Australasian Journal of
Educational Technology

2011, 27(3), 428-445

Collaborative model for remote experimentation laboratories used by non-hierarchical distributed groups of engineering students

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Remote experimentation laboratories (REL) are systems based on real equipment that allow students to carry out a laboratory practice through the Internet on the computer. In engineering, there have been numerous initiatives to implement REL over recent years, given the fundamental role of laboratory activities. However, in the past efforts have concentrated on laboratory groups interacting face to face, disregarding the capacities of distributed student collaborative environments. This article proposes a model for the implementation of REL in a distributed collaborative scenario, focusing on two crucial key elements: shared knowledge and interaction for collaboration. The model focuses on the methodological aspects of executing REL in a distributed collaborative scenario and disregards technical aspects of the implementation. This study analyses distributed collaborative scenarios where the teacher plays a fundamental role in REL configuration to ensure group collaboration. The new model introduced presents diverse aspects that are associated with the methodological implementation of REL in the field of engineering; hence it is to be regarded as a foundation for teachers developing REL in distributed collaborative scenarios.

1. Introduction

In recent years, the use of remote experimentation in the field of education has advanced greatly. Many authors, including Clough (2002), have reported that laboratories are the centre of science teaching and have a strong impact on students. Considering that engineering has a strong foundation on basic sciences, the majority of experiments in *Remote Experimentation Laboratories* (REL) occur in this area. Ma and Nickerson (2006) presented a study that revealed the prevalent use of remote laboratories in engineering. This progress allows an optimistic vision for the future development of e-learning, one of the paradigms that has become widespread over recent years in education. E-learning utilises information and communication technologies (ICT) to create, to promote, to deliver and to facilitate learning at any one moment, in different locations. This paradigm has been used mainly in areas where laboratory practice activities are not required. On the other hand, practice activities (labs) are essential in the field of engineering; therefore REL becomes significant in this scenario, expanding the possibilities of e-learning to the area of engineering. In addition, Gomes and García-Zubia (2007) presented a complete description of the progress of remote experimentation laboratories and experiments in e-learning.

Furthermore, ICT has produced significant changes in the area of laboratory practice. One of these changes has been the inclusion of new ways of executing lab practices, specifically in regard to simulated (e.g. McAteer et al., 1996) and remote laboratories (Gomes & García-Zubia, 2007) being alternatives to traditional laboratories. These ways of accomplishing a laboratory practice are seen by some authors as encouraging the learning process (Muller & Erbe, 2007), whereas other authors consider they inhibit it (Dewhurst, 2000, DiBiase, 2000). The opposing views reflect the fact that this is a newly emerging subject which needs to be explored in greater depth, over time. However, there are other elements that provide solid evidence supporting the advantages presented by simulated and remote laboratories compared to traditional ones.

In this event, REL needs to be viewed as non-competitive to traditional laboratories. Accordingly, the perspective REL explores is seen as a new paradigm providing scenarios for the use of remote laboratories that had been inconceivable up to now, such as:

i. The use of high cost equipment shared amongst institutions that would otherwise have been out of reach for individual universities.
ii. The development of complex and dangerous experiments that require distant handling.
iii. Laboratory demonstrations by teachers in the classroom.
iv. The use of the laboratory is efficiently improved by granting round the clock access to experiments for a larger number of students.
v. New working scenarios may be conceptualised when students collaborate from different locations in a laboratory experiment. Students learn significantly from handling the equipment, but also from a crucial additional component, namely social interaction.

Moreover, it is clear that a market for e-learning and b-learning has already been created (Samoila et al., 2006) and, as these gain ground, the positioning of REL will follow naturally.

The REL paradigm has aroused great interest from many researchers, and thus, various universities are developing initiatives in this area. Several initiatives are based on the concept of cooperation between higher education institutions that are prepared to share their knowledge, technologies and services for a joint mutual benefit. A clear example of collaboration in this context is the *RExNet project: Remote Experimentation Network – Yielding an Inter-University Peer-to-Peer e-Service* (Alves, et al, 2005), experience that motivated the work presented in this article. A consortium of eleven universities (six in Europe and five in Latin America) was formed by a group of universities that had previously been working in the field of remote experimentation for several years, when the newcomers were introduced to REL. Accordingly, the most important defined objectives were to share, harmonise and spread the capacities available for remote experimentation. The Consortium has produced and worked in various diverse projects including: *MARVEL*, a mechatronics training laboratory (Müller, 2005); *Linear Variable Differential Transformer* (Costa & Alves, 2005); *REXIB*, a laboratory for mobile robotics (Noguez, Huesca & Sucar, 2007); and web laboratories for teaching applications of automation in manufacturing (Chiang, 2007).

