

# REAL LABWORKS IN ELECTRONICS: YES! ... BUT REMOTELY CONTROLLED

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## Abstract

We present the implementation of a remote lab in electronics, that accounts for the following facts focusing on undergraduate students: (i) there is a general decrease in the recruiting of STEM students (science, technology, engineering, mathematics); (ii) the new generation of students is acquainted with mobility, Internet of Things, e-games; (iii) supervisory control and data acquisition is now widely used in industry to control remotely industrial processes. To address those points, we present a prototype called LaboREM. Its design is based on the mixing of three views together: a remote laboratory, a learning management system, and a game-like approach. Its use proved to increase student motivation.

Keywords: E-learning, game-based learning, industrial engineering, labwork, online education, remote lab, student motivation, supervision, virtual instrument, virtual lab.

## 1 INTRODUCTION

Developing a remote lab involves many issues. Firstly, one can address the *sociology* of technical knowledge, facing various public like poorly educated audience that needs to repeat and revise many times, employees having a full-time job and hence little day-time available, disabled people needing more time to complete an activity, people not affiliated to a university, etc. Here, we focus on first year undergraduate students (teenagers of 18-19 years old). For that target audience who often lacks personal motivation in studying, both game-based learning and adaptive learning are good solutions to promote in order to enhance students' motivation and autonomy.

Second, international cooperation between technological universities is made possible in engineering curricula where practice is important. Universities that do not have modern instruments at their disposal may use hardware devices available in another university thanks to an Internet connection. This is part of the *democracy* of technical knowledge (cf. UNESCO reports on world education).

A third major concern is the financial aspect: drastic cuts are made by governments in their education budget. One must reduce the costs of teaching, especially in technical fields that are demanding in lab activities. Mutualization of expensive equipment is thus a good solution. This is part of the *economy* of technical knowledge.

A fourth key point is to alleviate the constraints on non-financial resources (human, space and time) induced by hands-on activities (need of teachers, rooms and dedicated time slots). The sharing of resources and infrastructures via Internet is then part of the *ecology* of technical knowledge, for a sustainable society.

## 2 METHODOLOGY

In order to build a cooperative platform for remote labworks based on game, the methodology consists in the "3D steps": (i) Design, (ii) Develop, and (iii) Deploy. In the first task of Design, the definition of the platform is given based on the objectives, on the listing of the functional specifications, but also on the existing applications and on the actual available partners of the project (from academy and from industry). Thus, during the task of design, a financing plan is established and a list of participants is defined. The needs (as regards hardware and software) are clarified and the choices are proposed (technological, pedagogical, standards etc.). In the Development phase, the scenario is conceived with the necessary collaborative tools, the remote lab is implemented (with immersion tools, modular hardware etc.), the web service is built (data communication and client interface), the tools for traceability are created and the portability is taken in charge (multilingual translation, open solution). Finally, in the 3<sup>rd</sup> task of Deployment, the prototype is integrated (applications are produced and

broadcasted to the partners that will use it). The actors are instructed (deliverables, tutorials and meetings), a complete test is done (with students and teachers), and the evaluation is made (measures of efficacy, satisfaction surveys, audit). Fig.1 illustrates the process.

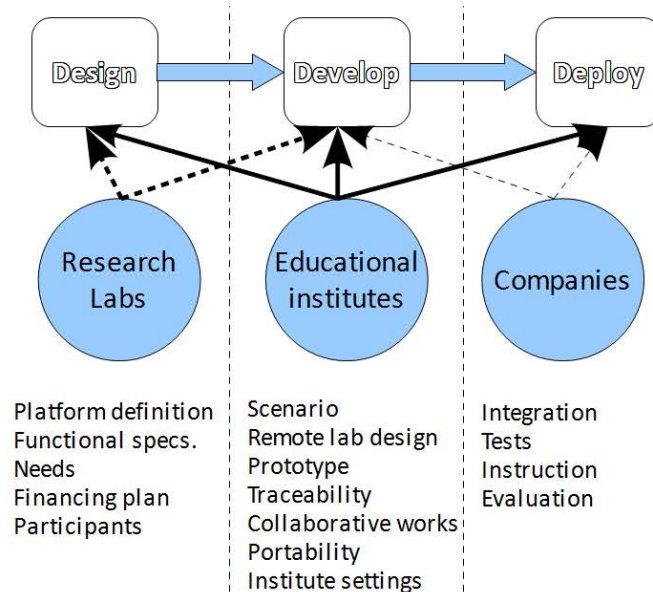


Figure 1 - Overview of the project.

