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Academic Evaluation Protocol for Monitoring Modalities of Use at an Automatic Control Laboratory: Local vs. Remote*

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This article describes an Academic Evaluation Protocol (AEP) designed and implemented in order to monitor various modalities of using an Automatic Control Laboratory by analyzing the quality of work that can be obtained from a specific student group when the proposed experimental practice is being conducted according to a particular type of lab-work modality. To serve this purpose, the types of use-modalities associated to different lab-works are classified as follows: Local Real Laboratory (RL), Remote Laboratory (R@L) and Local plus Remote Laboratory (RL+R@L). To estimate how a specific lab-work modality impacts upon the development of an experimental practice, parameters such as average utilization time and the ABET-Indicators are used. The results obtained from this pedagogical instrument are analyzed by various means, namely the ANOVA Test, a Descriptive Statistical Technique and Wilcoxon Testing. The findings reveal that the student groups involved in experimental lab-practices following the RL and RL+R@L modalities achieve better performance (when conducting the automatic control laboratory) than the student groups served with the remote system only. The analysis performed indicates that there is no statistical difference between working at the Local Laboratory (RL) or at a Local plus Remote Laboratory (RL+R@L). As a result, the use of the remote system combined with the local one does not improve significantly the ABET score, ruling out the idea that by placing special interest in using only the remote system, an improvement in students' comprehension is achieved.

Keywords: local laboratory; remote laboratory; Academic Evaluation Protocol (AEP); ABET Indicators

1. Introduction

Nowadays Information Technologies (IT) offer great support for learning and teaching academic processes, making it possible to conduct activities that were previously restricted to attendance-based environments. In this sense, remote laboratories that use IT, involving local processes for remote operation, truly extend the capabilities of classical laboratories associated to a specific teaching area, which in most cases tends to be limited in terms of time and availability of physical experiments.

Although the deployment of remote laboratories around the world currently represents an extensive field of engineering research; where Electronics, Robotics, Automation and Physics are the most outstanding areas [1]; little attention has been paid to designing and evaluating well-structured pedagogic-framed proposals [15] as well as assessing the impact of such proposals on student learning processes by focusing on the didactic use of remote-laboratory resources [2]. The rationale behind this statement is that most of the existing works are concerned with the technical aspects of remote laboratories (e.g., the network architecture or the technologies that were deployed for lab development [3, 4]), neglecting the academic matters that arise when actually making use of such technological resources.

The present work is concerned with the way Automatic Control Laboratories can be utilized as a didactic-pedagogic tool for carrying out different kinds of dynamic-work modalities; this approach uses a methodology that has been structured in a single Academic Evaluation Protocol (AET). In this sense, three (3) types of lab-work-associated sche-

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dules have been systematically defined in order to analyze the quality of work that can be obtained from a specific student group when the proposed experimental practice is being conducted according to a particular type of lab-work modality. These three lab-work modalities have been defined as follows: *Local Real Laboratory (RL), Remote Laboratory (R@L)* and *Local plus Remote Laboratory (RL+R@L)*. This set of experiments make use of the Multiuser Network System proposed in [11] for the remote activities.

In order to evaluate how the automatic control laboratory is used to perform the corresponding work, three (3) different instruments have been proposed. The first instrument allows estimating the average time span that a group of students takes to carry out the proposed experimental practice under a specific lab modality. To this end, a *Time Data Sheet* that contains the main activities to be performed by a particular student group when working at the automatic control laboratory has been designed.

The second instrument allows measuring the quality of work presented by different student groups regarding one specific lab-work modality. To achieve this aim, a rating matrix based on *ABET Indicators* [10] is proposed, and employed to indicate what concrete actions the students should be able to perform as a result of participation in the AET. This will allow the desired behavior of the students to be described, and will eliminate ambiguity concerning demonstration of expected competencies [29]. Performance indicators are made up of at least two main elements; action verb and content (referent). The expected behavior must be specified by name, using an observable action verb such as demonstrate, interpret, discriminate, apply or define [30].