These previous implementations have focused on the precise execution phase of the experiment, notwithstanding the significance of previous or subsequent phases of the experiment that are equally important. An additional issue is that the implementations have been considered mainly or exclusively in face to face interactions, and for that reason the possibilities of distributed participants working from remote locations has not been explored extensively. Significantly, a wider complex scenario is when the students work in a collaborative and distributed scenario, hence greater relevance needs to be applied to all phases of the experiment.

Whilst clearly there is concern to overcome technical aspects involved in implementing REL, the importance and attention pertaining to methodological aspects of its use are now being taken more seriously. *RExNet* functioned through a multi-level network, with regional, continental and intercontinental nets. The intercontinental nets arouse additional considerations that strongly justify the need for an implementation methodology for REL. Namely, the problems include different cultures, different languages (Spanish, Portuguese, German and English); different time zones and different socio-economic situations. These are frequently raised questions regarding the use and how to create straightforward implementations of REL within intercontinental collaborative environments.

This article presents a model for collaborative remote experimentation in non-hierarchical distributed groups. It defines three equally substantial stages in the REL: prior to the experiment, during the experiment, and post-experiment. Furthermore, the foundations of this model are two supporting pillars, group interaction and knowledge building. Due to these structures, a series of relevant aspects arise: tasks to be executed by the group; communication mechanisms, collaboration tools; as among others, and are further discussed. Presently there is a convergence between research on instructional design and *computer supported collaborative learning* (CSCL), where the groups are seen as a cognitive system (Dillenbourg, 2006). Importantly, the collaboration between members of the group is structured in order to promote specific types of interaction. The proposed model focuses on a knowledge building process considering these specific types of interaction through the various stages of REL.

The details of REL application scenarios are presented in section 2. The model components consist of shared knowledge that the group generates and the interaction in collaboration between group members which are equally addressed in depth in section 3.

2. Scenarios for remote experimentation

Remote experimentation laboratories (REL) attempt to reproduce traditional laboratories as accurately as possible. However, considering the intrinsic nature of REL, the intervention of technology opens up new possibilities of use from a methodological point of view. In this event, different application scenarios have been identified, according to the viewpoint of participant collaboration.

Figure 1 shows three possible scenarios for REL. Scenario (a) is the type mostly discussed in literature, during all the stages of REL the group has the ability to interact face to face and also, tools for virtual interaction. In this scenario the distribution of roles emerges naturally. Figure (b) shows the typical e-learning scenario, where interaction between the participants is always virtual. The groups are formed by students who are geographically distributed. Finally, scenario (c) is very significant, for the reason that it combines scenarios (a) and (b). In this situation, the groups are formed by students from different locations (see gray oval). As an example of this scenario, the teachers are required to coordinate as to configure the student groups from distributed locations. Thereupon, students are required to constantly interact virtually with peers from distributed environments and in conjunction, to interact face to face with peers from their acknowledged university. A specific case of this scenario is described in the work of Favela and Pena-Mora (2001). Furthermore, Nafalski et al. (2010) introduce recommendations for effective international collaboration in remote laboratories. In regard to this scenario, Gravier, Fayolle and Bayard (2008) have emphasised communication and awareness within the group during experimentation. Machotka et al. (2010) have described the Netlab REL collaboration experience in a distributed scenario.

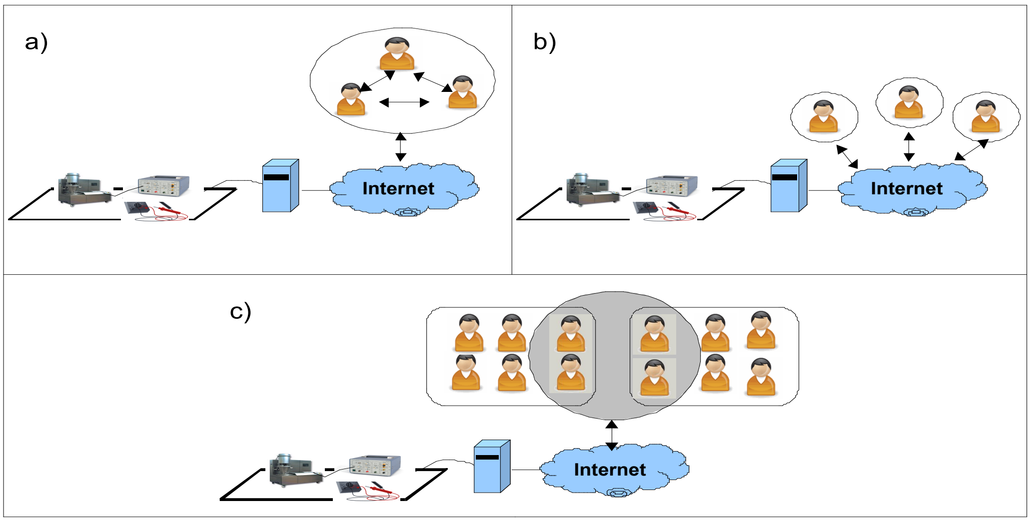

Figure 1: Different scenarios for remote experimentation

In previous years, the experience gained in the RExNet project has produced considerable advances particularly in technical aspects. The most successful cases were developed in scenario (a), the face to face interaction between students and teacher had immensely facilitated the development of laboratory activities. In these cases, the greatest benefits had been the increased availability of the laboratory and access to high cost equipment (Gomez et al., 2007). However, when the implemented experiments in distributed scenarios were reviewed by the Consortium, insufficient methodological standardisation was evident.

