as an integrated mechanism of validation when facing changes, evaluated through model-checkers.

Based on the aforementioned results, we can conclude that it is possible to design technological applications for the classroom that consider the requisites of collaborative learning, resource sharing, robustness in environment changes, and real time dynamism of learning scenarios. The learning validation must go hand in hand with the technical validation, where neither is more important than the other, because both deal with different problems. The choice of a type of experimentation and validation will depend on the requisites hoped to analyze.

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PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
ESCUELA DE INGENIERIA

ESPECIFICACIÓN, DISEÑO Y FORMALIZACIÓN DE ACTIVIDADES PEDAGÓGICAS EN EL AULA: EL CASO DEL LABORATORIO DE IDIOMAS.

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JUAN FELIPE CALDERÓN MAUREIRA

RESUMEN

El desarrollo de aplicaciones educativas para el trabajo en sala de clase debe contar con un adecuado diseño pedagógico, así como también con un adecuado diseño técnico que sustente los aspectos educacionales. En la literatura se observa que existen varias deficiencias y falencias en los estudios realizados, tanto en el planteamiento del diseño pedagógico/técnico, como también de su correspondiente validación.

Respecto del diseño pedagógico, los estudios en general simplifican e idealizan los escenarios de uso de sus aplicaciones, los cuales no consideran el dinamismo existente en una sala de clases. En este dinamismo es crucial el rol del profesor, pues no solamente es un experto pedagógico, sino que también controla el flujo de trabajo en la sala de clases, verificando el aprendizaje de sus estudiantes. Por esta razón, cuando estos escenarios son idealizados, los profesores simplemente son ejecutores de un script pedagógico no teniendo un control que les permita, por ejemplo, añadir o modificar las tareas que deben realizar los alumnos en tiempo real. En esta misma línea, otro aspecto observado es el poco aprovechamiento de los recursos técnicos ya existentes en las instituciones educacionales donde se implementan los escenarios pedagógicos propuestos en la literatura; en general se proponen sistemas que tienen recursos técnicos equivalentes (p. ej.: dispositivos móviles con las mismas características técnicas).

En el campo de la validación de estos diseños pedagógicos y técnicos, se observan también ciertas deficiencias. Desde un punto de vista educacional, las aplicaciones para el trabajo

en sala de clase son descritas y analizadas mediante estudios exploratorios, no existiendo mayormente estudios que aseguren su validez pedagógica. Desde un punto de vista técnico, las propuestas de aplicaciones educativas cuentan en general con especificaciones débiles y no analíticas, sin experimentación o formalización.

Atendiendo estas problemáticas, en esta tesis se propone la definición del diseño e implementación de una actividad pedagógica, mediante una metodología de trabajo incremental. Primero, se atiende la necesidad de crear y validar un escenario pedagógico, mediante el diseño de un laboratorio de idiomas colaborativo utilizando una metodología cuasi-experimental. Como resultado de este estudio, realizado en estudiantes de enseñanza básica en un colegio chileno, se obtuvo que un laboratorio de idiomas colaborativo presenta mejores resultados que uno individual en pronunciación y listening. También se observó el desarrollo de aspectos específicos al aprendizaje colaborativo, tales como la comunicación y coordinación entre estudiantes.

Luego, en el incremento siguiente y utilizando el escenario pedagógico previamente validado, se propone una arquitectura que sustente un mejor aprovechamiento de los recursos tecnológicos. Ello se logra mediante mecanismos de resource sharing y con características de robustness ante cambios en el entorno donde se desarrolla la actividad. Ello es validado mediante un estudio realizado de forma conjunta en una colaboración internacional con investigadores de Suecia y Chile, utilizando simulaciones de posibles escenarios de ejecuciones reales. Con ello se mostró que es posible la construcción de una arquitectura de este tipo, atendiendo los requisitos con los cuales fue diseñado mediante el uso de un sistema multi agente, y el mecanismo de self-adaptation.

Finalmente, en el último incremento, se incorpora la problemática del dinamismo en la sala de clases, bajo un enfoque formal. Este enfoque permite especificar un escenario pedagógico flexible, donde el profesor puede introducir cambios en tiempo de ejecución, los que son validados en tiempo real usando especificaciones basadas en los conceptos de workflows flexibles y petri-nets. Como resultado se obtuvo la modelación formal de la problemática, la creación de una metodología que permite el diseño de actividades pedagógicas de este tipo, como también un mecanismo integrado de validación ante cambios, evaluado mediante model-checkers.

A partir de lo anterior es posible concluir que es posible diseñar aplicaciones tecnológicas para la sala de clases que consideran los requisitos de aprendizaje colaborativo, resource sharing, robustness ante cambios en el ambiente, y dinamismo en tiempo real de los escenarios pedagógicos. La validación pedagógica debe ir de la mano de la validación técnica, donde ninguna es más importante que la otra, pues ambas abordan problemáticas distintas. La elección de una forma de experimentación y validación dependerá entonces de los requisitos que se esperan analizar.

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I. INTRODUCTION

The development of technological applications for classroom work has been dealt with from different perspectives in literature: from focusing on the learning aspects, going through others focused on the engineering aspects behind those applications. However, the research performed in this thesis has as a main subject the study of students who use their application, considering variables that measure learning, social behavior and user experience.

In the following subsections we present the analysis and the formulation of the problem, with its corresponding theoretical basis. Therefore, research questions, hypothesis, objectives and their corresponding results are presented.

I.1 Basis of the problem

In order to formulate the problem that this thesis seeks to solve, we used a revision made by the author of this thesis that presents a taxonomy classifying papers in the area of technology applied on education considering 263 papers. These papers were analyzed according to the knowledge area, the intervention's educational level, the technological platforms used, the type of interaction between students, the curriculum integration, the time of intervention, the type of study, the analyzed variables, and the geographic location. Used protocols, paper selection and analysis are specified at appendix B; also, references of analyzed papers are in appendix C. From these papers, the following issues were observed:

a) On the research methodology used

   In general, quantitative methodologies are used to measure students' learning and the engineering aspects of the applications (e.g. user experience engineering). Qualitative methodologies are used to analyze the students' social behavior and the teacher's work. The less analyzed variable is the teacher's work defined as participation in design, implementation and adaptation of pedagogical activity (Cviko, McKenney & Voogt, 2013). This aspect is observed in few works on this review (21 of 263), which consist of qualitative analysis: interventions of one or two teachers, interviews and follow-up.

b) On the investigation's scope

The observed investigations are, in general, exploratory studies (183 of 263) with small and limited scenarios. Although they incorporate content that is in line with the students' curriculum, they are not coordinated with regular classes, necessarily. This fact limits the power of generalization which an experiment or quasi-experiment can have.

c) On the research objective

As it was mentioned before, it is possible to observe some tendencies in the revised papers, according to what experimental variables are defined (one or more than one per work): those focused on pedagogical validation (155 of 263), those focused on the students' social behavior (115 of 263) and those that deal with the engineering aspects behind the presented applications (154 of 263). The latter are the ones that present the weakest aspects:

- Focus on user experience, there is no analysis of other engineering aspects of the software: lacking non-functional requisites and system quality and architecture definition. In general, the architectures are described, but not validated with the requisites that define them.
- Lack of more precise definitions in architectures, without a formal definition of the processes and requisites that they are fulfilling.

d) On the technological platforms used

The activities are generally mono-modal, associated with only one hardware platform and environment (234 of 263). The activities that run on PCs working in classrooms and virtual environments indistinctly are used for individual (e.g. using virtual worlds) and group-work (e.g. shared devices). However, the mobile platforms are mainly used for group work: 82.43% of mobile learning-related papers present social dynamics in dyads, small and large groups. Also, large shared screens (like tabletops, projectors or interactive screens) are mainly used for collaborative work in the classroom (98.4%). The students generally use hardware that is given by the investigation team or their educational institution, and they do not use their own devices (e.g. mobile phones).

e) On the students' work method

The students work individually or collaboratively. When there is collaboration, it is done in dyads, small (3 to 5 students) or large groups (more than 5 students). In 129 of 268 analyzed papers, students' work is collaboration in small groups.

f) On the integration of the application to the context

As observed in this analysis, the way in which presented learning activities are structured is that they follow a script previously defined, which turns into a series of steps that the students must follow (and the teacher if that is the case). There are studies where it is possible to see the exceptions management and emerging alternative flows, but they correspond to applications that are in a technical exploration phase (particularly user experience). On the other hand, observed applications are in general rigid in their specification, with a unique sequence of events, which is evaluated in context. Respect technological resources, in general, applications are mono-modal. This is less expensive, because interoperability and maintainability costs are reduced. However, this fact forces educational institutions to buy specific hardware (mainly, a lot of equivalent devices for each student), without taking advantage of installed technical resources capabilities in the institutions. These resources (e.g. hardware platforms, peripherals) are not homogeneous: it is possible that each device cannot satisfy technical requisites in order to support learning activity.

I.1.1 Work Methodology

The literature analysis will be the basis of formalization of the issues presented in this thesis. We followed an incremental work methodology (Larman & Basili, 2003), founded in the field of software engineering. The application of this methodology implies solving new requisites in the investigation for every new increment, adding to the previous increment's requisites. With this, at the end of the last increment we obtain the solution for all the objectives planned for the thesis.

For this thesis we define three increments. In each increment, problem definition is expanded and refined. In the first increment we define the base pedagogic scenario, which will be refined and incremented with requirements that satisfy some of issues presented in previous section.

I.1.2 Increment 1: Pedagogic scenario definition – learning a second language

An interesting problem from a pedagogic point of view and relevant for this thesis' objectives is learning a second language (SLA). This pedagogical skill has gained much importance in our continent and in our country, because learning another language (particularly English) allows people to adequately insert themselves in the current globalized context. Results of measuring the quality of learning English language in Chile show that only 11% of the students in 11^{th} grade have basic abilities in reading and listening comprehension (Mineduc, 2011). According with that, it is necessary to support learning throughout strategies that are adequately designed in a pedagogical way.

A way of improving learning a second language is supporting it through technology. A technological device that has been used with success is the language laboratory, which has allowed a development in listening comprehension and pronunciation. Throughout the years, the language laboratory has incorporated new technological elements, enhancing the students' experience through the use of multimedia resources: images, videos, music, visual recordings, etc. (Wagener, 2006). However, in spite of research in pedagogical aspects, the research in languages laboratories is not updated according with new trends in language learning supported by technology (Beatty, 2013; Salaberry, 2013), or with adequate use of technological resources (Levy & Stockwell, 2013):

- Individual learning of the language: The students work alone and don't communicate with others. The reinforcement only comes from the teacher. With this the advantages of having other methods, like collaboration among students, is lost.
- Teacher's role is static: the teacher acts only reinforcing contents in an individual way with each student. This is inefficient because it requires being in contact with each student during the session, but in a separate way.
- Homogeneous technological resources: the language laboratory, in its design, has individual workstations equal for all students (microphone, headset, visual aids, etc.) This means that, in order to have this type of laboratory, it is necessary to make a hardware and software setup that is ad-hoc to the laboratory, with the costs that it would imply (Miangah & Nezarat, 2012), versus other strategies, e.g. bring-your-own-device (BYOD) (Sangani, 2013), taking advantage of their media capabilities (Sharples et al., 2014).

As it was pointed out, a language laboratory supported by computer systems has the potential to become a platform that can support communication between students (Gohil, 2013), allowing them to develop face-to-face collaborative work, making the necessary technical and design adjustments. In addition, a language computer laboratory allows not only for a multimedia content display, but also the use of audio devices for speech development, pronunciation and hearing comprehension abilities (Munro & Derwing, 2011). This allows for assistance in the teacher's role as evaluator of the students' performance, introducing automatic elements in certain tasks (Blin & Munro, 2008). An example of this could be a system of voice recognition and evaluation for developing speech and pronunciation (Besacier, Barnard, Karpov & Schultz, 2014; Dalby & Kewley-Port, 2013).

Based on the aforementioned arguments, the following research question in this increment focuses on some of the previously mentioned trends, mainly pedagogical design and validation: Is it possible to build a language laboratory, using collaborative learning as pedagogical model, with automatic support for speech recognition for pronunciation evaluation?

I.1.3 Increment 2: Resource sharing and robustness in learning scenarios with dynamic environment conditions

As it was mentioned before, traditional language laboratories do not take full advantage of the technological resources and software available in educational institutions. Traditionally, language laboratories were set up as 1:1 systems that had homogeneous technical capabilities. . The initial scenario presented as a part of the first increment considers a groups of PCs, where each one of them had a system of automatic voice recognition and synthesis. This makes it necessary to install and keep updated that system in each one of the computers, with the costs that it implies. On the other hand, if there is a system failure in one of the computers, it is only possible to replace it by setting up another computer with the same configuration. A possibility is to outsource these processes though Cloud Computing (Ambrust et al., 2009). Under this paradigm, the technological resources are provided by a combination of computer systems that present such resources as services. Although under Cloud Computing you can outsource resource supplies, it is also possible to organize the computer systems in an internal network of resource sharing (Mei et al., 2008). In literature, there are experiences where it is possible to share resources using mobile devices, focused on sharing documents (Neyem et al., 2005), relevant information for upcoming events (Neyem et al., 2008) or simply on the exchange of data (Heinemann et al., 2003). A related approach is mobile cloud computing (Fernando, Loke & Rahayu, 2014), where mobile devices are used as thin clients of Cloud computing applications, as resource providers to other mobile devices, or as processing balancing nodes with other mobile devices and cloud services.

As previously analyzed, resource sharing in these types of activitie is possible using distributed architectures. In this case, a distributed architecture requires nodes where the application is executed with the necessity of an interconnection between them. With this, appears the need to have the satisfaction of non-functional requisites that seek to deliver certain levels of quality in the execution of these applications: e.g. using interconnection between mobile devices in order to provide resource sharing, availability and user mobility are improved, with respect to classical cloud compting. Combining with others cloud approaches, like external resources providers to mobile devices, a better workload is supported, improving performance and robustness (e.g. Cloudlet approach in Hoang, Niyato, Wang (2012)). Another aspect to consider regarding distributed learning applications, is that the environment where they are used is not necessarily determined: rising situations can exist, or situations that alter the normal execution of the learning activity that prevent achieving the objectives that are planned in them. These uncertainties can come both from the environment and from the devices themselves (Gil de la Iglesia, 2012). For this, the architectures with which these types of applications are built must have characteristics of robustness when facing changes in the environment. In distributed architectures where there is resource sharing, ideal scenarios of execution have been analyzed (Neyem et al., 2011; Sanaei, Abolfazli, Gani, A., & Buyya 2014; Dehlinger & Dixon, 2011) without considering the uncertainties that could arise, both at a technological and pedagogical level.

With this arises the second research question: Is it possible to design and build a platform for collaborative learning applications that allows the use of computational resources distributed in a heterogeneous hardware platform, guaranteeing robustness at the application domain level when facing changes in the environment?

I.1.4 Increment 3: Dynamism in the pedagogic script and property checking in real time

Idealizing pedagogic scenarios makes them appear rigid and with a flow that does not admit modifications. With this, when constructing a learning activity, the existing dynamism must be considered and defined within the script that supports it.

Scripting in learning activities allows formalizations of their elements. In the case of collaborative learning activities, the effort is devoted to provide a formalization in order to satisfy an effective learning (Weinberger et al., 2009).   A pedagogic script defines the tasks, goals, roles and resources used (Kobbe et al., 2007; Álvarez et al., 2011). In the context of a learning application, the dynamism in this script can be given by incorporating new tasks, or modifying tasks in real time during its development in the classroom, according to emerging events and exceptions (König & Paramythis, 2012).

Pedagogical scripts can be specified by Educational Modeling Languages (EML) (Botturi et al., 2006). An example is IMS-LD (Koper & Miao, 2007) as a language over XML with modeling techniques for describing roles and activity sequences, specifying levels of complexity specification. Another way of representing a pedagogic script is through a workflow. A workflow allows modeling in a formal way, the different elements that make up the pedagogical work. With this, a workflow allows defining specifications that can be managed automatically by a computer system, with the objective that it can regulate the flow of the learning activity (Palomino-Ramirez et al., 2013), particularly in collaborative learning scenarios (Lonchamp, 2010). This fact allows distribution and parallelism in the development of different tasks (Tayade & Chavan, 2011). This last characteristic of the workflows is relevant to the problem of resource sharing in distributed architectures because it allows representing the sequence and restrictions of the tasks that consider resource provision and use on the network of distributed nodes that constitute the architecture.

Several works are focused on learning specifications using workflow related approaches. They are related to solve issues of data flow management (e.g., Palomino-Ramirez et al., 2013), flexibility in runtime (e.g.: Villasclaras-Fernández et al., (2009), Magnisalis & Demetriadis, (2012a)) and flexibility in authoring (e.g.: Hermans, Janssen, & Koper (2015), Ben Sassi & Laroussi (2012)). These approaches solve some issues in original learning scripting languages (e.g. IMS-LD), extending their capabilities: e.g. events and exception supporting, creation and incorporation of new tasks, distributed data exchange. As observed, in general, they are limited to centralized and monolithic learning-management systems (Dagger et al., 2007). An exception is Magnisalis, I. D., & Demetriadis' work in service orchestration (2012b), focused on satisfying complex requirements in collaborative learning. This work presents an approach more related to the problem presented for this increment, using some distributed components and resources to satisfy pedagogical requirements: it uses IMS-LD as specification language and extends its capabilities using choreography with external resources in order to provide adaptation in content presentation to learners. This approach provides robustness features, related to group formation and external resources, but there is not flexibility related to description of tasks or exception handling related to activity work with learners.

On the other hand, to provide dynamic and flexible mechanisms for this kind of application, it is required that certain properties in these applications are verified. This is needed in order to determine whether the pedagogical goals or objectives can be still fulfilled before making any kind of modification in order to guarantee the robustness of the activity. Depending on how the pedagogic script is represented, incorporating the dynamism and its verification in real time may not be trivial. According to the literature, it is possible to make property verification in workflows through Petri-nets (van der Aalst, 1998; Buhler & Vidal, 2005; Ou-Yang & Winarjo, 2011). Petri-Nets correspond to a mathematical modeling language, in which it is possible to represent events and conditions, allowing with it, the formal modeling of processes and workflows. Its elements allow representing the semantics of the modeled process, and allow checking properties expected to be met during the execution of a workflow, such as deadlock-freeness, reachability, safety and liveness (van der Aalst, 1998).

With it rises the third research question: Is it possible to define a technique that allows incorporating dynamic changes during the execution of a learning activity supported by technology in a distributed schema, guaranteeing the robustness of the application semantics at a domain level?

I.1.5 Definition of pedagogic and technologic requirements in a learning application

As it was reviewed in the previous section, the construction of learning applications for classroom use has a pedagogical component, as well as a technological component (and not a minor one). Under this categorization, the requisites associated to the pedagogical component have a final objective of improving certain learning abilities in students. In consequence, the requisites related to the technological components seek to satisfy the pedagogical requisites. The technological requisites can seek satisfying the pedagogical requisites in two ways: giving a certain level of quality in the satisfaction of the pedagogical requisites, or allowing the implementation of a pedagogical requisite that would not be able to be made without technology.

In the case study presented in this thesis, the application of the collaborative language laboratory was conceptualized based on two main elements: the use of collaborative work to improve learning, and the automation of the evaluation of the students' pronunciation through speech recognition. The first step within its construction is to evaluate if the pedagogical objectives with which they were built are met. However, for this we have to define which technological requisites will serve as basis for the fulfillment of the proposed requirements, and how is the quality in the satisfaction in those requirements.

A minimum base of technological requisites must consider the relevance and dependencies between them in order to satisfy the proposed pedagogical requirements. In the scenario of the language laboratory, it was necessary to validate how the collaborative work and the automatic evaluation of the pronunciation allow a better learning of the English language. For this, the decision was made to design a language laboratory that would work locally, where students share the computer with a built-in speech recognition engine.

Having validated this scenario with the pedagogical requirements, it is possible to incorporate more requisites, such as dynamism in the pedagogical script, resource sharing and robustness. As it was mentioned before, incorporating these requisites must be according to relevance and dependency between them, because some requirements are pre-requirements for other. In this case's scenario, it is needed to provide robustness in the achievement of pedagogical requisites. In order to satisfy robustness, one of presented approaches to be implemented refers to techniques of resource sharing, providing quality levels. In this case, resource sharing allows to guarantee requirements related to some multimedia capabilities, as speech recognition and voice recording, in scenarios where not all devices have local access to that capabilities (e.g. lock in speech recognition engine or failure in voice recording). With it, the system itself can attend scenarios with defects, or allow to better use the existing technological resources. Another approach in order to provide pedagogical robustness is to incorporate dynamism in the pedagogical script. This approach allows to solve emerging situations, such as technical failures or pedagogical observations carry out by the teacher, changing tasks sequence, modifying existing task or incorporating new ones (König & Paramythis, 2012)).

Taking this in consideration, we must build the planning of increments that allow solving the complete problem of building the learning activity. With it, the following research question is defined: Is it possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way?

I.2 Research Questions

As it was mentioned in the previous sections, the research reported in this thesis has been driven by the following research questions:

1. Is it possible to build a language laboratory, using collaborative learning as pedagogical model, with automatic support for speech recognition for pronunciation evaluation?

2. Is it possible to design and build a platform for collaborative learning applications that allows the use of computational resources distributed in a heterogeneous hardware platform, guaranteeing robustness at the application domain level when facing changes in the environment?

3. Is it possible to define a technique that allows incorporating dynamic changes during the execution of a learning activity supported by technology in a distributed schema, guaranteeing the robustness of the application semantics at a domain level?

4. Is it possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way?

The answer to the proposed research questions is associated with one of the increments, and with it a group of areas of investigation with which they are related.

I.3 Research Hypothesis

Based on the research questions previously described, the research hypotheses that prompted this research project presented in this thesis are directly dependent with research questions. In this case, they correspond to affirmations built from corresponding research questions, which are validated by thesis results:

1. It is possible to build a language laboratory, using collaborative learning as pedagogical model, with automatic support for speech recognition for pronunciation evaluation.

2. It is possible to design and build a platform for collaborative learning applications that allows the use of computational resources distributed in a heterogeneous hardware platform, guaranteeing robustness at the application domain level when facing changes in the environment.

3. It is possible to define a technique that allows incorporating dynamic changes during the execution of a learning activity supported by technology in a distributed schema, guaranteeing the robustness of the application semantics at a domain level

4. It is possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way.

I.4 Objectives

The specific research objectives proposed in this thesis are the following:

1. Conceptualize and develop a model of language laboratory where collaborative learning is used as pedagogical model, and the automatic voice recognition as user interface.

2. Pedagogically validate the model of the collaborative language laboratory through experimental tests with the activities developed and study the collaboration conditions with which it was designed.

3. Conceptualize and develop an architecture for developing learning activities that allow resource-sharing and robustness when facing changes in the environment.

4. Conceptualize and develop a technique for collaborative learning activities specification, with flexibility and robustness features, with an automatic methodology of automatic checking of property integrity and pedagogic requirements.

I.5 Research Limitations

This thesis considers the development of an incremental research work, with a group of growing requisites that allows completely formulating the research problem presented. Being an incremental mode, the focus is to add new characteristics to the resolution of presented problems.

This thesis presents only one transversal pedagogical scenario in its development, which is validated in its pedagogical aspects at an initial stage. With it, it does not necessarily show the generalization capacity of the architectures and methodologies proposed in this thesis.

However, in the respective increments of this thesis, new elements and functions are added to the initial pedagogical scenario, which allows evaluating the respective problems according to the presented: incorporating resource sharing and robustness when facing changes in the environment is done in the second increment, meanwhile incorporating dynamism, the corresponding modeling and formal validation is done in the third increment. On the other hand, the characteristics with which the respective architectures and methodologies were designed make them applicable to different types of technological resources and admit other changes during execution time, within the groups and limitations described. In the case of dynamism and its formalization, it is possible to build new scenarios that have other types of tasks, given the flexibility of the flexible workflows and Petri-nets used in its formalization.

The pedagogic scenario corresponds to an instance of computer supported collaborative learning, supported both by single-display groupware and mobile devices (Zurita & Nussbaum, 2007; Infante et al., 2011). This thesis does not seek to propose a general support for learning activities in the classroom, but it seeks to propose the use of shared resources and dynamism in learning activities' execution in the context of collaborative learning. Regarding the use of that pedagogic scenario towards this thesis, requirements of self-adaptation approach presented in chapter 3 are evaluated using other learning scenario, in the context of a research collaboration. The aim of that collaboration was to propose a joint architecture for an ensemble of mobile learning complex requirements, solved using two approaches: multi-agent systems, and self-adaptation. The contribution from this thesis was a formulation of a distributed architecture using multi-agent system approach and nonfunctional requirements evaluation in order to satisfy robustness and resource sharing using a mobile language laboratory scenario. On the other hand, the other collaborator expands these results and provide a refined architecture, adding self-adaptation components in order to satisfy requirements related to robustness in scenarios with failures in hardware. This last requirements are considered as a future work of this thesis. Integration into the curriculum is presented by pedagogical orchestration (Dillenbourg, 2008), where the teacher's role is active with students in their learning process. In this thesis, this role is expanded, in order to provide the possibility of incorporating changes in tasks during runtime. However, this role is proposed and not measured from an educational point of view, thus the pedagogical contribution of incorporating this methodology remains outside this thesis' scope.

I.6 Thesis Outline

This thesis is structured in 3 chapters, each one of which corresponds to one of the increments presented in the introduction. These increments are registered as papers that were sent or published in an ISI journal. Two of these papers has already been accepted and published at the time this thesis was being written. The list of chapters is as follows:

II. A Single-display Groupware collaborative language laboratory. Calderón, J.F., Nussbaum, M., Carmach, I., Díaz, J.J., Villalta, M. *Interactive Learning Environments (2014), published online (http://www.tandfonline.com/doi/abs/10.1080/10494820.2014.917111)*

III. A Self-Adaptive Multi-Agent System Approacch for Collaborative Mobile Learning. Gil de la Iglesia, D., Calderón, J.F., Weyns, D., Milrad, M., Nussbaum, M. *IEEE Transactions in Learning Technologies, published online.*

IV. Integrated framework for defining and verifying properties of flexible workflows with decoupled rules. Calderón, J.F., Alarcón, R., Nussbaum, M. *to submit for publication.*

Chapter II consists of the paper: A Single-display Groupware collaborative language laboratory. This chapter presents the pedagogic scenario that is used in this thesis, which corresponds to a collaborative language laboratory based on single-display groupware for learning vocabulary, grammar, pronunciation and listening comprehension. This chapter describes the design and pedagogical merit of the SDG collaborative language laboratory. For this, a quasi-experimental pre-post comparison study is made, and an observation guideline to analyze whether the conditions for collaborative learning have been fulfilled is used.

Chapter III consists of the paper: A Self-Adaptive Multi-Agent System Approach for Collaborative Mobile Learning, which proposes the use of shared resources and robustness when facing changes in the environment and devices used. One of the pedagogic scenarios used corresponds to an adaptation of the scenario presented in chapter II to a one-to-one computer format, with shared technological resources. Constitutive elements of the architecture are used as multi-agent and self-adaptation system concepts. The requisites are validated through simulations.

Chapter IV consists of the paper: Integrated framework for defining and verifying properties of flexible workflows with decoupled rules. This chapter presents the proposed use of decentralized flexible workflows for the definition of the task sequence to be made and the incorporation of pedagogical rules in an uncoupled way. Altogether, it proposes a methodology of automatic verification of properties, which allows checking for changes during the time of execution. With it, we allow the teacher to add and modify tasks. For the validation we used simulations that use an extension of the pedagogic scenario from chapter II as base.

I.7 Thesis Structure

This thesis is structured around the research objectives mentioned previously: (1) conceptualize and develop a model of a language laboratory where collaborative learning is used as a pedagogical model, and the automatic voice recognition as user interface; (2) pedagogically validate the collaborative language laboratory model through experimental tests with the activities developed and study the conditions of collaboration with which it was designed; (3) conceptualize and develop an architecture for the development of learning applications that allows resource-sharing and robustness when facing changes in the environment; and (4) conceptualize and develop a platform that allows the teacher to make changes during the time of execution, that considers an automatic methodology for checking the integrity of the pedagogic properties and rules. The thesis' structure is summarized in Table I.1.

Table I.1 General Structure of the Thesis

Hypotheses	
H1	It is possible to build a language laboratory, using collaborative learning as pedagogical model, with automatic support for speech recognition for pronunciation evaluation.
H2	It is possible to design and build a platform for collaborative learning applications that allows the use of computational resources distributed in a heterogeneous hardware platform, guaranteeing robustness at the application domain level when facing changes in the environment.
H3	It is possible to define a technique that allows incorporating dynamic changes during the execution of a learning activity supported by technology, where they are done by the teacher, guaranteeing the robustness of the application semantics at a domain level.
H4	It is possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way.
Research Questions	
Q1	Is it possible to build a language laboratory, using collaborative learning as pedagogical model, with automatic support for speech recognition for pronunciation evaluation?
Q2	Is it possible to design and build a platform for collaborative learning applications that allows the use of computational resources distributed in a heterogeneous hardware platform, guaranteeing robustness at the application domain level when facing changes in the environment?
Q3	Is it possible to define a technique that allows incorporating dynamic changes during the execution of a learning activity supported by technology, where they are done by the teacher, guaranteeing the robustness of the application semantics at a domain level?
Q4	Is it possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way?
Objectives	
O1	Conceptualize and develop a model of language laboratory where collaborative learning is used as pedagogical model, and the automatic voice recognition as user interface.
O2	Pedagogically validate the model of the collaborative language laboratory through experimental tests with the activities developed and study the collaboration conditions with which it was designed.
O3	Conceptualize and develop architecture for developing learning activities that allow resource-sharing

	and robustness when facing changes in the environment.
O4	Conceptualize and develop a technique for collaborative learning activities specification, with flexibility and robustness features, with an automatic methodology of automatic checking of property integrity and pedagogic requirements.
Papers	
P1	A Single-display Groupware collaborative language laboratory.
P2	A Self-Adaptive Multi-Agent System Approach for Collaborative Mobile Learning.
P3	Integrated construction scheme and property verification for flexible workflows that incorporate uncoupled rules.
Results	
R1	A collaborative language laboratory based on single-display groupware.
R2	The collaborative language laboratory allows a better learning of pronunciation compared to an individual language laboratory.
R3	An architecture that allows building a learning application on mobile platforms, that allow resource-sharing and robustness when facing changes in the environment.
R4	A variation of decentralized, flexible workflows that allow the teacher to incorporate changes in real time, where the pedagogic rules are uncoupled.
R5	A property verification methodology based on petri-nets that allows automatically evaluating deadlock freeness and safety-liveness on a defined pedagogic scenario defined with the decentralized flexible workflow, with uncoupled pedagogic rules.

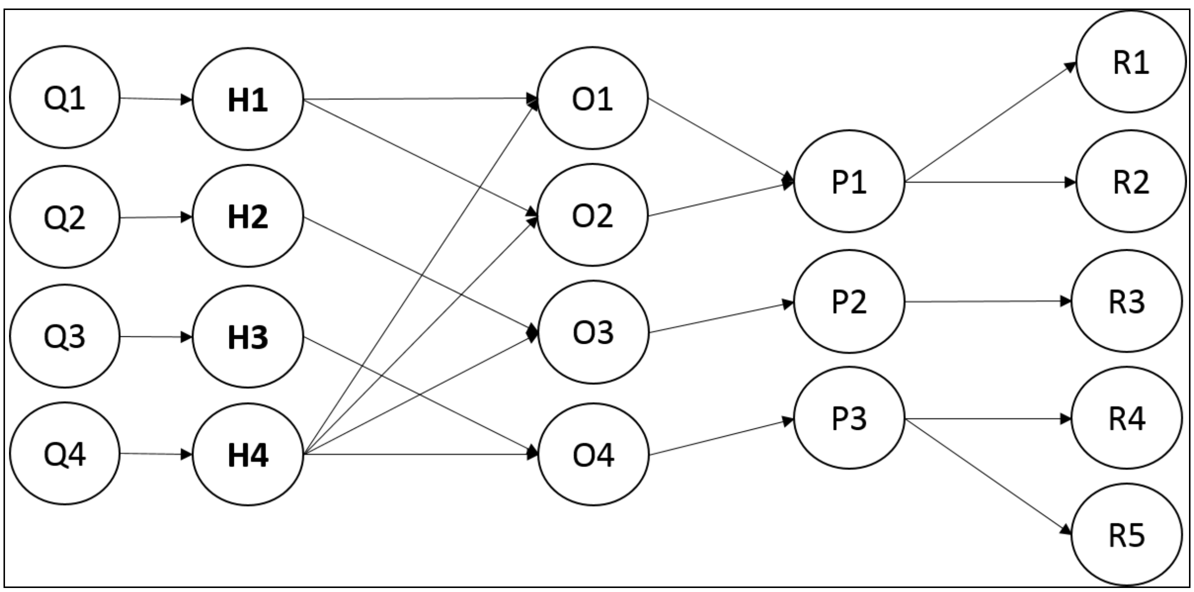

Figure I.1 Association diagram depicting the relationship between the Thesis components

Responding to hypothesis H1, i.e. “It is possible to build a language laboratory, using collaborative learning as pedagogical model, with automatic support for speech recognition for pronunciation evaluation.", research question Q1, and objectives O1 and O2, paper P1 proposes the construction of a collaborative language laboratory based on single-display groupware (result R1), together with its pedagogic validation (result R2). The latter showed that the collaborative language laboratory proved to be more effective in learning pronunciation and listening compared to the use of an individual language laboratory and a class that did not use a language laboratory.

In response to hypothesis H2, i.e. "It is possible to design and build a platform for collaborative learning applications that allows the use of computational resources distributed in a heterogeneous hardware platform, guaranteeing robustness at the application domain level when facing changes in the environment" research question Q2 and objective O3, paper P2 proposes an architecture that allows the construction of learning applications on mobile platforms, which allows resources-sharing and robustness when facing changes in the environment (result R3).