## 2.1 Objectives and needs for LaboREM

The first aim is to increase student motivation, especially for first year undergraduates in engineering. These students must also learn to work in a new way by doing remote activities, since SCADA (supervisory control and data acquisition) is more and more often encountered nowadays in industry. In addition, there is a need for an application that can be used anytime and anywhere (mobility, ubiquity). Indeed one wants to develop a learning tool that could also help other specific audience (e.g. handicapped people, life-long learning for employees, foreign universities).

For STEM curricula (science, technology, engineering, math), real labwork activity is mandatory. It should be accessible via the network. It should adapt to each student: indeed the best students can work fast, but others need to repeat an activity, or need more time to complete it. Therefore, an activity should be adaptive and fun: the itinerary must be polylinear (and possibly multilingual).

## 2.2 Prototype synopsis

To address those points, we develop a prototype called LaboREM (for remote laboratory). Its design is based on the mixing of three things together: a remote lab, a learning management system (LMS) and a game-like approach. LaboREM takes advantage of the innovation in several research fields (learning technologies, cognition, computer science, computer vision, automatic control) in order to be used by educational institutes for pedagogical programs (Fig. 2). Its implementation tries to be as simple as possible (classical client-server architecture), both for tutors to add a new lab activity, and for students to use it.

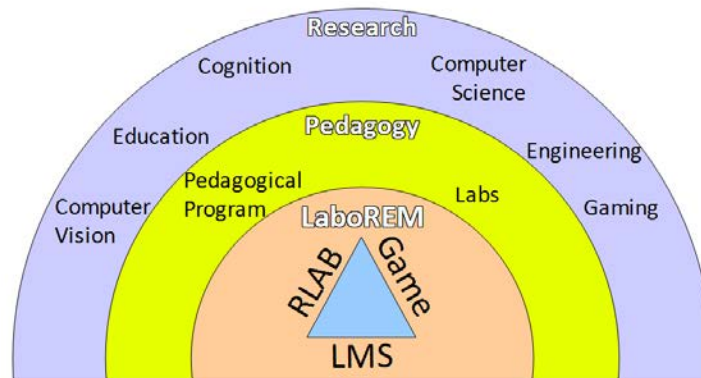


Figure 2 – LaboREM project.

The remote lab is supervised with NI-LabVIEW software: indeed the remote front panel protocol (RFP) is easy to use in order to build quickly an application that can pilot remotely the devices. The hardware uses a robotic arm (to mimic the user hand) and electronic components equipped with magnets (that are easy to pick and place on the electronic protoboard). A webcam with zooming control mimics the user eye. The cooperative platform is based on an LMS (like Moodle, Chamilo or Dokeos). The call to the labwork activity is simply done with URL addressing. Each experiment lasts less than 5 mn: a first-in first-out connexion management is used.

The scenario is based on a game-like approach including a treasure hunt with various learning paths adapted to the student competence and mood, and a Top10 of the best measurements. The game is based on four basic concepts that are usual in e-games (and easily implemented with counters): number of lives (repetitions allowed), time spent, points (score or mark obtained for an activity), levels (beginner, medium, advanced).

### 3 IMPLEMENTATION

LaboREM is a remote laboratory implemented for e-learning in electronics [1]. Being part of the bachelor of science degree in industrial engineering, the course of analog electronics deals with operational amplifiers (OA), active filters and oscillators. The learning objectives are to implement basic electronic functions, and to use test and measurement devices to characterize the circuits. The practical labwork can be done remotely, instead of classical hands-on sessions lasting 4 hours each. Practice is known to be an essential part of learning in engineering education; since access to real-world labs is restricted due to high number of students, cost of equipment, supply and maintenance needs, remote labs are great alternatives. In fact, a mixed pedagogy that includes hands-on, simulations and remote labwork is highly preferable, which is called *blended learning*.

The lab platform is based on the design and control of *virtual instruments* (VI) for the management of remote experimentation through the web, together with the use of a learning management system (LMS) for the supervision of students and for the collaborative work [2]. The client-server architecture allows remote control of instruments in real-time, with the management of both the stack of experiments and the list of users: it is a classical solution [3]. The originality of the proposed work is twofold: (i) a feeling of the lab via the use of a video camera and a robotic arm for placement of components, plus the optional use of computer vision to address user-specific requests to see the equipment in detail (zoom-in for displaying instruments or device under test DUT); this is intended to mimic both the user eye and user hand; (ii) a game-based scenario (treasure hunt) as learning approach, with an attempt to mimic the behaviour of students when they work close together (collaborative work through use of chat, forum etc.) and with a learning itinerary adapted to each student (difficulty level depending on the evaluated knowledge and motivation).