This article discusses a model for collaborative remote experimentation applied to scenarios (b) and (c).

The students who are situated in different geographical locations assume an individual role in the REL. As for example; the first person is to handle the experiment, the second person to systematise the results and the third person to coordinate activities of the group. The participating students synchronise a distribution of roles without a defined or imposed hierarchy. Accordingly, the model is oriented towards types of experiments that are feasible to perform in this context and the focus becomes on the experiments requiring minimal manipulation thus, a sequence of achievable steps are well defined and limited, compared to experiments imposing a high rate of handling.

In all these scenarios, the students are required to work in groups of two or more participants, where they achieve collaborative learning by developing the abilities for team problem solving. Collaborative learning introduces the consensual construction of knowledge through collaboration between group members.

In collaborative distributed scenarios for remote experimentation (Figure 1 (b) and (c)), difficulties remain. The most evident are technical problems associated with the students' hardware, software, and connectivity, including: version and type of web reader, bandwidth and plugins required, and minimum hardware required (video, sound, etc.). According to the technological progress and the development of standards, these problems will decrease in the future. On the other hand, there are methodological problems that are extremely important, for example what methodology needs to be used in a distributed scenario to accomplish a successful experiment through a REL. The experience obtained in the RExNet project (Alves, et al, 2005) demonstrated that two principal elements needed to be considered in the methodology for REL implementation, namely the aspects of shared knowledge and interaction. In shared knowledge, the teacher is required to provide the necessary documentation to be used at all stages of the REL (Herrera et al., 2006). Further, the group shares knowledge produced from the collaborative activities they execute at each stage of the REL.

In respect to interaction, this is a crucial element in distributed scenarios for instance; in the case of face to face teaching scenarios, the participants have the possibility to interact with the experiment and to discuss simultaneously with the other group members. However, in distributed scenarios with computer communications, major problems arise in user interaction, due to the reason of the lack of feedback and social interaction. Therefore, in the event when the REL is configured there is a set of required elements to be considered within group interaction; these elements are group size, types of communication, stages of REL, the phases of the knowledge building process, types of tasks or activities, etc. Each of these elements is described in Section 3.

3. Collaboration model for remote experimentation

There are various studies and publications reporting the positive effects that CSCL tools have on the learning process (Stahl & Hesse, 2009; Kapur & Kinzer, 2008). It has been observed that students learn not only from the use of the tools and the equipment, however, by the interaction with their peers and teachers. In this event, one of the most important facets of collaborative learning is the interaction between individual and collaborative learning activities – between divergent perspectives and shared knowledge building (Putambekar, 2006).

Furthermore, engineering students work in the ambience of technology so they have the natural tendency to be involved in collaborative experiences within the computer communications field. Indicating, REL is an ideal tool to assist the development of skills and abilities in distributed collaborative work, for the reason it displays the possibility of modelling teaching scenarios that are similar to the practices of working teams in engineering.

Previously, an effective application of REL had relied on independent successful experiences despite defining a model for the methodological orientation of the application. The concept is to take advantage of appropriate conditions to create a model which ensures the proficiency of the application of REL.

The execution cycle of a REL within a collaborative distributed environment consists of three principal stages: pre-experiment, experiment and post-experiment. The pre-experiment stage covers all the prior activities necessary to carry out the experiment, principally everything related with the distribution of tasks, introduction of the group members, study of theoretical contents, etc. The experiment stage is the synchronous moment when the group logs in the laboratory and carries out the experiment. Finally, the post-experiment includes all the activities related to reporting the outcome and the lessons learnt in the laboratory; for example, preparing a report of the results, summary, presentation, etc.

Considering scenarios (b) and (c), the proposed model addresses two essential elements, the mandatory structures in the planning and the execution stages of a REL practice for student groups who are geographically distributed. These two structured pillars, shared knowledge and the interaction for collaboration of the participants, are further discussed below.

An additional important concept we can infer from the previous sections is the fundamental role played by the tutors in setting the REL in a collaborative distributed scenario. They must ensure collaboration is implemented and is efficient, therefore they need to have thorough control over variables such as: size and distribution of the groups, tasks selected, and tools to be used. It is the task of the tutor to monitor the interaction of each group and to check that the collaboration mechanisms are being prompted. Previous investigation in regards with the monitoring of collaborative group interaction (Soller, et al., 2004), could supplement this work.