In response to hypothesis H3, i.e. "It is possible to define a technique that allows incorporating dynamic changes during the execution of a learning activity supported by technology, where they are done by the teacher guaranteeing the robustness of the application semantics at a domain level" research question Q3 and objective O4, paper P3 proposes a variation to the decentralized, flexible workflow concept that allows the teacher to incorporate changes in real time, where the pedagogic rules are uncoupled (result R4), along with a property verification methodology based on petri-nets that allows automatically evaluating deadlock freeness, and safety-liveness on a pedagogic scenario defined with decentralized and flexible workflow variation, with uncoupled pedagogic rules (result R5).

Finally, regarding hypothesis H4, i.e. "It is possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way." it is evaluated in a transversal way through the fulfillment of all the proposed objectives for this thesis. This is according a design based research approach (Wang & Hannafin, 2005), particularly regarding iterative and integrative research features. The methodology performed in this thesis is iterative because there is a development cycle where new requirements and redesign are supported. Also, it is integrative because several methods and techniques are used to answer corresponding research questions.

II. A SINGLE-DISPLAY GROUPWARE COLLABORATIVE LANGUAGE LABORATORY

Abstract. Language learning tools have evolved to take into consideration new teaching models of collaboration and communication. While second language acquisition tasks have been taken online, the traditional language laboratory has remained unchanged. By continuing to follow its original configuration based on individual work, the language laboratory fails to take advantage of the potential provided by collaborative learning. We propose the use of a language laboratory based on single-display groupware (SDG) for learning vocabulary, grammar, pronunciation and listening comprehension. By adopting SDG, the language laboratory benefits from the advantages of small group collaborative learning. In this paper, we first describe the design and pedagogical merit of the SDG collaborative language laboratory. We then share the results of a quasi-experimental pre-post comparison study, and use an observation guideline to analyze whether the conditions for collaborative learning have been fulfilled. Based on the results of this study, we conclude that developing pronunciation skills can be more effective when using a collaborative language laboratory versus an individual language laboratory. In addition to this, it can also be concluded that collaborative learning is most effective when accompanied by adequate instructional design.

II.1 Introduction

Second language acquisition (SLA) has become increasingly relevant on a global level. This is due not only to the increased need for learning a new language, but also to the introduction of new technologies. These technologies allow for new forms of communication and interaction between students, both face-to-face and remotely via the internet (Rama, 2012). When SLA is supported by the use of computers in this way, it is known as Computer-Assisted Language Learning (CALL).

The history of CALL can be divided into three stages, with the technological developments of each stage currently in co-existence (Warschauer & Healey, 1998):

- Behaviorist CALL: focuses on learning a second language by repetitively completing exercises on an individual basis. Here, the computer acts as a tutor by checking answers and giving the corresponding feedback (Lee, 2000).

- Communicative CALL: focuses on fostering communicative situations where students must be capable of producing texts and generating dialogs. Examples include systems that allow for the reconstruction of texts, role playing, and video games (Bax, 2003).

- Integrative CALL: focuses on integrating four basic skills needed for language learning (reading, writing, listening, and speaking) in a single activity. Here, the computer goes beyond the role of tutor by coordinating the entire learning process. In turn, these four skills should each be associated with other areas or concepts of language learning, such as grammar, vocabulary, pronunciation, and cultural awareness (Levy, 2009).

Although the teaching models applied to SLA have evolved, this evolution is not always reflected in the development of SLA applications. One such application is the language laboratory (Roby, 2004).

Language laboratories initially focused on listening comprehension and pronunciation activities without the support of a computer (Morton, 1960; Harvey, 1978; Vanderplank, 2009). Although students could receive feedback on their work from a teacher, this was often without direct interaction between the two. When language laboratories were first introduced, students used individual cabins equipped with headphones and a microphone, as well as recording and playback devices. With the development of computer technology, this new technology was incorporated into language laboratories in several different ways. Visual support was added to help organize the activities, as well as supplementary audiovisual materials (Barr, Leakey, & Ranchoux, 2005; Pranita, 2010). Automatic speech recognition (ASR) software was used to test pronunciation (Neri, Cucchiarini, & Strik, 2003; Xu & Seneff 2009). Synthesized voice was used to reinforce pronunciation (Handley, 2009). The internet was used to access materials and activities (Shingal, 1997; Hsu, 2005), and audiovisual recordings were used to create narratives (Wagener, 2006), among others. However, the incorporation of new technology into the language laboratory has not affected its pedagogical design. The reported evidence suggests that the role of the language laboratory should be focused on constant drilling and practice combined with interaction. This interaction can be achieved through individual and collaborative tasks monitored by the teacher (Vanderplank, 2009).

Socio-cultural theories of learning suggest that SLA technologies should promote the development of a methodology to foster communicative skills, in line with the following hypotheses (Nguyen, 2010):

- Student learning must focus on processes of interaction and collaboration that are relevant to the learner.

- SLA activities should encourage group work, role play, and projects that take the students beyond the confines of the classroom.

- The teacher is a facilitator and should monitor student learning in both cooperative and/or collaborative work.

Given the importance of communication and integrated language learning in the design of such systems, these hypotheses can be related to the “Communicative” and “Integrative” stages of CALL development. This is also evidenced by the fact that the computers, and not just the teachers, mediate communication between students. Applications designed with these hypotheses in mind have been shown to be effective when learning a second language and developing communication skills. However, they often fail to integrate the four main language learning skills, focusing instead mainly on oral communication (Yang, Gamble, &

Tang, 2011). Furthermore, an analysis of the contribution made by collaborative laboratories versus individual laboratories is also missing. This therefore gives rise to our first research question: when learning a language through integrated practice of the four skills, what advantages does a collaborative laboratory hold over an individual laboratory?

Collaborative learning (Dillenbourg, 1999) allows for skills such as negotiation and individual responsibility to be developed, as well as building group knowledge. These have all been defined as 21st century skills (ATC21S, 2012). Collaboration in SLA has been shown to allow peers to discuss comprehension, improve the quality of discourse and develop responsibility and independence in learners.

When collaborative learning is aided by technology, it is referred to as Computer Supported Collaborative Learning (CSCL). In this case, the technology allows the interaction between participants to be mediated. This is achieved by sharing information, administering homework assignments, establishing rules and roles, and facilitating the acquisition of new knowledge (Zurita & Nussbaum, 2004a). CSCL shares certain aspects from the categories proposed in the taxonomy by Warschauer and Healey (1998), especially the incorporation of technology to encourage communication and interaction among peers. In language learning, this concept is defined as Computer Mediated Collaborative Learning (Warschauer, 1997; Yamada, 2009). This concept has also been adopted by Levy (2009) in developing language learning skills by reviewing Sykes' analysis (2005) of three types of synchronous group discussion: written chat, oral chat and face-to-face discussion.

In order for collaborative learning to be successful, certain conditions must be fulfilled regardless of whether or not they are mastered (Szewkis, Nussbaum, Rosen, Abalos, Denardin, Caballero, Tagle, & Alcoholado, 2011). These conditions include the existence of a common goal (Dillenbourg, 1999), positive interdependence between peers (Johnson & Johnson, 1999), coordination and communication between peers (Gutwin & Greenberg, 2004), individual accountability (Slavin, 1996), awareness of peer work (Janssen, Erkens, Kanselaar, & Jaspers, 2007), and joint rewards (Axelrod & Hamilton 1981).

In the field of language learning, some of these conditions have already been analyzed within the specific context of developing cooperative work among peers. In particular, this analysis refers to the incorporation of positive interdependence or personal accountability in activity design (AbuSeileek, 2012). In general terms, it is noted that this is achieved when there is less interference by peers. This shows that when developing communication and speaking skills, the contribution made by each individual should be accepted by their peers (AbuSeileek & AbuAlshar, 2012). Further conditions or aspects have also been shown to develop within collaborative work. These include the emergence of an expert among peers, discussions about how a task should be performed, how students work when faced with challenges, and how they develop interpersonal relationships (Leahy, 2008). The presence of these additional conditions or aspects allow learner behavior to be analyzed within the context of CALL. This therefore gives rise to our second research question: when learning a language in a collaborative, face-to-face activity, which are the most relevant conditions of collaboration to be fulfilled?

Incorporating collaboration into CALL tools requires an understanding of the processes in which the students are engaged during these activities (Hampel, 2009). An important aspect to review is the influence of technology on student behavior regarding collaborative activities (Leahy, 2012). One such case is the use of mobile platforms and sensors. In this case, technology helps to organize and mediate social interactions, regardless of the place and time in which the activities are performed (Ogata, 2008). In language learning, advantage can be taken of the ubiquity of these devices to encourage collaboration when completing activities with common goals, using personalised context-aware techniques in order to enhance learner learning interest and efficiency (Chen & Li, 2010). This should be accomplished by using the devices' multimedia capabilities to record videos and images as a group (Ogata & Yano, 2003). Another example of that is virtual worlds, where real-life environments are generated in 3D (Shih & Yang, 2008) and simulated by the computer systems. In these virtual worlds, the participants are represented by avatars or representations of the users' identities (Li & Wong, 2010). It has been demonstrated that a virtual space for face-to-face interaction favors collaboration (Wang & Chen, 2010) and in particular the development of communication and peer support through voice and image interaction (Yamada, 2009). For example, Second Life provides a stimulating environment for learners to engage in a range of social interactions involving collaborative dialog (Peterson, 2012). The use of virtual worlds has also been shown to be effective in SLA at both utterance and discourse levels (Zheng, Young, Wagner, & Brewer, 2009), as well as the acquisition of communication skills (Berns, Palomo-Duarte,Dodero, & Valero-Franco, 2013), and the construction of meaning (Blake, 2011; Deutschmann, Panichi, & Molka-Danielsen, 2009). However, these models also have some disadvantages. One of the disadvantages is the high cost of implementation, given that they require one or more device per student. Furthermore, the computers are not shared, making it difficult for peers to be aware of each other's work. This is because each student's answers are only shown on their respective devices, both for the ubiquitous in-person activities as well as those in the virtual world. In the latter case, coordination and communication among peers can be compromised by connectivity and latency issues on the various different devices (Garrido-Iñigo & Rodriguez-Moreno, 2013). This situation is critical because the students require permanent connectivity in order to provide relevant and timely feedback and/or the possibility of mutual reinforcement between peers. Another concern is that the absence of face-to-face contact could result in less engagement by students. As students can only see the avatars and do not receive verbal or non-verbal cues from their fellow learners, this could result in problems with the interaction among peers (Macías-Díaz 2008b in Duncan, Miller, & Jiang, S 2012).

The SDG model has been used to develop collaborative learning (Stewart, Bederson, & Druin, 1998), which allows several students to learn collectively in front of a single screen (Infante, Hidalgo, Nussbaum, Alarcón, & Gottlieb, 2009). The information shown to users is shared on a single display device, with multiple input devices for shared control allowing the students to act simultaneously and in the same place (Kaplan, DoLenh, Bachour, Yi-ing, Gault, & Dillenbourg, 2009). One important aspect that promotes interaction between students is the fact that each student must work with their own objects on the screen using their own input device. This forces them to participate and play a central role in their own learning process (Infante et al. 2009). This interaction allows for the emergence of a shared interaction pattern, leading to the development of better quality discussions in environments where face-to-face interactions do not take place (Chung, Lee, & Liu, 2012).

In this study we propose the implementation of a language laboratory that uses small group collaborative learning as a teaching method. The laboratory is based on SDG, with the aim of studying the contribution of collaboration in the language laboratory and determining how the conditions of collaboration are fulfilled. First, we describe the design of the pedagogical activity, detailing the skills to be developed by the students. Next, we describe the experimental design and detail the result of the experiment, along with the corresponding statistical analysis. This is followed by a discussion of the analysis, where the conditions for collaborative learning are reviewed. Finally, we present the conclusions.

II.2 Collaborative Language Laboratory

Kessler and Bikowski (2010) highlight that it is possible to observe the following forms of collaboration in SLA activities:

- Joint Collaboration: individuals should have equal responsibilities.
- Parallel Collaboration: individuals should have different responsibilities, but work towards the same objective.
- Incidental Collaboration: individuals collaborate based on the requirements that come up as they are carrying out the task.

This section presents the collaborative language laboratory design, which uses collaboration as its guiding principle. This was chosen as the guiding principle as it aims to give all students the same level of responsibility while working towards a common goal.

The design of the laboratory should take into consideration not only the students who will use the laboratory, but also the teachers. The teacher’s role in this case is defined by orchestrations (Nussbaum, Dillenbourg, Dimitriadis, & Roschelle, 2013). These consist of previously-prepared lesson plans that integrate conventional and digital resources as well as combining the teacher's work with the students' laboratory work. In the practical laboratory work, the teacher's role includes explaining how to use the technological platform and offering instruction based on any difficulties faced by the students.

This project teaches the following skills: grammar, vocabulary, listening comprehension, and pronunciation (Table II.1). This skills were taken from the curriculum defined by the Ministry of Education (Mineduc, 2010). The aim of this subject is for students to learn English and be able to use it as a tool to communicate on a basic level in a range of situations. In order to achieve this, these skills are combined in such a way so as to allow the students to acquire the knowledge that they need in order to obtain information and develop communicative functions. So as to incorporate these skills, and by following the aims of the ministry, orchestrations were developed and defined by a script that combines collaborative learning with the rest of the students' and teacher's activities.

Table II.1 Skills taught and material created for the collaborative language laboratory.

Skill	Number of Sessions	Number of Activities per Skill
Grammar	4	40
Vocabulary	4	42
Listening	4	27
Pronunciation	Integrated into the previous skills	Integrated into the previous skills

The groups comprise three students as this has been shown to be the optimum number for collaborative learning in SLA (Hsu, Hsu, He & Chang, 2009). Each student has their own headset, which they can use to communicate with the system and listen to the system's instructions (Figure II.1). The collaborative learning is based on ordering a series of elements (Zurita & Nussbaum, 2004), where the students must work together to build an ordered sequence using the elements belonging to each individual. Each member of the group can see the sequence and everyone else's personal elements using the shared screen. The sequence to be put in order will depend on the skills being developed:

- Grammar: a sentence must be constructed based on the words belonging to each student (Figure II.2).

- Vocabulary: three photographs are presented, one per student, which must be matched with a word belonging to each of the students (Figure II.3).

- Listening: a sequence of words must be built based on the order in which they appear in a text, which is listened to by the three members of the group simultaneously (Figure II.4).

So that students will learn to accurately pronounce the words, they must select the words for each of the exercises by enunciating them. In order to build each sequence of words, each student must correctly pronounce the words that belong to them so that they are included in the sequence. For example, for the grammar exercise in Figure II.2, an example is shown where the student correctly pronounces the first word of the displayed sentence. When this happens, the word disappears from the student's workspace and appears in the shared space. If the students build a sequence incorrectly, the system will indicate that there is an error and make them repeat the whole exercise by reassigning the words.

The model used to develop student feedback must be simple, clear, and in line with the design of the activity in order for it to be effective (Hémard, 1997). Thus, when a student makes a mistake in their pronunciation, the feedback given by the system is based on the model proposed by Mackey (2006) for interaction feedback. In this model, an expert repeats the concept or phrase attempted by the student so that the student may repeat it correctly. Alternatively, the student can indicate that they do not understand, and the phrase will be repeated again.

In our case, the system acts as an expert by reproducing a recording of the word spoken by the student to the whole group. It then proceeds to give feedback to every member of the group through their headsets. When the student's pronunciation is similar enough for the word to be recognized but is still incorrect, the system offers feedback by repeating the correct pronunciation of the word (Figure II.5). If the pronunciation is too dissimilar for the word to be recognized, the system will indicate that the word is incorrect. When the other students in the group receive this feedback, they can help their classmate to correct their pronunciation in a next opportunity. This feedback design therefore resembles incidental collaboration as it relates to an emerging situation which can be addressed by the students using collaboration.

The Automatic Speech-Recognition (ASR) system is used to evaluate pronunciation, with a voice synthesizer used for feedback. Both of these are provided by the Speech API (SAPI) version 5.4 Recognition and Synthesis libraries, which work on a Microsoft Windows operating system. Chen (2011) suggests that this library, with the corresponding modifications, is a free yet powerful tool that can be used to train oral skills in second language students.

Once the exercise is completed by the students, the system verifies that the sequence is correct. In this case, positive feedback is given and the students continue on to the next exercise (Figure II.3, right). If the exercise was completed incorrectly, negative feedback is given and the same exercise is repeated (Figure II.4, right). Students can only continue on to the next exercise if the sequence is correct, regardless of how many attempts they make.

Figure II.1 In the foreground, students are using the collaborative language laboratory. In the background, students are using the individual language laboratory.

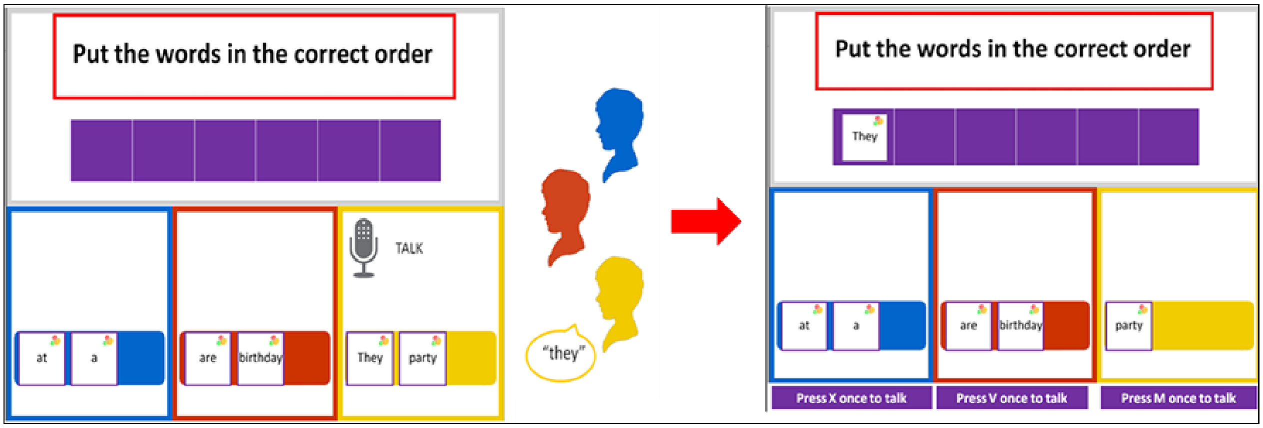

Figure II.2 Example of exercises from a grammar activity. When a student pronounces a word correctly, it is moved to the shared space where the sequence is constructed. At the end of the exercise, the system confirms that the sequence is in the correct order.

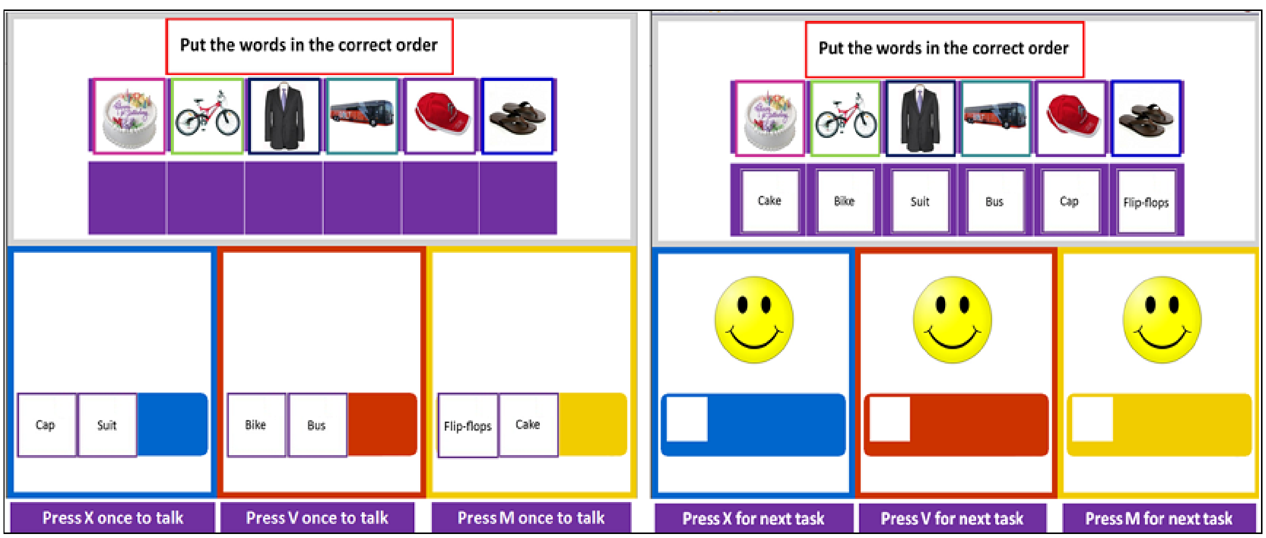

Figure II.3 (Left) Screenshot of an exercise from a vocabulary activity. Students must match the pictures with words by pronouncing them. (Right) The system provides feedback; in this case the sequence is correct.

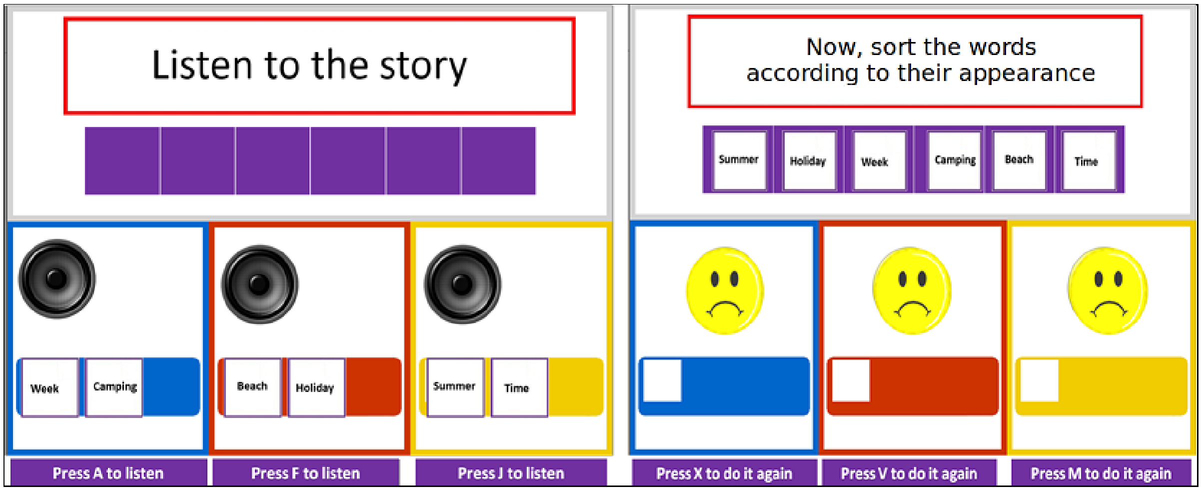

Figure II.4 (Left) Screenshot of an exercise from a listening activity. Students must put the words in order according to their appearance in the text they are listening to. (Right) The system provides feedback; in this case the sequence is incorrect.

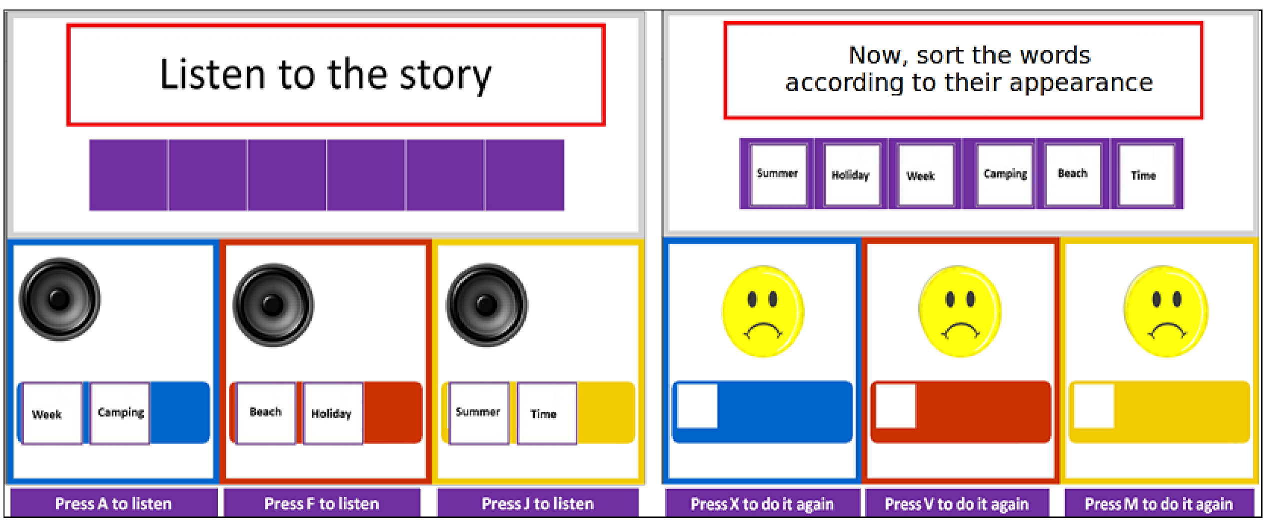

Figure II.5 Sample screen of a word pronounced incorrectly, and the corresponding feedback given during a grammar activity.

II.3 Experimental Design

II.3.1 Tools used

One of the questions that this study looks to answer is: when learning a language through integrated practice of the four skills, what advantages does a collaborative laboratory hold over an individual laboratory? Therefore, to carry out this study, a second version of the collaborative language laboratory described in section II.2 was built, with the same activities and technological resources, but adapted for individual work. The main difference is that there is only one set of elements, all of which belong to the student seated in front of the screen (Figure II.6). With this, the student must build the sequence on their own without collaboration.

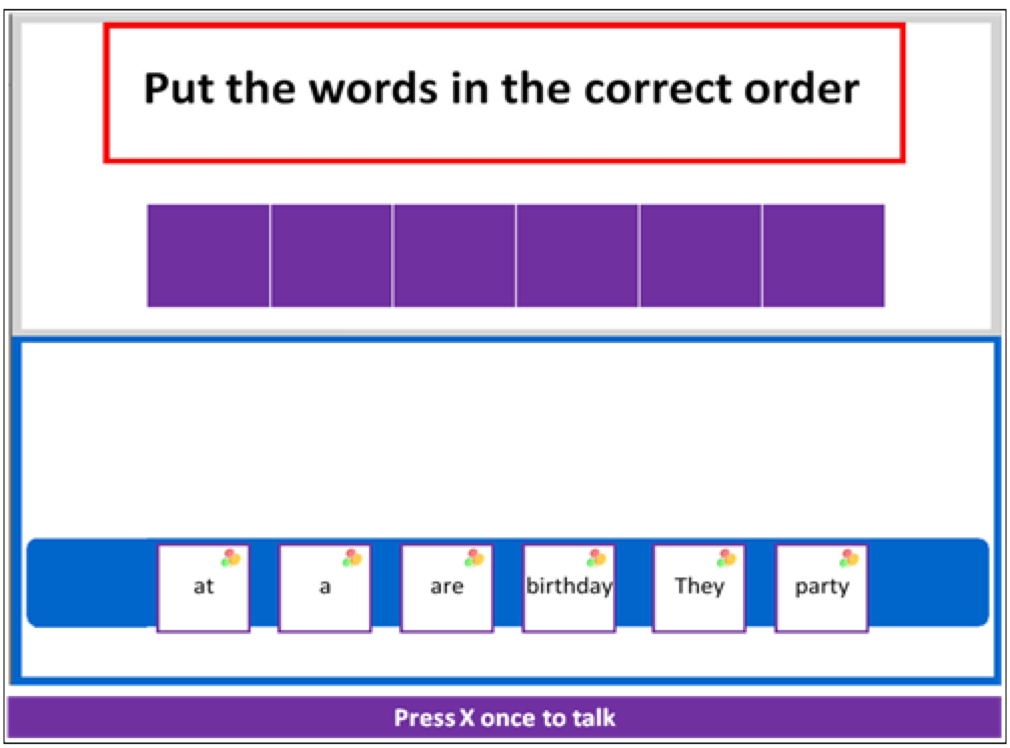

Figure II.6 Sample screen of a grammar exercise in an individual language laboratory.

II.3.2 Study participants and procedure

For this study, an investigation was carried out with a quasi-experimental, pre-post type design. This was because the various groups that were to be analyzed were not necessarily even. The sample was composed of 6th grade students from a state-subsidized elementary school, whose ages range from 11 to 13. Three groups were defined and selected at random:

- Group working without the use of technology (control) (N=20: 8 boys and 12 girls)
- Group working in a collaborative language laboratory (N=24: 11 boys and 13 girls)
- Group working in an individual language laboratory (N=15: 8 boys and 7 girls)

Samples with small groups have already been used in other studies of this kind, where learning results are measured using quantitative variables and learner behavior observed using qualitative variables (Lee, 2011). The three groups were taught by the same teacher, who worked by following the orchestrations provided for this study (see Appendix D) On the one hand, these orchestrations were designed to ensure that the teacher followed the curricular objectives set out by the Ministry of Education. On the other hand, they guaranteed that the teacher had the necessary resources to carry out the activity, ensuring that their use followed the scope and sequence proposed by the Ministry. The teacher plays a central role during the three phases of the orchestration. The teacher plays a central role during the three phases of the orchestration. Each phase and the respective activities are assigned an initial quantity of time a priori. In the first phase, the professor introduces the activities to be carried out by the students using an activity that is familiar to everyone. The aim of doing so is to activate prior knowledge and include any additional necessary explanations. The activity in the second phase incorporates the use of language laboratories, where the teacher moves between groups to supervise the students' work and answer any questions that come up during the task. Finally, in the third phase, the teacher does an end-of-class activity where student learning outcomes are reviewed. The teacher also answers questions while the students work and is able to make certain decisions according to what comes up during class. The teacher may also change certain aspects of the orchestrations in order to adapt them to the specific needs observed during the class.

The role of the technological platform is to evaluate the development of language skills and it is designed to encourage collaboration. This is complementary to the role of the teacher since it relies on the development of an activity that involves many students, allowing them to work in a coordinated manner through a system of hardware and software. Furthermore, the use of multimedia resources serves as a learning aid for all students, specifically in this case through the visual display of material and the use of a speech recognition/speech synthesis engine. As mentioned previously, the use of technology does not necessarily lead to an improvement in learning if it is not accompanied by an adequate design where both the teacher and students are well coordinated.

The students that worked without technology followed the same contents as the other two groups and worked on tasks that aimed to meet the same objectives. In this case, the teacher played a leading role by coordinating the interaction among students by following the same orchestrations as those for the groups using technology (Appendix D). However, the orchestrations were adapted so that they could be followed without the use of language laboratories. In order to do this, sequencing activities were incorporated that students solved individually on paper, while pronunciation practice was carried out with the whole class.

II.3.3 Pre- and post-tests

The pre-post instrument consisted of a test developed by an expert, which students had to answer by using a computer platform. The test was multiple choice and included questions that independently evaluated the following four skills: vocabulary, grammar, listening, and pronunciation.

To evaluate vocabulary, grammar, and listening, the items on the test followed a similar design to that used in the activities included in the orchestrations (see Appendix E). In order to measure the level of pronunciation, the same ASR engine from the language laboratory was used on the test. The items on the test evaluated the same skills and contents that the students developed in the activities. Table II.2 details the number of items associated with each unit and skill.

The pre- and post-test items were selected using an item response analysis (Wright & Stone 1979). The items selected in this analysis allowed for them to be effectively discriminated (value between 0.3 and 0.99, in a range between 0 and 0.99, where a higher value means a higher degree of item discrimination).

Table II.2 Skills, units covered, and number of items associated in the pre-post test.

Units	**Vocabulary**	**Grammar**	**Listening**	**Pronunciation**
Family and friends	5	6	2	7
Socializing	5	5	4	6
Celebrations	5	4	5	7
Holidays	5	5	3	7
Total	20	20	14	27

There were more items for pronunciation and fewer for listening because of the time it took to evaluate each one. In the case of pronunciation, each item corresponded to the evaluation of one word. The listening items also included a recording of a spoken text that students had to listen to (see Appendix E).

Analysis of the reliability of the pre-post instrument was conducted using Cronbach's Alpha, calculated for each of the tests that measure the various language skills (Table II.3).

Table II.3 Cronbach's Alpha for the instrument used.

Skill	Cronbach's Alpha
Vocabulary	0.77
Grammar	0.71
Listening	0.89
Pronunciation	0.76

Fourteen sessions were held over a period of three months, in a computer room where both collaborative and individual laboratories were set up simultaneously (Figure II.1).

II.3.4 Collaborative learning evaluation

The second objective of this study is to analyze how collaborative learning conditions are fulfilled by the students. In order to do so, classroom and video observations were carried out during 5 of the 14 sessions. These corresponded to the 1st, 4th, 7th, 10th, and 14th sessions, with the aim of observing how the variables that were analyzed evolved over time. In the field of CALL technology, various aspects have been analyzed regarding the interaction between learners, student attitudes towards the activity, motivation (Saggara & Zapata, 2008; Merisuo-Storm, 2007), development of communication in a face-to-face environment (AbuSeileek, 2012), and the quality of brainstorming when solving exercises (Leahy, 2008). To evaluate these aspects, an observation guideline was defined based on one that had been previously used in a study of collaborative SDG tools (Infante et. al 2009). The purpose of this guideline was to analyze the extent to which conditions for collaboration are fulfilled by incorporating the specific aspects of language learning described here. The aspects to be analyzed were the following:

- Communication: measuring the level of communication in a face-to-face setting (AbuSeileek, 2012). This is measured using the number of person-to-person dialogs, person-to-group dialogs, and the number of times that students ask for and receive help from the group regarding the solution to an exercise. This also quantifies the number of times that solutions were imposed by a group member and not taken on board, but acknowledged by the rest of the group without further discussion.

