

Spreading remote lab usage

A System – A Community – A Federation

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The VISIR+ Project

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Abstract— Experiments have been at the heart of scientific development and education for centuries. From the outburst of Information and Communication Technologies, virtual and remote labs have added to hands-on labs a new conception of practical experience, especially in Science, Technology, Engineering and Mathematics education. This paper aims at describing the features of a remote lab named Virtual Instruments System in Reality, embedded in a community of practice and forming the spearhead of a federation of remote labs. More particularly, it discusses the advantages and disadvantages of remote labs over virtual labs as regards to scalability constraints and development and maintenance costs. Finally, it describes an actual implementation in an international community of practice of engineering schools forming the embryo of a first world wide federation of Virtual Instruments System in Reality nodes, under the framework of a project funded by the Erasmus+ Program.

Keywords—engineering education; remote labs; VISIR; VISIR+; Community of Practice, online labs federation

I. INTRODUCTION

Remote labs stand for physical apparatus connected to computer-controlled instruments able to be remotely accessed for carrying out real-world experiments. This definition leads to the expression “remote experimentation” which denotes the type of experiments that can be done in remote labs, in opposition to “virtual experiments”, or “simulations”, which can be done in “virtual labs”. For a complete understanding, hands-on labs refer to physical spaces where users perform experiments by directly manipulating the instruments and/or apparatus under experimentation. The more recent expression

“hybrid labs” refers to a sort of environment where parts of the apparatus under experimentation and/or the instruments connected to those apparatus are real, and other parts are modeled, i.e. correspond to mathematical and data models running on a computer. These two parts interact during the course of an experiment, hence the word “hybrid”.

In historical terms, the value of experimentation in Science has long been recognized. For instance, the oldest Scientific Society in the world, the Royal Society, adopted the motto ‘Nullius in verba’ to “... *express the determination of its Fellows ... to verify all statements by an appeal to facts determined by experiment.*” [1]. This spirit has also long been part of the Education and Training process of both Scientists and Engineers, as reported by Feisel and Rosa in [2]. In particular, these authors trace back the value of combining theory and practice to the very first engineering school in the United States, the U.S. Military Academy, founded at West Point, N.Y. in 1802 [2, p. 122]. Although majorly focusing on the role of hands-on laboratories in Undergraduate Engineering Education, Feisel and Rosa also account for the provisions of both virtual and remote laboratories to that role.

The particular aspects of combining hands-on, simulated and remote laboratories into Science, Engineering, Technology and Mathematics (STEM) Education are well discussed in [3] and [4]. These papers also acknowledge virtual and remote labs to be the two most recent vertexes of this triangle, illustrated in figure 1. Froyd, Wankat, and Smith corroborate this statement by rightfully classifying simulations and remote labs as part of one of the five major shifts in 100 years of Engineering Education (EE), in particular of its 5th major shift, i.e. the influence of Information and Communication Technologies (ICT) in EE [5].

¹ “This project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein”

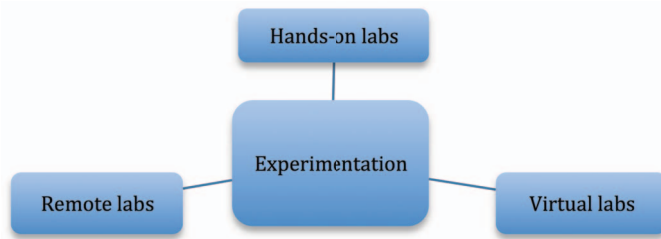


Fig. 1. Different lab environments for performing experiments in STEM.

But while the generalized use of simulations in Education followed the widespread usage of computers (70's), remote labs have a more recent history, mainly powered by the emergence of the World Wide Web (90's) [6]. Other aspects impairing the large adoption of remote labs, when compared to virtual labs, are the associated development and maintenance costs, and scalability constraints [7]. In this paper, we first briefly expand on this problematic and then present one strategy for spreading remote lab usage in EE.

The remainder of the paper is structured as follows: section 2 provides some background on the use of virtual versus remote labs, while also defining one particular application domain – experiments with electrical and electronic circuits; section 3 focus on one particular remote lab serving this domain; sections 4 and 5 deal with two crucial aspects for spreading remote lab usage, i.e. forming a strong Community of Practice (CoP) and federating existing remote labs; and, finally, section 6 presents the conclusions and future perspectives.