#### 3.1 Network architecture

The network technology should be compliant with various issues like accessibility, reusability, portability, security, scalability, interoperability, traceability, extensibility (to add new experiments). Therefore, a service-oriented architecture is adopted, where four main entities interact: (i) the client that uses the lab, (ii) the corporate webserver that gives access to the platform, (iii) the LMS that organizes

the learning activity, and (iv) the lab that operates the hardware resources for experiments. LaboREM architecture, which is based on the use of two servers, complies with this model (Fig. 3).

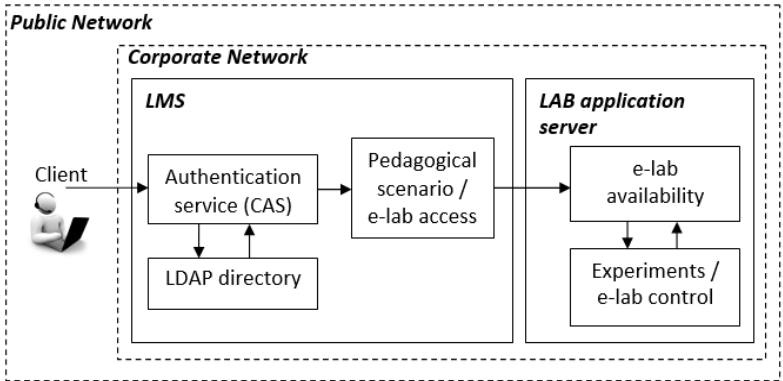


Figure 3 – Architecture.

It is designed to make the LMS communicate with the remote lab. The LMS is the middleware including databases for management of users (using lightweight directory access protocol LDAP), central authentication service (CAS), administration, content packaging, learning tools and evaluation, communication tools for collaborative work. The remote lab is the hardware part that includes instruments (with software drivers). The labwork is accessed through the use of the LMS, by calling, at specific steps in the learning sequence, the proper URL address corresponding to the remote VI to pilot. The e-lab availability service is taken in charge by the labserver itself (management of the queue of users to give access to experiments). The e-lab control service is in charge of piloting the remote devices (instruments, robot).

### 3.2 Hardware setup

In addition to the corporate webserver, the lab application server located inside the industrial engineering laboratory is a dedicated server for connection to the lab equipment (Fig.4). The hardware setup consists of various instruments (waveform generator, multimeter, oscilloscope), plus other equipment (data acquisition, electronic protoboard, switching matrix with relays, on-off button, robotic arm, camera, automatic background lighting) that are connected to the labserver through USB, PCI, GPIB or RS232.

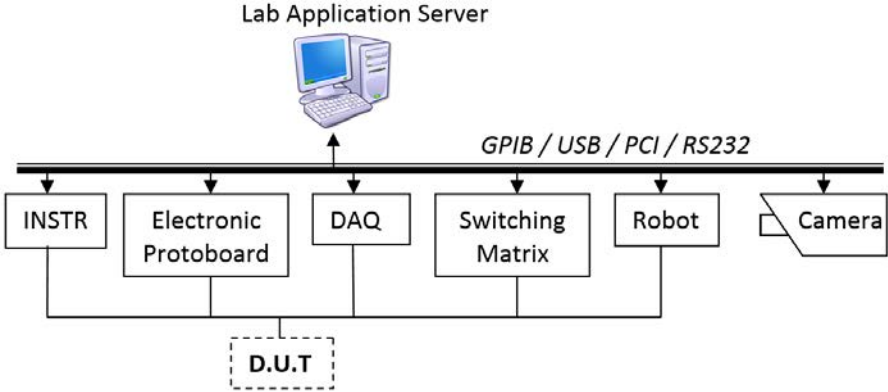


Figure 4 - Hardware setup: instrument (INSTR), data acquisition (DAQ), device under test (DUT).

LaboREM gives the opportunity to build a circuit thanks to an old-fashioned robotic arm (Fig.5).