- Interaction: observing aspects of the students' interaction, attitudes, and motivation (Saggara & Zapata, 2008; Merisuo-Storm, 2007). This is measured on a scale of 1 to 3, and sub-categorized as follows:
  - Positive interdependence: students feel that they are responsible for their own learning and that of their classmates.
  - Mutual trust: students trust each other; they do not question other group members' opinions, and they feel comfortable expressing their own.
  - Acceptance and tolerance: students are capable of accepting the opinions of other group members with whom they do not agree.
  - Motivation and interest: there is interest and motivation to work as a group to solve the problems in the activity.
- Coordination: observing aspects related to the students' attitudes towards the activity (Saggara & Zapata, 2008; Merisuo-Storm, 2007), and the quality of brainstorming when solving exercises (Leahy, 2008). This is measured on a scale of 1 to 3, and sub-categorized as follows:
  - Disciplined work: the established set of rules and roles are followed, with students working together as a group.
  - Requested support: support for performing individual or group activities is requested from people outside the group. A high score indicates that little support was requested from people outside the group; a low score indicates that a lot of support was requested.
  - Quality of brainstorming: students organize themselves to answer each exercise, with responses based not just on intuition but rather as the result of group planning.
- Appropriation: observing the students' attitudes toward the activity (Saggara & Zapata, 2008; Merisuo-Storm, 2007). This is measured on a scale of 1 to 3, and sub-categorized as follows:

- Suitable handling of material: students master the use of the system (hardware and software).
- Behavior towards the system: students develop adequate behavior towards the activity and its technological elements, without any discipline issues.

In order to apply this instrument, five observers were present (one per group) who had received previous training in how to apply the observation guidelines to a laboratory situation. Furthermore, videos were recorded for subsequent group analysis by the observers. This allowed the observations to be validated and for aspects that had not been considered by all the observers to be completed. The videos made it possible to agree on a set of criteria when applying the respective observation guidelines (see Appendix F).

II.4 Results

II.4.1 Pre-post test results

To analyze the results from the application of the pre-post test, a two-tailed, unequal variance T-test was used to measure the significant differences between the different groups. An analysis of covariance (ANCOVA) was also conducted with the goal of adjusting the sample results based on a pre-test. The post-test was used as a way of discerning the differences among the samples. Cohen's d was used to measure the impact or effect size of a given group.

Table II.4 shows the application of the T-Test on the samples, and Table II.5 shows the significant differences post ANCOVA between groups (p-value < 0.05), along with the effect size using Cohen's d.

Significant differences (p-value <0.05) can be observed for each skill and in every group between the pre- and post-tests (Table II.4). The only exception is for pronunciation in the group using the individual language laboratory.

The significance of the results when comparing groups are indicated by the p-values and Cohen's d (Table II.5). The three significant differences between the groups (p <0.05) are highlighted in grey. The collaborative learning group stands out as improving pronunciation when compared to the other two, and for listening when compared to the control group. The negative values of Cohen's d for the technological groups in terms of vocabulary indicate that the technological groups performed worse than the control group. However, this difference is not significant.

Table II.4 T-Test of the samples

		Pre test				**Post test**			
		Vocabulary	Grammar	Listening	Pronunciation	Vocabulary	Grammar	Listening	Pronunciation
Control	Min. value	3	0	3	1	5	0	3	1
N = 24	Max. value	19	9	11	16	19	9	12	15
	Average	8.45	2.45	6.65	9.2	11.15	3.45	7.35	10.05
	Std. Dev.	3.71	2.52	2.25	3.71	2.70	2.54	2.64	4.02
	p-value	--	--	--	--	<0.01	0.02	0.03	0.04
Collaborative	Min. value	2	0	1	2	4	1	2	6
N = 20	Max. value	13	15	14	15	17	18	14	17
	Average	7.21	2.58	6.67	9.71	9.58	4.83	9.33	12.67
	Std. Dev.	2.98	3.57	3.25	3.80	3.55	3.93	2.88	2.97
	p-value	--	--	--	--	<0.01	<0.01	<0.01	<0.01
Individual	Min. value	3	0	4	4	6	0	4	5
N = 15	Max. value	14	12	11	15	17	12	14	17
	Average	8.47	3.40	6.73	9.13	10.80	4.47	9.20	10.13
	Std. Dev.	2.88	3.16	2.52	3.20	3.00	3.16	3.36	3.89
	p-value	--	--	--	--	<0.01	0.01	<0.01	0.14

Table II.5 Significant differences between samples (post-ANCOVA), and effect size using Cohen's d.

	Vocabulary		Grammar		Listening		Pronunciation	
	p-value	**D**	**p-value**	**d**	**p-value**	**d**	**p-value**	**d**
Collaborative v/s Control	0.11	-0.23	0.18	0.38	0.02	0.70	0.02	0.92
Collaborative v/s Individual	0.28	-0.11	0.76	0.31	0.90	0.06	0.03	0.62
Individual v/s Control	0.72	-0.13	0.30	0.05	0.08	0.76	0.95	0.07

II.4.2 Collaborative learning results

Table II.6 shows the results from the analysis of the conditions required for collaborative learning in the collaborative group.

Table II.6 Results from the collaborative learning observations.

	Session	1st		4th		7th		10th		14th	
	Type of activity	Vocabulary		Grammar		Listening		Vocabulary		Listening	
	Duration	24 min.		29 min.		30 min.		33 min.		28 min.	
	Number of questions	4		4		5		6		5	
	Total number of words	12		25		15		18		15	
Category	**Variable**	**Avg.**	**Std.**	**Avg.**	**Std.**	**Avg.**	**Std.**	**Avg.**	**Std.**	**Avg.**	**Std.**
Communication	Person to person	31.25	7.36	43.50	9.37	34.00	6.74	32.63	6.99	28.88	6.49
	Person to group	14.75	2.43	21.88	5.33	14.88	2.90	15.50	2.45	16.25	2.60
	Receive support	5.63	1.30	13.00	6.97	5.75	2.25	5.50	2.14	5.38	2.33
	Request for support	3.88	1.73	8.50	6.07	3.75	2.43	3.88	2.42	3.75	2.49
	Peer-imposed solutions	4.13	2.42	9.25	3.99	3.63	2.56	3.50	2.20	3.13	1.81
Interaction	Positive interdependence	2.25	0.46	2.38	0.52	2.50	0.53	2.63	0.52	2.63	0.52

	Mutual trust	2.63	0.74	2.13	0.35	2.63	0.52	2.75	0.46	2.75	0.46
	Acceptance and tolerance	2.25	0.46	2.13	0.35	2.50	0.53	2.75	0.46	2.75	0.46
	Motivation and interest	2.00	0.76	1.75	0.89	2.25	0.46	2.38	0.52	2.38	0.52
Coordination	Disciplined work	1.88	0.64	2.00	1.07	2.13	0.83	2.25	0.46	2.50	0.53
	Requested support	2.13	0.35	2.00	0.53	2.25	0.71	2.25	0.71	2.25	0.71
	Quality of brainstorming	1.75	0.46	2.13	0.83	2.25	0.71	2.25	0.71	2.25	0.46
Appropriation	Suitable handling of material	1.25	0.46	2.38	0.52	2.38	0.52	2.50	0.53	2.75	0.46
	Behavior towards the system	2.13	0.83	2.75	0.46	2.75	0.46	2.75	0.46	2.75	0.46

From the quantitative data in Table II.6, it is evident that person-to-person and person-to-group dialogs are consistently present throughout the sessions, with a standard deviation of 5.61 and 2.98 respectively. This indicates that there is a greater dispersion in person-to-person dialogs. We can also see that the number of person-to-person dialogs always exceeds the number of person-to-group dialogs, something which is statistically significant (p-value of < 0.0003). This shows that the platform favors interactions that include the whole group over person-to-person interactions. It can also be noted that in all of the sessions, students were observed receiving more support than they requested; although this is not statistically significant (p-value > 0.05). Based on this, we can conclude that while students do not always necessarily receive more support than they ask for, it can be seen as a general trend. This could be attributed to the fact that the students are willing to support the rest of their peers proactively, without waiting for a specific request for help. On the other hand, the number of peer-imposed solutions from one peer to another decreased across the sessions, with the exception of the 4th session. Although this decrease was not significant (p-value > 0.05), the trend would suggest an improvement in communication among students.

With regards to the qualitative data, the results for the majority of the categories that were analyzed are consistently closer to the maximum value than to the minimum (avg. = 2.36, s.d. = 0.21). In general terms, the variables indicate that these attributes are developed among the students. There is also a session where we can begin to observe a trend in each of these behaviors, whether this trend be an increase, decrease or constant. As this changes from variable to variable, the students' behavior over the observed sessions is not necessarily consistent, as discussed below.

Of the variables that were observed, mutual trust had the highest, significant value that was constant across the sessions, (p-value = 0.027), with the exception of the 4^{th} session. This indicates that mutual trust is a characteristic which is constantly favored and that generally does not vary over time. The 4^{th} session corresponded to a grammar activity where there was a notably higher number of peer-imposed solutions (Table II.6). This can be aligned with a lower level of mutual trust given that the students tried harder to impose their opinions than in the other sessions and failed to acknowledge input from other group members.

Acceptance and tolerance and positive interdependence do not become constant until the 10^{th} session. This shows that in general although these aspects are achieved across the sessions, they were slow to become constant. This is related to the decline in the number of peer-imposed solutions, which, while not significant, do start form a trend towards the end of the study. This implies greater development of acceptance and tolerance and positive interdependence, given that an environment favoring equal communication among peers is essential for these to exist.

Motivation and interest is another variable that increased over time, eventually becoming constant after the fourth session (s.d. = 0.17 until the fourth session, versus. s.d. = 0.07 after the fourth session, p-value < 0.023). This indicates that it did not decrease as the sessions advanced, but instead reached a plateau. This also means it would not be affected even if the number of sessions were increased, suggesting that the students did not find the work to be tedious. In terms of the quality of brainstorming in solving each exercise, this clearly increases and becomes constant following the 7^{th} session. Although this increase is not significant (p-value >0.05), it does imply that a greater number of sessions would not improve the quality of brainstorming achieved by the 7^{th} session.

In terms of coordination, the students consistently required support from outside the group after the third session (p-value < 0.027). The level of disciplined work increased over time until the final session, although it never became constant. This could indicate that this particular aspect would continue to improve with further sessions. With regards to the students' appropriation of the platform, it is clear that their behavior towards the system became constant from the 4th session (p-value < 0.00002). This also indicates that the students' attitude towards the activity in general was positive and consistent. We can also observe that this is in direct relation to the achievements in motivation and interest, both of which remained constant from the 4th session onward. This also shows that working with the technological platform did not result in a loss of motivation towards the end of the study, despite the number of sessions. However, the suitable handling of material never became constant and instead increased continually until the end. As with the trend observed with disciplined work, this also suggests that the handling of materials could have improved with further sessions.

II.5 Discussion

Our first research question asked: when learning a language through integrated practice of the four skills, what advantages does a collaborative laboratory hold over an individual laboratory? As shown in the previous section of this paper, progress was made by all of the experimental groups (individual and collaborative language laboratory) in the four skills that were practiced: vocabulary, grammar, pronunciation, and listening. All of these results were significant, with the exception of the work on pronunciation in the individual laboratory. By comparing the results from the different groups (Table II.5), we can see that pronunciation skills are always favored by the collaborative language laboratory, with a medium effect size (Cohen's d > 0.62). The use of collaborative learning in a language laboratory therefore contributed significantly to the development of pronunciation skills when compared to an individual language laboratory or a class without technology. These skills have been analyzed in the literature, particularly the use of computer mediation in developing listening and pronunciation skills (Bodnar, Penning de Vries, Cucchiarini, Strik, & Hout, 2011). Although the reported results show that these kinds of tools improve learning, they do not take into consideration the incorporation of collaborative work (Yamada, 2009).

The development of students' collaborative skills will be evaluated in the PISA test from 2015 onward. This will be done by measuring students' capacity and willingness to solve problems by interacting with each other (Davidson 2012; De Jong, 2012). The collaborative language laboratory's differentiating element is the opportunity it provides for peer-to-peer communication within the groups, based around solving the proposed exercises. This happens when the solution requires the students to reconstruct the sequence of a sentence, and where the semantics vary depending on the skill being practiced. Another opportunity for observed communication is when some of the peers do not pronounce the word correctly. The design of the activities enabled mutual reinforcement of pronunciation between participants based on shared listening of the recordings generated by each student in the group. This allowed students using the collaborative language laboratory to develop their pronunciation skills significantly better than the others students. However, the collaborative and individual language laboratories do not show improved results in the acquisition of grammar and vocabulary skills when compared to a lesson which does not use technology.

In response to the second research question, "when learning a language in a collaborative, face-to-face activity, which are the most relevant conditions of collaboration to be fulfilled?", we look to understand how collaboration assists learning. In order to do this, we analyzed how the conditions for collaboration detailed in the introduction are present in the proposed collaborative laboratory. This analysis was based on the results obtained in the in-class observations using the observation guidelines.

An important aspect to highlight is that in the 4th session, the values for the communication variables are higher than in the rest of the sessions. This could be due to the comparatively large number of words in the grammar activity, which required greater dialog to solve each task. This also affected several of the other qualitative variables such as mutual trust, acceptance and tolerance, motivation and interest, all of which produced lower values than in the other sessions. As mentioned in the previous section, this could be due to the influence of a greater number of peer-imposed solutions within the group.

In communication, Table II.6 shows that positive interdependence is related to the larger number of person-to-person versus person-to-group dialogs. It is also related to the fact that each peer is responsible for the participation and learning of their classmates, based on the existence of a common goal. Another fact that supports this is that, while remaining constant over time, receiving help increases in proportion to the number of peer-imposed solutions, indicating that there was an awareness of the role played by peers within a group. This is also explained in terms of joint rewards, since the feedback is shared among peers and allows them to help one another.

As was mentioned in the results, the qualitative variables in the interaction, coordination and appropriation categories are closer to the maximum value, 3, than the minimum value, 1. In interaction, we can observe how the constantly high value of the mutual trust variable across the sessions contrasts with the variables of acceptance and tolerance and positive interdependence. These latter variables do not become constant until the 10^{th} session. This occurs because the students initially show behavior centered on accepting help from their peers, especially regarding the pronunciation of words. However, this becomes more participatory as there are fewer peer-imposed solutions and each student begins to acknowledge that their presence and the presence of others is essential to accomplish each task. This is confirmed by the peer-imposed solutions variable (communication) that decreases over time, with the exception of the 4^{th} session, as explained previously. Although the decrease itself was not statistically significant, the decreasing value also allows us to confirm the existence of individual accountability. This is because the students participate more as they become more confident in sharing their work and ideas with the rest of the group in order to achieve the common goal. The development of individual accountability, evident in the decrease in the number of peer-imposed solutions, has been observed in cooperative language learning tasks where no single student can dominate proceedings and discourage other members from participating (AbuSeileek, 2012). This is also confirmed by the relation of the quality of brainstorming, acceptance and tolerance, and positive interdependence variables, which increase until the 7^{th} and 10^{th} sessions before becoming constant (p-value <0.0001, Table II.6).

In the field of language learning, the use of positive interdependence and individual accountability have been analyzed separately, demonstrating that the latter presents significant advantages regarding the development of communication (AbuSeileek & AbuAlshar, 2012). In this study, the activity's design considers the use of mechanisms that attempt to fulfill all of the conditions for collaboration previously described. In a future study it would be interesting to analyze these conditions separately. This could be done by incorporating mechanisms that independently benefit each condition and using different versions of the same platform, as described by AbuSeileek & AbuAlshar (2012).

Furthermore, we conclude that better planning in solving the exercises (quality of brainstorming) shows acceptance and tolerance and positive interdependence. In the literature, the development of brainstorming has been considered as evidence of collaborative work and cooperation (Lee, 2011). It has also been considered as an opportunity for individual work prior to a face-to-face activity, where all students share their results (Long, 1990; Wen, Looi, & Chen, 2011). In the platform proposed in this project, the development of brainstorming is analyzed as a transversal element in the discussion generated by the students throughout the course of the activities. Based on this, we can suggest that the platform leads to higher quality discussions whenever the students plan how they would like to solve an exercise together. However, it is difficult to say which specific aspects could have benefited from this, since there is no phase explicitly designed for the development of brainstorming. This is something which as of yet has not been examined in the literature. Therefore, analyzing how specifically incorporating the development of brainstorming among peers into the design of collaborative language learning activities remains an interesting topic for future work.

The improvement over time in disciplined work (coordination) allows the students to coordinate and communicate better among themselves, something which is also related to the gradual improvement in the quality of brainstorming. Requested support (requested mainly from the teacher) remained constant from the 3rd observed session onwards. This shows that their help was always necessary in solving the exercises, especially in the later sessions. Quality of brainstorming and requested support can be connected to studies that have evaluated learner autonomy in relation to their own learning process in on-line language learning. Here, the same trend is present over time (Dang & Robertson, 2010). Based on this, we can suggest that autonomy benefits from the platform proposed in this project. This is achieved by developing the quality of brainstorming and requests for support, which in turn is proof of coordination and communication between peers and individual accountability.

With regards to appropriation, the students were able to behave according to rules established by the activity almost from the beginning. This can be seen in the improvement in the behavior towards the system between the first and second observation (4^{th} session) and the fact that it remains constant from then on. On the other hand, we observe that the gradual increase in the suitable handling of material variable also influenced the students' motivation and interest, the level of which increases over time (with the exception of the 4^{th} session). This occurs because better use of the system helps the students to solve the exercises, and therefore improves their willingness to use the system as a team.

Finally, in terms of the specific work done with the orchestrations for the various activities, there was no rigorous follow-up. This was because this was not one of the main objectives of this study. However, the teacher in charge of leading the class did follow them and found them to be useful, making the necessary changes and modifying approximately a third of the original script. Most of these changes related to teacher interventions, and were made in order to allow the teacher to adapt the orchestrations to their own teaching style. This shows us that an orchestration is a valuable guide for the teacher, and that it should be sufficiently flexible for them to adapt it to their own needs. Future studies could be done on the impact of orchestrations on student learning and an analysis of to what degree this is accepted by the teachers.

In this study, activities were developed to develop vocabulary, grammar, and listening skills, with integrated pronunciation practice. The model used consisted of assigning objects to students, which then had to be put in order by following the defined logic (Zurita & Nussbaum 2004). The aforementioned skills can be practiced using other models, such as identifying, categorizing, or completing sequences or associations (Nussbaum, Rosas, Peirano, & Cardenas, 2001). It can be left as future work to enhance the laboratory using these various models and see which skills are better developed through collaboration in each case.

II.6 Conclusions

Our first research question was: when learning a language through integrated practice of the four skills, what advantages does a collaborative laboratory hold over an individual laboratory? We conclude that the proposed collaborative language laboratory can further improve English language learning, particularly pronunciation, when compared with an individual laboratory or a lesson without technology. Further studies must be carried out with a larger number of students, and spanning an entire school year in order to be able to evaluate the significance of these results. Our second research question was: when learning a language in a collaborative, face-to-face activity, which are the most relevant conditions of collaboration to be fulfilled? We conclude that among all of the potential aspects of a language learning activity, communication and coordination are the most important, since they form the basis of positive interdependence, the nucleus of good collaboration, and the mechanisms for accomplishing individual accountability and awareness.

III. A SELF-ADAPTIVE MULTI-AGENT SYSTEM MECHANISM FOR COLLABORATIVE MOBILE LEARNING

Abstract. Mobile technologies have emerged as facilitators in the learning process, extending traditional activities conducted in classroom settings. Moving outside traditional learning contexts supported by mobile technologies brings elements of uncertainty, which may place the learning activities at risk. Technical aspects related to resource-sharing, reliability of services and system robustness are more difficult to manage in mobile settings and they may affect the learning outcomes for individual and collaborative performance. Despite of significant research carried out in the field of mobile learning, very few efforts have focused on and provided evidences of covering collaborative mobile learning requirements from a software engineering perspective. The work described in this paper focuses on aspects of the software architecture that aim to address the challenges related to resource sharing in collaborative mobile learning activities. This includes elements such as autonomy for personal interactive learning, scalability and richness for large group collaborative learning (both indoor and outdoor), as well as robustness for the reliability of the learning system. Additionally, we present the use of self-adaptation as a solution to mitigate risks of resource unavailability and organization failures that arise from environment and system dynamism. Our evaluation provides indications regarding the system correctness with respect to resource-sharing and collaboration concerns and offers evidences of self-adaptation benefits for collaborative mobile learning applications.

III.1 INTRODUCTION

Mobile technologies have emerged as facilitators in the learning process, offering new ways to access and use learning materials and defining the mobile learning paradigm (Sharples et al., 2005). Kukulska-Hulme (2005) states that learners should be able to engage in educational activities without being bound to a tightly-delimited physical location. In this context, mobile technologies have the capability to provide resources that meet a subset of the new learning needs, such as environment and contextual information (Sharples et al., 2009). Mobile technologies can enrich learning activities and satisfy requirements for individual and group activities. More specifically, these technologies might foster user interactions based on access to rich content across locations and at any time using portable equipments such as wireless laptops, personal digital assistants (PDAs) and smart phones (Sarrab et al., 2012).

In addition, mobile technologies can assist the development of collaborative learning activities. Ogata (2005) mentions the advantages related to the use of mobile technologies to organize and mediate social interactions, regardless of time and location in which the learning activities take place. Zurita and Nussbaum’s (2004b) work extends the list of potential benefits mentioning that mobile technologies can be used to facilitate information sharing, moderate the tasks to be completed, facilitate the management of rules and participant roles, and mediate the acquisition of new knowledge. Moreover, nowadays learning activities do not only take place in traditional learning environments (such as classrooms, lecture halls, etc.) but also in less traditional environments (such as outdoor settings, learning in public places, museums, exhibits, etc.). Therefore, there is a need to better integrate learning goals across these variety of contexts (Sharples et al., 2009). Mobile technologies play a crucial role in supporting these new developments by enabling users’ active participation in these new learning landscapes without taking into account the limitations imposed by space and time (Beetham & Sharpe, 2013). .

In a recent study, Lucke & Resing (2013) perform a extensive survey in the field of mobile learning, in order to identify current trends and challenges in the field. The authors mention Software and Hardware in their list of areas for future research in mobile learning. In the work described in this paper, we focus on a number of central software architecture-related aspects for the design of mobile learning applications. Initial efforts to focus on software related aspects for mobile learning are described by (Pettersson & Vogel, 2012), (Bollen, et al., 2012). Concerns such as platforms for scalability, software engineering methods for interoperability and strategies for deploying robust scalable applications were identified as challenges that the field needs to address. The collaborative nature of many Technology-

Enhanced Learning (TEL) activities seems to require a technological platform that supports resource sharing (resources are abstractly defined and controllable parts of a system, such as software and hardware components, devices, etc.). This has recently prompted the usage of distributed solutions on mobile devices. The first aim of this paper is to provide a software architecture that supports mobile learning activities where resources and data must be shared during execution.

Technology in education must avoid creating new barriers to teachers and students in their process to achieve learning goals (Fu, 2013). One of these barriers can be undesired system failures and diminishing of quality in the system services, as experienced in (Gil et al., 2012), (Vogel et al., 2009), (Damián-Reyes, 2011), (Zhang & Zhang, 2012). Mobile software applications generally take into consideration ideal cases of execution, based on a set of correctness assumptions. However, this view is not aligned with real environment deployment, where scenarios found at runtime do not confront assumptions taken during design and implementation (Gil et al., 2012), (Neyem et al., 2011). Outside the classroom settings, the environment involves several uncertainties itself. Classical examples of uncertainty in mobile applications are battery and network data conditions, which may be exhausted or interrupted and affect completing the collaborative tasks. Uncertainties can also be related to certain aspects of the system, such as the availability of resources needed to cover activity requirements. In certain scenarios, an activity may require resources not found in a mobile device. This could occur when the mobile device lacks a specific resource (i.e. a barometric pressure), the resources it possesses are not sufficient (i.e. powerful processor and large memory for demanding tasks such as specialized image and voice recognition with extensive databases) and because a requirement demands the combination of multiple devices. Obviously, the list of uncertainties can be substantially large. Therefore, a second aim is to design software architectures for collaborative mobile learning activities that can offer robustness to achieve the activity goals, despite certain uncertainties, and reduce human intervention to address undesired system behaviors. Self-adaptation is a well-established approach that attempts to provide certain desired quality aspects into software applications (Kramer & Magee, 2007). In order to avoid confusion due to the similarity with the term “adaptive educational systems”, the term “self-adaptive systems” should be understood as a characteristic of those systems that can modify their architectural structure or their system's behavior in response to the environment in which they are placed and to achieve specific software quality goals, such as robustness, performance and security (Cheng et al., 2009). The following research question (RQ) guides our work on providing an answer to the aims presented above:

RQ: How should we design a robust software system to support collaborative mobile learning activities that require shared resource capabilities?

In order to do so, we review current mobile learning applications (Section III.2) to identify the requirements that were determined in the literature review. We take into consideration requirements that are focused on both the learning and technical needs. Given that the applications found in the literature focus on just a few of the identified attributes, an architecture that considers all of these demands fulfills a large scope of learning scenarios. Such an architecture increases the possibilities of the learning activities, such as autonomy for personal interactive learning, scalability and richness for large group collaborative learning (both indoor and outdoor), as well as robustness for the reliability of the learning system. In order to validate our proposed architecture, we apply it to two mobile learning applications that meet all of the above technical and learning requirements. The rest of the paper is structured as follows: in Section III.2 we present related efforts in this research area to bring up current challenges in the state-of-the-art. Section III.3 presents two learning scenarios with requirements that serve as a basis for design, analysis and deployment. In Section III.4, we propose an architecture solution that addresses the identified requirements, which is evaluated in Section III.5. Section III.6 extends the proposed solution to address environmental uncertainties by applying self-adaptation techniques. In Section III.7 the conclusions of this work are presented and compared with related efforts in the field, together with a description of future efforts.

III.2 RELATED EFFORTS

In the field of collaborative TEL activities, the technological platform supporting the activity must provide spaces for individual and collaborative learning, and promote interactions among peers (Zurita & Nussbaum, 2004b). One of the main objectives of a collaborative learning activity is to provide individual support in the activity and to encourage collaboration, in order to increase the success rate in the learning process. Current mobile technologies possess a set of capabilities that can offer the means to enhance collaborative learning activities (Sarrab et al., 2012), through multimedia objects, positioning sensors, wireless connectivity, and other resources and sensors. As presented in the previous section, a current limitation in collaborative mobile learning activities is providing a software solution to offer resource sharing capabilities. In the software engineering field, this have been addressed by service composition approaches that combine multiple nodes. In our previous work, we address this challenge by the use of Mobile Virtual Devices (MVD) (Gil et al., 2010), where multiple mobile devices form organizations that provide mechanisms for offering and consuming resources located in them. One approach adopted in the mobile computing community is to consider mobile devices like thin clients that consume services located in the cloud (a virtual environment of distributed resources on large-capacity servers), also known as cloud-computing services (Dinh et al., 2013). This approach extends the capabilities of mobile devices, which consume local resources as well as services offered in the cloud (Huang & Yin, 2012), (Pocatilu et al., 2010) . One example is presented in (Huang & Yin, 2012) that provides a middleware layer to connect cloud-based services with mobile client through SMS services; and in (Rao et al., 2012), where the SMS channel is substituted with GPRS/WIFI connections. These solutions allow extendibility of the mobile device capabilities. However, they are limited to interactions between mobile devices and cloud services, which restrict desired peer-to-peer interactions to allow low-latency sharing of resources located in mobile devices.

In order to allow and promote interaction among users, some efforts have explored the use of peer-topeer approaches with mobile technologies. Coco (Johnson & Bhana, 2012) and

Mico (Johnson, 2009) are suites of collaboration applications that use peer-to-peer technology to enable spontaneous collaborations and share computing resources across a network. The aim of these platforms is to develop a peer-to-peer platform using XML-based protocols, achieving scalability, some level of flexibility and ad-hoc networking formation. Additional efforts, with document sharing approaches towards information collaboration, have applied ad-hoc network infrastructures among mobile devices (Neyem et al., 2008), (Broy et al., 2007). These solutions focus on content sharing, but ignore more complex resources sharing and coordination-related issues.

More recent solutions have employed distributed systems in their mobile learning activities through software agents in order to strengthen the individual and group tasks (Khan et al., 2011), (Garcia et al., 2012). These platforms receive the name of multiagent systems, also known as MAS (Wooldridge, 2002). The agents in a MAS are autonomous, which allow them to complete tasks individually, but also possess the necessary mechanisms to enable communication among agents, thus facilitating group activities (Haesevoets et al., 2013). The agent autonomy provides a chance to offer some levels of adaptation to fit the learning activities into environment context and users' settings (Andronico et al., 2003). Even though resources are distributed among the MAS platform, the current approaches are focused on sharing static resources (like multimedia content, documents, etc.), and not on sharing other more complex resources (e.g. hardware resources like camera, GPS sensors, processing capabilities, etc.). This still becomes a limitation to use specific hardware components that are not locally present in a device, and restricts the selection of mobile devices.

The above-presented studies offer an overview of the current trend related to the design of collaborative mobile learning technologies with regard to information and resource sharing aspects. One particular approach uses multiagent systems, to provide the functions for resource sharing within the platform and autonomy to allow individual activity assessment. However, none of the previous work completely covers the emerging technological requirements for collaborative mobile learning activities, that include group management, real-time collaboration, local and remote resource accessibility and service composition on mobile settings. New mobile learning technological platforms should offer resource-sharing mechanisms to consume local and external resources, in order to avoid mobile device hardware limitations and to support the set of requirements mentioned above. The following research questions refine the general research question in order to tackle the above identified challenges:

RQ1: Which are the most suitable characteristics that software architectures should possess to offer resource sharing for collaborative mobile learning activities?

RQ2: Which software elements are necessary for collaborative mobile learning applications, in order to satisfy resource-sharing requirements for individual performance and collaborative interactions?

RQ3: How to guarantee robustness with respect to supporting collaboration through the mobile applications in dynamic environments?

III.3 RUNNING EXAMPLES & REQUIREMENTS

This section introduces two scenarios that illustrate the aims mentioned above. The scenario descriptions result on a list of generic Use Cases and related requirements that help to describe future collaborative mobile learning applications. The list of requirements allows the elaboration of architectural characteristics and a refinement of the aims we address in this work.

III.3.1 English Numbers Sorting

Infante et al. (2009) presented a scenario that uses a single computer with multiple-mouses to support collaborative learning activities. Based on this concept, a new effort of collaborative language laboratories was developed using multiple-headsets (Calderón et al., 2014). The main goal of this learning activity was enhancing the students' English pronunciation and understanding. The system assisted the activity via a speech-recognition solution, in order to evaluate participants' pronunciation and provide automatic feedback.

This specific application had two main limitations. First, due to a shared physical space (display), the students could peek on their colleagues' information, which clearly diminishes the learning outcomes. Dividing the display into personal physical spaces would benefit the learning process, providing the suitable information to each participant in the activity (Ogata, 2008). Second, the application did not allow user's mobility.

We defined a new version, called English Number Sorting (hereafter, ENS), in order to address the mentioned limitations. The activity can be performed, in groups of three, in collocation in a shared lecture room during the classes and on distance from the students' home during homework. The activity is divided in two main phases: individual and collaborative. In Phase 1, each student is assigned a number, and he is requested to correctly pronounced in in order to proceed to Phase 2 (pronounced numbers are recorded to be used in the second phase). In Phase 2, the students must propose and agree on an incremental sequence of numbers. For this phase, the students do not visualize the numbers in the group, but they can hear their peers' recordings from Phase 1. Figure III.1 shows a group of three participants in the first phase of the ENS activity. The left-side member must still pronounce ”seven” to activate the assigned number; the center participant has correctly pronounced the number ”four” (”Right!” feedback), and the right-handed participant has incorrectly pronounced the number ”six” (”Wrong. Try again” feedback). All the students are required to correctly pronounce their assigned number in order to proceed with the second phase.

This scenario exemplifies the need for a system that supports individual performance (we define this functional requirement as FR.2) and collaboration (FR.5) for a learning activity. Based on the scenario description, a supporting system must offer multiple nodes (mobile phones) for the participants (FR.1) in the activity, and these need to be connected through a communication infrastructure in order to cover resource-sharing requirements (FR.4). In particular, a supporting system should offer mechanisms to distribute the assigned numbers among the students' devices (in phase one), share recorded audio files between participants in a group (in phase two). Due to current technological limitations, mobile devices may not be capable of locally perform speech-recognition processes with the desired level of accuracy. Therefore, an external server is required to operate this process (FR.4). In order not to interfere with the activity flow and not to interrupt the students' performance in the activity, we set 3 sec. as an acceptable lapse for system feedback (we define this non-functional requirement as NFR.1). This threshold has been defined according with requirements from the specific domain (Handley & Hamel, 2005), and from a study with experts in linguistics and second language acquisition in Chile.

Figure III.1 Group of three peers to sort randomly generated numbers.

III.3.2 The Hidden Treasure

"The Hidden Treasure" (hereafter, THT) provides a second example of collaborative mobile learning activity with resource-sharing characteristics and participants mobility in outdoor settings. THT is based on the previous work on fostering the understanding of geometric concepts for students between the age of 10 and 12 assisted by mobile technologies (Gil et al., 2012). During the activity, groups of participants perform distance measurements on the field in order to perform different geometric calculations (distance, perimeter, area, and volume). Mobile devices equipped with GPS are used as tools for distance measurement, which obtain the existing distance between the phones in a group.

In THT, the participants must apply triangulation techniques to find a hidden treasure. In order to complete the activity, each participant receives a mobile device with a customized application for the calculation of distances. Mobile devices can interact with an activity server, that specifies the set of tasks to be carried out in the activity and collects activity responses for each group. Additionally, participants receive a treasure map on paper (see

Figure III.2(a)). Points A and B on the map are as well marked on the field to make possible a mapping between the real world and the map representation. Given these two initial points, the distances between points (represented as A-G points and treasure in the map) and trigonometry concepts, the participants must determine the physical location of the treasure. Finding the treasure requires the discovery of the intermediate points, via triangulation. Triangulation tasks require the involvement of at least three participants. Thus, the participants must collaborate and coordinate their actions in order to determine the points in the map. Under the user request (attempt), the application must provide feedback in terms of current distances between members in the group. The feedback can then be compared with expected distances in the map, in order to determine if the attempt successfully corresponds with a desired location (Figure III.2(b))

This scenario requires a system that uses mobile devices with GPS capabilities (FR.1, FR.3). With respect to resource-sharing aspects, the participants must share their current location to perform the triangulation tasks (FR.4, FR.6). Additionally, the system must offer a communication channel between participants in a group to notify about the discovery of a targeted point and assist the coordination between individual and group performance (FR.2, FR.5). In order not to disturb the activity flow, the system is required to offer distance-calculation functionality when required and to have low latency delays for the feedback (NFR.1). Based on our previous experiences (Gil et al., 2012), we defined 10 seconds as a max. waiting time to offer distance functionalities (a location may not be available due to low positioning accuracy) and 1 second as the accepted latency to serve distance calculation requests.