II. BACKGROUND

A. Scalability constraints

One possible direction for analyzing the scalability problem of virtual versus remote labs is to look into the dimension and hierarchical structure of an Engineering School or Faculty, while focusing on the practical educational component. At the very basis one has a single experiment. The dimensional aspect can be reduced to 1: n for simplicity purposes. Regarding hierarchy one can consider: experiment – lab – course – degree – school – institution. Typically, n experiments are done in a laboratory, usually within a specific scientific domain or sub-domain, e.g. an electrical machines lab may accommodate basic electromagnetic experiments to demonstrate the basic principles of electrical machines, such as generators / motors (machines with rotating or moving parts) and transformers (non-rotating machine) to more specific experiments such as the electric efficiency of a motor coupled to a generator, or linear induction motors. A lab can then support one course or several courses. Those courses can be part of one single degree or belong to different degrees. An engineering school usually offers several degrees, e.g. Mechanical Engineering, Electrical Engineering, Civil Engineering, or Chemical Engineering, among other engineering degrees. Finally, one institution may have one single engineering school or several ones, depending on its dimension. An example could be a traditional university in Europe, located in a single city, with a single campus, or –in opposition– a federal university, in Brazil, with campuses located in different cities pertaining to the same state. Table I summarizes this simple overview.

TABLE I. A SIMPLE OVERVIEW OF THE DIMENSION AND HIERARCHY LEVELS RELATED TO ENGINEERING SCHOOLS

Dimension Heading	1	n
experiment	May range from a few minutes to a complete class. Usually the number of experiments done in a single class depends on the degree year. Initial years may accommodate more experiments due to their relative simplicity and more advanced years may imply experiments that take more time to complete. The situation of experiments taking more than one class to complete is rare.	A set of experiments may form one class (one lab script), span over two or more classes, or form one comprehensive module about a specific topic (e.g. "Introduction to DC circuits" may have 10-15 experiments that will take approx. 2-4 weeks to complete). One module may take more or less time depending of being part of the core scientific degree area or not.
lab	A lab may serve one course or several courses depending on its level (basic, intermediate, advanced). An example of a basic lab could be of one allowing introductory experiments with electric circuits. An example of an advanced lab could be "OptoElectronic Lab".	Although sometimes several labs are needed to support one single course (large number of classes, classes from different courses requiring the same lab, etc.), the usual situation is that a single degree often requires the support of several unique labs.
course	The basic "educational unit" in many educational institutions. Each course typically comprises a number of contact hours, divided into theoretical and practical ones, and non-contact hours.	In a typical semester scenario, each degree usually comprises 4 to 6 courses, depending on the number of European Credit Transfer System (ECTS) units.
degree	One degree may range from 6 semesters (180 ECTS) to 4 semesters (120 ECTS) depending on its level: undergraduate (BSc) or graduate (MSc). The number of students attending one degree varies quite much, depending on its scope (general, specific) and its level. Taking the example of the Polytechnic of Porto – School of Engineering, one degree may admit 20 new students (e.g. MSc in Computing Engineering and Medical Instrumentation) or 210 (e.g. BSc on Informatics Engineering).	The number of degrees offered, in simultaneous, by a single school depends upon several factors: geographical location, institutional history, type of institution (e.g. university / polytechnic), etc. Taking the same example, the Polytechnic of Porto – School of Engineering offers 14 degrees (undergraduate) and 12 masters (graduate). It is the number of degrees running at the same time that provides an idea of the school size, i.e. number of students, teachers, staff, labs, etc.
school	A school's size varies quite significantly. Taking the total graduate engineering enrollment numbers published in [8], it may range from 88 (Baylor University, Waco, TX, ranked #118) to 7,504 (Georgia Institute of Technology, Pasadena, CA, ranked #7), which means a factor scale of 85.	One institution may have one or more Engineering and/or Technological schools. One possible example comes from the Polytechnic University of Catalonia ² (UPC), Spain, which includes 12 STEM-related schools.

Another dimensional aspect concerns the size of each heading, e.g. the student population attending one degree. One

² <http://www.upc.edu/the-upc/the-institution/schools>

Engineering School may offer more traditional degrees, e.g. Electrical Engineering with a *numerus clausus* of 1-2 hundreds, alongside with more specific degrees, e.g. mechatronics or engineering cybernetics, which may just admit 20-30 new students every year. An example of this heterogeneous scenario is described in Marques et al. (2014), which analyzes application case studies of a particular remote lab [9]. In specific, the topic covered by that remote lab lasts from a minimum of 3 to a maximum of 14 weeks, while the number of students enrolled in the different courses ranges from 47 to 574 [8, p. 153, Table II].