3.1 Shared knowledge

All the knowledge generated within REL is considered the *shared knowledge*. Figure 2 shows the shared knowledge of the group from two main sources, the teacher and the group members.

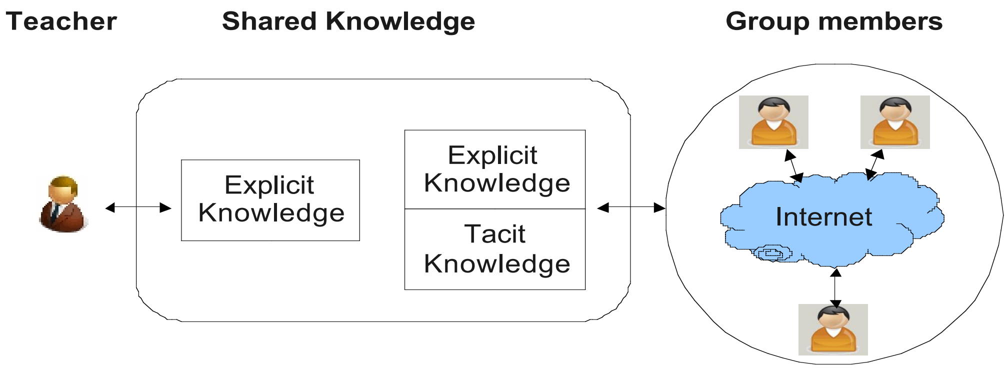

Figure 2: Shared knowledge of the distributed group

Explicit knowledge is generated by the *teacher* who provides the necessary documentation for the group to successfully develop the REL. This documentation is required at the three stages of experimentation. Furthermore, the group builds its collaborative, shared knowledge as a result of collaborative activities developed in the implementation of the REL. This knowledge can be explicit or tacit. Explicit knowledge is the formal documentation that is a product of experimentation complying with the teacher's guidelines (reports and summaries). In contrast, tacit knowledge is knowledge that allows the group to build up shared knowledge, considering mainly the negotiations the group has to perform.

Table 1 presents the explicit knowledge generated by the teacher and the group at each stage of experimentation.

Table 1: Explicit shared knowledge to be considered at each stage of the execution cycle of REL

Actor	Stage		
	Pre-experiment	Experiment	Post-experiment
Teacher	Technical requirements Theoretical guide	Laboratory guide Online help	Outcomes guide required
Group of students	Theoretical summary Complementary information	Results of the experiment	Technical report Experimentation conclusions

Primarily, from the teacher's perspective, reviewing the experiments performed in the context of the RExNet project, sets of knowledge (documentation or contents) supporting the remote experiment had been evident. However, not all the types of documentation described had been present in all the experiments. The model proposes a standard of minimum documentation that the teacher needs to consider, to be able to configure a REL (refer Table 1).

Each type of document is explained below, showing cases where they had been used in different experiments in the RExNet project.

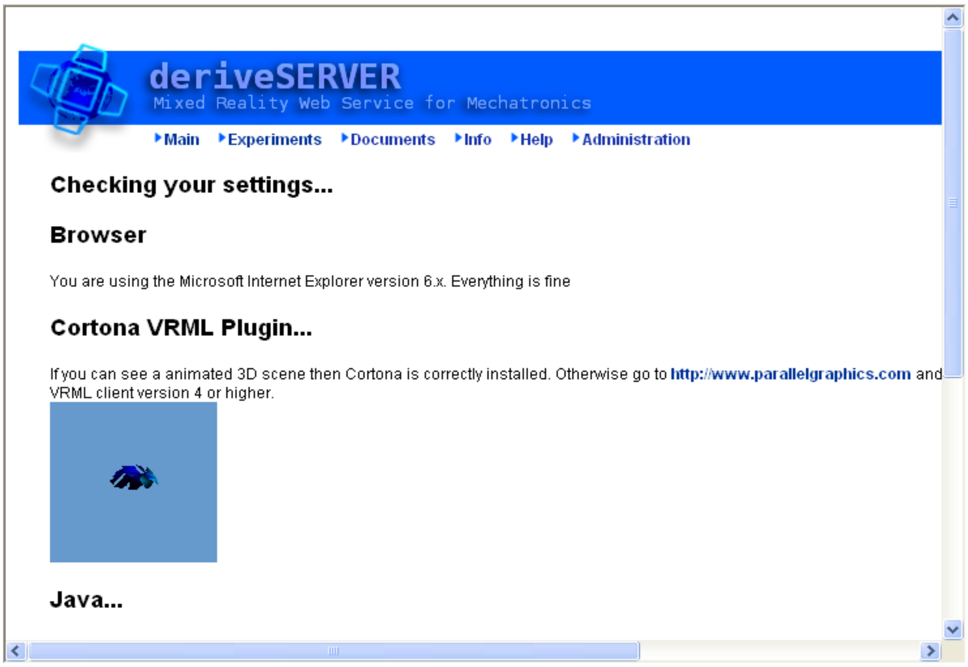

Figure 3: Technical requirements guide for the University of Bremen mechatronics REL