Based on these performance indicators, the results from the proposed AET could be sorted into each of the work-lab modalities.

The results are analyzed applying ANOVA Test and Descriptive Statistics for the ABET-SCORE; additionally, a Wilcoxon Test is conducted considering pairs of the three (3) lab-work modalities presented below as nominal variables and the ABET-SCORE as the measurable variable.

ANOVA or Analysis of Variance is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. This method, based on the collection of statistical models, allow analyzing the differences between group means and their associated procedures, such as variation among and between groups, in which the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups [18].

For this reason, ANOVA are useful in comparing (testing) three or more means (groups or variables) for statistical significance and that is why this method have been implemented in order to analyze if there are statistical differences between the three lab-work modalities (RL, R@L and RL+R@L) by using the ABET Score data obtained from the AEP.

Considering the present research, the ANOVA technique is applied in order to analyze the effect of the factor level (k) [28], represented in this case by the lab-work modalities, and to determine how the measured observations, means ABET Scores from each student-group, could be affected by the variations such spent usage time (total) given in the three factor levels that are related to *Local (RL), Remote (R@L)* and *Local plus Remote* laboratory modalities. In this sense, our statistical test model is in agreement with a between-subject design experiment: the lab modality (with three levels) is the independent variable, thus the "between-subject" variable or factor in our case; the ABET Score is the dependent variable, the measures from the subjects (the "within-subject variable" in this experiment). Since there is only one factor, the statistical model corresponds to a One-Way ANOVA.

Based on these results, which also include the probability of error (*p-value*) involved in accepting our research hypothesis about the existence of a difference between the three categories of observations (lab-work modalities), and that are obtained following the computational procedure for ANOVA technique and "*t-test*" described in [19], improvements for the AET may be proposed for future applications at automatic control laboratories or at any other kind of labs.

This article is structured as follows. Chapter II provides a brief description of the general potentialities of the remote academic laboratories. In Chapter III, the proposed Academic Evaluation Protocol (AET) is explained taking into account various aspects, namely the experimental practice designed for the present proposal, the work sequence that was implemented for each of the analyzed laboratory modalities, and the instruments provided to estimate lab-work usage in terms of time and quality of work achieved by particular student groups selected to carry out the AET. Finally, in Chapters IV and V, results and conclusions on the analysis drawn from the implemented AET are presented.

2. Remote academic laboratories—academic potentialities and applications

Nowadays, the great importance of having practical experiences when gaining competences during engineering training is unquestionable, and so it is when such experience helps engineers find solutions to real situations in the context of automatic control. Moreover, current advances in Information Technologies (IT) allow taking new approaches to knowledge acquisition in the field of scientific and technological teaching by developing remote academic laboratories.

In this context, from a didactic perspective, stating that a remote academic laboratory represents a useful educational resource means that the pedagogic potentialities of such a laboratory can be explored in order to turn it into a helpful tool for promoting the development of complex knowledge processes; which are necessary to instill a scientific-technological profile into future engineers. It also should be considered that a remote academic laboratory is mainly different from a local one because physical equipment is used to make local trials but using a software-implemented interface, allowing remote user access. In this case, it is reasonable to think that a remote laboratory means experimental work, in the strict sense, related to the development of genuine practices [16].

Continuous technological development; especially in the field of information technologies that involve *data storage, records, presentations and communication structures*; seems to indicate that it is possible to change the pedagogical frame adopted by institutions at any educational level. In Milton Glaser's words, a Commission Boyer Member [5], "technology is never neutral; it is the duty of universities to make technology widely positive". It means that institutions must carefully and systematically design academic courses in which technology succeeds in enhancing the learning process, instead of replacing it. Equally careful consideration must be given to the professionals under training since they are to use each one of the basic and necessary tools that will allow them to explore, discriminate, analyze and build knowledge, widening their scope instead of limiting it.

In this way, practical experiences must lead this kind of professionals to a symbolic conclusion about their constructed knowledge in such way that they can measure the capabilities and skills developed within this pedagogical context, whose constituent "Engineering Design" standards are *The Nature of Engineering Design, Initial Reflection, Design Process, Representation Design and Final Reflection* [6].