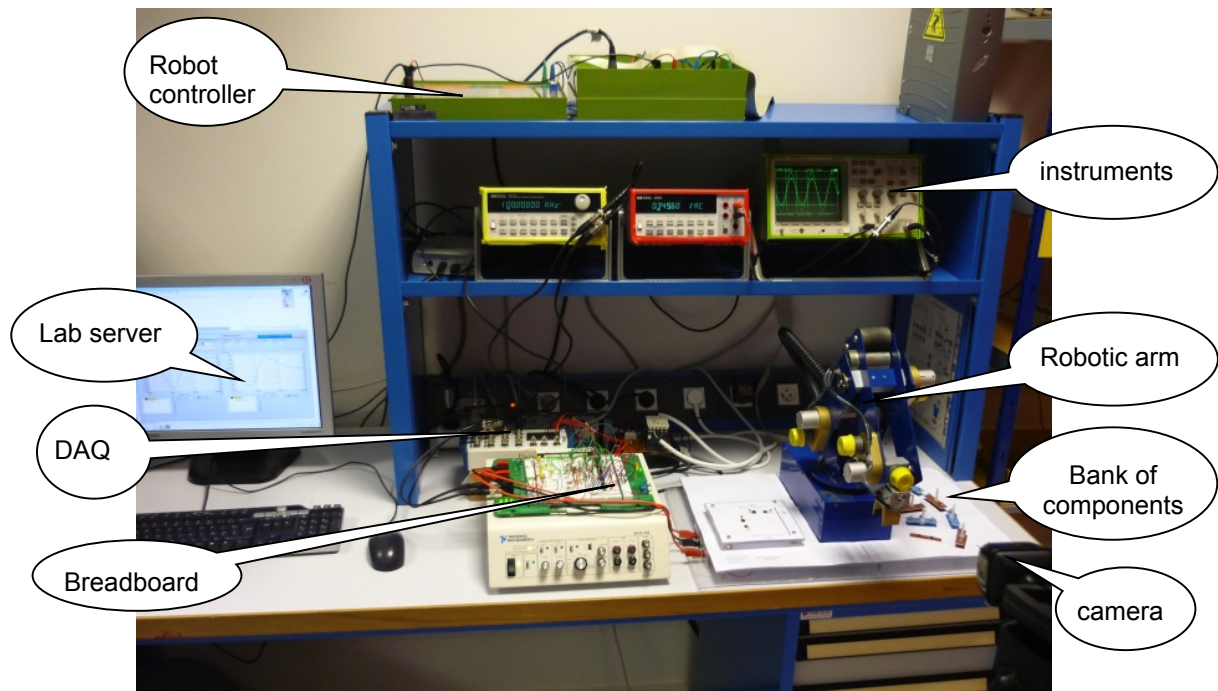


Figure 5 - Remote lab (with robot and camera on the right side).

The DUT are circuits consisting of OA, resistors and capacitors only (no inductance). Thus, a simple solution for easily placing components is to equip them with magnets, so that the right place and good connection contact are achieved, without needing high spatial precision or big mechanical effort. Fig.6 shows the components and the robot action: first, pick one component from the bank of components; then, move and place it on the receiver board connected to the breadboard where OA are already wired. In addition to the robot-built filters, there are also precabled passive and active filters on the breadboard, so that the student can choose either to build his own filter, or to use precabled ones among high-pass, low-pass, band-pass, rejection, plus one extra unknown filter to be uncovered. Choosing the DUT is done in the client interface by selecting the type of filter and component values (currently they can be chosen among 8 values of resistors and capacitors). Note that in case of failure of the robot placement, the client can switch to precabled filters instead, that do not require the robot use.



Figure 6 – a) Components equipped with magnets; b) Robot placing a component on the board.

### 3.3 Software Application

The block-diagram of the lab application is shown in Fig.7. The application consists of 4 main functions that are designed and controlled with NI-LabVIEW software.