i. Technical requirements

The technical requirements for running each experiment need to be outlined. For example; specific software is to be downloaded (e.g. a plugin), a particular version of a software program or a virtual machine needs to be installed, and these examples have to be clarified to the students. Figure 3 shows an example of the technical specifications for a remote laboratory in the area of mechatronics belonging to the University of Bremen (Faust & Bruns, 2003). The diagram below not only specifies requirements but also performs a real time check of the user's configuration, explaining all the guidelines needed in case they only have part of the requisite elements.

ii. Theoretical guide

Includes all the theoretical aspects needed to comprehend concepts and to execute the experiment. Figure 4 shows an interface for access to all the theoretical contents to be applied in the remote laboratory; this REL belongs to the Monterrey Institute of Technology, Mexico, in the area of mobile robotics (Noguez, Huesca & Sucar, 2007). (Figure 4; no English version).

Figure 4: Access interface to the theoretical guides, the basis of the remote laboratory. Monterrey Institute of Technology

iii. Laboratory guide

Specifies the activities to be executed step by step during the experiment. This is the reference guide for hands on laboratories. In the various REL within RExNet, this guide was published as part of the corresponding LMS.

iv. Online help

Considering the possible complexity of each experiment it is required that online guides outline the experiment for the use of the laboratory. These need to clearly explain each component's functions; any restrictions; points requiring special care; sequences to be followed; etc. It is equivalent to a user's manual for the experiment.

Figure 5 shows an example of the help interface for a *Linear Variable Differential Transformer* experiment (Costa & Alves, 2006). In this case, the same interface used for running the experiment allows the user to "navigate" through the various options the experiment offers.

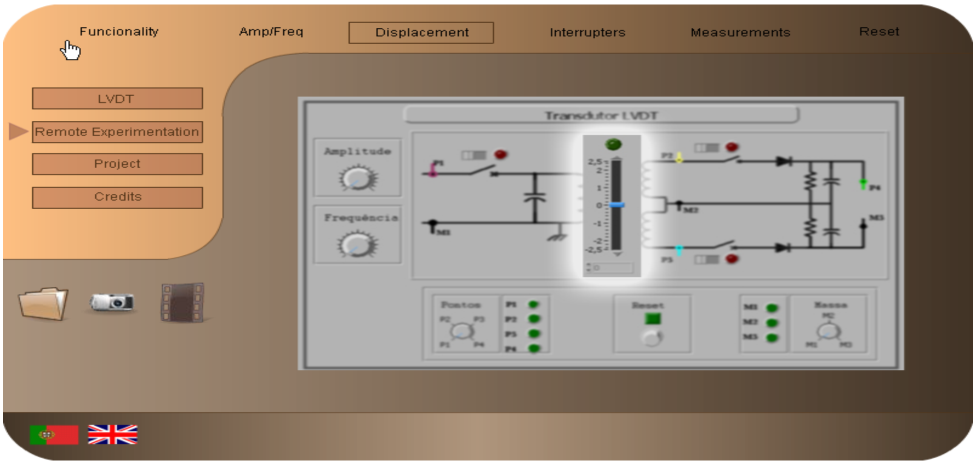

Figure 5: Online help interface of Linear Variable Differential Transformer REL

v. Outcomes guide required
The teacher is required to specify clearly how the laboratory practice will be evaluated. Commonly, in the *RExNet* project, the requirement had been a report of the results according to the laboratory guide. Therefore, specific instructions need to be specified in regards to the format, means of delivery; contents to be included, evaluation rubric; etc.

Figure 2 also indicates the shared knowledge built from a student's perspective. A process of knowledge construction is implemented from the different activities and tasks the group carries out during the development of REL. In this event, each participant initially handles individual perspectives and through a collaborative process based on negotiation, builds the shared knowledge. Herrera and Fuller (2005) define a life cycle of knowledge in the group construction process. They define the states of this life cycle with individual and group perspectives, thus incorporate a process of knowledge negotiation. In addition, the group proposes concept maps as a tool to facilitate knowledge building.