By considering the description above, one may ask the following question within this pedagogical frame: how valid is the learning and teaching process when based on this practical experimental frame? In other words, is there any significant change in the type of applied learning, experienced by trainees, when handling a specific practical task either in a local or remote way?

As is presented in [21] and [22] a related affordance of local (physical) laboratories is that they can take advantage of tactile information that, according to theories of embodied cognition, fosters development of conceptual knowledge by using physical equipment where students can develop practical laboratory skills, including troubleshooting of machinery, and can experience the challenges many scientists face when planning experiments that require careful setup of equipment and observations over long time spans.

On the other hand, virtual experiments offer efficiencies over local experiments because they typically require less setup time and provide results of lengthy investigations instantaneously [23]. This enables students to perform more experiments and thus to gather more information in the same amount of time it would take to do the local experiment. Physical or local experiments, however, typically include authentic delays between trials that encourage careful planning to develop the lab-work activity [24].

Although the present work is not intended to emphasize the learning process that occurs when an academic laboratory experiment is carried out, it does explore the impact of using different laboratory modalities (namely local laboratory, remote laboratory or a combination of both) on the learning process, particularly in the case of automatic control practices taking into account the recommendations offered in [25] for combining the two to strengthen engineering learning.

3. Proposed academic evaluation protocol

Despite the fact that the laboratory in general has given a central and distinctive role in science and engineering education, at this time, some educators still ask them self about the effectiveness and the role of laboratory work, aspects that according to [26] have not been well targeted for research, especially if nowadays these want to be analyzed in the modalities of use of an automatic control laboratory, local and remote.

Based on the above and taking into account that the laboratory is a medium of instruction in introductory engineering teaching [27], an *Academic Evaluation Protocol (AEP)* is proposed in order to explore how effective could be an automatic control laboratory work when this is carried out through the modalities local and remote, as well as, a combination of both.

In order to design the *AEP* for monitoring the modalities of use at an automatic control laboratory, an experimental practice using a servo-drive

Table 1. Main activities that were discriminated for carrying out the lab-work in Local and Remote Laboratory

Item	Activities Carrying out for Local Laboratory	Activities Carrying out for Remote Laboratory
1	Request of lab-work equipments.	Request to the System—Connecting to the Remote Interface.
2	Assembly and system connection (Hardware).	Performance Testing.
3	Development of the application to acquire data array for modeling the system.	Employment of Remote Interface for knowing the process.
4	Performance Testing (Calibration and Adjustments).	Employment of Remote Interface to obtained data array for modeling the system.
5	Data Acquisition #1 (For Modeling).	Data Acquisition # 1 (For Modeling).
6	Calculation of the identification parameters, state model representation and controller design including simulation.	Calculation of the identification parameters, state model representation and controller design including simulation.
7	Development of the application to implement the control the system.	Employment of Remote Interface to control the plant.
8	Data Acquisition #2 (From Control Stage).	Data Acquisition #2 (From Control Stage—Camera Web Interaction)
9	Experience Verification—Adjustment for the Controller.	Experience Verification—Adjustment for the Controller.
10	Data Acquisition #3 (From the Adjustment of Control).	Data Acquisition #3 (From the Adjustment of Control).
11	Writing Document Report.	Writing Document Report.

system was structured. In this case, the development of the practice itself focused on the study of a classic problem: position control using the state feedback technique. Thus, after obtaining a data array from the local plant, a group of students had to calculate the identification model of the process—i.e., a first order transfer function with an integrator—and then turn the model into a controllable state representation, which subsequently allows the design and implementation of a state feedback regulator that controls the servo-drive position using the system-state-variable information, namely the values of speed and angular position.

Following the experimental design process [14], a first approach allowed classifying the main activities, to be performed by the student group, in order to accomplish the proposed work, either at a local laboratory or at a remote one. These activities, presented in Table 1, were classified assuming the availability of all the necessary elements and equipment to conduct the local experimental practice at the laboratory.