This brief analysis paves the way to the scalability problem of virtual versus remote labs. While, for instance, one of the most widely known virtual labs in the whole world, i.e. the PhET Interactive Simulations, from the University of Colorado, US, reports over one hundred million (100,000,000) simulations delivered in 2013, after a time period of approx. 10 years [10]³, a particular remote-controlled laboratory, which was considered the best one in its category⁴, registered thirteen thousand accesses (13,000) in 2015, for a period of approx. 8 years [11]. To make it comparable, one user access to the Virtual Instruments System in Reality (VISIR) usually accounts for 1 to 10 experiments, i.e. every time an user clicks on the “Perform Experiment” button, one real, remote-experiment is done, hence the total number of experiments may be around 100,000 for the recorded number of accesses. Additionally, the numbers reported in [11] refer to 4 different VISIR nodes (i.e. servers), while the PhET Interactive Simulations are delivered through a single web location. Finally, VISIR supports remote experiments with electrical and electronic circuits (one specific topic, within Electrical and Electronics Engineering), while PhET Interactive Simulations cover several scientific domains like Physics, Chemistry Biology, and Maths, among others.

Although the observable simulated-to-remote experiment ratio of this example (in the range of 1:1,000) may be considered as just one possible case, non-representative of all possible comparative cases, the fact is that one simulation corresponds to running a given number of code lines, which can either occur at the server or client-side, depending on the technology used. A server with a processing power of hundreds to thousands of Millions of Instructions Per Second (MIPS) can thus deliver many simulations per second, whereas the time duration of a remote experiment is dictated by its physical nature. In the electrical and electronic domain, these experiments may typically take less than a second to complete [12], however one may quickly think of other experiments that may take several minutes to complete in the real world (e.g. *check relationships between volume and amount of solute to solution concentration*) and only a few seconds to simulate, depending on the user’s speed (e.g. <https://phet.colorado.edu/en/simulation/concentration>).

A final note on this topic concerns the access/delivery type of a remote versus a virtual lab. A remote lab can either work

interactively or in a batch mode [13]. In the batch mode, a remote lab receives a request from a user, setups the experiment, runs it, and then sends the result(s) to the user. In the interactive mode one single user is in control of the entire lab for the duration of a pre-defined time slot. There are remote labs that work on the batch mode, interactive mode, or both. An example would be a remote telescope. In the batch mode, a user defines a particular set of coordinates and filter lens and submits the request to the lab. The lab will accommodate the request on the 1st possible time frame and then send the result(s) to the user. In the interactive mode, a user will remotely control the telescope for e.g. one hour, changing its parameters in real-time, and obtaining the results in real-time.

B. Development and maintenance costs

The topic of development and maintenance costs, applied to virtual and remote labs, can be divided into its software and hardware components. While a virtual lab typically consists of a server (the hardware component) running the simulations (the software component), a remote lab may include more than one server, as illustrated in [14], the whole experimental apparatus –these two parts forming the hardware component–, and the several software layers that form the interface between the remote user and the apparatus under experimentation. The larger number of parts forming the hardware and software components of a remote lab, and the possible existence of consumables, are just two supporting evidences that remote labs present higher development and maintenance costs than virtual labs.

These higher costs, however, sustain the advantages of using remote experiments, in opposition to just using simulations, in the following cases:

- Simulation results may be quite different from the result of real physical experiments, for instance in mechanical engineering influences like vibration, torque, and friction can not be studied and understood, so well, in simulations.
- In order to approach simulation results to real physical experiment results, developers try to improve the accuracy of mathematical and data models. However, this effort has two main drawbacks: (i) it implies higher development costs and (ii) higher computational power, either from the server or the client side. Concerning (i) one could consider the cost of placing online a simple real experiment of a driving motor coupled to a load, versus the cost of developing the most accurate model accounting for all physical variables present in this system and its environment (temperature, humidity, etc.). Respecting (ii), present *m-learning* scenarios, i.e. the use of mobile hand-held devices for teaching and learning purposes, still do not account for the possibility to run highly demanding applications, for two main reasons: a) very large apps require too much memory and time to download, and b) hand-held devices often present less computational power than portable computers.