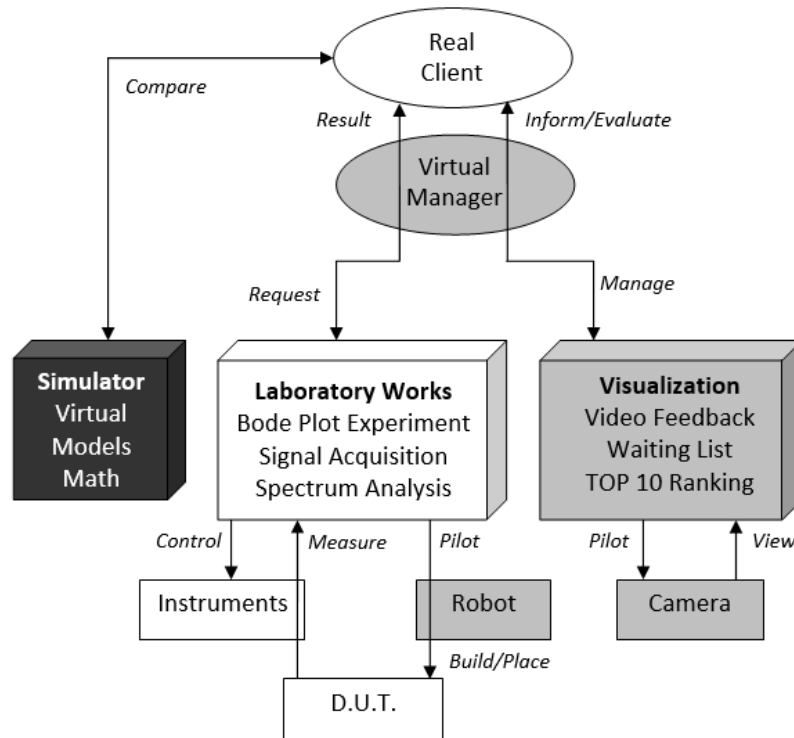


Figure 7 - Application block-diagram: blocks in gray depict functions that are added to get a remote lab, starting from a hands-on lab (blocks in white).

**LaboratoryWorks** is the main function of the remote lab. It enables to select the type of experiment (currently Bode plots or signal acquisition and spectrum analyses) and the type of filter. It allows to control the instruments and the robotic arm to build the DUT, to make measurement, to recover data graphs and to participate to Top 10 ranking. The client has full control over this function. **Visualization** gives a feedback of the remote lab. The client can observe it. It includes three tasks: (i) *VideoFeedback* is in charge of video capture and image processing in real-time (to focus selectively and zoom on each of the devices); (ii) *WaitingList* displays the waiting queue of users that are requesting the control on instruments. (iii) *TOP10* displays the ranking in a "hall of fame" (best answers to measurement requests). **Simulator** is the virtual lab (as opposed to the remote lab) directly accessible via the LMS. It offers numerical simulations of the various DUT. It gives students the opportunity to make comparison between simulation and actual measures. Since it does not communicate with any instrument, there is no waiting queue to manage: many users can run simulations in the same time. **VirtualManager** is in charge of the lab management. It ensures 3 main tasks: (i) *Storage*: it stores data of each experiment (username, timer, experiment selection, Top 10 answers); (ii) *Scheduling*: it manages the waiting queue of connected clients. It uses a specific tool (Remote Panel Connection Manager) for the management of remote front panel connections. There is no sophisticated scheduling mechanism nor concurrency problem, since a user is allowed 5 minutes only, and a first-in first-out solution is adopted (no time slot reservation); (iii) *Initialization and Security*: it reinitializes the system (interface and robot) to its default state, each time an experiment ends, or if another user takes the control of the lab.

### 3.4 Client communication interface

A 1<sup>st</sup> solution is to use the RFP protocols available with NI-LabVIEW webserver. Starting from an existing VI including drivers to communicate locally with instruments, the web publishing tool, with remote control option activated, allows to create a HTML file embedding the front panel object code, so that a VI is visible and controllable from Internet in real-time. As soon as the lab application server is started, the HTML file is accessible over the Internet through its specific URL address. Therefore it is both easy for a client to use the lab and for a tutor to add a new lab activity: there is very little programming overhead needed to publish new VI on the web. The front panel seen by the remote client is exactly the same as the one seen within the local application: the interface is rich and convivial. The main drawback is that RFP client-server data communication uses a proprietary non-



http protocol. It might be detected and stopped by firewalls, anti-viruses or proxies. A second drawback is that the client has to download and install the shareware LabVIEW RunTime Engine (LVRTE) which is a plugin of size 40Mbytes. Fortunately, since the latest release of LabVIEW 2014, most browsers support this plugin: Internet Explorer, Chrome, Firefox, Netscape, Safari or Opera. A final point worth mentioning is that the VI is executed on the server-side. Clients who are connected to the remote front panel, and waiting to get the control over the VI, can observe what the current client who has the control is doing. Note that this can be a good point for student collaboration.

A 2<sup>nd</sup> solution is the use of webservices [4]. The advantage is to conform to standard communication protocol fully compatible with any network and web browser configuration (no restriction due to firewall or antivirus, mobile device compatibility). A specific URL address with command parameters generates dataflows in real-time, containing output data described in XML, TEXT or JSON format. This solution may even be deployed starting from a LabVIEW project (that provides a tool to build Restful Webservices). This alternative yields a remote interface that avoids the use of the non-http RFP protocol. Its main drawback is that the remote graphical interface requires dedicated programming: adding a new lab activity is not straightforward since it requires extra coding.