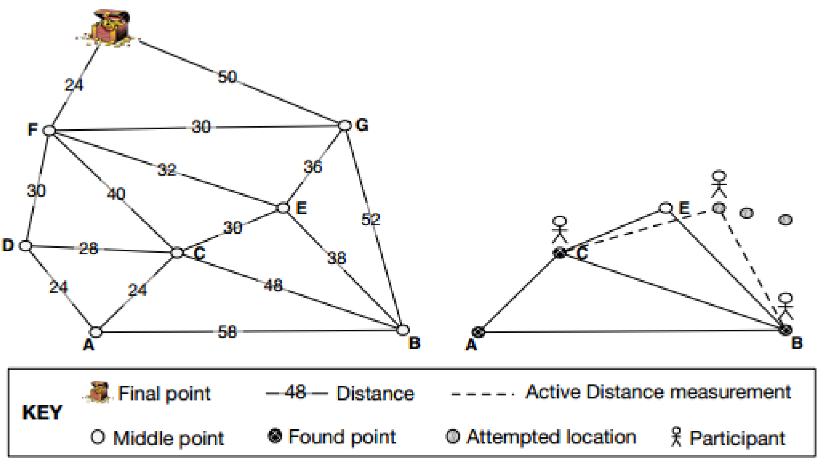

Figure III.2 (a) Treasure map. (b) Instance of a point search.

III.3.3 Requirements Overview

Figure III.3 offers a use case diagram to show the use cases identified in the two previous learning scenarios. The use cases will offer key points for design and validation of a solution for the collaborative mobile learning activities. Based on the use cases, we provide the following list as a set of requirements that a software system should offer:

- FR.1 One device per participant
    - ENS: to Sort Number, Access microphone, Access audio recording (Perform individual task)
    - THT: to Calculate distance, Accept found point (Perform individual task)
- FR.2 Activity flow management
    - ENS & THT: to Perform Individual Task, Perform collaborative task

- FR.3 Local resource accessibility
    - ENS: to Access microphone
    - THT: to Access GPS location
- FR.4 Remote resource accessibility. Resource-sharing capabilities.
    - ENS: to Share audio recording, Check pronunciation, Validate sequence of numbers
    - THT: to Share GPS coordinates, Validate treasure location
- FR.5 Group management, coordination & collaboration
    - ENS: to Sort numbers ∗ THT: to Calculate distance
- FR.6 Service composition
    - ENS: to Check pronunciation
    - THT: to Calculate distance
- NFR.1 A defined QoS in terms of response time.
    - ENS & THT: to Perform Individual tasks, Perform collaborative task, Share local resource, Manage group
- NFR.2 A defined QoS in terms of service robustness.
    - ENS & THT: to Perform Individual tasks, Perform collaborative task, Share local resource, Manage group ´

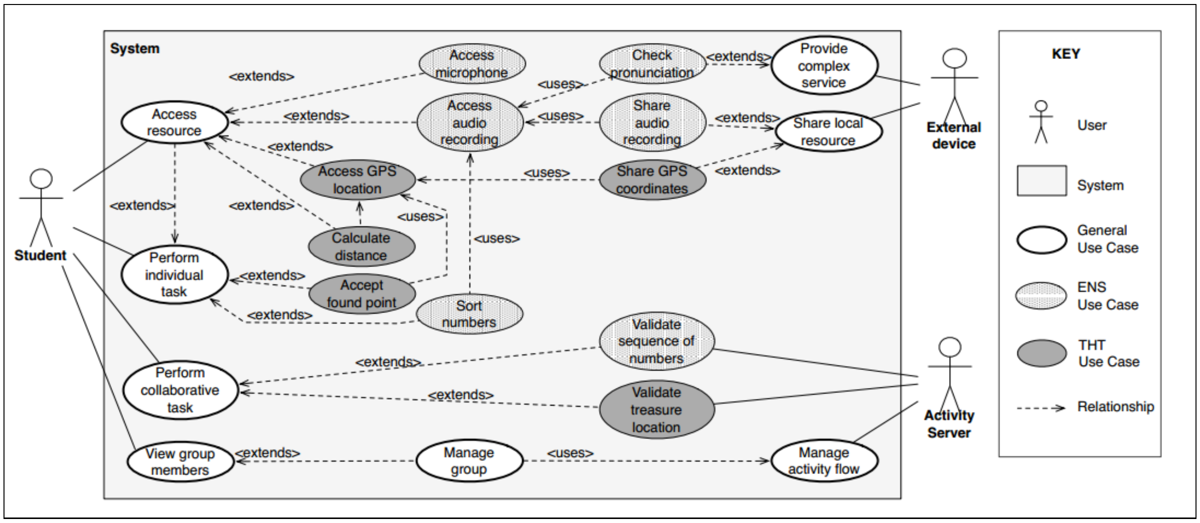

Figure III.3 Use cases for described learning scenarios.

III.4 The software architecture

In this section we propose an architecture to support collaborative mobile learning activities. The architecture has been designed following the requirements identified in the use cases presented in the previous section. We describe the software decisions taken for the architecture definition showing the relation with respect to requirements and use cases, thus providing an answer to RQ1. Later, we specify a description of the architecture design, elaborating on the software elements that are involved in the architecture, answering RQ2. RQ3 and NFR.2 (robustness) are not considered in this part, and studied in Section III.6.

III.4.1 Software Decisions

According to the use cases presented in Section III.3, we require a distributed architecture that provides the infrastructure for individual assignment of devices and offers one device per participant in the activity (FR.1). Distributed architectures can facilitate the distribution of resources among the participants in the activity and can offer capabilities for sharing resources within the activity.

In particular, we advocate for the use of multi-agent systems as an approach of implementing a distributed system. MAS are composed of multiple devices with autonomous capabilities for decision taking (Wooldridge, 2002), (Haesevoets et al., 2013). In a MAS, each agent holds a set of behaviors that describe the logic that specifies the actions and the communication protocols in order for the agent to interact with other autonomous agents. These autonomous capabilities are highly beneficial for the definition of individual student tasks (to determine the individual performance) and to define the flow, participation and collaboration criteria for collaborative tasks (Ciancarini et al., 2000). Also, multi-agent systems provide mechanisms for low latency communication that result in an increasing message transmission performance thus reducing emerging bottleneck issues (Ferber, 1999) when compared with center-based distributed approaches. In our design, each mobile device becomes an agent of the MAS.

In the context of this work, agents are capable of autonomous decision-making for tasks that should be completed locally (e.g. choosing a service among various service providers, FR.3), and facilitate delegation of certain atomic responsibilities with respect to the entire system (i.e. numbers sorting and calculation of distances, FR.4, FR.6). These features give autonomy to the nodes, in comparison to a centralized coordinator solution. A decentralized solution reduces response times in large scenarios where partial and located knowledge is sufficient, as it avoids potential bottlenecks (NFR.1). Based on these characteristics, an architecture based on autonomous agents has good potential for scalability. With the definition of autonomous specific behaviors for the mobile devices it is possible to define the autonomous logic to use the phone microphone during the Phase 1 of the ENS scenario, to define criteria to access the GPS in THT scenario, and to provide personal feedback locally and autonomously on the mobile device.

Multi-agent systems frameworks provide mechanisms for communication via specialized protocols for data exchange between agents (Wooldridge, 2002). This supports the communication needed for a collaborative activity. For instance, this feature has been used to offer communication between peers in the activities, between the mobile devices and activity servers and for resource sharing capabilities.

Resource sharing mechanisms are required to satisfy the lack of particular resources in user nodes. MAS enable devices to access remote resources (offered as services by other agents in the MAS), when these type of resources are not available locally, using standard approaches (e.g. yellow pages services offer mechanisms for service registration and discovery). In our previous work (Gil et al., 2010), we presented an approach for resource-sharing in organizations with mobile devices called mobile virtual device (hereafter, MVD). A MVD consists of the aggregation of multiple mobile devices to create a virtual entity that shares resources located on mobile devices within the MVD. The MVD also allows the service composition of existing services and resources located on the devices. Accordingly, the combination of a MAS with a MVD middleware provides the capabilities for the use of local and remote resources within the work group, which covers the necessary technological needs in order to satisfy the previous use cases. Table III.1 summarizes and relates Requirements with Use Cases and Software Design Decisions.

Table III.1 Mapping learning scenarios requirements with software decisions

Concern	**Requirement / Use Case**	**Software Design** Decisions
Individual work	(FR.1) One device per participant (FR.2) Activity flow management: Perform individual task (FR.3) Local resource accessibility: Microphone, GPS location	Autonomous agents deployed on mobile devices
Collaboration (communic.)	(FR.2) Activity flow management: Perform collaborative task (FR.4) Remote resource accessibility GPS location, Audio recording (FR.6) Service Composition	Use of a distributed system through Multi-agent systems
Collaboration (organization management)	(FR.5) Group Management: View group members (FR.6) Service Composition: Provide complex service	Agents on devices self-organize dyna- mically as MVD
Resource Sharing	(FR.6) Service Composition: Provide complex service	Multi-agent system, MVD
Adequate Response Time	(NFR.1) QoS (response time): Perform indiv./collab. task Share local resource Provide complex service	Communication via a Multiagent system

III.4.2 Architecture Design

Here, we first introduce the suggested architecture through a layer diagram that provides a high level of abstraction of the deployment of the distributed system (Figure III.4) in order to answer the requirements acquired in Section III.4.1. Second, we enter in a deeper level of detail with a component diagram in order to identify the basic components in the system and understand their roles and interactions within the system (Figure III.5). Three main layers have been defined in the layer diagram in order to construct the distributed system (see Figure III.4). The User Interface (UI) layer offers the points of interactions with the user, such as windows, buttons, videos and feedbacks regarding the activity. This layer is allowed to use the underlying layer, MultiAgent System (MAS), which is in charge of providing domain specific functionalities that are required for the activity in place. The MAS layer contains an Agent and an Organization Middleware (MVD), based on the MVD concepts as described in (Gil et al., 2010). Agents are in charge of executing the roles that are necessary to perform tasks in the activity, such as accessing mobile device resources (both local (FR.3) and remote (FR.4)), managing the activity logic (FR.2), providing interaction between mobile devices and servers and interaction between members in a group. In order to manage group-related aspects, such as the identification of members in the group, the MAS layer includes the MVD. Together, the Agent and Organization middleware are capable of providing functionalities for collaborative tasks (FR.5), such as distance calculation between mobile devices (FR.6). Finally, the Communication Infrastructure (CI) layer provides mechanisms necessary for communication within the platform, such as channels and protocols.

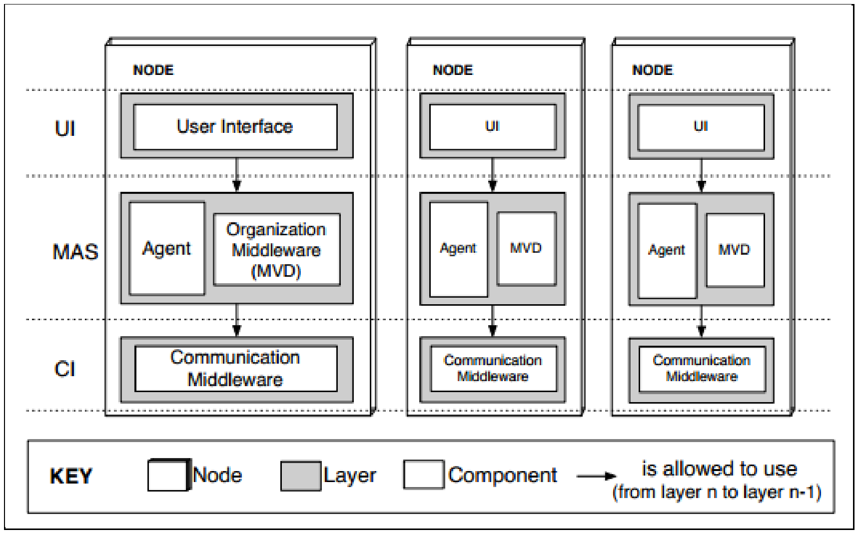

Figure III.4 Architecture described through a layer diagram

Figure III.5 shows the participation of multiple nodes in the platform that create the distributed system. In a first analysis, we classify the nodes in four different typologies depending on their role in the distributed system. These are the mobile devices, the activity servers, service proxies for external services and infrastructure servers. Typically, mobile devices are the point of interaction for participants in the activity, as these provide the application interface, some local resources and mobility features that are required for the mobile learning activity. The activity server entities have the role to control the activity flow of the participants in the activity. Nodes with this role manage the groups, defining the participants in each of them; track their performance (in terms of the group response to each task in the activity); and handle the activity flow by providing the proper feedback to the participants. Notice that this role may be provided by one of more nodes in the system, which may offer levels of specialization (i.e., in terms of the feedback to be provided) and redundancy. In some cases, the distributed platform may lack resources that can be relevant for the activity. Under these conditions, an optional service proxy can extend the platform functionalities by providing a linkage to external service providers. One example is a proxy node to access Google Speech API services in the ENS scenario. Proxy nodes can as well be used for concerns such as learning content provision through a Learning Management

System (such as Moodle), and remote information access (such as access to news RSS feeds). Finally, an infrastructure node is required to provide functionalities for the infrastructure, such as agent and service-registration services, messaging channels and logging repositories.

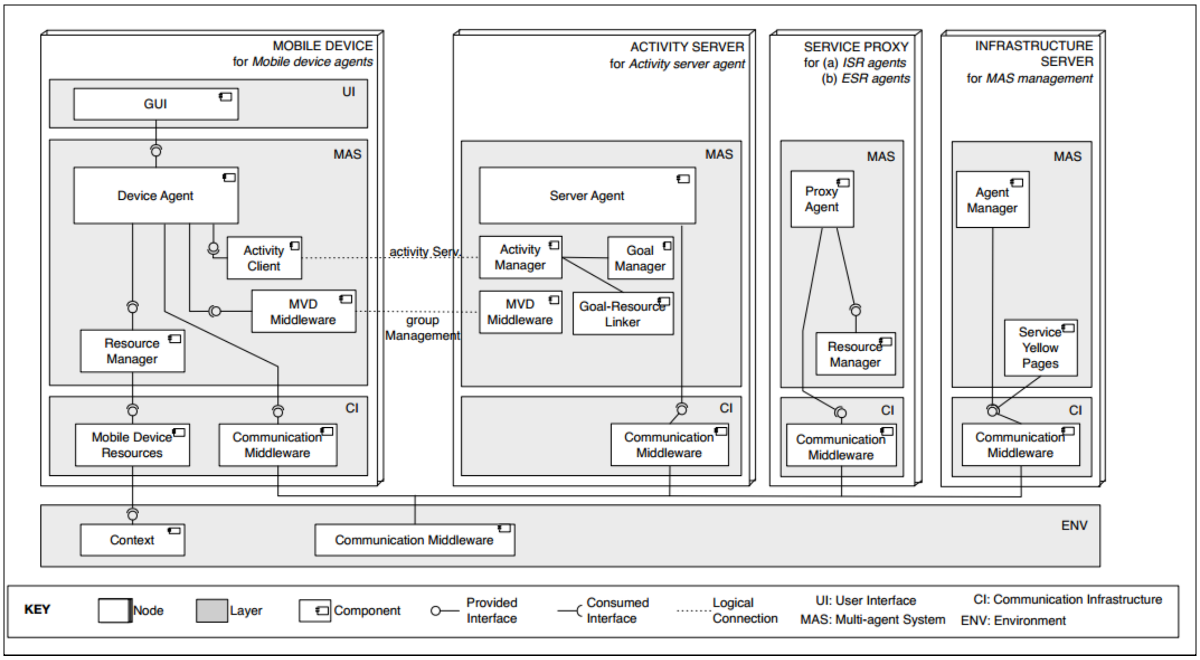

Figure III.5 The proposed architecture described through a components diagram.

Figure III.5 shows the top-level components of the architecture, in order to introduce the key components that are necessary for this MAS-MVD distributed solution. Additionally, the figure incorporates the environment (ENV) layer, which includes such components interacting with the system (i.e. GPS satellites communicating with GPS devices) and channels for communication among devices MAS.

The Activity Manager and Activity Client components are responsible for managing the activity flow, such as a student-teacher interaction mechanisms, in order to achieve desired goals. The responsibilities of these components may include the control of the activity flow, presentation of task announcements, feedback and complementary materials needed for the activity at hand and the specification of needed resources.

In order to participate in the MAS, all nodes require a software agent. This component is responsible of executing the node's behavior. This behavior can contain the global activity logic (Server Agent in the activity server), individual behaviors for tasks within the activity (Device Agent in mobile devices), behaviors that offer access to resources via services and additional behaviors for managing the MAS (Agent Manager in the infrastructure server) and connecting to remote services (Proxy Agent). Agents in mobile devices have the autonomy to execute local behaviors. This feature covers the requirement of performing individual tasks in the learning activities.

The agents in the MAS possess the capabilities to exchange messages. This feature is used for the collaborative aspects that are required in the groups. However, an additional component MVD Middleware is necessary to support this collaboration (FR.5). The MVD middleware component manages knowledge with respect to the members belonging to the groups, so meaningful communications can be established only between the relevant agents in the groups. Additionally, nodes offering composed services (through service composition), may use the MVD middleware to determine the location of services in the MVD that are required for such service composition. I.e., a distance calculation requires 2 or more coordinates to be performed. This may imply that 2 GPS resources (offered by GPS services) may be requested. A distance-calculation service can be therefore offered as a composition of 2 GPS services.

The Resources Manager provides the required mechanisms for accessing local resources in a node and resources in the rest of the platform. Among its responsibilities, the resource manager should be able to locate needed resources for the activity and register local resources (as services) in the Yellow Pages component so other nodes in the platform can make use of them. The Resource Manager can as well be used to provide information about services offered outside the MAS, making use of a Proxy agent in Service Proxy nodes. Finally, the communication infrastructure should contain components that are specific for the communication requirements in the distributed system, to allow communication among agents (Communication Middleware), and to communicate with the environment, such as reading the GPS coordinates (Context). More information regarding the different components and its roles can be found in the project website (http://homepage.lnu.se/staff/digmsi/SA-MAS/).

III.5 Implementation and assessment

In this section we present two implementations that we created following the architecture design presented in Section III.4. The implementations answer the requirements for the activities presented in Section III.3. We offer the assessment review through the analysis of the implementations. We start by providing a description of the implementations. Afterwards, we describe the metrics used for the assessment, the settings used for the assessment (deployment and relevant environmental conditions) and reason about and link the results to the research questions. Log traces and software implementations can be downloaded from the project website for review and replication purposes.

III.5.1 Implementation Description

The implementation of the MAS is based on JADE (Bellifemine et al., 2008). JADE provides a framework for creating software agents and declaring the desired agent behaviors. JADE is available for multiple platforms, including Android mobile devices. Using JADE we define specific behaviors for agents that run on the mobile devices and on the activity server. On the mobile devices, we implement behaviors for audio recording, position gathering and other domain specific functionalities. On the activity server, we implement a behavior to manage groups of participants, control the activity flow for the groups, and register group performance.

Communication between agents is supported via FIPA messages (Bellifemine et al., 2008) (which implement the Communication Middleware). Additionally, JADE offers mechanisms for agent and service registration and discovery; i.e., an Agent Manager offers agent registration management and a Directory Facilitator offers the yellow pages' role. Some specific functionalities are not feasibly deployable on mobile devices, such as a high accuracy speech recognition service for our English learning purposes. Therefore, the system is complemented with multiple instances of proxy agents on servers to provide such services. One example is the ISR Agent (internal speech recognition), deployed on a server in the MAS, designed to provide Microsoft SAPI services. The Microsoft SAPI is limited to one recognition request at a time. We include a second speech recognition service via a proxy agent that we call ESR Agent (external speech recognition), to access the Google Speech API.

Organization concerns are deployed among nodes in the MAS using the MVD design (Gil et al., 2010), including servers and mobile devices involved in the platform. The MVD allows local management of groups and identification of existing resources in the platform. I.e., on the Activity Server node, the MVD component declares the number 2. of groups that participate in the activity and the members assigned in each group. On mobile device nodes, the MVD components identify peers and the physical mobile devices that are used by participants in the group. Physical device identification is necessary to determine resources shared in the group. More detailed information regarding the software architecture can be found in the project web.

III.5.2 Functionality Availability Assessment

ENS Scenario. We studied the desired functionalities in the ENS activity with the involvement of 6 participants divided in two groups. We assessed the functionalities needed for the use cases presented in Figure III.3 by checking their correct behavior and availability. The activity took place in Santiago of Chile and had 40 minutes of duration. We studied the microphone recording (access microphone resource (FR.3)), the audio playing (access audio recording (FR.3)), and the speech recognition feedback functionalities (FR.4), by checking whether or not the functionalities were present or not when required with the mobile devices nodes. The MAS deployment included one dedicated computer (Intel Core I5, 4GB RAM) to offer the Activity Server role and offer Microsoft SAPI service (ISR), a Service Proxy computer (Intel Core I3, 2GB RAM) to access Google Speech API services (ESR) and 6 Lenovo tablets with a 2.1GHz processor, 1GB of RAM and running Android 3.1 as Mobile Devices.

Service availability issues were only found in the Check Pronunciation use case, in which the speech recognition was required. The Microsoft SAPI was defined as the preferred service, and the Google Speech API service as an alternative option when the first was not accessible (blocked processing another audio file). During an initial test (in Table III.2), the speech recognition process was initiated 49 times (instances). 2 instances were not correctly initiated on the mobile device due to mobile client issues accessing the microphone. The remaining 47 instances fired a request to consume the local speech recognition resource (Internal in MAS), from which 32 could be directly processed, indicating a 68.09% of availability of Microsoft SAPI resource. However, 15 needed to be forwarded to a remote speech recognition resource (External to MAS) because the Microsoft SAPI was blocked by another ongoing request. From these 15 instances submitted to the External to MAS resource, 12 were successfully processed (i.e. 80% of availability in Google Speech API resource), while the remaining 3 resulted in a time-out error from the External to MAS resource (not complying with NFR.1).

Table III.2 Results of availability, performance and complexity analysis on the ENS application

	Metric	Local to the Node (Microsoft SAPI)	Internal in MAS (Microsoft SAPI)	External to MAS (Google Speech API)
Test1 (Resource Selection Assessment)	Involved Components	7	10	12
	Resource selection (number of requests)	N/A	47	15
	Resource availability (successful responses [%])	N/A	32 [68.09%]	12 [80%]
Test2 (Communication Overhead)	Number of samples	100	125	125
	Resource selection (avg. in ms)	10	18	18
	Resource usage (avg. in ms)	23	23	24
	Resource response time (avg. in ms)	33	42	480
	Total time (avg. in ms)	43	65	498
	Overhead (avg. in %)	N/A	51.16%	1058.14%
	Re-transmissions (%)	N/A	2.7%	2.9%

THT Scenario. In a previous experiment of the THT scenario, 12 mobile devices were used in outdoor settings, in order to use GPS's in a real environment. The activity took place Växjö, south of Sweden and had 55 minutes of duration. The mobile devices were HTC Hero running Android 2.3 with a 600MHz processor. During the execution process, the participants performed distance calculations between members in the group (Gil et al., 2012). However, in some conditions, the mobile devices could not provide accurate measurements for the distance calculations (FR.6). The errors became present in 2 mobile devices. Human involvement was required to recover from the errors, by restarting the mobile devices. This restart process had a duration of around 5 minutes (not complying with NFR.2), since the student identified the phone as failing until a manual recovery was effectuated (by a technician). Based on our logs, these failures represented a 1.51% of the expected up-time for distance calculation functionality, and 2 over 4 groups that experienced problems during 5 minutes, which can become frustrating (affecting their future performances) and even harmful for the learning activity (as they may learn misleading concepts).

100% availability of resources and services (NFR.2) is far from common in mobile device applications. We address this robustness concern in Section III.6.

III.5.3 Performance and Complexity Assessment

Concerning non-functional requirements, we focused on how the implementation fulfills domain requirements and how architecture software decisions satisfied the desired system response time. We studied performance and complexity of the system measuring communication overhead and identifying the number of components involved in the service consumption, as a metric to study the complexity of a service consumption in a distributed system.

ENS Scenario. We selected the ENS scenario implementation for this assessment, due to the richness of the case. To assess the system performance and overhead (NFR.1), we studied three different cases for resource consumption, whether the resource was found in the same node it originated the request (Local to the node), in another node inside the MAS (Internal in MAS) or in a node external to the MAS (External to MAS). Local resource consumption provides a point of reference for the measurements. The last two cases describe situations in which the resource to be consumed is not located in the same node, but it is present in another node in the MAS (Internal in MAS) or it is external to the MAS and accessed through a Proxy Agent (External to MAS). We studied Local resource consumption by requesting speech recognition services from the ISR agent itself. Internal in MAS is represented by requests initiated on a mobile device to consume Microsoft SAPI services in the ISR agent. External to MAS is represented by requests initiated on a mobile device to consume Google Speech Recognition services in the ESR agent.

During the test, we analyzed the resource selection complexity with respect to the location of the selected resources. The Local to the Node resource consumption for speech recognition service requires the involvement of 7 components, including the following: (1)Activity Client, (2)Activity Manager, (3)Device Agent, (4)Server Agent, (5)MVD Middleware, (6)Communication Middleware and (7)Resource Manager. The first six enumerated components are involved during the process of acquiring the assigned number to pronounce. The seventh, offers access to the local resource. For an Internal in MAS resource consumption, the number of components involved increases to 10. In addition to the previous six components for number acquisition, four more components are used to access external resources. (7)Agent Manager, (8)Yellow Pages, (9)ISR: Proxy Agent and (10)ISR: Resource Manager. The Agent Manager communicated with the Yellow Pages component in order to identify the location of the desired resource. Once this is located, the resource is consumed through the Proxy Agent. The consumption of speech recognition resources External to the MAS requires two additional components, (11)ESR: Proxy Agent and (12)ESR: Resource Manager, in order to access Google Speech API services. External to MAS resources are only requested if Internal to MAS resources are not available, therefore, components (9)ISR: Proxy Agent and (10)ISR: Resource Manager need to be requested as well.

The access to the speech recognition services requires the discovery of resource location, the usage of the network infrastructure that supports the MAS and the use of Service Proxies. When compared with local resource consumptions, the speech recognition service consumption presented an additional overhead. This overhead is due to required internal communication to consume services in the MAS, and additional Internet communications to access External to MAS resources. The comparison between the three latency measurements made possible to determine the efficiency of the system in the searches and provisions of resources, which will enable future comparisons in terms of performance with systems providing equivalent functionalities.

The communication overhead was studied measuring the time involved in the selection of a speech recognition resource for Internal in MAS and External to MAS cases and compared with time required to consume an equivalent resource Local to the Node (see Test2 in Table III.2). The audio files to be processed had a weight ranging between 90-100KB, and the network settings consisted of a dedicated 48Mbps WIFI connection and a 2.4Mbps Internet connection. In order to measure the communication overhead variables, 250 speech recognition requests were performed (125 using the Internal in MAS resource and 125 using the External to MAS resource - Microsoft SAPI). Additionally, we measured 100 executions of service consumptions that were locally originated in the ISR agent (server offering the

Microsoft SAPI service), in order to study the overhead implications of using distributed services in the platform in comparison to local resource consumption.

We measured the elapsed time in four different points during the service consumption process. The first comprises the time required to determine the location of the speech recognition service (Resource selection in the table). Local resource discoveries were faster (10ms) than external resource discoveries (18ms). This overhead can be explained by the need of using the Yellow Pages services in order to determine the location of the desired resource. The second metric offers a view on the time used by the service provider to process the speech recognition (Resource usage), and indicates a similarity between Microsoft and Google solutions.

We defined the total time for a service delivery (Resource response time) as the time spent for the service execution plus the time spent during communication processes. It is not surprising to identify that this lapse of time substantially increased when resources External to MAS were accessed. When using the Microsoft SAPI Local to the Node, only internal node calls are required (33ms) to consume the service. When accessing resources Internal in MAS, the communication overhead (42ms) is limited to a local network usage both used for service discovery through the Yellow Pages and for the service consumption. When requiring resources External to MAS, the overhead values are increased (480ms), due to the use of Internet connections, which severely impact latency measurements. Through these numbers we can observe that the usage of a distributed infrastructure based on a MAS can affect the system's performance in terms of delivery times. When services are located in the MAS, these increases are negligible in terms of absolute values (65ms vs. 43ms) and due to Yellow Pages requests and WIFI communications. However, the latency increases considerably when services need to be found outside the MAS, and Internet communications are required. In this case, the latency has a ten times growth to consume resources External to MAS.

When consuming MAS services, an alternative approach is to consider direct connections between agents, avoiding Yellow Pages services. Such approach would improve performance and latency measurements (NFR.1), but would affect the system's scalability, maintainability and extensibility, as resources should be known in forehand by the agents involved in the platform.

The use of External to MAS resources could have more implications besides performance and latency. Even response-time within desired time constrains is a variable for robustness, reliability of the services should also be considered. Reliability could be not guaranteed, which becomes a threat with respect to system robustness, and can lead to risks for the learning activity. One example is the use of Google Speech API in our learning scenario. In this case, services are not managed by the platform, but external actors are involved (Google). The availability of the external service (due to high request load, maintenance processes, system failures, among others) becomes an uncertainty. Additionally, for the THT scenario, we found GPS reliability issues, which may influence the activities' outcomes. In the following section we present an extension of the platform that provides mitigation mechanisms to provide guarantees for certain quality concerns, such as robustness in our case.

III.6 Self-Adaptation

The assessment study showed a lack of resource availability in particular cases (NFR.2), mostly due to uncertainty regarding the resource and service state. Resource availability and system robustness are critical concerns that must be provided in collaborative mobile learning applications, and widely present in multiple other domains. New system's design and implementation to address robustness concerns can imply an increase of systems complexity. To avoid this complexity increase, the state of the art advocates the application of self-adaptation (hereafter, SA) mechanisms (Cheng et al., 2009), which principle is based on the separation of concerns. A self-adaptive system is divided into two subsystems: the managed system (which supports functions that are specific to the domain) and the managing system (responsible for contributing with quality properties to the system) (Weyns et al., 2013).

SA mechanisms are placed on top of a managed system, and aim at providing selected quality concerns via designed adaptations. A well-established approach to realize SA is through MAPE-K (Monitor-Analyze-Plan-Execute and Knowledge) feedback loops (Kephart et al., 2003). A MAPE-K loop is composed of four main roles that Monitor the environment and managed system states, Analyze the completeness of the system with respect to the desired goals, Plan mitigation actions in order to address identified errors, and Execute the selected plan. These four activities are supported on a Knowledge base that provides a level of abstraction of the activity, managed system, environment and goals.

In our case, robustness is achieved (only) if the groups involved in an activity include the number of resources that are required for the activity goals (FR.3, FR.4), and these resources provide the desired service quality (NFR.2). Due to space limitations, we use the THT scenario as a running example in this section. The THT system is robust when the groups in the activity have the required number of GPS resources when needed (which can vary depending on the task) and provide location under a specified accuracy measurement (accuracy tolerance may vary depending on the task). In Figure III.6, we illustrate an extension of the previous MAS architecture, in order to guarantee robustness through a SA layer, based on (Weyns et al., 2013). In order to center the focus on SA aspects, the UI and ENV layers have been removed from the figure. In our particular case, the managed system represents the distributed system that we described in Section III.5. The managing system is responsible for analyzing the current behavior of the managed system and, in case of service failures, adopting the necessary measures to maintain system's robustness.

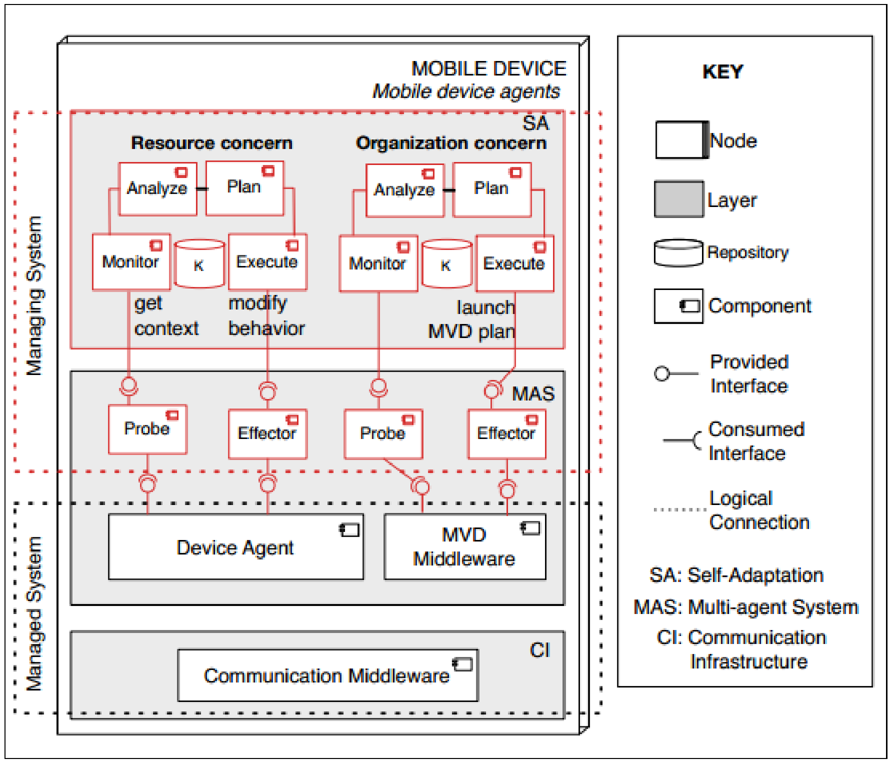

Figure III.6 Self-adaptive components on mobile nodes

Two SA loops are designed in the solution in order to provide robustness for two separate concerns. A first MAPE-K loop is concerned on the consistency of the accuracy that GPS resources provide (FR.3, NFR.2). In other words, the first feedback loop is concerned with managing the GPS service availability based on the current GPS service quality. The second MAPE-K loop is concerned with managing the number of GPS resources in a group (FR.4, NFR.2), so it can achieve the activity goals.