On the other side, there are areas where the whole development is based on simulations (e.g. Systems on a Chip), and the real experiments are the way to test, but not to develop.

³ The PhET Interactive Simulations website, located at <https://phet.colorado.edu>, reports 360 million accesses in 06.06.2016.

⁴ According to the Global Online Laboratory Consortium (GOLC), which granted this award, on its 1st edition (2015), to VISIR.

So in any case, both methods are needed in any solid engineering formation.

III. THE VISIR SYSTEM

VISIR is a remote laboratory for wiring and performing experiments with electrical and electronic circuits. The basic characteristics of the VISIR platform were described in [15].

If we consider the remote lab itself we can highlight some innovative aspects. Based on the interaction of a simulation of real equipment and real instruments at distance, VISIR creates a real electronic lab environment to the student, which can be accessed at any time and from anywhere as long as the student has a PC connected to Internet [15]. Within such environment, student interact with real instruments and electric / electronic components. They adjust the instruments and wire the circuits with their PC-mouse; then, the lab sends the measurement results to them, on their PC-screen. Stimulus (e.g. power supply voltages and input signals) can also be controlled by students.

As a platform system, VISIR has its own web interface in which the lab contents are arranged and through which they are accessed. It contains many access and administration features such as: Registration, Log-in, Booking, account types, etc. The availability of the lab contents depends on the user account type. Each user account type has its own features, privileges and limits. Some universities have integrated VISIR into their own Learning Management System (LMS), and/or their Remote Lab Management System (RLMS), allowing the utilization of the provided LMS services besides the lab work to create a rich integrated online educational platform. So, VISIR may be considered as a remote workbench, equipped with the same instruments that exist in a hands-on laboratory for conducting experiments with electric and electronic circuits. These workbenches are similar to each other, no matter of what part of the world they are used for supporting lab classes with such circuits. This means VISIR has a quite universal and familiar interface that facilitates its use, with a minimal learning curve. Its limited scope comes as an advantage, because all users immediately know what they are interacting with, either being students, teachers, or project partners.

IV. COMMUNITY OF PRACTICE

In brief, a CoP is a group of people informally bound together by shared expertise, a set of problems, or interest in a topic or fulfillment of goals [16]. In addition, a CoP focuses on sharing best practices and creating new knowledge to advance a domain of professional practice.

The formation of a CoP around VISIR was inspired by general discussions around the following question: “*What is the added value of Remote Experimentation to Education?*”. This question was discussed in a former collaborative research project named Remote Experimentation Network – Yielding an Inter-university Peer-to-Peer e-service (RexNet-yippee), which involved several Higher Education Institutions (HEI) from Europe and Latin America [17]. Although not completely answered, this question was partially addressed by the simple equation presented on figure 2. In face of the difficulty in

reaching a precise quantitative formula able to compute such added value, the proposed qualitative formula was simple enough to point directions on how to increase it. In simple terms, if one increases the educational value of a given remote experiment and, simultaneously, also decreases its development and maintenance costs, then the resulting added value will increase.

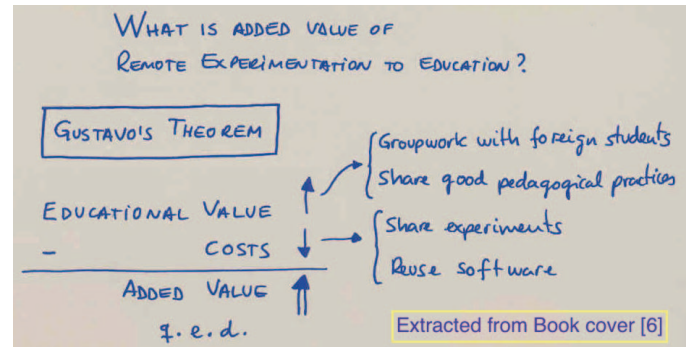


Fig. 2. A simple formula for evaluating the added value of remote experimentation to education [13].

The two guidelines suggested in the formula for increasing the educational value are in line with the objectives of a CoP, and hence they form part of a project proposal submitted to the Erasmus+ program⁵, for enlarging a CoP around VISIR with European HEI that already have this system and a number of Latin American HEI, which have a rich experience on the use of remote experimentation, but do not have VISIR. An important aspect, which should be highlighted at this stage, is that such collaboration implies a shared knowledge and interest in a given scientific area. In the case of VISIR+, this concerns the teaching and learning of electric / electronic circuits theory and practice.