We have tested the 2 solutions for LaboREM, and we advocate the 2<sup>nd</sup> solution using webservices. The prospective use of HTML5, merging JavaScript and XML, is the best technical choice. Among others, it allows to address the flexibility and ubiquitous use of the application on mobile devices (smart phone, tablet) which is desirable for gaming purpose. Nevertheless, as the 1<sup>st</sup> solution based on RFP does not require extra-coding and provides a rich interface, we present here the results based on RFP. Fig.8 shows a typical interface seen by a client (remote student) when asking for plotting Bode curves to characterize the transfer function of active filters. The user builds his own circuit by piloting the robotic arm, makes measurements in real-time, exploits graphs thanks to cursors and markers, optionally takes part in the Top 10, has a visual feedback of the lab through a camera, and gets information about the waiting list of users with a timer, so that he knows exactly when he will be served. In the meanwhile, he can switch to other activities proposed in the pedagogical scenario.

### 3.5 Pedagogical scenario

#### 3.5.1 Game-like strategy

Games are characterized by 6 key-dimensions [5]: fantasy, clear rules and goals, sensory stimuli, challenge, mystery and control. They are taken into account as follows: mystery (unknown filter to uncover), sensory stimuli (visual feedback and robotic motion), challenge (Top 10), control (choice of DUT), rules (limited time and number of trials), clear goals (learning objectives with three difficulty levels to choose from), fantasy (freedom to conceive one's own circuit).



Figure 8 – Remote client interface seen by the student while doing the labwork.

The student has the choice between various filters: some of them are known (SallenKey, Wien etc.) or can be built by the student himself; others are unknown and should be identified during the lab session. Depending on the filter chosen for study, and on the exactness of answers, the student accumulates more or less points during his "travel" and may take place in the "hall of fame". If he discovers what the unknown filter is, he has reached the final objective of the "quest". If he fails, he may choose to backtrack and try again (limited repetitions).

All the scenario is managed by the LMS. The game-like scenario conceived to boost student motivation is based on 4 concepts as in e-games: levels, lives, points, and time. Four counters are used for evaluating student's activity: a timer, a counter for highest level achieved (difficulty level), a counter for number of lives used (number of trials), a counter for scoring (marks obtained to online quizzes and final exam). This allows to automatically estimate a participation index and a performance index which are taken into account for driving motivation in auto-regulated distance e-learning [6]. A polylinear learning path is implemented in the LMS as a "treasure hunt", that is adapted to the competence level and motivation of the student. Depending on the level, a flag (red, orange or green) is generated to guide the student towards the best path and with the best workload according to the student's profile (Fig.9).

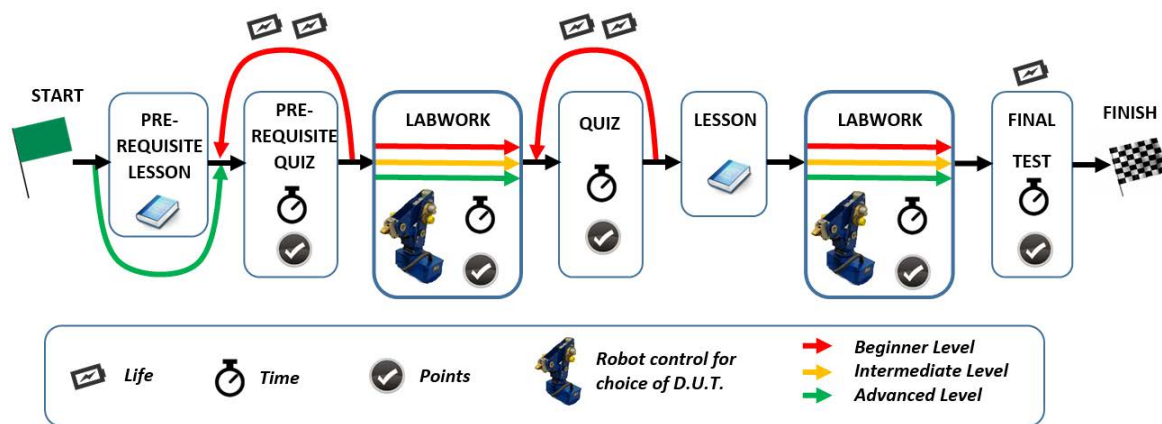


Figure 9 - Learning map (simplified version).

A typical scenario consists of: (i) videopresentation of the lab; (ii) test on prerequisites; (iii) lesson (online documentation); (iv) formative test; (v) remote labwork with three levels of difficulty; (vi) comparison with simulator (virtual lab); (vii) final summative test with upload of work report; (viii) satisfaction survey.