Below, we provide a description of components in the managed and managing systems (Weyns et al., 2013), that are required to provide SA. This shows the required modifications in a legacy system in order to provide points for monitoring and transferring the adaptations into the managed system.

III.6.1 The Managed System

The managed system requires domain specific components that provide the necessary functions necessary for the activity. In addition to these system's components, it is necessary to include points of interaction into the managed system so that SA can be applied. There are two types of components that are the touch points for interactions between the managed and managing systems. The former are called Probes, and Effectors the latter.

The Probe components' role is to enable gathering information from the system, in order to allow the reasoning processes performed in the SA mechanisms. Probe components are expected not to interfere with managed system's behavior. In particular, for the THT scenario, probe components have been implemented to allow data acquisition with respect to the GPS accuracy in the mobile devices, the current state of the organizations in the groups (represented in the MVDs) and the activity requirements. Therefore, probes must have access to read certain parameters from the Device agent component (current acquired GPS accuracy) and from the MVD middleware component (current organization deployment).

Analogously, the Effector components deal with transmitting the adaptation tasks, decided by the managing system, into the managed system. For The Hidden Treasure scenario, Effectors have been implemented to manage the GPS service in accordance to the GPS accuracy, deactivating or activating the GPS service when required; and to modify the group compositions when required. Those two types of components are the only communication points between the managed and managing system, which enable the system monitoring and the carrying out of adaptation decisions to address the quality concerns.

III.6.2 The Managing System

The managing system focuses on the provision of quality properties that are desired in the managed system. Our particular quality concern in the collaborative mobile learning activities has focused on providing robustness of the system in the face of resource failures.

In order to provide SA for such concern, it is necessary, first, to Monitor the necessary system and environment parameters that can have an influence in our concern. In the case of The Hidden Treasure scenario, it becomes necessary to monitor the current state of the managed system in terms of accuracy of each of the GPS resources and the number of GPS resources in a group, and monitor the current activity requirements in terms of the required GPS accuracy and required number of members in a group to fulfill the activity goals. Second, it becomes necessary to Analyze the correctness of the managed system behavior. I.e., it is necessary to analyze the GPS service quality with respect to the activity requirements; or the completeness of a group, in terms of GPS resources. Third, a Plan needs to be designed to mitigate detected issues. An example is to deactivate a GPS service if its performance is not accurate, or determine an additional GPS resource to be integrated in a group if this is found incomplete. And fourth, Execute the planned actions to transfer the mitigation to the managed system.

Given the nature of the scenarios, the suggested solution is based on a distributed system. Therefore, it becomes necessary that the components of the managing system are distributed among the nodes of the MAS. I.e., in order to self-adapt GPS services, it is necessary that nodes in the MAS locally contain the Monitor, Analyze, Plan and Execute components. For concerns that refer to distributed nodes, it becomes necessary to deploy the SA components in a distributed manner as well (Weyns et al., 2013). For instance, for group SA, it becomes necessary to locate Monitor and Execute components in each of the members of the organization, while the Analyze and Plan components can be located on specific member of the group, following a master-slave pattern approach (Weyns et al., 2013).

In our studies, aspects such as the service quality in the use of GPS coordinates and the availability of audio and microphone service are some of the parameters monitored on mobile device nodes and the quality (in terms of availability) of speech recognition service is a parameter monitored on the server side. The SA mechanisms may be customized to address the quality concerns that are desired for the system at hand. Thus, SA mechanisms for GPS accuracy may be different from the SA mechanisms used for microphone recording services.

III.6.3 Self-Adaptation Assessment

We present the assessment process of the self-adaptation applied to THT scenario to provide robustness for GPS service reliability and group completeness in front of GPS inaccuracy.

A first set of SA mechanisms has been designed to manage the GPS services. SA is based on GPS accuracy, deactivating the GPS service and un-publishing it (from the Yellow Pages) if the GPS quality is not satisfying or activating and publishing the GPS service if the quality recovered. The GPS service self-adaptation is deployed in all the mobile devices involved in the activity and it is locally and individually managed in the nodes. In other words, the SA mechanisms are locally controlled and implemented on each of the mobile devices, providing autonomy and decentralization to the SA solution. The GPS service SA is represented in Figure III.6, by the Resource concern MAPE loop on the mobile devices SA layer.

The deactivation of GPS services, as a result, can lead to groups having lack of resources necessary to cover the MVD requirements. Therefore, a second MAPE-K loop is designed to monitor the completeness of the groups in the activities and, to mitigate potential issues, to incorporate additional phones to the group when required (Organization concern MAPE loop on the mobile devices). This SA loop is shown in Figure III.6 with the Organization concern MAPEK loop. One device in each organization is selected as a master device to be in charge of the SA decisions. This device is then responsible to gather information with respect to the organization state, the activity requirements (in terms of number of GPS resources) and to determine mitigation plans when required. Due to the distributed deployment of a group, the Monitor role is distributed among the nodes in the organization, which means that all the mobile devices are in charge of monitoring the current GPS service state and to notify the master device when changes are monitored. Equally, the Execute role is distributed in the organization, in order to transfer the mitigation actions across the members in the organization. The interested reader can find more information with respect to this selfadaptation behavior in (Gil de la Iglesia, 2013).

The assessment is performed in lab settings based on The Hidden Treasure scenario, with an activity that requires 3 GPS resources per group, and a minimum accuracy of 10 meters for the GPS service. We assess the GPS selfadaptation through Test1 with one mobile device running Android 2.3 on a 1.2GHz processor and 1GB RAM. We use a dedicated 3MB/s WIFI connection for the communication aspects. In order to study the self-adaptation in detail, we include an additional component that emulates the GPS behavior. This component emulates GPS locations and accuracies, which let us provoke GPS inaccuracies on devices and to study the SA in place in high stress scenarios (in terms of GPS failures). A total of 200 failures and recoveries were emulated on the GPS services. 100 of these failures emulate the behavior of a GPS module affected by cloudy conditions, giving inaccurate measurements (errors >10meters) during 3 seconds. This behavior is played in a loop that lasts 42sec. The other 100 errors emulate a flapping GPS device behavior having inaccuracy measurements during 0.5s every 22 seconds.

SA incurs with a processing overhead, not only during the adaptation processes (to mitigate risks when a failure has been detected), but also during desired system's behavior due to the periodic monitoring process. An initial cost of self-adaptation is originated by a GPS probe component that would periodically monitor the GPS service quality, with a period of 500ms (milliseconds). The figures represented in GPS columns in Table III.3 offer an overview of the additional overhead produced by the implemented SA layer and the efficiency of the SA' behaviors with respect to selfhealing. For local GPS service SA, the processing overhead does not result in a considerable increase. It is interesting to notice that, in this first SA experiment, all the failures and recovers were correctly treated by the implemented SA mechanism. One reason for this success lays on the fact that, in the worst-case scenario, the SA mechanism will require 411ms to adapt the GPS service in the system. This number was always lower than the changes in the environment, which updated the GPS state in a 500ms frequency-basis.

Table III.3 Results of the self-adaptation mechanisms.

	Test1 (GPS)		Test2 (MVD)	
Variable	Avg.	Max.	Avg.	Max.
Self-Adaptation overhead (%)	1.38%		3.15%	
Failure detection (ms)	14	63	511	973
Alternative plan identification (ms)	19	78	1338	15994
Correction application (ms)	75	411	1435	16197
Effectiveness of failure correction (% of resolved failures)	100%		97.50%	

With respect to the organization robustness concern, the SA was expected to identify lack of resources in a group and heal these states by autonomously integrating a new device in the group. In our lab settings, a lack of GPS resources in a group can be originated by GPS service failures. Test2 was performed to assess the organization SA. Five mobile devices were involved in this test, emulating a scenario with groups of three participants and two additional spare devices for contingency issues. In Test2, the GPS behavior were defined to have a 10% failure rate (in terms of accuracy) during periods between 10s and 20s. The results are shown in the MVD columns in Table III.3.

Based on the scenario requirements defined in Section III.3, we consider the SA to be successful when a group can be recovered in less than 10 seconds (defined by previous experiences (Gil et al., 2012)). During our test, 40 failures were provoked on GPS resources in the MVD. 39 group incompleteness were recovered in less than 2s. However, the remaining consumed around 16s for the recovery. In this case, the self-adaptation had an effectivity of 97.50%.

The network infrastructure plays an important role in the SA process due to the distributed deployment of the nodes, which implies higher periods for managing organizational failures that when compared to local self-adaptation. For example, the detection of a failure in a slave (a GPS being turned off in one member of the organization) requires a communication process between the slave and the master and it took up to 973ms.

The SA mechanisms presented in this section have been designed to mitigate potential risks that the system may face at runtime. Although the mechanisms have demonstrated a high level of effectiveness in front of failures, not all the failure instances are correctly addressed. Therefore, it is necessary to invest further efforts in analyzing the SA mechanisms and understanding the environmental conditions that can head to the not-addressed particular cases. This aspect demands the use of rigorous methods (such as the application of formal methods (Gil de la Iglesia, 2013)) to specify the behaviors of system and SA mechanisms. However, the potential impact of the SA is evident. Human involvement can be extremely reduced, moving from 5 minutes required to manually recover a group to an average of 1.435s.

III.7 Conclusions and Future Efforts

Mobile devices are quickly being adopted in education due the numerous possibilities they can offer, such as personalization and mobility, among others (Echeverría et al., 2011). In this work we pinpointed and focused on two critical aims, resource-sharing and robustness. We proposed a software architecture to cover these aims in order to increase the range of possible scenarios in collaborative mobile learning activities. The main aspect of this proposal is to combine the benefits of multi-agent system solutions together with self-adaptive mechanisms. One critical aspect in collaborative mobile learning scenarios is the autonomy of actions taken by the participants in the activity combined with resource sharing aspects for collaboration. The RQ1 “Which are the most suitable characteristics that a software architecture should possess to offer resource sharing for collaborative mobile learning activities?” concerns the software architecture aspects that are necessary to support such activities. We propose the use of a distributed system architecture composed by mobile devices and servers to support the activity. Based on a multi-agent system (MAS) architecture, we propose the design of a software architecture that offers one device per participant with a certain level of autonomous behavior (for individual performance aspects) extended with communication features (in order to support collaboration with the rest of the participants in the activity). Additionally, a distributed architecture solution, in which each participant carries a personal mobile device, offers scalability to the system, in terms that new mobile devices can be integrated to the system by registering them into the MAS. In terms of resource access, our approach allows that nodes in the system can access local and remote resources, as soon as they are offered by nodes in the distributed system.

With respect to the RQ2 “Which software elements are necessary for collaborative mobile learning applications, in order to satisfy resource-sharing requirements for individual performance and collaborative interactions?”, we want to provide a more detailed level of description of the structural architecture design for a collaborative learning application. We suggest the use of a set of components for local and distributed resource management, node behavior management and organization management that we illustrate in Figure III.5. Efforts like Huang & Yin (Huang & Yin, 2012), and Rao et al., (2012) have tackled the resource management issue by extending mobile device capabilities with cloud-computing approaches. Even though these efforts can extend the set of functionalities present on a mobile device, these still lack features with respect to resource-sharing between mobile devices. Johnson’s group (Johnson & Bhana, 2012) , (Johnson, 2009) provides an innovative solution in the mobile learning community, that brings a peer-to-peer based solution to offer resource-sharing between devices. However, this solution does not provide instant communication between peers, but all mobile devices are supported by a server-instance where resources (mainly data) are stored and pulled in a periodic basis. Our solution is one step forward with respect to Johnson’s approach. A solution based on MAS is presented by Khan et al. (2011). This solution uses agents with the purpose of sharing services located in each of them. In their case, the creation of organizations is specific for the activity, existing centralized negotiators, coordinators and manager agents for their creation. We also suggest the use of a MAS-based solution to allow peer-to-peer and low-latency communication, in order to accomplish the response-time restrictions that are set for mobile learning scenarios. However, we offer a decentralized solution in which organization concerns are distributed among the nodes in the MVD middleware. This particular aspect is the concern expressed in the RQ3 “How to guarantee robustness with respect to supporting collaboration through the mobile applications in dynamic environments?”. Through our experiments, we identified that a distributed architecture based on mobile MAS can cover response-time constraints that are necessary in order not to restrain collaborative mobile learning applications. Moreover, due to the MAS based approach, this solution suggests good scalability properties in the scope of learning scenarios. Future research will focus on providing evidences in medium and large scale scenarios.

Finally, we have focused on robustness concerns for collaborative mobile learning applications to complete the answer to RQ3. We have presented an extension of the MAS solution with self-adaptation capabilities towards resource and organization robustness aspects, which offer guarantees for specific QoS. Additionally, we studied the processing overhead that self-adaptation mechanisms can imply on a legacy system, showing that SA-related overheads do not create a noticeable negative impact on the system. On the contrary, we have presented that the implemented self-adaptation mechanisms (for THT scenario) could self-adapt service states in around 75ms and organization issues in 1300ms. This contrasts to our previous experiences, where human involvement was necessary, and fixing service and organization could require more than 5 minutes.

To the best of our knowledge, there are few relevant efforts that have focused on failure recovering in collaborative mobile learning applications. More studies should emphasize providing quality properties to learning activities.

The designed self-adaptation mechanisms imply changes in the behaviors of the nodes in the MAS. This aspect becomes more relevant when working in a distributed environment, as it may affect the behavior of groups in the system or, in the worst case scenario, even the overall system. Formal methods should be used to evaluate the correct design of a system of this fashion, and verify that the desired goals and the required property qualities are achieved through the self-adaptation processes (Weyns et al., 2012).

We consider that the presented work is a first step towards the definition of a reference architecture for the field, which covers the aims related to resource-sharing and application robustness.

In our future efforts, we consider the study of the new possibilities regarding pedagogical activities that the proposed software architecture offers by covering resource sharing and robustness aims.

IV. INTEGRATED FRAMEWORK FOR DEFINING AND VERIFYING PROPERTIES OF FLEXIBLE WORKFLOWS WITH DECOUPLED RULES

Abstract. Flexible workflows allow processes to be defined based on a sequence of tasks that can vary in run-time. However, this flexibility is only limited to certain pre-defined sections of the workflow and it does now allow more significant changes to be made. The flexibility is also limited by how the transition from one task to another is defined. One way of defining this transition is to use the workflow's implicit rules. As there is no exact definition of the properties that are affected by the changes to the workflow, it is hard to define a working flexibility mechanism. Furthermore, an inherent problem with using flexibility in workflows is verifying whether or not the changes that are made break one of the workflow's essential properties. This is particularly true of the requirements for defining certain quality control parameters.

This paper proposes a framework for creating flexible workflows where the definition of the rules is decoupled from the definition of the tasks. A process for verifying properties in real time is also proposed. This process allows the user to check whether or not the changes have affected the workflow's essential rules. In order to do, a translation to Petri-net is proposed, where the definition of both the rules and the workflow are translated. By doing so, a single definition is created based on both of these specifications. A scenario was defined to validate these proposals, with a series of test cases used to evaluate the validity of both proposals. The results show that a scenario involving changes to the run-time can be successfully created and run. These changes can be based on properties that are intrinsic to the scenario, as well as on others that are related to Petri-nets.

IV.1 Introduction

A workflow is created as a sequence of steps, where certain tasks are carried out. These tasks work towards meeting the workflow's pre-defined goals (van Der Aalst, 2009).

Executing a workflow involves creating a thread to record the running instances (Reichert et al., 2009). When executing a workflow, changes cannot normally be made to the tasks, entry parameters, validation conditions, or running order without having to restart the system (i.e. suspending the execution and incorporating the changes to the definition of the workflow before executing it again). This is because the state of the workflow instance must be reset to its original value (Qiu & Wong, 2007).

Previous research has looked at introducing changes without having to restart the entire system; these approaches are called *flexible workflows* (Leitner & Rinderle-Ma, 2014; Sadig et al., 2005). Flexibility in this type of workflow can work in three ways. The first is to delay decision making when faced with an event (i.e. leaving a spot or gap to be filled). The second is to allow new tasks to be added or changes to be made to the order of the workflow immediately, both for current and future executions. The final way is to ignore the current model by skipping tasks and/or violating restrictions that were in place with the previous tasks and running order (van Der Aalst, 2009).

The literature shows that workflow management systems do not provide enough flexibility support to cope with the broad range of failure situations and changes that may occur during workflow execution and life-time (Müller, 2002; Reichert et al., 2009; Reichert & Weber, 2012). One example of a flexible workflow is DYNAMITE (Herr et al, 2005). This software adds flexibility to workflow management systems by allowing them to make changes during execution. The approach used by DYNAMITE is to mix the standard definition of the workflow by defining certain points or hotspots within the workflow where new tasks can be added. Declare offers a different approach (van Der Aalst, 2009), where the workflow is specified in a declarative language. This allows the properties to be verified should a task be added, although it does not allow changes to the running order.

Furthermore, workflows can be classified as centralized or distributed. A distributed workflow distributes the processes and execution across computers using various approaches. For instance, a centralized version of the workflow can be replicated across various computers (network nodes), or a group of nodes can each host a fragment of the workflow. In this case, the workflow is fully distributed (Knuplesch et al., 2013).

A particular problem with distributed workflows is related to their use with technology (e.g. projectors, microphones, specialized libraries, services, etc.), which is distributed across the nodes that represent the workflow. These resources are not necessarily available all of the time; nor can they be evenly assigned across the nodes (Joeris, 2000; Ehrler et al., 2006).

The problem of flexibility in distributed workflows has been approached in different ways. One of these is to incorporate multi-agent systems, where there is an agent in each node that hosts a fragment of the workflow (Müller et al., 2004; Van der Aalst, 2004; Buhler & Vidal, 2005). Another approach is to make nodes available to play the role of both data and control servers, as well as executors of the workflow. This allows distributed control of the process, in addition to the migration of the execution of processes between nodes (Reichert et al., 2009). The advantage of these systems is the autonomy they can provide each node for making decisions. However, this autonomy can result in potential problems with syncing and locks given the way they are set up as a distributed system.

To define a workflow it is necessary to define the control-flow and rules of the domain conditions (axioms) that must be upheld during execution of the workflow. These must also be transversal or determine the direction of the flow at certain points (conditional control-flow). A rule is understood as being a statement that defines or constrains some aspects of business. It is intended to assert business structure or to control or influence the behaviour of the business. The business rules approach distinguishes between terms (definitions), facts (connection between terms) and rules (constraints, derivation or reaction rules) (Nagl et al., 2006). Depending on how they are included in the definition of the workflow, they can also provide the workflow with elements of flexibility. The rules are not usually defined explicitly, or are stored and executed in ad-hoc systems (engines) that are run and maintained in parallel. This is considered as a limitation as it starts to couple the workflow system with the rule engine. It also limits the maintenance and means that the whole system lacks robustness when dealing with changes. As highlighted above, the rules are present explicitly or implicitly in the workflow. The way that the rules are inserted will depend on the language in which the workflow is programed (Schonenberg, et al, 2008). For workflows programed in an imperative language, these focus on how tasks should be performed by specifying an order. The rules govern the workflow by following this approach and are represented implicitly based on the order and relationship between the tasks (i.e. they are not hard coded in the workflow). An example of this is the process of putting on shoes and socks. The first step is to put on the socks, followed by the shoes. Based on this order, as a rule it can deduced (i.e. it is not coded) that the socks must be covered by the shoes. Workflows which follow a declarative approach are focused on achieving the goals that are defined for the execution of the workflow; not on how these are achieved. Given this, rules which represent the restrictions of the workflow's domain are explicitly defined as predicates. The order in which the tasks are executed is not coded as it is deduced implicitly (van Der Aalst, 2009).

Workflow management systems that follow either an imperative or declarative approach will perform equally well when dealing with changes that involve adding tasks during run-time (Schonenberg et al., 2008). This differs depending on whether the change is limited to one particular workflow instance or to all future instances. However, changes that involve deviations in the workflow model, such as requests to skip tasks, go back to a previous step, or even undo a step, are only possible with an imperative approach. This is because the concept of running order does not exist in the declarative approach (Schonenberg et al., 2008; Reichert & Weber, 2012).

There are few examples in the literature of attempting to incorporate the change within the workflow itself. One of the main attempts has been to integrate rules into imperative workflows that explicitly represent the restrictions of the domain. An initial approach is to directly incorporate blocks of code that represent the rules into the code where the workflow is defined. However, this makes changes to the workflow difficult and therefore makes it hard to maintain or inflexible (Reichert & Weber, 2012). The rules that can be defined using this approach must be simple (i.e. without using variables that represent the state of the workflow). They must also be local, without including workflows with distributed elements

(Cicirelli et al., 2010; Reichert et al., 2009). One way of solving these problems is to take full advantage of using service-oriented architecture by explicitly decoupling the sequence of tasks in the workflow from the rules. The aim of this is to provide the workflow with flexibility and maintainability. For example, the rules are stored and performed in external rule engines, which are requested by the workflow (modelled in BPEL) at certain pre-determined points using web services (Nagl, Rosenberg & Dustdar, 2006). This allows a posteriori flexibility as it defines hotspots where the rules that are contained in a web service and remain decoupled from the workflow can be modified. Nevertheless, this leads to another limitation as it does not allow changes to the running order when the workflow is being performed. This is because such changes could affect the rules or require new rules.

When incorporating mechanisms for flexibility and distribution into a workflow, it must be verified that certain global properties maintain their integrity despite the change. The aim of this is to discover whether or not they meet the workflow's execution goals. In the case of a declarative workflow this is a trivial matter as its definition is based on the complete set of global properties. Given this, any change to the workflow must maintain these properties, regardless of their degree of complexity and/or distribution. However, for imperative workflows (the most commonly used in the industry) this is not a trivial issue. An example of this is when the rules are not coded within the workflow and are instead deduced based on the order of the tasks (i.e. implicit transition rules). In that case, verifying the rules can be tedious as there is no concrete definition of the rules contained within the workflow's code. The following research question therefore arises: Is it possible to incorporate complex rules into an imperative workflow so as to allow dynamic changes (during run-time), both to the properties that govern it as well as the order in which the tasks are defined and performed, guaranteeing the integrity of the rules that govern the problem's domain?

Creating a workflow with the characteristics indicated above makes the process of verifying properties after changes more complex. According to the literature, the verification of properties in imperative workflows, as well as in coded rules can be done independently for each of these using Petri-nets (van der Aalst, 1998; Buhler & Vidal, 2005; Ou-Yang & Winarjo, 2011). Petri-nets come from a language for mathematical modelling which allows distributed systems to be described using a bipartite graph. With Petri-nets it is possible to represent events and conditions, allowing processes and workflows to be modelled formally. Their elements also represent the semantics of the modelled process and allow properties which are expected to be met during the execution of a workflow to be checked. These include properties such as deadlock-freeness, reachability, safety and liveness (van der Aalst, 1998).

One disadvantage of separately verifying the properties of workflows and rules is that the compliance to these properties cannot be checked. This is because there is dependency between the workflow tasks and the rules which govern the transition between these tasks. This assessment is necessary when making changes to the workflow that affect the running order or the definition of the set of rules. This is because inconsistencies may appear due to the changes that are made. Furthermore, an additional technical dependency is created as it requires the existence of a translator or interpreter that can do these processes combined. With this, the second research question arises: Is it possible to define a methodology for automatic property verification based on Petri-nets for the workflow proposed in the first research question?

This study looks to answer these research questions by proposing a methodology which provides a framework that integrates a workflow and its set of associated rules. By doing so, the integrity of the changes made to both the rules and the order of tasks can be verified, thus allowing flexible workflows.

This paper is structured as follows: section IV.2 reveals the existing formalizations in the field of Petri-nets applied to the context of workflows and rules. This is shown separately from the introduction so as to lay the foundation in section IV.3 for a proposal to answer the research questions and their respective formalizations. Following this, a strategy for validating the proposal is defined in section IV.4, while in section IV.5 the results of this are presented and analysed using a test scenario. Finally, the conclusions of this study are included in section IV.6, as well as suggestions for future work.

IV.2 Petri-nets as a requirement for modelling workflows and rules

In the literature, an approach for modelling and formally defining workflows has been performed explicitly using Petri-nets (Buhler et al., 2005). In this work, the authors propose direct translations of code written in BPEL4WS to patterns defined using classic Petri-nets. These patterns, or templates, correspond to configurations of places and transitions that are bijective to the definition in BPEL. With these, it is possible to define flexible workflows that are restricted to a pool of situations. Using this concept, the definition of a workflow can be directly translated to a representation in Petri-net. The flexibility is incorporated by inserting snippets or blocks of code into the BPEL. These snippets can be directly translated to a certain pattern in Petri-net. Although this allows for some flexibility, it is only to a certain extent. The changes are limited to adding and modifying tasks, but do not allow rules that establish a transition from one task to another to be incorporated. As a consequence, the validation of the changes is based on how these match with the patterns in Petri-net. While the creation of these is well defined according to the methodology, this is not the case for a change in the rules that govern the workflow.

Nevertheless, there are approaches that take into account the problem of flexible rules, although they do not consider the definition of a workflow. An example of this are approaches based on fuzzy logic applied to Petri-nets (Lui et al., 2013). These allow a world to be represented where changes can be made to the context of the problem. However, this leads to the following problems:

- Complex rules (i.e. rules that are made up of other rules through disjunction and conjunction) can return different results for the same input.
- Given that Petri-nets use decision thresholds to make decisions, calibrating this type of system leads to a high overhead for incorporating flexibility.

IV.3 Integration of Worflows and Rules

This study proposes the definition of a framework for integrating workflow and rules, with a methodology for verifying properties. An approach similar to that described in Nagl, Rosenberg & Dustdar (2006) is used to develop the integration between workflow and rules. With this approach, the following elements must be defined separately:

- The definition of the rules that govern the application's domain. These rules are defined as they are logic propositions, programed in a certain language. With this, two types of rules must be distinguished: those which are invariant to the application's state (i.e. that must always be met), and those which regulate the change from one state to another (i.e. those that are used to control the flow of the sequence of tasks).
- The definition of the workflow that represents the temporal sequence of the tasks to be performed

IV.3.1 Formalization.

This section gives a formal account of workflows integrated with rule. Before defining our workflows we define formally what we mean by a variable. We assume that a *variable* v is a mathematical object with an associated domain Dom(v). An *assignment* is a set of tuples(v,k), where v is a variableand k is a value in Dom(v). Given a set of variables V, a *rule* is defined inductively as:

- *v OP K* is a rule when OP is in $\{=,<,>\}$, *v* is in *V* and *K* is a value in v's domain.
- OR(R) where R is a finite set of rules. Intuitively OR is the Boolean OR operation.
- AND(R) where R is a finite set of rules. Intuitively AND is the Boolean OR operation.

The truth value of a rule r can be determined given an assignment *a* that assigns a value to every variable in V. We say that r evaluates to true in A if r reduces to true given the assignment A, and we say that r evaluates to false in A if r reduces to false given A. An inductive definition is straightforward and we omit it here. For example rule AND(v=k,u>m) evaluates to true iif A assigns k to v and A assigns a value to u that is greater than m.

A workflow integrated with rules W is defined as a tuple $\langle V, v_{init,}, S, s_{init,} s_{end}, T \rangle$, where:

- V is a finite set of variables.
- v_{init} is an (initial) assignment of values to all of the variables in V.
- S is a set of sentences. There are two classes of sentences: (a) assignment of values to variables, denoted by $var := value$, where $value$ is in the domain of variable var and (b) $var := proc$, where var is a value and $proc$ is a distinguished constant which intuitively denotes a procedure call.
- T is a set of tuples $\langle s, r, s_+, s_- \rangle$ where s, s_+, s_- are sentences and r is a rule.

  Intuitively, tuples model transitions of the workflow. Tuple $\langle s, r, s_+, s_- \rangle$ represents the fact that after finishing the execution of s the control will transfer to s_+if r takes the value True, and to s_- otherwise. To model unconditional transitions, which do not involve a rule (i.e. go from one task to another regardless of the state), we can use an expression that is always true (e.g. $1 = 1$) for r, and $s_+ = s_+ = s$.

- $s_{init} \in S$ is the initial sentence.
- $s_{end} \in S$ is the final sentence.

IV.3.1.1 Execution

Given a workflow integrated with variables, we now define the semantics of an execution. To this end, we start off by defining *instant descriptions* which are mathematical representations of snapshots of the state of execution. Then we define how execution can move from one instant description to another.

Formally, an instant description is a tuple $\langle s, a\rangle$, where s is a sentence and a is an assignment to all variables in *V*. In addition, we define the binary relation $\vdash$ between two instant descriptions, such that $\langle s, a\rangle \vdash \langle s', a'\rangle$ intuitively means that $\langle s', a'\rangle$ is reachable from $\langle s, a\rangle$ in one step of computation. Formally, $\langle s, a\rangle \vdash \langle s', a'\rangle$ if and only if:

1. when $s = v := b$ then a' is like a, but with the assignment of variable v replaced with value b. Thus, a' assigns all of the variables in $V - \{v\}$, in the same way as a, and assigns b as a value of v.
2. if $s = v := proc$ then a' is like a, with v assigned to some value of the domain of v
3. for some r and some s', $\langle s, r, s', s''\rangle$ belongs to T and r evaluates to true in a' or $\langle s, r, s'', s'\rangle$ belongs to T and r evaluates to false in a'.

An execution of W is a sequence $\langle s_0, a_0\rangle\langle s_1, a_1\rangle \ldots \langle s_n, a_n\rangle$, where $s_0 = s_{init}$, $a_0 = v_{init}$, and $\langle s_i, a_i\rangle \vdash \langle s_{i+1}, a_{i+1}\rangle$ for all i in $\{0, \ldots, n-1\}$.

An execution $\langle s_0, a_0\rangle\langle s_1, a_1\rangle \ldots \langle s_n, a_n\rangle$ is *successful* if $s_n = s_{end}$.

IV.3.1.2 Formalization of Petri-nets.

A Petri-net P is defined as a tuple $\langle L, M, N, p_0, F\rangle$ where:

- L corresponds to the set of places
- M corresponds to the set of transitions
- N corresponds to a set of tuples of the form $\langle p_0, t_k, p_1\rangle$, where p_0, p_1 are places, while t_k corresponds to a transition, which directly relates two places to each other, from p_0 to p_1 .
- p_0: initial place.
- F: set of final places of the Petri-net

IV.3.1.3 Translation.

Given a workflow integrated with rules, W, we define below a procedure for generating a Petri-Net

1. For each variable v, we define one place $p_{v,i}$ for each value i in $Dom(v)$.
2. For each sentence s, we define a place p_s.
3. For each transition $\langle s, r, s_+, s_- \rangle$
   a. If s is s_{init} or s_{end}, we define two places, p_{init} and p_{end}.
   b. If it corresponds to the assignment of a value to the variable, a transition, m_k, is defined, where k corresponds to the index of the sentence.
4. Following this, a transformation pattern to Petri-net is applied to each sentence, resulting in a sub Petri-net.
5. After this, each resulting sub Petri-net is added iteratively, depending on the function of the associated transition. With this, and depending on whether or not r_k can be true or false, the place represented by each value of the evaluated variables is added to the corresponding entries to the sub Petri-net that must be executed if r_k is true or false.

An example of some of the transformation patterns are included below. In the case of the rules, these are based on the work by Nazareth (1993) and Chu et al. (2003).

- AND: a pattern that represents an AND conjunction is represented as a Petri-net with as many entry places as there are rules in the conjunction. Each of these points to a transition, which in turn is directed to an exit place. This also makes it possible to add other conjunctions and disjunctions as they are also established as rules.

- OR: a pattern that represents an OR disjunction is represented as a Petri-net with as many entry places and transitions as there are rules in the disjunction. Each entry place points to a transition, and each transition points to the same exit place. This also makes it possible to add other conjunctions and disjunctions as they are also established as rules.

- Comparison = (equality): is represented as a Petri-net that has several entry places: one that corresponds to the value of the variable that is being evaluated in the comparison (i.e. the answer to the rule is True), others that correspond to the values that do not correspond to those that were evaluated (i.e. the answer to the rule is False), as well as another place that corresponds to the previous task that comes before the evaluation of the comparison. There are two exit places. The first is one that connects the place corresponding to the value of the variable that returns True with the place of the previous task using an AND. The other connects the places corresponding to the values of the variable that return False with the place of the previous task using an AND. Both have an exit place that connects with the sub Petri-net that represents the relevant task to be performed once the condition has been evaluated, regardless of whether it is True or False.

An example of a formalization of a workflow and rules following the proposed outline is detailed below. Figure IV.1 shows the visual representation of part of the resulting Petri-net, showing the transformation patterns, assignment of variables, rules and transitions. The purpose of this example is to show the process of an speech-recognition system used for language learning.

Context:
A student has to correctly pronounce a word. They have three opportunities to do so.
Rules (in natural language)
R1: The word must be correct in order to advance to the next activity
R2: There are three opportunities to correctly pronounce a word
Variables (V) and their initial configuration (v_{init}*)*
correctWord = 0, attempts = 0;

Formalized rules

r_1: correctWord = 1

r_2: OR(attempts = 0, attempts = 1, attempts =2)

Tasks

t0: sinit

t1: isCorrect := 0;

t2: isCorrect := validatePronunciation()

t3: attempts = attempts + 1

t4: send

Transition function (T)

<t0, {1=1},t1,t1>

<t1,{1=1}t2,t2>

<t2,r1,t4,t3>

<t3,r2,t2,t4>

Goals (G)

<isCorrect = 1, t4>

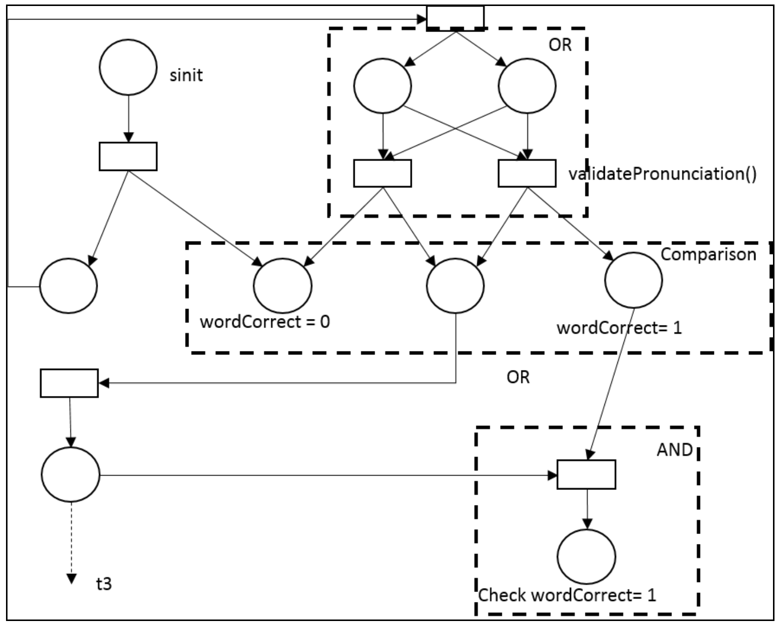

Figure IV.1 Example of resulting Petri-net.