As it can be observed in Table 1, the Local Laboratory (RL) and the Remote Laboratory (R@L) involve almost the same amount of activities for completing the lab-work in full. The two sets of activities end requiring students to write a draft report. However, for the present research, it was proposed that activities (1, 3, 4) be replaced in the local laboratory modality in order to make the whole practice more similar to the remote lab practice. Hence, the student groups working with the local system did not have to request equipment, or develop a software application for modeling and controlling the plant; neither did they have to performance a calibration testing task.

On the other hand, it must be considered that the system in the local laboratory modality is already requested at the workplace and set up including its manipulation interface, which has been previously developed and calibrated to be used by the corresponding student-group user. In summary, it is assumed that part of the whole practice is already set and therefore cannot be included for evaluation purposes, provided that students do not get involved in the fully hands-on learning process (i.e., lab setup is provided) [7].

Once the local and remote activities were defined, three (3) types of lab-work modalities were systematically structured in order to analyze the quality of work that could be obtained from a specific group of students after performing the proposed experimental practice in a particular type of lab-work modality. These three lab-work modalities were defined as follows: *Local Laboratory (RL), Remote Laboratory (R@L)* and *Local plus Remote Laboratory (RL+R@L)*. Four student groups (4-G) were selected to participate in each of the modalities, as shown in Fig. 1.

The experiments were physically conducted at Universidad de los Andes—Colombia—and can be accessed via Internet. Using the remote interface, student-groups can set parameters, carry out the experiments and then display the results on screen in

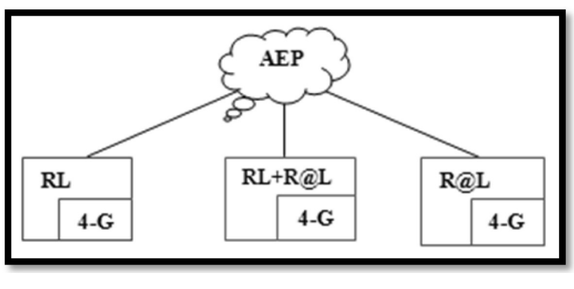

Fig. 1. Patterns Lab-Works proposed to structure the Academic Evaluation Protocol.