### 3.5.2 LMS interface

Fig.10 is a snapshot of the screen seen by a client when asking for the remote lab within the LMS: one can download a preformatted text-file for writing the report to answer the questions (left button), click on "Travaux Pratiques" (middle button) to run real experiment, or run the simulator (right button). The traffic light indicates the best difficulty level to choose from, depending on previous answers to quizzes. The student can also watch a tutorial that explains the use of the remote lab by playing a video (bottom movie) [7].





Figure 10 - LMS interfacing the entry to the remote lab.

## 4 RESULTS

### 4.1 Student motivation

In 2011, a first group of 29 students was tested. An a priori survey (pre-inquiry) about their motivation showed that their main motivation was intrinsic acquisition of knowledge (mean score of about 3.8/5), far before their ranking compared to the other students (mean score of about 2/5). Sample statements used for measuring motivation were, among others: "It is important for me to learn"; "It is important for me to look like being proficient"; "I am motivated by this remote learning activity"; "I am motivated by the final mark I will obtain for this labwork" etc. To enhance their external motivation, the Top 10 was added in 2013, that gives in real-time the best score achieved during measurement activity ("hall of fame"). Moreover, the robotic arm was also added. This proved to increase extrinsic motivation by about 20%. The average values for extrinsic motivation were measured from pre- and post-inquiries based on two different types of questionnaire (before and after the lab activity) in 2011, 2012 and 2013 (75 students altogether). The increments between 2012 and 2013 measured on a 5-point Likert scale give +0.47 (starting from 1.95 in pre-inquiry) and +0.55 (starting from 2.55 in post-inquiry). It is worth to mention that the students who most participated in the Top 10 were not necessarily the "best" of our students (in terms of academic marks). Indeed, competitiveness increased their motivation [8].

### 4.2 Student traces, statistics and satisfaction surveys

The LMS delivers all the traces for each student: number of accesses, time spent, number of trials, performance achieved, difficulty level reached, answers given to quiz (Fig.11a). The statistics of connection to the lab is particularly noteworthy (Fig.11b): most connections occur the last day before the labwork deadline: this imposes to have an access management that is robust to many simultaneous users, which is a key issue when hardware is concerned.

To assess the quality of a remote lab, both a technical and a pedagogical evaluation were conducted with about 125 students [9]. Two anonymous questionnaires were used for the surveys: a detailed questionnaire with 70 questions, and a global satisfaction survey scoring ten main issues: comfort of interaction; technical quality; game-like scenario; pedagogical efficiency; remote control of devices; space-time constraints; collaborative work; autonomy; online docs and prerequisites. The average satisfaction is about 13.5/20 (20/20 being the best and 0/20 being the worst).