Figure 6 shows the life cycle of knowledge. This commences with a state of individual proposals; from this point the group progresses to the other states where they negotiate the proposals jointly in order to approve or reject them. Each of the arrows represents the decision making that causes a change in the state of the knowledge. The life cycle of knowledge involves seven main states, represented in the figure by the rounded rectangles. The initial state of knowledge is the *Proposal*, reflecting the participant's intention to incorporate new knowledge into the shared knowledge repository; for instance, theoretical information related to the experiment. The person who makes the proposal has control over it, and decides whether to present it to the group or not. At this point, the participants work from an individual perspective, incorporating those elements determined by their own experience. In the *Under Approval* state, the knowledge is subject to discussion and the components of the knowledge may undergo modifications derived from the group negotiations. In the *Under Revision* state, the participant who made the proposal submits the knowledge for review, incorporating the changes derived from the negotiation. The *Approved* state represents the shared knowledge. The *Outdating process, Outdated* and *Rejected* states are included in the outcome of the negotiation.

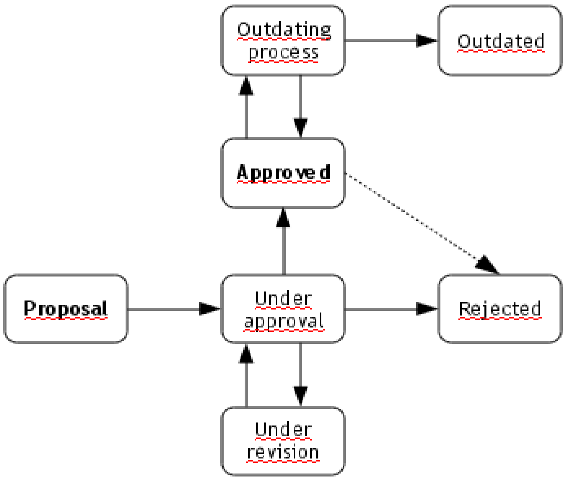

Figure 6: Life cycle of knowledge for a distributed group

In the context of REL, pre-experiment and post-experiment are the main stages where the group builds this new knowledge. These stages involve largely asynchronous work due to the length of extended time needed as to the experimental stage. As a result, these stages are more reflexive in the sense of task requirements; for instance, agreement; negotiations, conclusions; etc. Respectively, the teacher needs to explicitly mention the requirements that will guide the knowledge building process for these two stages.

At each stage, this life cycle is used by the group to construct the generated shared knowledge, as shown in Table 1. This corresponds to:

i. Theoretical summary: the teacher asks the students to draw up a concept map that summarises the theory needed to develop the REL.
ii. Complementary information: any additional information to support the REL activity. This includes supporting documents, links of interest; examples, hypermedia; and so forth, which are attached to the framework of the concept map.
iii. Results of the experiment: knowledge that depends exclusively on the lab guide and documentation of the results obtained during the experiment.
iv. Technical report: final report required by the teacher.
v. Experimentation conclusions: Concept map summarising the conclusions of the experiment.

The tasks and outcomes of each stage are addressed with the knowledge building model, supported by a tool called *ShaKnoMa* (Herrera et al., 2000). This tool uses concept maps as a visual language for the process that acts as scaffolding for the construction of shared knowledge (Herrera & Fuller, 2005).

During the pre-experiment, the group is required to manage all the theoretical aspects to ensure a good performance in the laboratory. For this, the group is requested to construct a concept map summarising all the theoretical elements. To execute this task the group is required to organise according the theoretical guide and any additional information available. The knowledge building process is determined by a group negotiation model, allowing the group to validate the knowledge proposed by each of the participants. The discussion that is generated from this process by negotiation, is accessible to students and teachers, and thereafter becomes part of the shared knowledge of the group.

In the post-experimentation stage, students need to conclude the results of the experiment, so aside from the expected outcomes guide; a concept map is to be delivered summarising the conclusions of the experiment.

3.2. Interaction for collaboration

Interaction for collaboration is another key pillar of the model. The conditions necessary for collaboration to occur and be effective need to be created. REL is a learning experience that is required to be structured before the interaction begins, and continues throughout the process. For this reason, certain conditions have to be considered; the size and composition of the group, distribution of roles; selection of tools for communication and learning, defining tasks and activities; communication media, measurement of the degree of conflict between students; measurement of the quality of shared knowledge generated by the group.

Table 2: Activities carried out in the different stages of REL, by type of communication

Type of communication	Pre-experiment	Experiment	Post-experiment
Non task-oriented	- Planning: Defining roles, meeting schedule, definition of interaction protocols. - Technical: Support for the use of tools. - Social: Introduction of each student. - Nonsense: Any other kind of communication.	- Technical: Problems with connection or access to the experiment.	- Planning: Definition of strategies for reviewing the results. - Social: Appreciation, valuing.
Task-oriented	- New information: Complement to theoretical guide (links, attachments). - Explanation: To analyse information proposed by a partner and to propose examples that go into the proposal in more depth.	- New information: Opinions concerning how to conduct the experiment. - Evaluation: To compare theoretical results with experimental ones.	- New information: Interpretation of results - Explanation: Discrepancy or supplement to the interpretation of results. - Evaluation: Discussion and negotiation to reach agreement on the conclusions of the experiment.