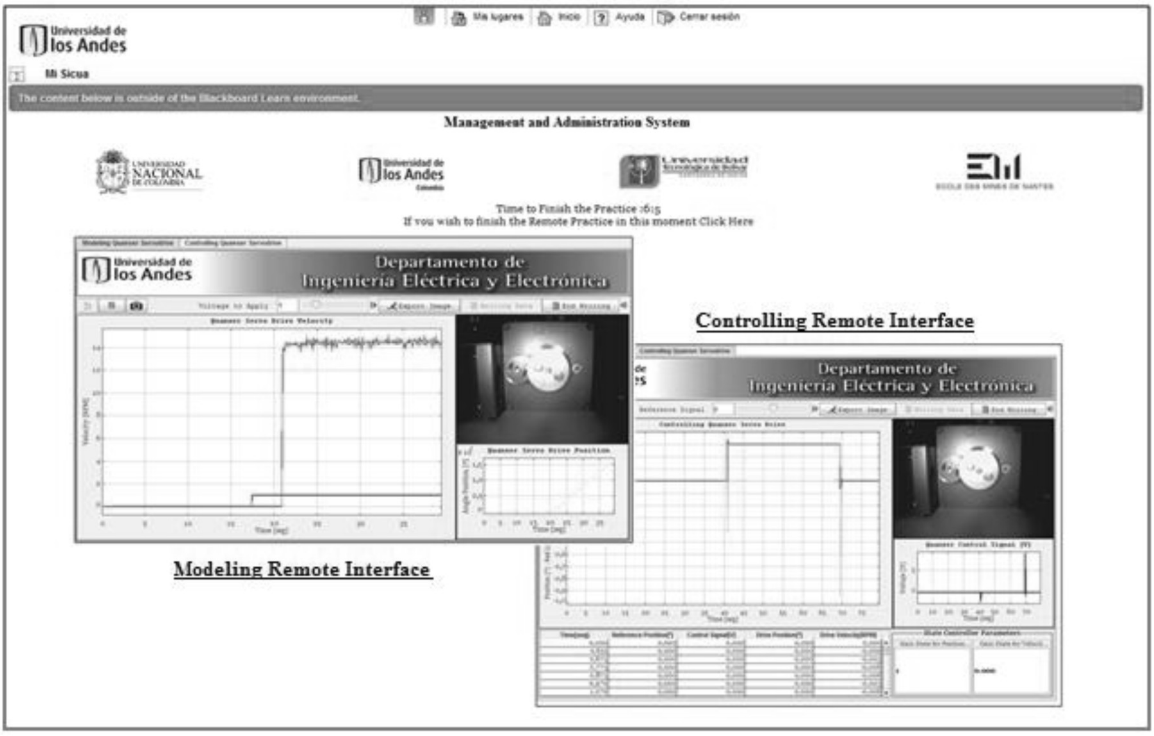

Fig. 2. Screenshot of the experiment (Modeling and Controlling) carried out for the Remote Laboratory.

the form of diagrams and tables, including the possibility of saving the data. Fig. 2 shows a screenshot of the remote servo-drive experiment. For the local experimental practice, a similar interface was developed using the LabVIEW software working environment.

For each one of the lab-work modalities presented in Fig. 1, twelve (12) groups of students enrolled in the control-systems course were selected to participate in our academic testing, and were asked to follow the work sequence shown in Table 2.

4. Sample organization

An important constraint on the described lab-work modalities is that the academic features of performance (provided for the student groups that get involved in a specific lab-work modality) have to be kept as homogeneous as possible in order to avoid noise in the results of the AEP. Thus, for the described laboratory modalities there is at least, one (1) group with good average grades, (2) two groups with acceptable average grades and one (1) group with lower average grades.

This filtering process can be conducted by using the information that we have about the students enrolled in the control-systems course. Such information consist of a variety of items, namely *Undergraduate Grade Point Average, Number of Credits Taken by Students, Number of Credits Attained by Students,* and *Percentage (%) of Complete Credits*. We were able to calculate average features of performance for the groups in order to organize them according to uniform profiles for the lab-work modalities, as shown in Table 3.

As it can be observed in Table 3, the sample taken from the whole course (control course) at Universidad de los Andes has been organized according to the academic restrictions defined above.

Thus, the *Undergraduate Grade Point Average* (GPA) is considered as the main academic-performance feature, and it is used to sort the samples into

Table 2. Work Sequence for the proposed Lab-Work Modalities

Lab-Work Modality	Work Sequence
RL [Local Lab]	Four groups (4-G) selected to develop the working-lab at the physical laboratory from the University. Also, they have the possibility to explore the remote laboratory.
RL+R@L [Local Lab + Remote Lab]	Four groups (4-G) selected to begin the development of the working-lab at the physical laboratory from the University and then, finishing this work on the remote laboratory.
R@L [Remote Lab]	Four groups (4-G) selected to develop the working-lab only over the remote laboratory using the network system proposed for this aim.

Table 3. Sample organization that has been taken from the Control Course in the AEP

Working Laboratory Modality	Group	Career Average (CA)	Number of Studied Credits Average	Number of Approved Credits Average	Percent of Approved (%)
RL	1^{M}	3.51	137.33	115	85%
	3^{M}	3.77	134.13	119.5	90%
	10^{E}	3.88	157.5	141.38	92%
	11^{R}	3.43	112	98.5	88%
	SUBTOTAL	3.65	135.24	118.6	89%
RL+R@L	2^{R}	3.37	157.75	131.75	83%
	5^{M}	3.57	125.2	106.6	86%
	6^{E}	3.82	114.63	104.13	91%
	7^{M}	3.65	152.25	134	89%
	SUBTOTAL	3.6	137.46	119.12	87%
R@L	4^{M}	3.51	132.63	109.38	82%
	8^{M}	3.51	131.25	117	89%
	9^{R}	3.44	128.6	98.5	77%
	12^{E}	4.12	144.38	136.88	95%
	SUBTOTAL	3.65	134.22	115.44	86%

E: Group with Great Grades. **M:** Group with Medium Grades. **R:** Group with Regular Grades.

the three presented laboratory modalities regarding the following definition: Group with Good Grades (E) whenever GPA > 3.8; Group with Acceptable Grades (M) whenever 3.5 ≤ GPA ≤ 3.8; Group with Lower Grades whenever GPA < 3.5.