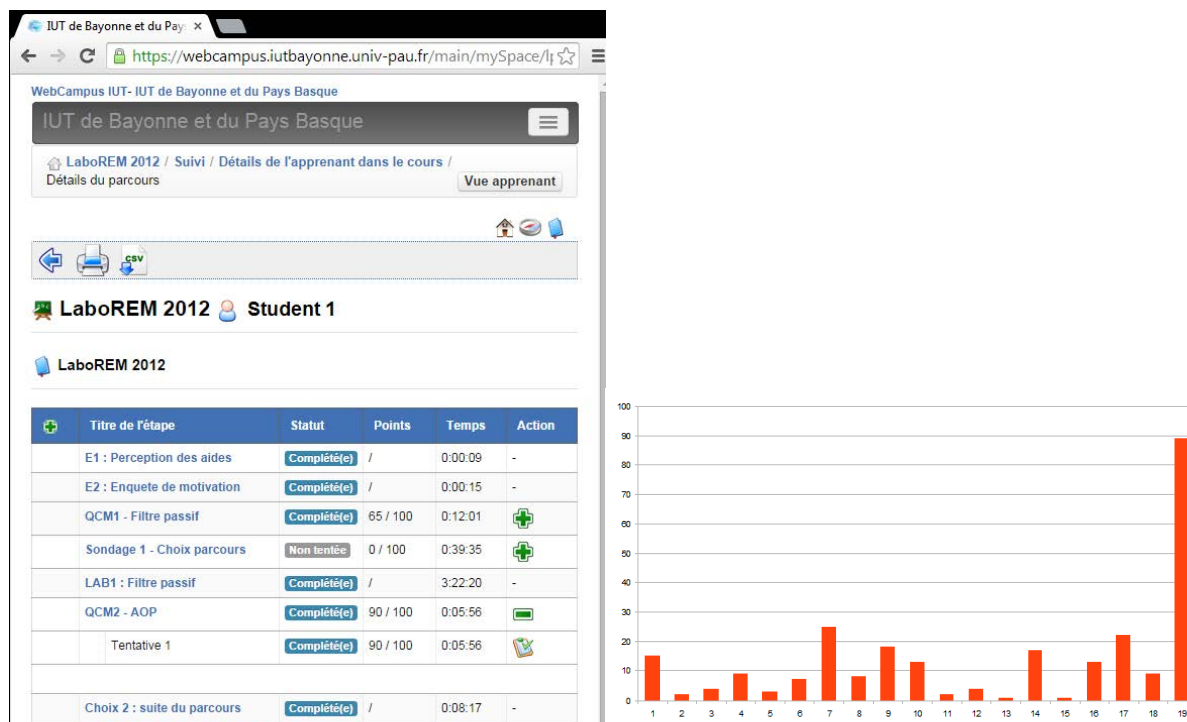


Figure 11 – a) Traces of student activity; b) Number of connections vs. time (before lab deadline).

## 5 CONCLUSIONS

From our experience, student motivation increased by 20% thanks to the introduction of Top10 and robotic arm with visual feedback. If motivation increase is proven, we do not claim better learning outcomes, compared to hands-on. LaboREM platform is one supplementary tool to help students in their studies, in an autonomous and student-centered context, as recommended in Europe by the Bologna process. Moreover, this tool is exhibited each year during the “open doors day” of the university and proves to be attractive for visitors which are teenagers coming from high schools. It contributes to increase the number of students willing to undergo a STEM curriculum.

The perspective of this work is manifold. A multi-server solution is of high interest to give access to experiments in various remote labs (cf. iLab shared architecture [10]). We intend to make LaboREM fully compliant with SCORM standard for complete integration of the weblab into the LMS [11].

*Additional tools:* There is a cognitive need to better evaluate the actual collaboration on the cooperative platform. There is also a technological need of web services for mobility (open solution), and of more immersion. For that purpose, a mini-drone equipped with a micro-camera flying over the lab at user's request is under investigation (Fig.12a). In addition to the wide-angle camera that supervises the whole scene, the minidrone will fly over the lab and take a specific position at user's request. There is also a need of more advanced image processing, especially face analysis on the client side to induce the behavior, emotion or mood of the student (angry, happy, inattentive). Face expression analysis may help to know the state of motivation of a student. Giving control of the camera to the client is attractive for closer collaboration with a colleague or tutor.

*New applications:* Future work aims also at adding other lab activities, namely piloting photovoltaic panels and wind turbines on the roof of the university buildings: a serious game approach will allow students both to manually control the system, and also to get acquainted with, and more conscious of the importance of renewable energies.

*Generic modular hardware:* As LaboREM should be easy to use for students, tutors and developers, a motherboard linked to material plugs has to be implemented. This approach will allow to plug easily new experiments and so, to make the platform modular. This motherboard is an electronic card which enables data communication between the circuits (one plug for each circuit) and the external components placed by the robot (connectors Cij), the instruments and DAQ board (Vin, Vout1, Vout2), and the power supply (Vcc, Vee, GND). Fig.12.b illustrates the interaction between the motherboard and the equipment. Plugs have to be designed with a unique pin mapping: it will allow to plug any

circuit anywhere on the motherboard. For example, if the developer or tutor wants to add a new experiment, a new plug is designed (following pin mapping described in Fig.12.c) and the client interface is updated to include this new experiment.

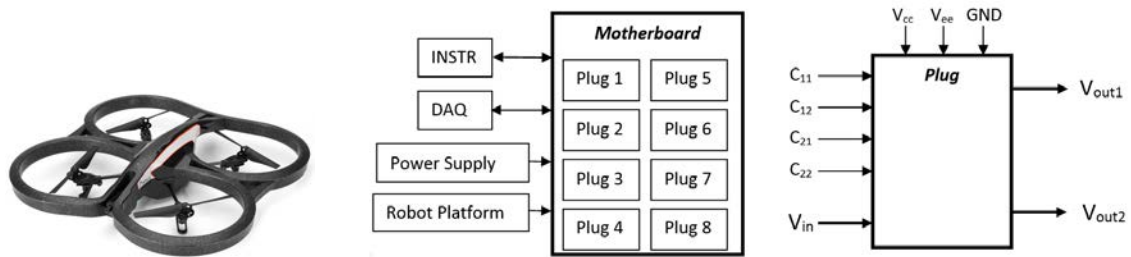


Figure 12 –a) Minidrone with camera ; b) Modular motherboard; c) Plug's pin mapping.

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