This model incorporates some elements of research used in interaction for collaboration. One aspect is the type of communication developed by group members. Veerman & Veldhuis-Diermanse (2001) classify this communication as 'not task oriented' communication or 'task-oriented' communication. They distinguish four categories of 'not task oriented' communication: planning, technical; social, and nonsense. On the other hand, task-oriented communication considers three basic activities of cognitive processes: introduction of new information, explanation and evaluation. These types of communication are present for each stage of REL; some cases are shown in Table 2.

At the pre-experiment stage, it is possible that 'non task oriented' communication is perceived as being more important. At this point group members need to be acquainted with each other, and need to define how they will work together in order to achieve the objectives of REL. In contrast, 'task oriented' communication becomes increasingly important in the post-experiment. In this event the knowledge building process is essential within the framework of group discussion and negotiation.

An additional element incorporated into the model is the collaboration mechanisms defined by Dillenbourg & Schneider (1995). These authors present eight mechanisms that allow the acquisition of knowledge through collaboration, namely conflict; the alternative proposal; self-explanation, internalisation; appropriation; shared cognitive load; mutual regulation, and social grounding. Furthermore, for collaborative learning to be effective, they propose that certain conditions must be met under the following categories: group composition, task features, and communication media. Table 3 depicts the mechanisms triggered by tasks and conditions in REL, though, it is not to be considered a strict correspondence.

Table 3: REL tasks and conditions - how they relate to the collaborative learning mechanisms

Task or condition	Collaborative learning mechanisms						
	Con-flict	Altern-ative proposal	Self-explan-ation	Internali-sation	Appro-priation	Shared cognitive load	Social ground-ing
Group heterogeneity	X			X	X		X
Theoretical summary				X			
Complementary information	X		X	X			
Experiment-ation					X	X	
Technical report			X		X		
Experiment conclusions	X	X	X	X			
Roles definition				X			

With regard to group composition, small heterogeneous groups need to be considered. Heterogeneity is ensured in scenarios (b) and (c), by the groups which are composed of students from different locations, different cultures, different education levels, different performances, different ages, time zones, etc. This "optimum" heterogeneity ensures interaction is generated due to the differences of viewpoints from participants. Furthermore, heterogeneity triggers conflicts and requires social grounding; in addition, heterogeneity is implicit in socio-cultural theory. Therefore, the related mechanisms, internalisation and appropriation, are developed through effective communication tools in distributed scenarios. In conjunction with the *characteristics of tasks* presented, the group needs to apply the collaboration mechanisms. Given these characteristics, the participants activate the collaboration mechanisms. In the pre-experiment stage there are tasks that lead to the performance of individual reasoning processes, e.g. the study of the theoretical guidelines and the remainder of the explicit knowledge delivered by the teacher. Moreover, interaction occurs when the students begin to assemble their individual results in tasks, for instance theoretical summary and complementary information.

An additional condition that must be fulfilled is suitable communication. Even with proper configuration of groups and associated tasks, without an appropriate communication medium, collaboration is unsuccessful. The model ensures proper communication through various tools, both synchronous and asynchronous. These tools may be adapted to the non-task-oriented communication or task-oriented communication. In Table 4 a framework of interaction tools, according to the type of communication for each of the stages of REL, is suggested.

Table 4: Interaction tools used in the various stages of REL

Type of communication	Stages		
	Pre-experiment	Experiment	Post-experiment
Non task-oriented	Email Chat (voice, text) Video streaming Booking Calendar	Chat (voice, text)	Email Chat (voice, text) Video streaming
Task-oriented	Concept map Forum Wiki Shared repository	Shared whiteboard Video streaming Chat (voice, text) Floor control	Collaborative editor Concept map Forum Shared repository Email

Many items of commercial and free software may be used to implement the tools cited in Table 4. Given this diversity, no particular software is advised by the model, however it needs to be defined considering the particular situation in which the REL will be performed. A number of these tools provide support for synchronous activities whereas others support asynchronous activities. The asynchronous tools prevail in distributed learning scenarios. However, in order to approximate the distributed scenario in the vicinity of a face to face situation, text, voice and video communication tools are required to be available. Synchronous tools (chat, video, interactive whiteboard) are required largely during the experiment, being a stage where the group is compelled to interact at the same time. In contrast, pre-experiment and post-experiments are largely asynchronous.

A separate explanation is required for systems that integrate tools to facilitate interaction. A particularly commonly used system for interaction in remote experimentation is an LMS (learning management system), incorporating various tools, for example a shared repository, calendar, discussion forum, etc. In particular, for this purpose *Moodle* is a popular system due to the reason it is an open source system and extensions can be developed. Specifically in the *RExNet* project, Ferreira and Cardoso (2005) developed a booking tool as an extension of *Moodle*, in order to allow the student to sign up for an experiment. Also, Bochicchio and Longo (2010) propose an extension that links *Moodle* with the *Micronet* remote web laboratory.