The CoP around VISIR actually started as a Special Interest Group (SIG) of the International Association for Online Engineering (IAOE)⁶, circa 2006. While initially gathering researchers interested in enhancing and spreading the VISIR system [18], it soon started to benefit from the input of a larger number of users, i.e. from teachers and students, and effectively growing into a CoP. The following list presents some of the results achieved by this CoP, in the past 10 years:

- A number of technical improvements in the VISIR hardware (the relay matrix) and software (the user interface) directly resulting from the received user feedback [11] [19].
- Outreaching a larger number of students and teachers, effectively helping in expanding the existing CoP. So far, approximately 50 teachers and 5.000 students have used VISIR, in particular considering its use in a Massively Open Online Course (MOOC) developed by the Spanish National Distance Education University (UNED) [20].

⁵ The Project proposal acronym is VISIR+

⁶ http://online-engineering.org/SIG_visir.php

- Evidence of collaborative episodes involving teachers and students from different world regions, namely from Europe, Latin America, Middle East, and also Australia [21] [22].

But, in order to effectively support an even larger community, the simple existence of several VISIR nodes is not enough. The reasoning is simple and implies two directions: number of available experiments and number of students and teachers served in simultaneous. Considering all the experiments done with electrical and electronic circuits, in a single semester, it is clear that, even with a large relay matrix, one single VISIR system is unable to serve one single school. Considering a simple, yet widely performed experiment like, e.g. an RC low-pass filter, it is obvious that one single VISIR system is unable to serve all engineering schools. The solution to this scalability problem is presented in the next section.

V. A FEDERATION OF VISIR NODES

The two other guidelines suggested in the formula for decreasing the development and maintenance costs of remote labs are better understood within the conceptual definition of a federation. When sharing experiments, institutions may choose to: (i) simply open the access to them, to anyone hitting the webpage where they are located; (ii) disseminate their existence (and access to) through a repository; or (iii) join a federation that allows some sort of Single Sign-on (SSO) facility. Examples of (i) are the Control System Online Lab⁷, developed by Jim Henry and hosted by the University of Tennessee at Chattanooga, US, or any VISIR system, when accessing the demo page and using the guest login⁸. Examples of (ii) are the European Go-Lab portal, which provides access to hundreds of online labs [23], or the Lab2Go portal [24]. Finally, examples of (iii) are the Labshare institute [25], or the iLab Service Broker [26]. Unfortunately, option (i) does not really provide any sort of rewarding mechanism, as there is no structured way to access other remote experiments. Although the possibility to search the web for any particular, open, remote experiment still exists, it is a random, time-consuming process, where the guarantee of a quality-of-service (e.g. the remote experiment remains open for an entire course duration) is null. Option (ii) is more structured and facilitates the task to search and use a given remote experiment. However, it is up to the owner of the repository to set up the rules defining how a given remote experiment is made publicly available and what sort of service level must be provided. Usually, by joining such a repository, a given institution will have to provide but also be able to use remote experiments provided by other institutions. In some cases, the repository is totally open, i.e. all the remote experiments listed in the repository are open, often with some sort of restriction (limited access time, diminished complexity, etc.). Again, this sort of sharing presents more advantages to users rather than to providers, i.e. the two directions (provider-client and client-provider) are not balanced in terms of benefits.

A federation implies a different quality of service level, in relation to a repository. It offers a server or now often cloud

based user and lab management in one system. Administrators can define lab and user groups and define roles and offer pre-defined access types to the online labs and remote experiments. Via special web-services (smart gateways [27]) these systems can be connected to an LMS by single-sign-on, if the LMS supports the Learning Tools Interoperability (LTI) protocol. The lab owner in every case defines the use policy (time-frames, actual number of users etc.) of his lab. But he accepts, that all (usually identified) users, which are inscribed to the lab group of the federation, to which his lab is connected, have access to his experiments.

P. Orduña et al. expose the advantages of a federated system [27] concerning the experiments shareability: “*once students of a particular institution can access through the Internet to a particular laboratory, it can also be accessed by students of other universities*”. This advantage is bidirectional through RLMSs in which a federation is established: two institutions providing the same remote lab –or the same practical experiment from a specific remote lab– can balance their clients/users load. This feature, inherit to RLMSs, improves the users’ immersion in the remote lab environment due to the improved time response.