IV.3.2 Implementing the formalization.

BPEL is used to define the workflow in order to implement the methodology. BPEL was chosen as the language for representing the workflows because it is considered the industry standard and because it fully integrates into a service architecture. Furthermore, there are standardized methodologies for BPEL, as well as automatic translations to representations in Petri-nets. More specifically, the following tasks must be carried out:

- Define a WSDL file that represents the rules as a service. In this file, each rule is used through an entry-point. With this, the coding of the rule remains independent from the BPEL.
- Define synchronous calls to service in the BPEL that represents the workflow. This service represents the rules using the *invoke* and *receive* BPEL commands. The invoke command will reference the corresponding rule (using the name of the corresponding entry-point) and the receive command will save the result of the request (true or false) for use controlling the flow of the application.

The BPEL2oWFN tool is used to translate the workflow to Petri-nets (Lohmann, 2007). This allows the translation to multiple representations of Petri-nets, to which the formalization presented above adjusts. To integrate the resulting Petri-nets, of both the workflow and the rules, a semi-automatic methodology was used to recognize the places and transitions in Petri-nets, based on the patterns used in the translation of BPEL2oWFN.

With this it is possible to find the points where the requests are made to the service representing the rules. Here, the initial and final points of the Petri-nets that represent each rule are inserted.

IV.3.3 Validation and correction.

A model-checker for Petri-nets must be used for verifying the properties. The chosen model-checker is Mc-Kit (Schröter, Schwoon, & Esparza, 2003), which allows properties that are intrinsic to the Petri-nets to be examined, as well as ad-hoc properties that are expected of the domain (i.e. adherence to the proposed rules). These properties must be analysed every time there is a change to the application, whether it be to the workflow or the rules. The properties that were analysed are the following:

- Deadlock-freeness analysis: checks whether there are any possible configurations of the Petri-net that lead to deadlock. It does not require parameterization.
- Reachability analysis: checks that each of the expected states is reached (i.e. the goals defined in the workflow). It requires the specification of the test input sets.
- Safety-Liveness analysis: Determines the temporal logics according to the sequence of the workflow. In order to be evaluated, the valid sequence of steps in the workflow is determined, before determining whether or not the rules are adhered to. In order to follow the indicated flow, the proposed rules must also be followed. Therefore, the introduction of valid inputs (i.e. the evaluation of reachability) must be analysed together. The input model consists of the following elements:
    - Petri-net with model to be tested
    - Valid and invalid inputs for each rule
    - Expected states (post-conditions or goals)

  - Valid sequences within the context, written in Linear Temporary Logic – LTL –. The model-checker generates a combination of possible sequences (not necessarily feasible and/or consistent with the rules), with the aim of testing the Petri-net against boundary conditions.

Given that the Safety-liveness evaluation includes the other properties, the resulting output from the verification is the following:

- Safety-liveness evaluation: indicates points in the Petri-net where all of the possible combinations of sequences fail.
- Reachability evaluation: indicates whether all of the expected states were reached.
- Deadlock-freeness evaluation: indicating the points in the Petri-net where deadlocks occur.

IV.4 Validating the proposal

An extension of the scenario presented by Calderón et al. (2014) was used to validate the proposal presented in this study. This scenario consists of an application for learning a foreign language, based on Single-Display Groupware (SDG) (Stewart et al., 1998) and collaborative learning. In the original application, three students work in front of a shared screen, interacting with the application using headsets. The application allows the students to carry out activities which develop their grammar, vocabulary, listening skills and pronunciation. Automatic feedback is given by the system using a speech recognition engine and speech synthesizer. Both the use of multimedia in this scenario (such as the speech engines), as well as the collaborative learning dynamic, are of interest to this study because, based on these, new requirements can be developed. With these new requirements it is possible to formulate new task definitions and make changes to those that already exist. This enables the definition of a new scenario using a flexible workflow. With this, the original scenario is extended to include the following features:

- Interconnection between the computers where the activity takes place.

- Unbalanced distribution of resources. E.g. not all of the computers necessarily have a speech-recognition engine available all of the time.
- Possibility for the teacher to change the sequence that is followed during an activity: adding new tasks, modifying tasks, changing certain rules etc.

IV.4.1 Instance for the integrated framework for workflows and rules

The methodology proposed in this study was followed in order to develop this scenario. First, the pedagogical rules that govern the system were clearly defined. In parallel to this, the sequence of tasks was also defined. Each rule is specified by an ID, with the aim of categorizing the purpose of each rule and detecting possible dependency between rules. There are two types of rules: rules that must be followed in order for there to be a specific transition between tasks in the workflow (IR), and rules that must always be followed in order for there to be any transition between tasks in the workflow (RR). The repetition of a figure in the ID indicates that there is dependency between rules. For example, rule 05IR depends on rule 055IR. The pedagogical rules that govern the activity are shown in Appendix G. The sequence of tasks to be performed and the associated pedagogical rules written in natural language are included in Appendix H.

IV.4.2 Instance of the validation model

To validate the implementation of the proposed methodology, it is necessary to validate the fulfilment of all of the elements that comprise the pedagogical context. In this case, this corresponds to the pedagogical rules and respective sequence of tasks. The evaluation criteria used will correspond to properties that can be evaluated in a Petri-nets model (Table IV.1).

Table IV.1 Elements to evaluate and properties evaluated in the respective elements

Element to be evaluated	**Properties of the element evaluated**
Adherence to pedagogical rules	Reachability, Deadlock-freeness
Adherence to expected sequence	Safety-liveness (using LTL), Deadlock-freeness and reachability (derived from the adherence to the pedagogical rules)

IV.4.3 Defining alternative situations

One aspect to evaluate is the robustness of the proposal presented in this study when faced with the incorporation of new tasks and changes to existing tasks. With this, a set of alternative situations to the existing sequence determined by the workflow and rules is defined. These are then incorporated into the modelling of the problem. When incorporating these situations, it must be verified that there are no inconsistencies with the pre-defined rules. Adherence to the pedagogical rules and expected sequence must also be evaluated, based on the properties included in Table IV.1. The definition of the alternative situations can be found in Appendix I, with the respective rule that triggers each one. A nomenclature similar to that used for rules was adopted to identify the alternative situations, using the keyword RP.

IV.4.4 Test cases

To carry out the validation, simulations are performed using the Petri-nets that were generated based on the transformation methodology proposed in section IV.3. 4 different models were created based on the definition of the proposed pedagogical scenario: one that considers the original sequence of tasks, and three others that each separately incorporate an alternative situation. With this, the robustness of the modelling can be analysed separately for each of the proposed alternative situations.

The use of 1, 2, 3, 4 and 5 nodes was considered for evaluating each of these models. A limited number of nodes were used as it measures the robustness of the modelling without taking into account requirements of scalability. According to the definition of the scenario, each node corresponds to a computer shared by 3 students. Each configuration is tested using both valid and invalid input sets with regards to the specifications of the scenario. The respective models were coded using LTL in order to evaluate adherence to both the expected execution sequence, as well as the execution sequences deriving from the alternative situations. This code is used by the model-checker to evaluate the validity of the Petri-net in following the tested sequence. Furthermore, the model-checker also generates the entire set of combinations for the order of tasks for each of the test cases. This allows all possible execution situations to be reviewed.

IV.5 Results

As described in section 3, the analysis of the results is focused on the behaviour of the Petri-net with regards to the properties that it must fulfil. In the proposed scenario, this analysis is performed for the aspects detailed below. Together, these aspects allow the validity of the modelling to be checked in terms of its translation to Petri-net, as well as in terms of the properties that must be fulfilled when incorporating changes into the original formulation, as described in Table IV.1. The aspects are as follows:

- Appearance of inaccuracies (i.e. violations of the rules) in the model for all of the test cases. This is implicit in the reachability analysis and LTL.
- Detection of deadlock-freeness problems when expected.
- Detection of reachability (i.e. fulfilment of the expected states).
- Detection of problems in LTL (i.e. if an expected sequence is not adhered to).

IV.5.1 Detection of deadlocks

The appearance and detection of deadlocks was observed when there was no alternative to the use of the speech recognition engine. No other deadlocks appeared (Table IV.2).

Table IV.2 Results of the deadlock-freeness analysis.

Scenario	1 node	2 nodes	3 nodes	4 nodes	5 nodes
Original	OK	OK	OK	OK	OK
Original + 10RP	OK	OK	OK	OK	OK
Original + 11RP	OK	OK	OK	OK	OK
Original + 12RP	Fail	OK	OK	OK	OK

IV.5.2 Reachability analysis and LTL

Reachability analysis is performed implicitly when evaluating the expected sequence order using LTL. This is because not adhering to the sequences ensures that not all of the expected states are reached in the Petri-nets. In particular, the following situations are observed as causing problems with reachability:

- When the order of the tasks in the original sequence is automatically altered by the model-checker (i.e. models generated by the model-checker vs. expected sequences).
- When there is incorrect input. With this, not all of the expected states are reached.

In the reachability analysis for the cases that were used to test the proposed modelling it can be observed that all of the expected states are achieved when inserting alternative situations (Table IV.3).

Table IV.3 Results of reachability and LTL analysis.

Scenario	1 node	2 nodes	3 nodes	4 nodes	5 nodes
Change in order of tasks	Fail	Fail	Fail	Fail	Fail
Incorrect input	Fail	Fail	Fail	Fail	Fail
Original	OK	OK	OK	OK	OK
Original + 10RP	OK	OK	OK	OK	OK
Original + 11RP	OK	OK	OK	OK	OK
Original + 12RP	OK	OK	OK	OK	OK

IV.6 Conclusions

The research question "Is it possible to incorporate complex rules into an imperative workflow so as to allow dynamic changes (during run-time), both to the properties that govern it as well as the order in which the tasks are defined and performed, guaranteeing the integrity of the rules that govern the problem's domain?", was answered by creating an integrated framework when developing an imperative workflow. This framework allows rules to be explicitly incorporated, as well as offering great flexibility in a distributed setting. This was achieved by proposing a definition of the workflow using BPEL and integrating rules using service orientation approach. The changes that were introduced can be introduced at any point of the workflow and rules. These changes include adding and eliminating tasks, changing a rule, and changing the order of the tasks, and must be programed in the same language as the language used to program the workflow and rules. Both the workflow and rules are translated to Petri-nets in order to check that these changes are consistent. This answers the research question "Is it possible to define a methodology for automatic property verification based on Petri-nets for the workflow proposed in the first research question?" In order to do so, a methodology was proposed in which the workflow and rules are translated to Petri-nets and then integrated into a single network. This allows the validity of the changes that were introduced to be evaluated jointly, verifying intrinsic properties of the Petri-nets and Linear Temporal Logic.

Based on the execution of the example presented in this study, it was seen that the proposal is robust when incorporating alternative situations into the original sequence of tasks. Alternative situations were formulated based on the requirements of the problem, with the observation that the expected results were achieved in terms of the properties of deadlock-freeness, reachability and safety-liveness. The latter of these is a critical property as it takes into account the adherence to an expected order of the tasks, meaning that the other properties depend on safety-liveness. In the context of the application presented in this study, the use of collaborative learning allowed for more complex dynamics to be developed, including sequences with interdependency between the activity's participants. With this, any change to the order of the tasks has a high incidence in the non-fulfilment of safety-liveness. This is contrasted with the incorporation of new tasks within the sequence. In that case, the original sequence is maintained but new possibilities are added to the activity. These can bring with them possible pedagogical requirements, or indeed they can correct certain problems that could have otherwise hindered the fulfilment of the pre-defined requirements.

As shown in sections IV.3 and IV.4, certain steps of the methodology were done semi-automatically. This made it difficult to use the methodology transparently in a real setting. It remains as future work to build a workflow engine that automatically carries out all of the stages in the methodology. Another limitation is related to the reach of the requirements of the problem that was presented in this study, as is a scalability analysis. With this, the growing incorporation of more multimedia resources and a larger number of nodes remains as future work. Finally, another limitation has to do with the generic nature of the scenario that was presented. Although a pedagogical setting was chosen as the basis for this study, the reach of the proposed methodology is not restricted just to this context. However, the chosen scenario must have characteristics, which allow the requirements relating to flexibility to be formed, as well as the definition of the rules that govern the domain of the problem, with the aim of satisfying the model presented in this study.

V. CONCLUSIONS

The research presented in this thesis shows that it is possible to design technological applications for the classroom that consider a series of requirements that involve collaborative learning, resource sharing, robustness and dynamism in the execution of the pedagogic script. As it was presented in this thesis, a possible approach is to divide the corresponding problem in smaller parts for it to be dealt with from different perspectives. Also, it is related to design based research, regarding iterative and integrative research features.

One of the analysis perspectives is pedagogic validation of the developed applications. In order to show that this type of application properly achieves its essential objective—improve learning in a determined area of knowledge—it is not sufficient with exploratory proof or laboratory simulations; it is necessary to consider studies that apply the applications within the pedagogic work developed by the teacher in a real context. The use of exploratory studies, that do not consider an experimental design, has the objective to prove the concept of the application used. With it, it is possible to raise new requisites that will later provide feedback to the application's design. On the other hand, studies that have a quasi-experimental or experimental methodology allow obtaining results with higher validity within its context. Although the quasi-experimental results mark the generalization of the problem, they possess scientific validity and allow confirming the fulfillment of the pedagogic validation criteria in a determined context. In the context of this thesis, the definition of the pedagogic scenario was not only conceptual, but it also consisted in a pedagogic validation with basis on a quasi-experimental study. This allows providing a scientific support for the presented problem, as well as conceptualizing the incorporation of new requirements in this pedagogic scenario. With it, we could incrementally respond to each one of the research questions.With studies that allow confirming the pedagogic validity of a learning application, it is possible to fulfill one of software engineering's functions: showing a product's ability of satisfying requisites based on a design. Proposing new architectures for computer applications goes through a design process based on requirements specification. To show that these requisites are satisfied, there are diverse methodologies to make the corresponding validation and verification. The case of applications with learning purposes is not the exception: from them emerge new requirements, both functional and non-functional, that respond to a certain domain. However, two different problems must be distinguished: the proposal of a new learning activity, supported by technological architecture previously built, and the proposal of a specific scenario of an architecture that supports a learning activity. In the first problem, a technology-supported learning activity can be supported on an architecture that does not present changes (i.e. same components and connectors) when it is reused by other learning application (e.g. only changing learning script). In the second problem, a case of proposing an ad-hoc architecture, what we seek is to show its capacity for generalization of satisfying a determined group of requisites. It is not possible to build every possible instance in order to determine that the architecture is valid. The proposal of this thesis tries to deal with this issue in two ways: an empiric approach and a formal approach. Empiric approaches do not allow demonstrating the architecture's general capacity of fulfilling requisites, but they do show that it is possible to satisfy these requisites in a determined scenario (Wohlin et al., 2012). Therefore, making empiric studies in the field of software engineering could be similar to exploratory studies that seek to validate the concept of learning activities (Van den Akker et al., 2006). The information obtained from these approaches allows validating certain type of requirements that can be satisfied by the architecture in a particular scenario. This thesis shows through an empiric approach, based on scenario simulation under controlled conditions, that it is possible to propose a technique for design a software architecture that satisfy the robustness and resource-sharing requirements of a dynamic, software-based, learning application for a language laboratory. In this case, an incremental approach was used, in order to provide two ensemble of requirements, implemented in their respective increments.

Formal approaches allow demonstrating the validation of a certain application, deployed over an architecture against its formal specifications, through property modeling, verification, and validation techniques. This allows incorporating a great number of varied scenarios without testing them in the field. This thesis developed a technique that allows incorporating changes in a learning activity in runtime by the teacher, what is proposed and validated using a formal approach. The proposed formal approach in this thesis permits incorporating validation mechanism in real time, which allows incorporating dynamism to the learning activities guaranteeing the satisfaction of the pedagogic requirements. In corresponding design, several elements were considered from similar approaches, based on learning scripting and workflows. Separation by concerns was essential in the design of the technique, proposing the specification of task flow in BPEL language and pedagogical requirements in a rules engine language. It is similar to other approaches (e.g. levels in IMS-LD), in order to incorporate requirements and features to specification. According distribution of learning scripts, the validation processes generalize the source of specifications, based on BPEL elements, in order to distribute elements as services, similar to other distributed approaches based on orchestration by choreography. Finally, Petri-nets approach allows a complete flexibility in specification and validation, independent of semantic, but incorporating temporal logics in order to evaluate requirements satisfaction. More details of implementations are presented in appendix J.

Regarding methodological approaches applied in this thesis, each one was used according to the research objective defined in this thesis. In the case of first increment, quantitative and qualitative approaches were applied in order to validate pedagogical requirements and collaboration work. Therefore, a complete system analysis is incomplete if only high-level requirements (as pedagogical requirements) are evaluated. In that case, the main objective was an educational validation, without a technical evaluation because the focus was not to solve technical issues, but to propose a new learning activity based on SDG. In second and third increments the focus is into software engineering and formal approaches respectively. In both cases, a field research work (in realistic conditions) will provide results according to presented scenarios, but they are not generalizable. In software engineering case, requirements can be evaluated according their nature. Laboratory experiences can be used to test some of those requirements, particularly related to non-functional or quality requirements (in this thesis, robustness, availability, etc.). This approach allows evaluating systematically in a wide of testing scenarios, several times, using black box proofs. Those tests are a first stage before a high level evaluation, related to system and user functional requirements. As shown in the introductory chapter, in general learning applications are evaluated using exploratory studies in order to evaluate some system functional and usability requirements. In the case of formal approaches, they also can be evaluated by design (e.g. using some formal demonstration), allowing generalization, or using simulations. Last technique was used in this thesis; with this, it is not possible to generalize conclusions to other domains, but it allows evaluating a wide variety of scenarios in a short time, in order to validate the presented technique.

As seen before in problem and methodological analysis, there is no one approach to deal with the problem of creating technological applications for the classroom. However, if the problem is dealt from one point of view, many sides are left unconsidered. If the problem is tackled from a purely pedagogic perspective, the pedagogic activity becomes an isolated element, without considering that a relevant part of it is a hardware and software product that seeks satisfying those pedagogic specifications. In order to achieve satisfying these specifications, the necessary engineering must be applied. On the other hand, if we attack the problem from a solely engineering and technical perspective, we will only have a reduced vision of the problem, building applications that are valid regarding their specifications, but not regarding the context where they are to be used. This makes the engineering approaches described in this thesis, both of empiric verification of requisites and of formal modeling, incomplete if there is not a pedagogic validation.

Finally, by answering the global research question: is it possible to define a scheme of learning applications construction for the classroom, where it is possible to incorporate robustness to pedagogical requirements satisfaction, in an incremental way? shows that it is possible to do so by making an adequate planning of increments. In this thesis, the planning of increments considered the initial implementation of the scenario with a group of technological requisites that can build a minimum base that allows evaluating the validity of the scenario against the pedagogic requisites. The incorporation of the other technological requirements, we must consider the relevance they have for the scenario from a pedagogic point of view, as well as the technical dependencies that exist between them. A special case is the incorporation of technological requirements that allow making new tasks within the already validated scenario. With these requirements you can potentially broaden the area of action of the learning application with the incorporation of new tasks, or changes in them. However, these changes can affect the integrity of the application, becoming inconsistent with the pre-existing pedagogic requisites with which it was built. In the case of technological requisites that give quality to the pedagogic requisites, although they are associated with the pre-existing pedagogic requisites, in their planning they may interfere with some requisites. In this line, the application of a formal validation methodology, such as the one built in this thesis, also allows reviewing the consistency between the pedagogic requisites and the new technological requisites incorporated into the increment planning.

VI. FUTURE WORK

The methodology used in the development of this thesis is incremental. Within this context, the pedagogic validation is done in an initial increment, where in the following increments new elements are added to the problem at hand. In this case, some research areas could be developed by future work in some aspects of this thesis.

Respect to methodological topics, quasi-experimental, empirical and formal approaches was used in this thesis in order to perform pedagogical, social, software verification and software validation. However, an aspect not considered in this thesis is the development of a methodological proposal that incorporates a testing process that allows evaluating the pedagogic validity is not affected by incorporating new technical requirements to the application. A possible approach is performing regression tests, widely used by software engineering community (e.g. Goues et al.(2012); Fraser & Arcuri, (2011, September)). This testing must consider the development of tests that measure if what was already pedagogically validated is still so. Although this thesis presents a proposal that allows formal validation, considering the pedagogic rules involved, there is no certainty that the proposed technique for dynamism in runtime in the pedagogic activity has educational validity.

Other relevant aspect is how proposed formal technique for specification and validation of learning applications are adopted by educational community: designers, instructors and researchers. This fact depends on how the pedagogical activity was specified (e.g. specification language, user experience in design and deployment time by instructors). In this thesis, the technique proposed in chapter 4 was checked formally and experimentally, but human and learning aspects are not covered. A future work is compare the proposed technique with other approaches presented in the introduction, related to workflow approach (e.g. other dynamic workflows specification) and learning design educational modelling languages. In the workflows design area, a proposal is specify the technique using metamodels (e.g. as shown in Rutle et al. (2012, July) and Rabi et al. (2014) works).

As seen on chapter 3, other future work is the validation of specific self-adaptation features, using an experimental approach.

An essential element of a right pedagogic validation is incorporating technological applications within the context of a pedagogic orchestration. In this thesis, the scenario is initially specified using educational orchestrations (Roschelle, Dimitriadis & Hoppe, 2013) however, it becomes necessary to make a deeper analysis of how these orchestrations impact the validity of the results in a quantitative and qualitative way, considering in this last aspect, the contribution and the adoption that the teacher has made.

This thesis used the development of a collaborative language laboratory as a validation context. Although the architectures and methodologies proposed in this thesis can be generalized to similar problems because of its construction, these were not tested on other contexts. The proposition and validation of other pedagogic scenarios that share general requisites with the architecture and methodologies, does not per-se allow demonstrating a generalization, but what they do is confirm that these continue satisfying the scenarios created. However, this does allow proving that it is possible to create new instances based on the results of this thesis, giving it a broader applicability and areas where these results can be implemented.

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VII. APPENDICES

APPENDIX A: ARTICLE ACCEPTANCE CONFIRMATION

The following message is an acceptance confirmation from Interactive Learning Environments, acknowledging that the article presented on chapter II of this thesis, entitled “A Single-Display Groupware Collaborative Language Laboratory”, has been accepted for publication.

Interactive Learning Environments - Decision on Manuscript ID NILE-2013-0147.R1
1 message

psotka@msn.com <psotka@msn.com> Sun, Feb 16, 2014 at 4:57 PM
To: jfcalder@ing.puc.cl

16-Feb-2014

Dear Mr Calderon,

Ref, A Single-Display Groupware Collaborative Language Laboratory

Our referees have now considered your paper and have recommended publication in Interactive Learning Environments. We are pleased to accept your paper in its current form which will now be forwarded to the publisher for copy editing and typesetting. The reviewer comments are included at the bottom of this letter, along with those of the editor who coordinated the review of your paper.

You will receive proofs for checking, and instructions for transfer of copyright in due course.

The publisher also requests that proofs are checked and returned within 48 hours of receipt.

Thank you for your contribution to Interactive Learning Environments and we look forward to receiving further submissions from you.

Kind regards,
Joseph Psotka
Co-Editor, Interactive Learning Environments
psotka@msn.com, joepsotka@gmail.com

Reviewer(s)' Comments to Author,

Editor's Comments to Author,

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APPENDIX B: PAPERS CLASSIFICATION DETAILS

Note: this appendix corresponds to an adaptation of a draft of a future publication in the field of technology in education, where thesis' author is co-author.

In the systematic literature review shown in chapter 1, a taxonomy is proposed to explore current trends in technology-supported learning in classrooms, in order to characterize and understand current research foci from an international perspective, considering a set of criteria with threefold aims and scope: (1) reflecting on epistemic and pedagogical aspects of emerging learning activities supported by ICTs, (2) understanding the ways in which technology is being used as a tool to support teaching and learning in classrooms, and (3) verifying the extent to which novel technology-supported learning activities have been validated in realistic classroom settings. From a methodological point of view, in the present work we seek to generalize findings from single scientific works and describing patterns and gaps in the research field (Frohberg et al., 2009; Fettke, 2006), for which we consider that a review is a proper scientific method to accomplish the abovementioned aims, in order to provide classification criteria and a taxonomy for the analyzed papers.

We consider epistemic and pedagogical and aspects of the learning activities in criteria (signed by CC acronym): 'CC1: *What* is taught?', i.e., the learning domain in which the learning activities have been conducted, 'CC2: *How* it is taught?, that is, social structure, student engagement and assessment in the learning activities, and 'CC3: *Who* is learning?', meaning the education levels in which technology-supported learning activities have been conducted. Regarding the technological aspects of the learning activities reviewed, we include 'CC4: *What* ICTs are used?', i.e., the types of devices and connectivity that are utilized in the classroom, 'CC5: *How* are ICTs used?', namely, whether devices are shared or used individually, and if multimodality is present, and 'CC6: *Where* are ICTs used?', that is, geographic location in which the learning activities have been conducted. Finally, concerning the validation of the technology-supported learning activities, we include criteria 'CC7: *What* is measured?', which includes the dependent variables under study, and 'CC8: *How* it is measured?', which encompasses the research design, methods and validation period (i.e., number of sessions and number of days).

The articles included in our review include meet the inclusion criteria shown on Table 5. We consider articles that report application of technology-supported instructional methods in classrooms in formal education institutions, and published between January 2008 and December 2013. Selected articles present empirical validation of the reported learning activities in realistic classroom settings. We neither consider articles in which technology is not used for pedagogical purposes, nor articles in which technology only involves commodity applications such as office suites, personal note taking, calculators, dictionaries, etc.

Table 13. Inclusion and exclusion criteria for review articles.

Inclusion Criteria	**Exclusion Criteria**
IC-a. Must report at least one technology-supported instructional method. IC-b. Must report application of the technology-supported instructional method in a formal education institution. IC-c. Must report empirical validation of the technology-supported instructional method in a face-to-face environment (classroom, lecture hall or laboratory). IC-d. Must be published between January 2008 and December 2013.	EC-a. Technology is not used for educational purposes. EC-b. The technology used solely relies on commodity applications (e.g. office suite, calculator, electronic dictionary).

The classification of selected articles based on the criteria presented in **Error! Reference source not found.** yields a dataset that can be queried in a multiplicity of different ways. For instance, one could ask how many articles originating in Western Europe use tablet devices and interactive whiteboards, and incorporate formative assessment methods and small group collaborative learning, and how this compares to the reality in North America.

Review Method

Our research has comprised a systematic review and analysis from a mixed data pool composed of two major sources: online bibliographic databases containing journal articles and conference proceedings, and articles from SCI Expanded and SSCI-indexed journals (see Table 5). Our systematic review process for online database search included searching for the following sets of terms occurring in the article metadata (i.e., title, abstract and keywords): ‘classroom technology’, ‘classroom and computer assisted learning’, and ‘classroom interactive learning’, and was restricted to articles published during the period 2008 to 2013.

Table 5. Bibliographic sources used in the systematic review

Source Type	**Source Name**	**Selected Articles**
Online bibliographic databases*	IEEE Xplore Digital Library	34
	ACM Digital Library	20
	Taylor & Francis	45
	Wiley Online Library	28
SCI Expanded and SSCI Journals	Australasian Journal of Educational Technology (AJET)	28
	British Journal of Educational Technology (BJET)	7
	Computers & Education (C&Ed)	21
	Computers in Human Behavior (CHB)	10
	Educational Technology & Society (IFETS)	19
	Educational Technology Research & Development (ETR&D)	16
	Interactive Learning Environments (ILE)	10
	International Journal of Computer-Supported Collaborative Learning (ijCSCL)	13

	Journal of Computer Assisted Learning (JCAL)	18
	Total	263

*Excludes articles from the ISI-indexed journals listed below

Two raters, with background in the field of educational technology revised the search results in complementary datasets, and pre-selected articles whenever the abstract indicated the existence of research about instructional methods utilizing technology in classrooms under formal education settings. A cross validation between raters and datasets was performed in order to manage inter-rate convergence. In the review process for journal articles the raters scanned all article abstracts in the respective volumes and issues in search for the pre-selection criteria. Later, all the pre-selected articles were obtained in full text versions by the raters and filtered according to article Inclusion (IC) and Exclusion Criteria (EC) (see Table 13).

The articles meeting the inclusion criteria were 263, and these were analyzed further based on more specific Classification Criteria (CC) shown above on **Error! Reference source not found.**, and detailed in Table 15. Criterion CC1 relates to the knowledge domains and academic disciplines under which the analyzed interventions were conducted. Classification of the selected articles according to the criteria shown in Table 15 was conducted by another rater (a scholar with experience in the field of educational technology).

Table 15. Detailed article classification criteria.

Criterion	**Categories**	**Multivalued***	**Attributes**	**Remarks**
CC1: What is taught?	Humanities	Yes	History, Language and Linguistics, Literature, Performing Arts, Philosophy, Religion, Visual arts	We considered the taxonomy of knowledge domains and academic disciplines used by Wu et al. (2012)
	Social Sciences		Anthropology, Archaeology, Area studies, Cultural and ethnic studies,	

			Economics, Gender and sexuality studies, Geography, Political science, Psychology, Sociology	in their study, which is based on Franklin (1999) and Wanner et al. (1981).
	Natural Sciences		Space sciences, Earth Sciences, Life Sciences, Chemistry, Physics	
	Formal Sciences		Computer sciences, Logic, Mathematics, Statistics, Systems science	
	Professions and Applied Sciences		Agriculture, Architecture and Design, Business, Divinity, Education, Engineering, Environmental studies and forestry, Family and consumer science, Health Sciences, Human physical performance and recreation, “Journalism, media studies and communication”, Law, Library and museum studies, Military science, Public administration, Social work, Transportation.	
CC2: How it is taught?	Social Structure	Yes	Individuals, Dyads, Small groups, Large groups	Small groups involve 3 to 5 participants. Large groups involve more than 5 participants.
	Student Engagement	No	Active Instruction, Passive Instruction	
	Assessment	Yes	No assessment, Formative Assessment, Summative Assessment	
CC3: Who is learning?	Education Level	Yes	Pre-school, K-12 (prep), K-12 (high), Higher education, Graduate education	

CC4: What ICTs are used?	Interaction Devices	Yes	Clickers, Digital pen/Smartpen, Graphic tablet, PDAs, Mobile phone, Tablet, Tabletop, Laptop, PC, Projector, Interactive whiteboard, Haptic controller, VR/AR glass, RFID scanner/tags, Motion controller, Robot, Other	
	Connectivity	Yes	Local connectivity, Outside connectivity, No connectivity	The categories listed here refer to the use of network connectivity in the classroom activity. Activities may rely on local connectivity, either Personal (PAN) or Local Area Network (LAN) connectivity, and/or outside connectivity (e.g. to the Internet, or SMS/MMS capability), or no connectivity at all.
CC5: How are ICTs used?	Device use	No	Individual, Shared	Individual and Shared attributes are non-exclusive.

				Individual device use implies that one device is used at most by one person. Shared use refers to shared use by two or more users.
	Multimodality	No	Yes, No	
CC6: Where is ICT implemented?	Geographic Location	Yes	North America, Latin America & Caribbean, Africa, Western Europe, Eastern Europe, Middle East, Asia, Oceania	
CC7: What is measured?	Dependent Variable	Yes	Learning, Social behavior, Teacher work, Student attitude, Usability	
CC8: How is it measured?	Research Design	No	Quantitative, Qualitative, Mixed	
	Research Method	No	Descriptive research, Experimental design, Design-based research, Action Research, Mixed research method	
	Validation period	No	Number of sessions, Number of days	Number of sessions accounts for the number of different occasions in which the learning activity was validated. Number of days refers to the total period of time from the start to the end of the

				intervention. For instance, one session accounts for one day, and three weekly sessions account for 15 days.

*In multivalued categories an article may meet more than one attribute, otherwise only one attribute is chosen for classification.

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Fettke, P., & Loos, P. (2006, November). Using reference models for business engineering-state-of-the-art and future developments. In *Innovations in Information Technology, 2006* (pp. 1-5). IEEE.