Social networks are an additional type of system incorporating various interaction tools. Social networks started to appear in about 2001, and today there are many, for instance, *MySpace, Facebook, Friendster, Habbo, Window Live Space, Twitter, Hi5*, etc. These networks may introduce a notable benefit to the initial contact of the group members, by providing spaces for interaction that go beyond just the academic.

The model includes minimal planning to ensure successful development of the REL. For every stage of the REL, objectives and associated activities are defined. This planning can be completed with milestones, dates and relations between tasks, and thus, this is left open to the individuals of each REL. Objectives and activities of each stage of REL are shown in Table 5.

Table 5: Objectives and activities carried out in the various stages of REL from the interaction point of view

Planning elements	Pre-experiment	Experiment	Post-experiment
Objectives	To introduce the group To define activities and roles To define interaction protocols Booking of timetable	To execute the experiment	To prepare and to deliver the results and conclusions
Activity	Integration session Coordination session	Running of experiment	Closing session

Based on the experience obtained in the *RExNet* project, the minimum activities to be considered from the point of view of interaction, in distributed scenarios, are:

i. Integration and coordination session

In the case where a group is working together for the first time, a session is required to be held for mutual introductions of the members. Both synchronous and asynchronous tools may be used. An example of a synchronous tool for introductions would be chatting by text, voice or video whereas, asynchronous tools may be used for an introduction forum, either a personal web site or a social network to facilitate and complement the synchronous session. In this initial contact it becomes necessary to have effective non-task-oriented communication; to allow the role of each member of the group and the working schedule to be defined, to set the protocols for communication within the group and to make the booking for the experiment.

ii. Running of the experiment

Interaction in this stage is fundamental, considering it attempts to lead the group in the close proximity to a face to face scenario. In *RExNet*, the majority of experiments include tools for interaction during the experiment. However it is advisable to provide synchronous communication support tools that are reasonably reliable and presently universal, for instance, *MSN, Skype*, etc. The use of these may be defined during the initial contact, when the protocols and mechanisms for interaction are being established. In reference to the *RExNet* project experience, thus, the set of experiments implemented, it had been evident where an individual student has to manage the experiment with the acknowledgment from the group. An additional technological and methodological challenge is that the implementation of REL can be coordinated and handled amongst several participants at the same time, or by floor control. A successful experience in a similar context is presented by Favela and Peña-Mora (2001) in an education project on collaborative software engineering.

iii. Closing session

On the completion of the experiment, the results and lessons learnt need to be presented as indicated in the teacher's requirements. One or more sessions must be programmed with the aim of generating and discussing the reports or documents required from the experiment. Tools for collaborative document production may provide important support in this stage, for instance, *Google Docs* (Dekeyser & Watson 2006).

4. Discussion and conclusions

A framework has been presented that leads actions when implementing a collaborative remote experimentation activity in distributed scenarios. Three stages for knowledge development are clearly identified: pre-experiment; experiment; and post-experiment, where collaboration and communication are essential. The two supporting pillars of this framework are shared knowledge and interaction for collaboration, hence including all elements needed for REL design.

Similar experience available mainly describes collaboration and interaction characteristics, and fails to consider shared knowledge as a crucial element for remote experimentation in the proposed scenario.

It becomes clear that collaborative distributed scenarios in remote experimentation will proliferate. Therefore, the present work contributes from a pedagogical and methodological perspective to tackle the implementation of activities in these scenarios. Despite the difficulties of conducting an experiment of this magnitude, from a social point of view the students gain by generating learning that would be unachievable in face to face environments.

Concluding, the model we are presenting can serve as a starting point for teachers who are working in the area of remote experimentation, or those who plan to explore this area, with particular reference to REL in the field of engineering in distributed collaborative scenarios. This model may be approached from different angles however we are providing a constructive foundation to the order that can be applied to present methodological aspects within this paradigm where, previously, it has encountered obstructions.

The current technological progress challenges us to develop new methodologies that advance accordingly. Frequently, we are overwhelmed by technology and use it without regard to methodology. Thus, as new technologies emerge we need time to explore and exploit the boundaries for developing methodologies that will allow an efficient use of technology. This methodology has built a bridge, constructed from experiences in collaborative knowledge; we need to continue to structure bridges and develop a learning network for the future.

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Please cite as: Herrera, O. & Fuller, D. A. (2011). Collaborative model for remote experimentation in non-hierarchical distributed groups. *Australasian Journal of Educational Technology*, 27(3), 428-445.
http://www.ascilite.org.au/ajet/ajet27/herrera.html