Laboratory time response depends on several factors: circuit, frequency, number of measuring requests, etc. In any case, there is a physical constraint to the number of concurrent users performing measurements; threshold limit value is 60 in VISIR. Even though it is very unlikely that all connected users perform measurements simultaneously –laboratory time is mostly allocated to circuit assembling and configuring the equipment– much more than for measuring, a balanced users’ load for some particular experiments in strong demand, would provide a better time-response, and hence a better immersion.

This particular aspect is visible through the following sequence of experiments, done with a single VISIR node.

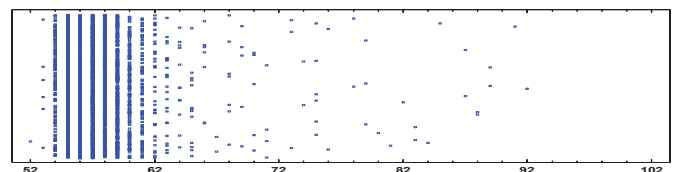


Fig. 3. Unique user, time response in milliseconds; 5 minutes in continuous mode

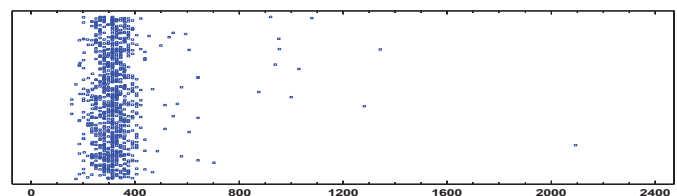


Fig. 4. 5 users simultaneously measuring, sample time response in milliseconds; 5 minutes in continuous mode.

⁷ <http://chem.engr.utc.edu/webres/Stations/controlslab.html>

⁸ <https://physicslabfarm.isep.ipp.pt/index.php?sel=guestlogin>

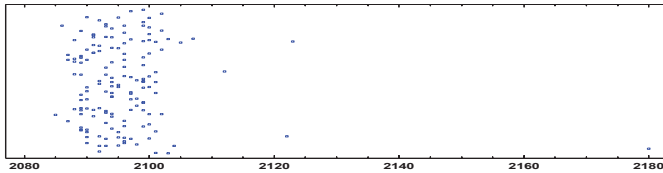


Fig. 5. Over 20 users simultaneously measuring, sample time response in milliseconds; 5 minutes in continuous mode.

This sequence shows the increasing delay in serving an increasing number of simultaneous users, based on the batch operation mode of VISIR. The number of potential users, in a single engineering school, presented in section II, helps to understand the limitations of having a VISIR node operating in an isolated fashion.

Another approach to build a VISIR federation is to carry it out following a strategical design of the practical experiments offered by the different VISIR nodes. Every VISIR node of the community could share a “percentage” of its matrix to the VISIR federation. If every VISIR node offers a rich and broad specialized block of experimental practices (i.e. Node 1: Basic circuits and electrical laws; Node 2: Diodes experimentation; Node 3: transistors experimentation; Node 4: OpAmp experimentation; etc.) the overall VISIR nodes would share a huge and plentiful electronics practices repository, enriching exponentially the availability and quality of practical experiments. This repository could also be extended to practical guides and additional documentation, forming a VISIR community not only for sharing resources but also for a continuous improvement at all levels.

Finally, this whole notion of building a federation of individual nodes is not unique to remote labs; rather there are also examples of proposals emerging from the area of simulations, as presented in [28].

VI. CONCLUSION AND FUTURE PERSPECTIVES

Although the project is in process, some aspects that arise from analyzing the constant growing of the VISIR community should be remarked. The real possibility, technically achieved, which emerges from the federation of remote labs, allows sharing resources and widens opportunities for remote experimentation. This means that whereas at the first moment, each partner has its own VISIR system, to be used by teachers and students, and shared with other institutions, the next step will be to federate the VISIR systems of the various institutions. What could be achieved from this federation can be described with an example. If the VISIR system of one participating engineering school, located in Argentina, and the VISIR system of another participating engineering school, located in Spain, are integrated into a federation, those institutions’ students and teachers, when accessing to its remote labs’ system, will have access to both systems, instead of accessing first to one and then to the other. This is much more than what each institution has developed individually and is able to offer to its teachers and students, alone.

In this way, VISIR+ can be considered the first necessary step to have a federation of VISIR nodes, in which each partner is a supplier and a user at the same time.

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