APPENDIX C: REFERENCES OF CLASSIFIED PAPERS

Source	Year	Title	Authors
2009 13th International Conference on Computer Supported Cooperative Work in Design	2009	A PDA-based Collaborative Tool for Learning Chemistry Skills	Hurtado, Carlos Guerrero, Luis
2009 13th International Conference on Computer Supported Cooperative Work in Design	2009	MCPresenter: A mobile tool supporting various collaborative learning practices in the classroom	Juretic, Dusan Zurita, Gustavo Baloian, Nelson
2010 IEEE Frontiers in Education Conference (FIE)	2010	Implementing Collaborative Project-Based Learning Using the Tablet PC to Enhance Student Learning in Engineering and Computer Science Courses	Avery, Zanj Castillo, Mauricio Guo, Huiping Guo, Jiang Warter-Perez, Nancy Won, Deborah S. Dong, Jane
2012 IIAI International Conference on Advanced Applied Informatics	2012	Using the Multi-Mouse Quiz System for Quiz Making Activities in an Elementary School	Zhou, Juan Mori, Mikihiko Kita, Hajime
3rd international Conference on Tangible and Embedded interaction	2009	TinkerSheets : Using Paper Forms to Control and Visualize Tangible Simulations	Zufferey, Guillaume Jermann, Patrick Dillenbourg, Pierre
African Journal of Research in Mathematics, Science and Technology Education	2013	Competencies in using Sketchpad in Geometry Teaching and Learning: Experiences of preservice teachers	Mdutshekelwa Ndlovua; Dirk Wesselsb; Michael de Villiersc
Assistive Technology: The Official Journal of RESNA	2013	Comparative Observations of Learning Engagement by Students With Developmental Disabilities Using an iPad and Computer: A Pilot Study	Sajay Arthanat; Christine Curtin; David Knotak
Australasian Journal of Educational Technology	2009	Advancing the m-learning research agenda for active, experiential learning: Four case studies	Laurel Evelyn Dyson, Andrew Litchfield, Elaine Lawrence, Ryszard Raban and Peter Leijdekkers
Australasian Journal of Educational Technology	2010	Netbooks in sixth-grade English language classrooms	Janet Mei-Chuen Lin and Yi-Jiun Wu
Australasian Journal of Educational Technology	2010	A comparative study of collaborative learning in Paper Scribbles and Group Scribbles	Chen Fang Hao
Australasian Journal of Educational Technology	2010	Talking about science in interactive whiteboard classrooms	Karen Murcia and Rachel Sheffield
Australasian Journal of Educational Technology	2010	Using interactive whiteboards in pre-service teacher education: Examples from two Australian universities	Chris Campbell and Peter Kent

Source	Year	Title	Authors
Australasian Journal of Educational Technology	2010	Use of audience response systems for summative assessment in large classes Summative assessment in large classes	
Australasian Journal of Educational Technology	2011	Relativity in a rock field : A study of physics learning with a computer game	
Australasian Journal of Educational Technology	2011	Perceptions of interactive whiteboard pedagogy in the teaching of Chinese language	
Australasian Journal of Educational Technology	2011	Technology enabled active learning (TEAL) in introductory physics : Impact on genders and achievement levels	
Australasian Journal of Educational Technology	2011	Integrating book , digital content and robot for enhancing elementary school students ? learning of English	
Australasian Journal of Educational Technology	2011	Implementing clickers to assist learning in science lectures : The Clicker-Assisted Conceptual Change model	
Australasian Journal of Educational Technology	2011	Using computer-based instruction to improve Indigenous early literacy in Northern Australia : A quasi-experimental study The NT context	
Australasian Journal of Educational Technology	2011	Facilitating digital video production in the language arts curriculum	
Australasian Journal of Educational Technology	2012	Enhancing teachers ? ICT capacity for the 21st century learning environment : Three cases of teacher education in Korea Teacher ICT capacity for the 21st Century learning	
Australasian Journal of Educational Technology	2012	Comparing computer game and traditional lecture using experience ratings from high and low achieving students	
Australasian Journal of Educational Technology	2012	Computer-based concept maps for enabling multilingual education in computer science : A Basque , English and Spanish languages case	
Australasian Journal of Educational Technology	2013	Using the interactive whiteboard to scaffold a metalanguage : Teaching higher order thinking skills in preservice teacher education	
Australasian Journal of Educational Technology	2013	So the kids are busy , what now ? Teacher perceptions of the use of hand-held game consoles in West Australian primary classrooms	
Australasian Journal of Educational Technology	2013	The effective presentation of inquiry-based classroom experiments using teaching strategies that employ video and demonstration methods	

Source	Year	Title	Authors
Australasian Journal of Educational Technology	2013	A mindtool-based collaborative learning approach to enhancing students ' innovative performance in management courses	
Australasian Journal of Educational Technology	2013	Effects of online procedural scaffolds and the timing of scaffolding provision on elementary Taiwanese students ' question-generation in a science class	
Australasian Journal of Educational Technology	2013	Capturing dynamic presentation : Using technology to enhance the chalk and the talk	
Australasian Journal of Educational Technology	2013	Implementing the interactive response system in a high school physics context : Intervention and reflections Design of IRS questions	
Australasian Journal of Educational Technology	2013	Understanding the role of prior knowledge in a multimedia learning application	
Australasian Journal of Educational Technology	2013	Effects of experiential-based videos in multi-disciplinary learning	
Australasian Journal of Educational Technology	2013	Using a personal response system as an in-class assessment tool in the teaching of basic college chemistry	
Australasian Journal of Educational Technology	2013	Evolving technologies require educational policy change : Music education for the 21st century	
Australasian Journal of Educational Technology	2013	Interactivity with the interactive whiteboard in traditional and innovative primary schools : An exploratory study	
British Journal of Educational Technology	2010	Active classroom participation in a Group Scribbles primary science classroom	Wenli Chen; Chee-Kit Looi
British Journal of Educational Technology	2010	Learning by creating and exchanging objects: The SCY experience	De Jong, Ton Van Joolingen, Wouter R. Giemza, Adam Girault, Isabelle Hoppe, Ulrich et al.
British Journal of Educational Technology	2011	An interactive tangible user interface application for learning addition concepts	Starcic, Andreja Istenic Zajc, Matej
British Journal of Educational Technology	2011	Development of a peer-assisted learning strategy in computer-supported collaborative learning environments for elementary school students	Tsuei, Mengping
British Journal of Educational Technology	2012	Multi-touch tables and collaborative learning	Higgins, Steve Mercier, Emma Burd, Liz Joyce-Gibbons, Andrew

Source	Year	Title	Authors
British Journal of Educational Technology	2012	Applying tangible story avatars to enhance children's collaborative storytelling	Liu, Chen-Chung Liu, Kuo-Ping Wang, Pi-Hui Chen, Gwo-Dong Su, Mu-Chun
British Journal of Educational Technology	2013	Design-based research on the use of a tangible user interface for geometry teaching in an inclusive classroom	Starcic, Andreja Istenic Cotic, Mara Zajc, Matej
C&C'09, October 26–30, 2009, Berkeley, California, USA	2009	Children's storytelling and programming with robotic characters	Ryokai, Kimiko Lee, Michael Jongseon Breitbart, Jonathan Micah
Canadian Journal of Science, Mathematics and Technology Education	2012	Examining Factors That Influence the Effectiveness of Learning Objects in Mathematics Classrooms	Robin H. Kaya
CHI 2011	2011	The effects of interaction techniques on talk patterns in collaborative peer learning around interactive tables	Jamil, Izdihar O'Hara, Kenton Perry, Mark Karnik, Abhijit Subramanian, Sriram
CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.	2011	Enhancing Genomic Learning through Tabletop Interaction	Shaer, Orit Strait, Megan Valdes, Consuelo Feng, Taili Lintz, Michael Wang, Heidi College, Wellesley St, Central Olin, Franklin W Way, Olin
CHI 2012	2012	From Participatory to Contributory Simulations : Changing the Game in the Classroom	Kreitmayer, Stefan Rogers, Yvonne Laney, Robin Peake, Stephen Keynes, Milton
CHI'09	2009	Tabletop Displays for Small Group Study : Affordances of Paper and Digital Materials	Piper, Anne Marie Hollan, James D
CHI'12, May 5–10, 2012, Austin, Texas, USA	2012	Phylo-Genie: Engaging Students in Collaborative 'Tree-Thinking' through Tabletop Techniques	Schneider, Bertrand Strait, Megan Muller, Laurence Elfenbein, Sarah Shaer, Orit Shen, Chia
Children, Youth and Environments	2009	Learning by doing with shareable interfaces	Rick, Jochen, Yvonne Rogers, Caroline Haig and Nicola Yuill
Computer Applications in Engineering Education	2009	An experimental study of the inclusion of technology in higher education	Hernando Bustos Andreu and Miguel Nussbaum

Source	Year	Title	Authors
Computer Applications in Engineering Education	2009	Using multiple choice questions as a pedagogic model for face-to-face CSCL	Ricardo Valdivia and Miguel Nussbaum
Computer Applications in Engineering Education	2010	Music in MATLAB: A series of programming challenges for an introductory course	S. Scott Moor
Computer Applications in Engineering Education	2010	Teaching undergraduate students to model use cases using tree diagram concepts	Reyes Juárez-Ramírez, Guillermo Licea, Alfredo Cristóbal-Salas
Computer Applications in Engineering Education	2010	3D-CAD learning environment through interactive modular system (AIMECDT-3D)	Pablo Pando Cerra, Pedro Alvarez Peñin, Rafael Garcia Diaz, Maximo Perez Morales
Computer Applications in Engineering Education	2010	Computational fluid dynamics (CFD) models in the learning process of Hydraulic Engineering	P. A. López*, J. J. Mora, F. J. Martínez, J. Izquierdo
Computer Applications in Engineering Education	2011	A new developed educational approach to improve conventional teaching methodology of the power electronics laboratory	H. Y. Yamin, I. A. Altawil, A. F. Al-Ajlouni, A. S. Al-Fahoum
Computer Applications in Engineering Education	2011	Teaching and learning enhancement in undergraduate machine dynamics	El-Sayed Aziz
Computer Applications in Engineering Education	2011	A software based on MATLAB for teaching substation lightning protection design to undergraduate students with emphasize on different striking distance models	B. Vahidi, A. A. Damaki Aliabad
Computer Applications in Engineering Education	2011	Multi-sensory method for teaching-learning recursion	Zoltan Katai
Computer Applications in Engineering Education	2011	Using virtual instruments to teach surveying courses: Application and assessment	Hui-Lung Kuo, Shih-Chung Kang, Cho-Chien Lu, Shang-Hsieh Hsieh, Yong-Huang Lin
Computer Applications in Engineering Education	2011	Computer technology for enhancing teaching and learning modules of engineering mechanics	Babur Deliktas
Computer Applications in Engineering Education	2011	A computer-based tool to foster engineering students' interest in dynamics	Juan Llado, Beatriz Sanchez
Computer Applications in Engineering Education	2011	Description of EduCOM: A graphical modeling and programming language for teaching and learning digital communication systems	Jake Gunther, Brandon Eames, Darin Nelson
Computer Applications in Engineering Education	2011	Virtual web sound laboratories as an educational tool in physics teaching in engineering	P. Martínez-Jiménez, M. Varo, M. C. García, G. Pedrós Pérez, J. M. Martínez-Jiménez, R. Posadillo, E. P. Varo-Martínez
Computer Applications in Engineering Education	2012	Synchronous collaboration of virtual and remote laboratories	Carlos A. Jara, Francisco A. Candelas, Fernando Torres, Sebastién Dormido, Francisco Esquembre

Source	Year	Title	Authors
Computer Applications in Engineering Education	2012	A 3D learning tool for a hydroelectric unit	Marcos Paulo Alves de Sousa, Manoel Ribeiro Filho, Marcus Vinícius Alves Nunes, Andrey da Costa Lopes
Computer Applications in Engineering Education	2012	Highway design software as support of a project-based learning course	Maria Castro
Computer Applications in Engineering Education	2012	Construction and evaluation of Flash Media Server based collaborative virtual hydraulic circuits/equipments	Zhenguo Gao, Shaobin Cai, Yunlong Zhao, Yanwen Liu, He Xu
Computer Applications in Engineering Education	2012	An educational tool for wireless sensor networks	F. Losilla, P. Sánchez, B. Alvarez, A. Iborra
Computer Applications in Engineering Education	2012	Simulation tool for teaching and learning 3D kinematics workspaces of serial robotic arms with up to 5-DOF	T.J. Mateo Sanguino, J.M. Andújar Márquez
Computer Applications in Engineering Education	2013	Dynamic three-dimensional illustrator for teaching descriptive geometry and training visualisation skills	Jorge Martín-Gutiérrez, Francisco Albert Gil, Manuel Contero, José L. Saorín
Computer Applications in Engineering Education	2013	Interactive MATLAB-based demo program for sum of independent random variables	Gordana Jovanovic Dolecek
Computer Applications in Engineering Education	2013	An empirical study on factors influencing the effectiveness of algorithm visualization	Vassilios Lazaridis, Nikolaos Samaras, Angelo Sifaleras2
Computer Applications in Engineering Education	2013	Implementation of an embedded mobile device based feedback system for real-time audience feedback	Antti Knutas, Harri Hämäläinen, Jouni Ikonen, Jari Porras
Computer Applications in Engineering Education	2013	An interactive educational tool for the teaching of manoeuvres in electrical substations	Darío Monroy-Berjillos, Alfonso Bachiller-Soler, Pedro J. Martínez-Lacañina
Computer Applications in Engineering Education	2009	Network in a Box: Facilitating problem-based learning through network emulation	Yusuf Ozturk
Computer Applications in Engineering Education	2011	A tool for facilitating the teaching of smart home applications	Manuel Jiménez, Pedro Sánchez, Francisca Rosique, Bárbara Álvarez, Andrés Iborra
Computer Assisted Language Learning	2013	Analysis of the effect a student-centred mobile learning instructional method has on language acquisition	Andrew Oberga; Paul Danielsb
Computer Assisted Language Learning	2012	Improving English as a foreign language writing in elementary schools using mobile devices in familiar situational contexts	Wu-Yuin Hwanga; Holly S.L. Chena; Rustam Shadievb; Ray Yueh-Min Huangb; Chia-Yu Chenc
Computer Assisted Language Learning	2012	Learners' attention to input during focus on form listening tasks: the role of mobile technology in the second language classroom	María José de la Fuente

Source	Year	Title	Authors
Computers & Education	2009	Multiple Mice based collaborative one-to-one learning	Infante, Cristián Hidalgo, Pedro Nussbaum, Miguel Alarcón, Rosa Gottlieb, Andrés
Computers & Education	2009	Collaborative robotic instruction: A graph teaching experience	Mitnik, Rubén Recabarren, Matías Nussbaum, Miguel Soto, Alvaro
Computers & Education	2009	Technology as small group face-to-face Collaborative Scaffolding	Nussbaum, M Alvarez, C Mcfarlane, A Gomez, F Claro, S Radovic, D
Computers & Education	2010	What do students do in a F2F CSCL classroom? The optimization of multiple communications modes	Chen, Wenli Looi, Chee-Kit Tan, Sini
Computers & Education	2010	Using computer supported collaborative learning strategies for helping students acquire self-regulated problem-solving skills in mathematics	Lazakidou, Georgia Retalis, Symeon
Computers & Education	2010	Collaborative activities enabled by GroupScribbles (GS): An exploratory study of learning effectiveness	Looi, Chee-Kit Chen, Wenli Ng, Foo-Keong
Computers & Education	2010	From handheld collaborative tool to effective classroom module: Embedding CSCL in a broader design framework	Roschelle, Jeremy Rafanan, Ken Estrella, Gucci Nussbaum, Miguel Claro, Susana
Computers & Education	2010	In the mind and in the technology: The vicarious presence of the teacher in pupil’s learning of science in collaborative group activity at the interactive whiteboard	Warwick, Paul Mercer, Neil Kershner, Ruth Staarman, Judith Kleine
Computers & Education	2011	A framework for the design and integration of collaborative classroom games	Echeverría, Alejandro García-Campo, Cristian Nussbaum, Miguel Gil, Francisca Villalta, Marco Améstica, Matías Echeverría, Sebastián
Computers & Education	2011	Recurrent routines: Analyzing and supporting orchestration in technology-enhanced primary classrooms	Prieto, Luis P. Villagrá-Sobrino, Sara Jorrín-Abellán, Iván M. Martínez-Monés, Alejandra Dimitriadis, Yannis

Source	Year	Title	Authors
Computers & Education	2011	Design guidelines for Classroom Multiplayer Presential Games (CMPG)	Villalta, M. Gajardo, I. Nussbaum, M. Andreu, J.J. Echeverría, A. Plass, J.L.
Computers & Education	2012	Utilising a collaborative macro-script to enhance student engagement: A mixed method study in a 3D virtual environment	Bouta, Hara Retalis, Symeon Paraskeva, Fotini
Computers & Education	2012	The effectiveness of using procedural scaffoldings in a paper-plus-smartphone collaborative learning context	Huang, Hui-Wen Wu, Chih-Wei Chen, Nian-Shing
Computers & Education	2012	Using synchronous peer tutoring system to promote elementary students' learning in mathematics	Tsuei, Mengping
Computers & Education	2012	Digital storytelling for enhancing student academic achievement, critical thinking, and learning motivation: A year-long experimental study	Yang, Ya-Ting C. Wu, Wan-Chi I.
Computers & Education	2013	Collboard: Fostering New Media Literacies in the Classroom through Collaborative Problem Solving Supported by Digital Pens and Interactive Whiteboards	Alvarez, Claudio Salavati, Sadaf Milrad, Marcelo Nussbaum, Miguel
Computers & Education	2013	Designing augmented reality for the classroom	Cuendet, Sébastien Bonnard, Quentin Do-Lenh, Son Dillenbourg, Pierre
Computers & Education	2013	Design for classroom orchestration	Dillenbourg, Pierre
Computers & Education	2013	Problem solving by 5–6 years old kindergarten children in a computer programming environment: A case study	Fessakis, G. Gouli, E. Mavroudi, E.
Computers & Education	2013	A constructivist computational platform to support mathematics education in elementary school	Garcia, I. Pacheco, C.
Computers & Education	2013	Orchestration in a networked classroom: Where the teacher's real-time enactment matters	Looi, Chee-Kit Song, Yanjie
Computers & Education	2013	Scaffolding argumentation in intact class: Integrating technology and pedagogy	Lu, Jingyan Zhang, Zhidong
Computers & Education	2013	A collaborative game-based learning approach to improving students' learning performance in science courses	Sung, Han-Yu Hwang, Gwo-Jen
Computers in Human Behavior	2011	Comparative study of netbooks and tablet PCs for fostering face-to-face collaborative learning	Claudio Alvarez; Christian Brown; Miguel Nussbaum

Source	Year	Title	Authors
Computers in Human Behavior	2011	Facilitating peer knowledge modeling: Effects of a knowledge awareness tool on collaborative learning outcomes and processes	Mirweis Sangin; Gaëlle Molinari; Marc-Antoine Nüssli; Pierre Dillenbourg
Computers in Human Behavior	2011	Group awareness of social and cognitive performance in a CSCL environment: Effects of a peer feedback and reflection tool	Chris Phielixa; Frans J. Prinsa; Paul A. Kirschnera; Gijsbert Erkensa; Jos Jaspersa
Computers in Human Behavior	2011	Introducing synchronous e-discussion tools in co-located classrooms: A study on the experiences of 'active' and 'silent' secondary school students	Christa S.C. Asterhan; Tammy Eisenmann
Computers in Human Behavior	2012	How do interactive tabletop systems influence collaboration?	Stéphanie Buisinea; Guillaume Besacierb; Améziane Aoussata; Frédéric Vernier
Computers in Human Behavior	2012	An observational study of undergraduate students' adoption of (mobile) note-taking software	Astrid Schepmana; Paul Rodwaya; Carol Beattieb; Jordana Lamberta
Computers in Human Behavior	2012	Exploring different technological platforms for supporting co-located collaborative games in the classroom	Alejandro Echeverría; Matías Améstica; Francisca Gil; Miguel Nussbaum; Enrique Barrios; Sandra Leclerc
Computers in Human Behavior	2012	Exploring regulatory processes during a computer-supported collaborative learning task using process mining	Cornelia Schoora; Maria Bannertb
Computers in Human Behavior	2013	Conversational learning integration in technology enhanced classrooms	Yacine Atif
Computers in Human Behavior	2013	Computer-supported collaborative learning with digital video cases in teacher education: The impact of teaching experience on knowledge convergence	Jan M. ZottmannCorresponding; Karsten Stegmann; Jan-Willem Strijbos; Freydis Vogel; Christof Wecker; Frank Fischer
Computers in the Schools	2013	Collaboration by Design: Using Robotics to Foster Social Interaction in Kindergarten	Kenneth T. H. Leea; Amanda Sullivanb; Marina U. Bersb
Computers in the Schools	2013	Getting in Touch: Use of Mobile Devices in the Elementary Classroom	Katia Ciampaa; Tiffany L. Gallaghera
Computers in the Schools	2013	Guiding Explorations: Design Principles and Functions of Interactive Diagrams	Elena Naftalieva; Michal Yerushalmya
Cooperative Design, Visualization, and Engineering (pp. 181-188). Springer Berlin Heidelberg.	2010	Multi-User Multi-Touch Setups for collaborative Learning in an Educational Setting	Schneider, Jan Derboven, Jan Luyten, Kris Vleugels, Chris Bannier, Stijn Roeck, De Verstraete, Mathijs

Source	Year	Title	Authors
CSCL	2009	Around the table: Are multiple-touch surfaces better than single-touch for children's collaborative interactions?	Harris, Amanda Rick, Jochen Bonnett, Victoria Yuill, Nicola Fleck, Rowanne Marshall, Paul Rogers, Yvonne
CSCW 2010, February 6–10, 2010, Savannah, Georgia, USA.	2010	Telling the Whole Story: Anticipation, Inspiration and Reputation in a Field Deployment of TellTable	Cao, Xiang Lindley, Siân E Helmes, John Sellen, Abigail
Education and Information Technologies	2011	Students' perceptions of clickers as an instructional tool to promote active learning	Oigara, James Keengwe, Jared
Educational Technology & Society	2009	Effect of Computer-Based Video Games on Children: An Experimental Study	Tsung-Yen Chuang , Wei-Fan Chen
Educational Technology & Society	2009	Engaging students in multimedia-mediated Constructivist learning – Students' perceptions	Mai Neo, Tse-Kian Neo
Educational Technology & Society	2009	Comparing Learning Performance of Students Using Algorithm Visualizations Collaboratively on Different Engagement Levels	Laakso, M.-J., Myller, N., & Korhonen, A.
Educational Technology & Society	2009	Analysis of Peer Interaction in Learning Activities with Personal Handhelds and Shared Displays	Liu, C.-C., Chung, C.W., Chen, N.-S., & Liu, B.-J.
Educational Technology & Society	2010	Effect of an Interactive Courseware in the Learning of Matrices	Hoon, T. S., Chong, T. S., & Binti Ngah, N. A.
Educational Technology & Society	2010	Development and Evaluation of an Interactive Mobile Learning Environment with Shared Display Groupware	Jie Chi Yang,- Yi Lung Lin
Educational Technology & Society	2010	Pattern Discovery for the Design of Face-to-Face Computer-Supported Collaborative Learning Activities	Capponi, M. F., Nussbaum, M., Marshall, G., & Lagos, M. E.
Educational Technology & Society	2010	From MMORPG to a Classroom Multiplayer Presential Role Playing Game	Susaeta, H., Jimenez, F., Nussbaum, M., Gajardo, I., Andreu, J. J., & Villalta, M.
Educational Technology & Society	2011	Using a Wiki to Scaffold Primary-School Students' Collaborative Writing	Woo, M., Chu, S., Ho, A., & Li, X.
Educational Technology & Society	2011	Screen-capturing System with Two-layer Display for PowerPoint Presentation to Enhance Classroom Education	Lai, Y.-S., Tsai, H.-H., & Yu, P.-T.
Educational Technology & Society	2011	Supporting Mobile Collaborative Activities through Scaffolded Flexible Grouping	Boticki, I., Looi, C.-K., & Wong, L.-H.
Educational Technology & Society	2012	A Study on Exploiting Commercial Digital Games into School Context	Panoutsopoulos, H., & Sampson, D. G

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Educational Technology & Society	2012	Are One-to-One Computers Necessary? An Analysis of Collaborative Web Exploration Activities Supported by Shared Displays	Chang, C.-J., Liu, C.-C., & Shen, Y.-J.
Educational Technology & Society	2012	A Cognitive Apprenticeship Approach to Facilitating Web-based Collaborative Problem Solving	Kuo, F.-R., Hwang, G.-J., Chen, S.-C., & Chen, S. Y.
Educational Technology & Society	2012	Digital Competition Game to Improve Programming Skills	Julián Moreno
Educational Technology & Society	2013	Investigating the Activities of Children toward a Smart Storytelling Toy	Kara, N., Aydin, C. C., & Cagiltay, K.
Educational Technology & Society	2013	Integrating Traditional Learning and Games on Large Displays: An Experimental Study	Ardito, C., Lanzilotti, R., Costabile, M. F., & Desolda, G.
Educational Technology & Society	2013	Developing and Implementing a Framework of Participatory Simulation for Mobile Learning Using Scaffolding	Chengjiu Yin.- Yanjie Song .- Yoshiyuki Tabata .-Hiroaki Ogata.- Gwo-Jen Hwang
Educational Technology & Society	2013	How Flexible Grouping Affects the Collaborative Patterns in a Mobile-Assisted Chinese Character Learning Game	Lung-Hsiang Wong.- Ching-Kun Hsu .- Jizhen Sun.- Ivica Boticki
ETR&D- Educational Technology Research and Development	2009	Computer-supported aids to making sense of scientific articles: cognitive, motivational, and attitudinal effects	Julie A. Gegner, Donald H. J. Mackay, Richard E. Mayer
ETR&D- Educational Technology Research and Development	2009	Prompting students' context-generating cognitive activity in ill-structured domains: does the prompting mode affect learning?	Pantelis M. Papadopoulos, Stavros N. Demetriadis, Ioannis G. Stamelos, Ioannis A. Tsoukalas
ETR&D- Educational Technology Research and Development	2009	Towards an idea-centered, principle-based design approach to support learning as knowledge creation	Huang-Yao Hong, Florence R. Sullivan
ETR&D- Educational Technology Research and Development	2010	Examining the effects of computer-based scaffolds on novice teachers' reflective journal writing	Guolin Lai, Brendan Calandra
ETR&D- Educational Technology Research and Development	2010	Design and effects of representational scripting on group performance	B. Slof, G. Erkens, P. A. Kirschner, J. G. M. Jaspers
ETR&D- Educational Technology Research and Development	2011	A study of learning and motivation in a new media enriched environment for middle school science	Min Liu, Lucas Horton, Justin Olmanson, Paul Toprac
ETR&D- Educational Technology Research and Development	2011	The effect of two different cooperative approaches on students' learning and practices within the context of a WebQuest science investigation	Zacharias C. Zacharia, Nikoletta A. Xenofontos, Constantinos C. Manoli
ETR&D- Educational Technology Research and Development	2011	Aligning game activity with educational goals: following a constrained design approach to instructional computer games	Brett E. Shelton, Jon Scoresby

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ETR&D- Educational Technology Research and Development	2011	An investigation of the artifacts and process of constructing computers games about environmental science in a fifth grade classroom	Ahmet Baytak, Susan M. Land
ETR&D- Educational Technology Research and Development	2012	A teachable-agent-based game affording collaboration and competition: evaluating math comprehension and motivation	Lena Pareto, Magnus Haake, Paulina Lindström, Björn Sjödén, Agneta Gulz
ETR&D- Educational Technology Research and Development	2012	Role of dual task design when measuring cognitive load during multimedia learning	Cornelia Schoor, Maria Bannert, Roland Brünken
ETR&D- Educational Technology Research and Development	2012	Computer-based feedback and goal intervention: learning effects	Alfred Valdez
ETR&D- Educational Technology Research and Development	2013	An evaluation of interactive tabletops in elementary mathematics education	Alexander T. Jackson, Bradley J. Brummel, Cody L. Pollet, David D. Greer
ETR&D- Educational Technology Research and Development	2013	The Assessment Agent System: design, development, and evaluation	Jianhua Liu
ETR&D- Educational Technology Research and Development	2013	The effect of contextualized conversational feedback in a complex open-ended learning environment	James R. Segedy, John S. Kinnebrew, Gautam Biswas
ETR&D- Educational Technology Research and Development	2013	The influence of the use of technology on student outcomes in a blended learning context	María V. López-Pérez, María C. Pérez-López, Lázaro Rodríguez-Ariza, Eva Argente-Linares
European Journal of Education	2013	'Old Wine in Even Newer Bottles': the uneasy relationship between web 2.0 technologies and European school collaboration	Anastasia Gouseti
European Journal of Engineering Education	2012	Example of good practice of a learning environment with a classroom response system in a mechanical engineering bachelor course	Ines Lopez Arteagaab; Esther Vinkenc
European Journal of Engineering Education	2012	From 'doing' to 'doing with learning': reflection on an effort to promote self-regulated learning in technological projects in high school	Moshe Baraka
European Journal of Engineering Education	2013	Learning in a game-based virtual environment: a comparative evaluation in higher education	Igor Mayer; Harald Warmelink; Geertje Bekebrede
ICLS 2010	2010	Facilitating Group Learning in Science Laboratory Courses Using Handheld Devices	Chung, Chen-wei Kuo, Wang-hsin Liu, Chen-chung
IDC '13, Jun 24-27 2013, New York, NY, USA	2013	Scripting and orchestration of collaborative inquiry in smart classrooms Mike	Tissenbaum, Mike
IDC 2009, June 3–5, 2009, Como, Italy	2009	Putting interference to work in the design of a whole-class learning activity	Moher, Tom

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IDC 2010, June 9–12, 2010, Barcelona, Spain.	2010	Mobile Collaboration: Collaboratively Reading and Creating Children's Stories on Mobile Devices Jerry	Fails, Jerry Alan Druin, Allison Guha, Mona Leigh
IDC 2011, June 20–23, 2011, Ann Arbor, USA.	2011	Beyond One-Size-Fits-All : How Interactive Tabletops Support Collaborative Learning	Rick, Jochen Marshall, Paul Yuill, Nicola
IDC 2012	2012	Group Interaction on Interactive Multi-touch Tables by Children in India	Jamil, Izdihar Perry, Mark O'Hara, Kenton Karnik, Abhijit Marshall, Mark T. Jha, Swathi Gupta, Sanjay Subramanian, Sriram
IEEE 13th International Conference on Advanced Learning Technologies	2013	Developing a Well-Focused Learning through a Kinect-Based Collaborative Setting	Shih, Kai-Wen Wu, Chia-Jung Chen, Gwo-Dong
IEEE Transactions on Education	2009	Modeling a Collaborative Answer Negotiation Activity Using IMS-Based Learning Design	Valdivia, R. ; Nussbaum, M. ; Ochoa, S.F.
IEEE Transactions on Education	2009	Experimental Validation of the Learning Effect for a Pedagogical Game on Computer Fundamentals	Sindre, G. ; Natvig, L. ; Jahre, M.
IEEE Transactions on Education	2010	Pedagogy and Processes for a Computer Programming Outreach Workshop—The Bridge to College Model	Tangney, B. ; Oldham, E. ; Conneely, C. ; Barrett, S. ; Lawlor, J.
IEEE Transactions on Education	2010	A Matlab/Simulink-Based Interactive Module for Servo Systems Learning	Aliane, N.
IEEE Transactions on Education	2011	Game-Themed Programming Assignment Modules: A Pathway for Gradual Integration of Gaming Context Into Existing Introductory Programming Courses	Sung, K. ; Hillyard, C. ; Angotti, R.L. ; Panitz, M.W. ; Goldstein, D.S. ; Nordlinger, J.
IEEE Transactions on Education	2011	Using LEGO NXT Mobile Robots With LabVIEW for Undergraduate Courses on Mechatronics	Gómez-de-Gabriel, J.M. ; Mandow, A. ; Fernández-Lozano, J. ; Garcia-Cerezo, A.
IEEE Transactions on Education	2011	Using Tablet PCs and Interactive Software in IC Design Courses to Improve Learning	Simoni, M.
IEEE Transactions on Education	2013	WiFiSiM: An Educational Tool for the Study and Design of Wireless Networks	Mateo Sanguino, T.J. ; Serrano Lopez, C. ; Marquez Hernandez, F.A.
IEEE Transactions on Education	2013	The Use of Video-Gaming Devices as a Motivation for Learning Embedded Systems Programming	Gonzalez, J. ; Pomares, P. ; Damas, M. ; Garcia-Sanchez, P. ; Rodriguez-Alvarez, M. ; Palomares, J.M.

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IEEE Transactions on Education	2013	Physical Student–Robot Interaction With the ETHZ Haptic Paddle	Gassert, R. ; Metzger, J. ; Leuenberger, K. ; Popp, W.L. ; Tucker, M.R. ; Vigaru, B. ; Zimmermann, R. ; Lambercy, O.
IEEE Transactions on Education	2013	Integrating Mobile Robotics and Vision With Undergraduate Computer Science	Cielniak, G. ; Bellotto, N. ; Duckett, T.
IEEE Transactions on Education	2013	A Contest-Oriented Project for Learning Intelligent Mobile Robots	Hsin-Hsiung Huang ; Juing-Huei Su ; Chyi-Shyong Lee
IEEE TRANSACTIONS ON LEARNING TECHNOLOGIES	2012	An Ambient Awareness Tool for Supporting Supervised Collaborative Problem Solving	Alavi, Hamed S Member, Student Dillenbourg, Pierre
Innovations in Education and Teaching International	2013	New uses for a familiar technology: introducing mobile phone polling in large classes	Susanne Voelkel; Daimark Bennett
Interactive Learning Environments	2009	Collaborative versus individual use of regulative software scaffolds during scientific inquiry learning	Sarah Manlove, Ard W. Lazonder* & Ton de Jong
Interactive Learning Environments	2010	Examining the effects of learning motivation and of course design in an instructional simulation game	Y. C. Changa*, H. Y. Pengb & H. C. Chaoa
Interactive Learning Environments	2010	Co-located collaborative learning video game with single display groupware	Cristián Infante*, Juan Weitz, Tomás Reyes, Miguel Nussbaum, Florencia Gómez & Darinka Radovic
Interactive Learning Environments	2011	Face-to-face collaborative learning supported by mobile phones	Alejandro Echeverría*, Miguel Nussbaum, Juan Felipe Calderón, Claudio Bravo, Cristián Infante & Andrea Vásquez
Interactive Learning Environments	2012	The study of surface computer supported cooperative work and its design, efficiency, and challenges	Wu-Yuin Hwang* & Jia-Han Sub
Interactive Learning Environments	2013	Factors affecting perceived learning of engineering students in problem based learning supported by business simulation	Julián Chaparro-Peláez, Santiago Iglesias-Pradas, Félix J. Pascual-Miguel & Ángel Hernández-García
Interactive Learning Environments	2013	Study of co-located and distant collaboration with symbolic support via a haptics-enhanced virtual reality task	Shih-Ching Yeh, Wu-Yuin Hwang*, Jin-Liang Wang & Shi-Yi Zhan
Interactive Learning Environments	2013	Digital Learning Playground: supporting authentic learning experiences in the classroom	Gwo-Dong Chen, Nurkhamid, Chin-Yeh Wang*, Su-Hang Yang, Wei-Yuan Lu & Chih-Kai Chang
Interactive Learning Environments	2013	A comparative study of the learning effectiveness of a blended and embodied interactive video game for kindergarten students	Jon-Chao Hong, Chih-Min Tsai, Ya-Jiuan Ho, Ming-Yueh Hwang* & Ching-Ji Wu

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Interactive Learning Environments	2013	Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system	Hao-Chiang Koong Lina; Mei-Chi Chena; Chih-Kai Changa
International Journal of Computer-Supported Collaborative Learning	2009	Earth science learning in SMALLab: A design experiment for mixed reality	Birchfield, David Megowan-Romanowicz, Colleen
International Journal of Computer-Supported Collaborative Learning	2010	CSCL for intellectually disabled pupils: Stimulating interaction by using a floor control mechanism	Cress, Ulrike Wodzicki, Katrin Bientzle, Martina Lingnau, Andreas
International Journal of Computer-Supported Collaborative Learning	2010	Scaffolding problem-based learning with CSCL tools	Lu, Jingyan Lajoie, Susanne P. Wiseman, Jeffrey
International Journal of Computer-Supported Collaborative Learning	2010	Can the interactive whiteboard support young children’s collaborative communication and thinking in classroom science activities?	Kershner, Ruth Mercer, Neil Warwick, Paul Kleine Staarman, Judith
International Journal of Computer-Supported Collaborative Learning	2011	Guided reciprocal questioning to support children’s collaborative storytelling	Gelmini-Hornsby, Giulia Ainsworth, Shaaron O’Malley, Claire
International Journal of Computer-Supported Collaborative Learning	2011	A multimodal approach to coding discourse: Collaboration, distributed cognition, and geometric reasoning	Evans, Michael a. Feenstra, Eliot Ryon, Emily McNeill, David
International Journal of Computer-Supported Collaborative Learning	2011	Linking teacher beliefs, practices and student inquiry-based learning in a CSCL environment: A tale of two teachers	Song, Yangjie Looi, Chee-Kit
International Journal of Computer-Supported Collaborative Learning	2011	Collaboration within large groups in the classroom	Szewkis, Eyal Nussbaum, Miguel Rosen, Tal Abalos, Jose Denardin, Fernanda Caballero, Daniela Tagle, Arturo Alcoholado, Cristian
International Journal of Computer-Supported Collaborative Learning	2012	Scripted collaborative learning with the cognitive tutor algebra	Rummel, Nikol Mullins, Dejana Spada, Hans
International Journal of Computer-Supported Collaborative Learning	2012	Learning physics through play in an augmented reality environment	Enyedy, Noel Danish, Joshua a. Delacruz, Girlie Kumar, Melissa
International Journal of Computer-Supported Collaborative Learning	2012	Interactive visual tools as triggers of collaborative reasoning in entry-level pathology	Nivala, Markus Rystedt, Hans Säljö, Roger Kronqvist, Pauliina Lehtinen, Ernovv

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International Journal of Computer-Supported Collaborative Learning	2013	Co-located single display collaborative learning for early childhood education	Gómez, Florencia Nussbaum, Miguel Weitz, Juan F. Lopez, Ximena Mena, Javiera Torres, Alex
International Journal of Computer-Supported Collaborative Learning	2013	Analyzing group coordination when solving geometry problems with dynamic geometry software	Oner, Diler
International Journal of Mathematical Education in Science and Technology	2013	Creating discussions with classroom voting in linear algebra	Kelly Clinea; Holly Zulloa; Jonathan Duncanbc; Ann Stewartd; Marie Snipese
International Journal of Mathematical Education in Science and Technology	2013	Finnish upper secondary students' collaborative processes in learning statistics in a CSCL environment	Juho Kaleva Oikarinen; Sanna Järveläa; Raimo Kaasilaa
International Journal of Science Education	2010	Role of the Teacher in Computer-Supported Collaborative Inquiry Learning	Urhahne, Detlef; Schanze, Sascha; Bell, Thorsten; Mansfield, Amie; Holmes, Jeff
ITS '09, November 23-25 2009, Banff, Alberta, Canada	2009	Actions Speak Loudly with Words : Unpacking Collaboration Around the Table	Fleck, Rowanne Rogers, Yvonne Yuill, Nicola Marshall, Paul Carr, Amanda Rick, Jochen Bonnett, Victoria Keynes, Milton
ITS'12, November 11–14, 2012, Cambridge, Massachusetts, USA	2012	Orchestrating a Multi-tabletop Classroom: From Activity Design to Enactment and Reflection Roberto	Martinez-maldonado, Roberto Kay, Judy Yacef, Kalina
ITS'12, November 11–14, 2012, Cambridge, Massachusetts, USA.	2012	Tangible Paper Interfaces: Interpreting Pupils' Manipulations	Bonnard, Quentin Jermann, Patrick Legge, Amanda Dillenbourg, Pierre
Journal of Computer Assisted Learning	2009	Interaction between tool and talk: how instruction and tools support consensus building in collaborative inquiry-learning environments	H. Gijlers,*, N. Saab, W.R. Van Joolingen, T. De Jong, B.H.A.M. Van Hout-Wolters
Journal of Computer Assisted Learning	2009	Learning to collaborate by collaborating: a face-to-face collaborative activity for measuring and learning basics about teamwork†	C. Cortez, M. Nussbaum, G. Woywood, R. Aravena
Journal of Computer Assisted Learning	2009	Socio-cultural aspects of prompting student reflection in Web-based inquiry learning environments	A. Furberg
Journal of Computer Assisted Learning	2009	Characteristics of students assigned to technology-based instruction	John A. Ross*, Tim Sibbald, Catherine D. Bruce

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Journal of Computer Assisted Learning	2009	Integrating technology in the classroom: a visual conceptualization of teachers' knowledge, goals and beliefs	F.-H. Chen, C.-K. Looi, W. Chen
Journal of Computer Assisted Learning	2010	Vocabulary learning by mobile-assisted authentic content creation and social meaning-making: two case studies	L-H. Wong, C-K. Looi
Journal of Computer Assisted Learning	2010	A comparison study of polyominoes explorations in a physical and virtual manipulative environment	Y. Yuan, C.-Y. Lee, C.-H. Wang
Journal of Computer Assisted Learning	2011	Collaborative learning with a wiki: Differences in perceived usefulness in two contexts of use	L. Naismith*, B.-H. Lee, R.M. Pilkington
Journal of Computer Assisted Learning	2011	1:1 mobile inquiry learning experience for primary science students: a study of learning effectiveness	C.-K. Looi*, B. Zhang, W. Chen, P. Seow, G. Chia, C. Norris, E. Soloway
Journal of Computer Assisted Learning	2011	Facilitating collaboration in lecture-based learning through shared notes using wireless technologies	T. Valtonen*, S. Havu-Nuutinen, P. Dillon, M. Vesisenaho
Journal of Computer Assisted Learning	2011	The role of digital artefacts on the interactive whiteboard in supporting classroom dialogue	S. Hennessy*
Journal of Computer Assisted Learning	2011	Collaborative learning with screen-based simulation in health care education: an empirical study of collaborative patterns and proficiency development	L.O. Häll*, T. Söderström, J. Ahlqvist, T. Nilsson
Journal of Computer Assisted Learning	2012	Ubiquitous games for learning (UbiqGames): Weatherlings, a worked example	E. Klopfer*, J. Sheldon, J. Perry, V. H.-H. Chen
Journal of Computer Assisted Learning	2012	The impact of collaborative and individualized student response system strategies on learner motivation, metacognition, and knowledge transfer	M.E. Jones, P.D. Antonenko*, C.M. Greenwood
Journal of Computer Assisted Learning	2012	Comparison of 1:1 and 1:m CSCL environment for collaborative concept mapping	C.-P. Lin*, L.-H. Wong, Y.-J. Shao
Journal of Computer Assisted Learning	2012	Integrating computer-supported collaborative learning into the classroom: the anatomy of a failure	M. Baker*, F.-X. Bernard, I. Dumez-Féroc
Journal of Computer Assisted Learning	2013	Argument graph as a tool for promoting collaborative online reading	Carita Kiili
Journal of Computer Assisted Learning	2013	Investigating face-to-face peer interaction patterns in a collaborative Web discovery task: the benefits of a shared display	C-W. Chung, C-C. Lee, C-C. Liu*
Journal of Educational Computing Research	2011	Revealing Significant Learning Moments with Interactive Whiteboards in Mathematics	Catherine D. Bruce; Richard McPherson; Farhad Mordy Sabeti; Tara Flynn

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Journal of Educational Computing Research	2012	Effects of Peer E-Feedback on Turkish EFL Students' Writing Performance	Hatime Ciftci; Zeynep Kocoglu
Journal of Science Education and Technology	2009	Teaching and Learning in the Mixed-Reality Science Classroom	Tolentino, Lisa Birchfield, David Megowan-Romanowicz, Colleen Johnson-Glenberg, Mina C. Kelliher, Aisling Martinez, Christopher
Journal of Science Education and Technology	2011	Life in the Hive: Supporting Inquiry into Complexity Within the Zone of Proximal Development	Danish, Joshua a. Peppler, Kylie Phelps, David Washington, DiAnna
Journal of Technology and Teacher Education	2011	Collaborative Software and Focused Distraction in the Classroom	Rhine, Steve; Bailey, Mark
Journal of Universal Computer Science	2012	Co-Designing Collaborative Smart Classroom Curriculum for Secondary School Science	Tissenbaum, Mike Lui, Michelle Slotta, James D
Journal of Universal Computer Science	2009	MC-Supporter: Flexible Mobile Computing Supporting Learning though Social Interactions	Baloian, Nelson Zurita, Gustavo
Learning, Media and Technology	2013	An analysis of teacher-defined activities with mobile technologies: predecessor and successor tool use in the classroom	Louise Mifsudab; Anders I. Mørchb; Sigmund Liebergc
Learning, Media and Technology	2013	Mobile phone images and video in science teaching and learning	Sakunthala Yatigammana Ekanayake; Jocelyn Wishartb
Mathematical Thinking and Learning	2012	Graphing in Groups: Learning About Lines in a Collaborative Classroom Network Environment	Tobin Whitea; Matthew Wallacea; Kevin Laia
MobileHCI '09	2009	Studying multi-user settings for pervasive games	Leichtenstern, Karin André, Elisabeth
OZCHI'12, November 26–30, 2012, Melbourne, Victoria, Australia	2012	Evaluation of preschool children's fantasy play in the tabletop environment	Mansor, Evi Indriasari
Personal and Ubiquitous Computing	2010	The effectiveness of using a robotics class to foster collaboration among groups of children with autism in an exploratory study	Wainer, Joshua Ferrari, Ester Dautenhahn, Kerstin Robins, Ben
Proceedings of the 2010 ACM conference on Computer supported cooperative work - CSCW '10	2010	Multiple mouse text entry for single-display groupware	Amershi, Saleema Morris, Meredith Ringel Moraveji, Neema Balakrishnan, Ravin Toyama, Kentaro
Studies in Higher Education	2013	Increasing anonymity in peer assessment by using classroom response technology within face-to-face higher education	Annelies Raes; Ellen Vanderhoven; Tammy Schellens

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Taylor & Francis (informaworld)	2013	Picking Up the Mantle of “Expert”: Assigned Roles, Assertion of Identity, and Peer Recognition Within a Programming Class	Deborah Fields; Noel Enyedyb
Taylor & Francis (informaworld)	2012	Primary children's management of themselves and others in collaborative group work: ‘Sometimes it takes patience …’	Ruth Kershner; Paul Warwick; Neil Mercer; Judith Kleine Staarmanb
Taylor & Francis (informaworld)	2012	Teaching image-processing concepts in junior high school: boys’ and girls’ achievements and attitudes towards technology	Moshe Barak; Khaled Asad
Taylor & Francis (informaworld)	2012	Teaching literacy in primary schools using an interactive whole-class technology: facilitating student-to-student whole-class dialogic interactions	Damian Maher
Taylor & Francis (informaworld)	2013	Collaborative 3D learning games for future learning: teachers’ instructional practices to enhance shared knowledge construction among students	Raija Hämäläinen; Kimmo Oksanen
Taylor & Francis (informaworld)	2013	Evaluation of Computer-Assisted Instruction for Math Accuracy Intervention	Thomas J. Gross; Gary Duhon
Taylor & Francis (informaworld)	2013	Getting real: the authenticity of remote labs and simulations for science learning	Megan Sauter; David H. Uttal; David N. Rapp; Michael Downing; Kemi Jona
Taylor & Francis (informaworld)	2013	Supporting active learning in an undergraduate geotechnical engineering course using group-based audience response systems quizzes	Shane Donohue
Taylor & Francis (informaworld)	2012	The effectiveness of computer-based EFL instruction among primary school students in Israel	Haya Shamir; Erin Phinney Johnson
Taylor & Francis (informaworld)	2013	The influence of perceived convenience and curiosity on continuance intention in mobile English learning for high school students using PDAs	Chi-Cheng Chang; Kuo-Hung Tseng; Chaoyun Liang; Chi-Fang Yan
Taylor & Francis (informaworld)	2013	The role of physicality in rich programming environments	Allison S. Liu; Christian D. Schunn; Jesse Flot; Robin Shoop
Taylor & Francis (informaworld)	2013	Use and evaluation of a technology-rich experimental collaborative classroom	Diane Salter; David L. Thomson; Bob Fox; Joy Lam
Taylor & Francis (informaworld)	2013	Using clickers to facilitate interactive engagement activities in a lecture room for improved performance by students	Malefyane Tlhoaele; Adriaan Hofman; Ari Naidoo; Koos Winnips

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Taylor & Francis (informaworld)	2012	Using Primary Language Support via Computer to Improve Reading Comprehension Skills of First-Grade English Language Learners	Cathi Draper Rodríguez; John Filler; Kyle Higgins
Taylor & Francis (informaworld)	2010	Tablet PCs in engineering mathematics courses at the J.B. Speed School of Engineering	Jeffrey L. Hieb; Patricia A.S. Ralston
Taylor & Francis (informaworld)	2010	Collaborative learning in teaching information management	N. Natho; L. Knipping; O. Pfeiffer; C. Schröder; E. Zorn; S. Jeschke
Taylor & Francis (informaworld)	2010	Comparing Simple and Advanced Video Tools as Supports for Complex Collaborative Design Processes	Carmen Zahn; Roy Pea; Friedrich W. Hesse; Joe Rosen
Taylor & Francis (informaworld)	2011	Your verbal zone: an intelligent computer-assisted language learning program in support of Turkish learners' vocabulary learning	Ömer Esit
Taylor & Francis (informaworld)	2011	Audience Response Systems: Using “Clickers” to Enhance BSW Education	Laurie A. Smith; Herb Shon; Rowena Santiago
Taylor & Francis (informaworld)	2011	Challenging assumptions: Mobile Learning for Mathematics Project in South Africa	Nicky Roberts; Riitta Vänskä
Taylor & Francis (informaworld)	2011	Student-teachers’ use of Google Earth in problem-based geology learning	Ilkka Ratinen; Tuula Keinonen
Taylor & Francis (informaworld)	2011	Benefits of Computer-Assisted Instruction to Support Reading Acquisition in English Language Learners	Paul Macaruso; Alyson Rodman
Taylor & Francis (informaworld)	2009	Educational Research in Developing 3-D Spatial Skills for Engineering Students	Sheryl A. Sorby
Taylor & Francis (informaworld)	2009	Teaching and learning with a visualiser in the primary classroom: modelling graph-making	Diane Mavers
Taylor & Francis (informaworld)	2009	The joint negotiation of ground rules: establishing a shared collaborative practice with new educational technology	Judith Kleine Staarman
Taylor & Francis (informaworld)	2009	Using Peer Instruction and I-Clickers to Enhance Student Participation in Calculus	Adam Lucas
Technology, Pedagogy and Education	2013	Immersive simulations for smart classrooms: exploring evolutionary concepts in secondary science	Michelle Luia; James D. Slotta
Technology, Pedagogy and Education	2013	No student left behind: a collaborative and competitive game-based learning environment to reduce the achievement gap of EFL students in Taiwan	Hui-Chun Hung; Shelley Shwu-Ching Youngb; Chiu-Pin Linc
Wiley InterScience	2009	Collaborative Dialogue Between Thai EFL Learners During Self-Access Computer Activities	KIM MCDONOUGH, WICHIAN SUNITHAM

APPENDIX D: EXAMPLE OF ORCHESTRATION

Subject Area: Foreign Language: English	**Unit Name:** My Family	**Designated Time:** 1 lesson (45 minutes)

Number of Lessons Per Week:	**Grade (s):** 6

Difficulty: (X) Easy ( ) Medium ( ) Difficult	**Language Skills:** (X) Listening ( ) Reading (X) Speaking	

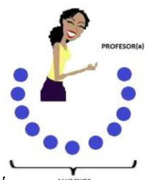
Unit Learning outcomes:
Demonstrate understanding of commonly used phrases and expressions in brief and simple dialogs or oral presentations using direct language.

Skills and Attitudes to develop:
Listening comprehension.

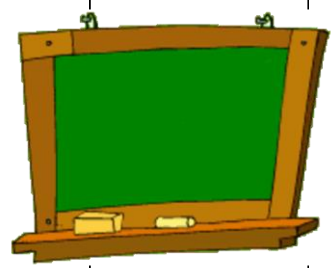
Speaking

Class Objective:
Present family members vocabulary, then use it to perform reading comprehension and oral production tasks.

Necessary Prior Learning Skills:
Personal Pronouns: I, he, she, it, we, you, they.
Vocabulary: Members of the (nuclear) family

Class Stage	**Class Activities**	**Teaching Materials**	**Designated Time**
Beginning of Class: Introduction of Contents	 The teacher **begins the class** showing students a family photo where they can identify the following members: father, mother, brothers and sisters, grandparents, among others. Then the teacher **<u>asks</u>**: ***- Who are the people in this photograph? How are they related to me?*** Students are expected to respond orally to these questions, making suggestions about the picture and the people that appear in it. Then students are expected to identify that the picture is of the teacher's family and identify the names of the family members. Next, the teacher **<u>explains</u>** to students what today's class is about: ***- Today we are going to review vocabulary about family members in an activity on the computer to practice and use what we've learned.***	-Family Photo	**5 minutes**

Class Stage	Class Activities	Teaching Materials	Designated Time
Class Progress: Exercising Contents	*This part of class consists of 2 activities: brainstorming and recall on the board, and a listening exercise integrating the unit vocabulary, with supplementary ICT resources.* **Activity 1**: The teacher draws a tree on the whiteboard and asks students if they know what a family tree is and how to make one. The teacher **invites** the class to make a tree together, writing the names of family members in Spanish. **The objective here is to recall keywords referred to in the unit.** Next, the teacher sticks a label with the name of each family member in English next to each name in Spanish. Then the students are invited to practice pronunciation, repeating the words individually and as a group. Once the students have understood and practiced pronouncing the vocabulary, the teacher must **give the following instruction**: ***-Now that we've remembered the keywords for this topic, we're going to work in groups on the computer practicing this vocabulary by listening to a story. Let's go to the computer room.***	- Whiteboard. - Marker. -Labels (names of family members in English)	**Activity 1.5 minutes**



Class Stage	**Class Activities**	**Teaching Materials**	**Designated Time**
Class Progress: Exercising Content	**Activity 2**: Next the teacher invites the students to work in groups, listening to a paragraph and ordering three words that appear in it. The teacher reminds students that listening closely, identifying words, their order, coming to a consensus and practicing pronunciation are crucial in the activity.  During the course of the activity the teacher: **Monitors** the **students' work and helps** those that appear to need more help with pronunciation. **Registers** the **words with the highest level of appropriation** in pronunciation, to include in future activities. **Registers** the **phonemes that cause the greatest** problems in pronunciation, to work on in future activities.	Computer room set the task. ning ses: 3, 7, 14, ,22,24	**Activity 2.3 minutes**

Class Stage	Class Activities	Teaching Materials	Designated Time
End of Class: Final Content Review	*At this time the class consists of 1 activity: oral expression in a group setting and summary of the contents of the class.* **Activity 1**: The teacher **invites** students to describe a member of their family physically, in English. In order to do this, the teacher writes a list of physical features and the following phrase on the board: **"My…is…"** Students are expected to mention a member of their family and the feature, based on the work done in class. At this time the teacher monitors and registers the appropriation of vocabulary practiced in class, and **makes a list of the most repeated words** to start introducing new words in the following classes.	-No extra materials required.	**Activity 1: 5 minutes**

Figure B.1: "My family" orchestration

APPENDIX E: EXAMPLE OF PRE-POST TESTS ITEMS

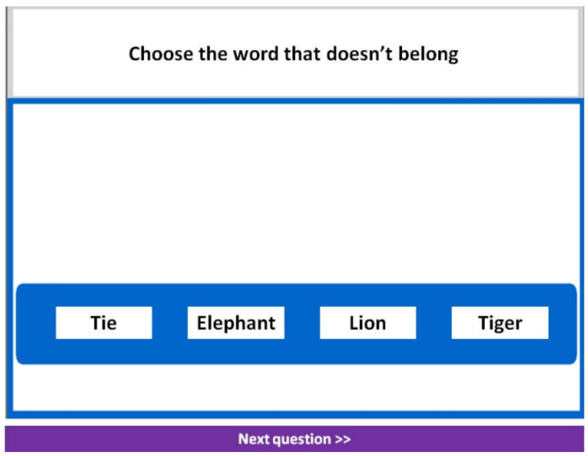


Figure C.1: Vocabulary item

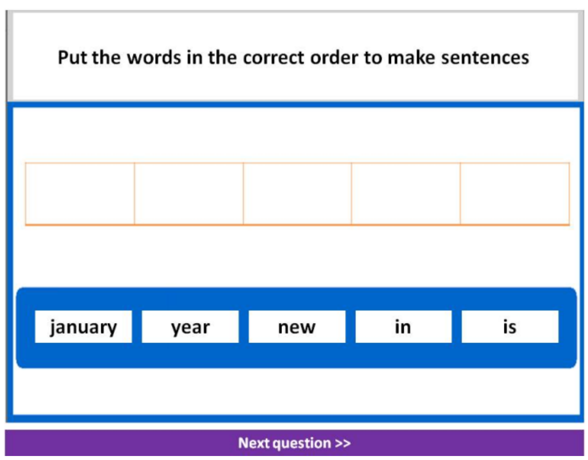


Figure C.2: Grammar item

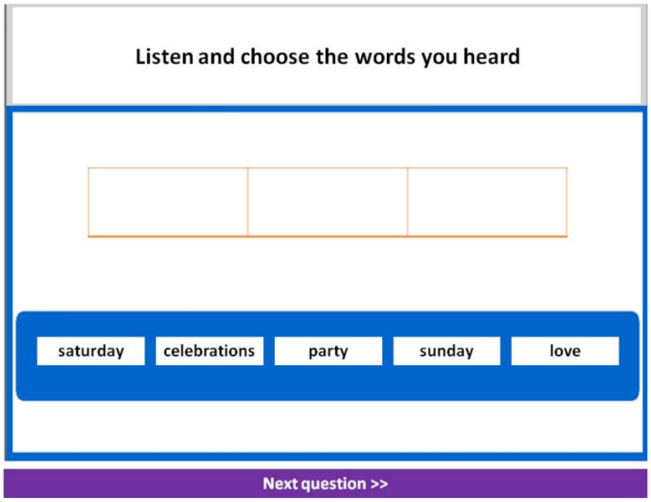


Figure C.3: Listening item

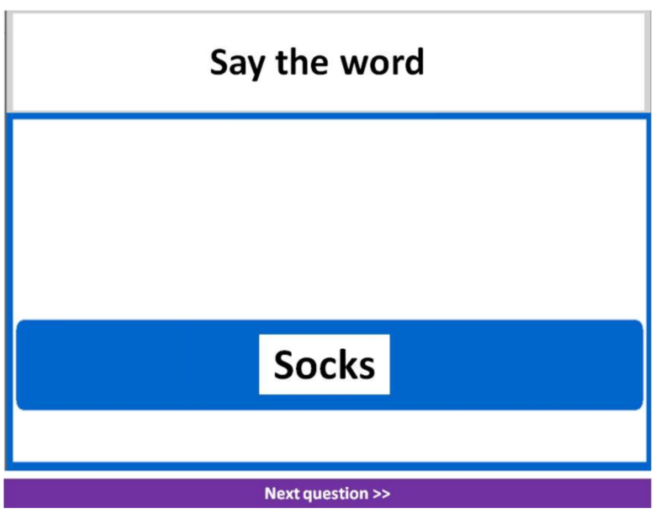


Figure C.4: Pronunciation item

APPENDIX F: OBSERVATION GUIDELINE

Observation guideline

GROUP:

Session/ Date:	
Level:	6^{th} Grade
Assignment:	English
Unit:	

STUDENTS

1.	
2.	
3.	

Start | **End**

Category	**Variable**	**Metric**	**Type***	**1**	**2**	**3 / G**
Communication	Person to person	# dialogs	I			
	Person to group	# dialogs	I			
	Receive support	# requests	I			
	Request for support	# requests	I			
	Peer-imposed solution	# events	G			
Interaction	Positive interdependence	Scale of 1 to 3	G			
	Mutual trust	Scale of 1 to 3	G			
	Acceptance and tolerance	Scale of 1 to 3	G			
	Motivation and interest	Scale of 1 to 3	G			
	Quality of brainstorming	Scale of 1 to 3	G			
Coordination	Disciplined work	Scale of 1 to 3	G			
	Requested support	Scale of 1 to 3	G			
Appropriation	Suitable handling of material	Scale of 1 to 3	G			
	Behavior towards the system	Scale of 1 to 3	G			

* (I) Individual; (G) group work

APPENDIX G: PEDAGOGICAL RULES

IdRule	Rule
01IR	For a given problem there are three words available that must be arranged according to a pre-determined logic.
02IR	Each student must choose a word and pronounce it correctly.
03IR	The stored pronunciation of the three available words is compared with the student's pronunciation. If the pronunciation passes a certain pre-defined threshold, it is accepted.
04IR	The student has 5 opportunities to correctly say the chosen word.
05IR	For the student to advance to the next stage of the activity, the words must have been pronounced correctly and said by following the pre-defined logic for those three words.
055IR	Before validating the sequence, each student must correctly pronounce each word.
06IR	Each student is responsible for one word assigned by the system, which is shown on the screen.
07IR	The system only accepts a word as well-pronounced if this word was assigned to the respective student.
08RR	At each node, the number of students must be 3.
09RR	The maximum number of requests for voice recognition for each node which has the speech-recognition engine is 1.
095RR	The maximum waiting time for a resource to become available is 10 seconds.

APPENDIX H: RULES ASSOCIATED TO THE TASK EXPRESSED IN NATURAL LANGUAGE

Task	**Associated rule**
0. The students are grouped into groups of 3.	08RR: At each node, the number of students must be 3.
1. Each group receives a problem where there are 3 words available and which must be arranged according to a pre-determined logic.	01IR: For a given problem there are three words available that must be arranged according to a pre-determined logic. 06IR: Each student is responsible for one word assigned by the system, which is shown on the screen.
2. Each student chooses a word and pronounces it.	O2IR: Each student must choose a word and pronounce it correctly.
2.1 The system records the word that is pronounced and compares it with the student's pronunciation.	O3IR: The stored pronunciation of the three available words is compared with the student's pronunciation. If the pronunciation passes a certain pre-defined threshold, it is accepted.
2.1.a If pronounced correctly, i.e. if the pronunciation passes a certain pre-defined threshold, it is accepted.	O3IR: The stored pronunciation of the three available words is compared with the student's pronunciation. If the pronunciation passes a certain pre-defined threshold, it is accepted.
2.1.b If the chosen word is not within the validity threshold, the system informs the student that the word was not pronounced correctly and that the student must pronounce the word again, returning to stage 2. The number of attempts increases by 1.	03IR: The stored pronunciation of the three available words is compared with the student's pronunciation. If the pronunciation passes a certain pre-defined threshold, it is accepted.
2.2 The number of attempts by the student is checked.	O4IR: The student has 5 opportunities to correctly say the chosen word. 07IR: The system only accepts a word as well-pronounced if this word was assigned to the respective student.
2.2.a If the number of attempts is less than 5, they go to step 2.3.	O4IR: The student has 5 opportunities to correctly say the chosen word. 07IR: The system only accepts a word as well-pronounced if this word was assigned to the respective student.
2.2.b If the number of attempts is greater than or equal to 5, the system informs the teacher.	O4IR: The student has 5 opportunities to correctly say the chosen word. 07IR: The system only accepts a word as well-pronounced if this word was assigned to the respective student.
2.3. Repeat 2 until all of the students have pronounced each of the corresponding words correctly.	055IR: Before validating the sequence, each student must correctly pronounce each word. 07IR The system only accepts a word as well-pronounced if this word was assigned to the respective student.

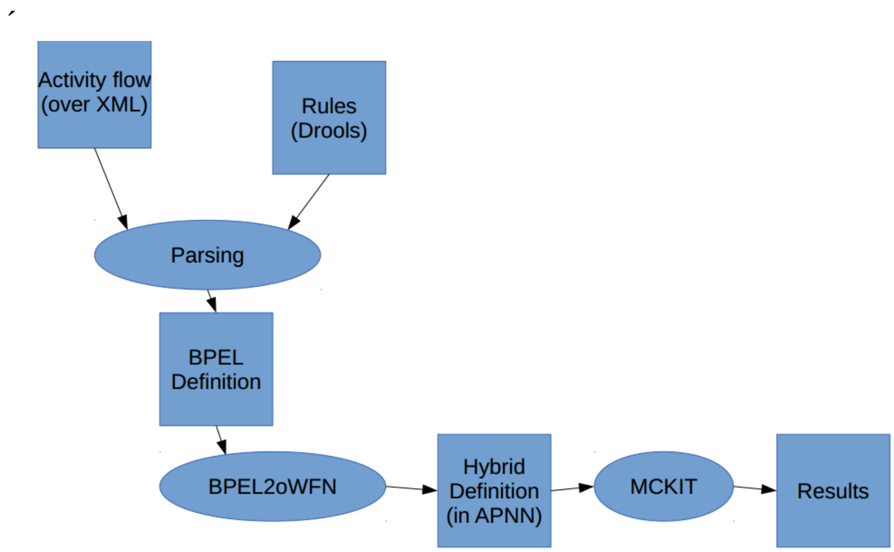
3. The system checks if the students pronounced the words in the expected sequence.	05IR: For the student to advance to the next stage of the activity, the words must have been pronounced correctly and said by following the pre-defined logic for those three words.
3.1.a If the order of the sequence is what was expected, the students move on to the next problem by returning to step 1 with a new problem. If there are no more problems, the activity finishes.	05IR: For the student to advance to the next stage of the activity, the words must have been pronounced correctly and said by following the pre-defined logic for those three words.
3.2.b If the order of the sequence is not what was expected, the entire cycle is repeated from step 1 of the process with the same problem.	05IR: For the student to advance to the next stage of the activity, the words must have been pronounced correctly and said by following the pre-defined logic for those three words.

APPENDIX I: ALTERNATIVE SITUATIONS

ID	Base rule	System action	Sequence of alternative situations	Consequence
10RP	(04IR) The student has 5 opportunities to correctly say the chosen word.	The student completes the maximum number of attempts. System → Informs teacher of the situation.	(a) The teacher chooses to suspend the activity at the node where the alternative event is triggered. (b) Based on their observation of the student, the teacher decides to introduce a new activity for the students, using the projection resource at another node. (b.1) If the resource is at a node where the activity needs to be suspended, → Teacher must choose to suspend the activity for another node.	→ Other students cannot pronounce their respective words (i.e. advance in the activity) Problems of reachability (PC05)
11RP	(08RR) At each node, the number of students must be 3.	A student retires from the activity.	(a) The teacher allows two students to work on the activity at the node in question. (i.e. they modify rule 08RR) (b) The system displays the activity	Problems of reachability (PC06)
12RP	(09RR) The maximum number of requests for voice recognition for each node which has the speech-recognition engine is 1.	There is more than one request at a time for the associated resource.	(a) The system looks for another speech-recognition resource among the other nodes. (a.1) If there is a speech-recognition resource available, it uses it. (a.2) If there is not, it waits for up to 10 seconds until another is available. (a.2.1) If the waiting time is exceeded, the system informs the teacher of the situation.	Possible deadlock, and problems of reachability (PC03)

APPENDIX J: FORMAL TECHNIQUE DETAILS

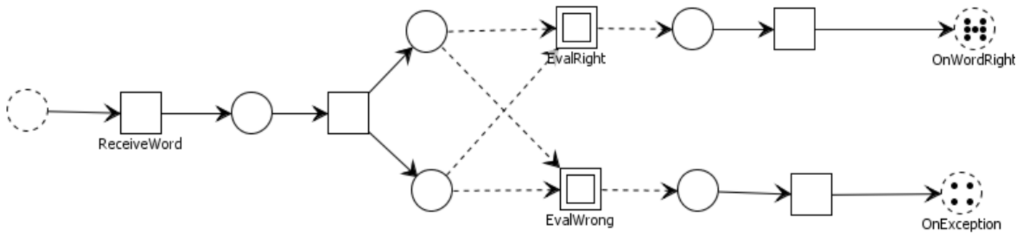
a) Technique elements diagram



b) Transformation algorithm to Petri-Net

1. Define workflow over BPEL
2. BPEL2oWFN (as component) analizes structure and applies petri-nets patterns respect to BPEL constructs.
3. Search transitions corresponding to invocations (tag "invoke") and their results ("receive), corresponding to rules, associated to pedagogical requirements.
4. For each found transition
   1. Select corresponding rule from rules engne
   2. Separate each rule in atomic propositions, according AND & OR.
   3. For each atomic proposition
      1. Represent as a linear graph P-T-P
      2. Transform transition T in to a OR-Exclusive operator.
      3. Join graph with other proposition using corresponding transitions

c) Example of OR-Exclusive operator



d) Example of subworkflow representing a new task, according to alternative scenario.

```
<partial>
  <entrypoint line="xx" do="replace"/>
  <resource type="speechEngine" rules="09RR,09.5RR">
  <postevents>
    <postevent rules="09RR,09.5RR">
        <case result="true">
          <continue/>
        </case>
        <case result="false">
          <sequence>
            <execute id="SearchResource">
              <param id="resource" content="speechEngine"/>
            </execute>
            <postevents>
             <postevent rules="09.5RR,SearchResource">
               <case result="true">
                 <continue/>
               </case>
               <case result="false">
                 <execute id="searchResource">
                   <param id="message" content="SpeechNotAvailable,$node"/>
                 </execute>
               </postevent>
          <postevents>
        </case>
    </postevent>
  <postevents>
<partial>
```