The other three academic features of performance were used as validation items to guarantee low deviation in average calculations made for each participant student-group. The main purpose was to assign groups with uniform profiles to the three evaluated laboratory modalities.

5. Instruments

Taking into account the described protocol, the following three (3) instruments were implemented in order to evaluate the utilization environment of the automatic control laboratory.

5.1 Time data sheet

In order to evaluate usage in terms of time for each lab-work modality, a *Time Data Sheet* was designed. The sheet includes some particular items connected with the general activities that should be completed for the three kinds of lab-work modalities. The activities include: knowing the process, acquiring data for model identification, regulator (controller) design and testing, and writing reports.

The activities for this Time Data Sheet were classified considering the kind of work that is carried out by the student-groups, either outside labs, in the local lab or in the remote lab, as shown in Table 4.

With the instrument described above, it was possible to analyze how these activities are developed in time depending on the group's laboratory modality. Consideration was also given to the fact that the presented activities were probably being conducted in a simultaneous or overlapped way depending on students skills and organization within each group, so it would not be possible to start a new time slot every time a new activity was started; instead, the student-group could estimate the approximate time spent in the development of a particular activity, with regard to its corresponding

Table 4. The Time Data Sheet provided to analysis the usage in time for the Lab-Work Modalities

			Work Outside Labs						Work in Real Laboratory								Work in Remote Laboratory							
Date [dd/mm/yy]	**Start Time**	**End Time**	Reading Instructions	Planning Experiment	Data Processing	Math Calculations	Simulation Analysis	Writing Report	Reading Instructions	Hardware Assembly and Connection	Testing Set up	Doing Experiment	Data Processing	Math Calculations	Simulation Analysis	Writing Report	Reading Instructions	Connecting to Remote Interface	Testing Set up	Doing Experiment	Data processing	Math Calculations	Simulation Analysis	Writing Report

time slot, thus providing us with an idea of how activities change in time.

5.2 ABET indicators

In order to evaluate the quality of work presented by the student groups (on the basis of report quality), a rating matrix based on ABET Indicators was designed. According to the items presented in Table 5, two evaluative instruments were implemented.

The first instrument contains all the main points that student groups have to cover during their practices, facilitating self-grading. The other instrument, which uses the ABET Indicators, was intended for the teacher to grade the final reports. Evaluation was based on student performance according to [17], where the letters a , b, c, and k are related to ABET indicators, while the number refers to a specific performance indicator used by the university as evidence during the assessment procedure.

Also, in order to grade the performance level attained by each group, a four-level rubric [12] was used for this proposed as it is shown in Table 6. The final ABET Score for each student-group is estimated by calculating the average of the six grades obtained in each ABET Indicator.

Every level of each performance indicator was described, and the results are analyzed based on multivariate statistics studies as references in [8].

6. Results and discussion

According to the proposed Academic Evaluation Protocol, which was successfully implemented, the following results were obtained.

Table 7 shows the average ABET Score obtained by each student-group associated to each lab-work

Table 5. ABET Indicators used to evaluate the work‘s quality presented by the student-group as a Document Report in each lab-work modality

ABET Indicator	ABET Standard Description
a4	Engineering knowledge is applied (design, programming, optimization, and engineering basic sciences) to solve the problems.
b5	Relationships, hypothesis, models, explanations, solutions and answers are validated or inferred supported on the identified evidences for the analyzed problem.
c1	For the system, dispositive or analyzed process, its specifications and constraints are in detail identified and described.
c5	The performance for the developed design is evaluated. Improves for future designs are proposed.
k1	Problems are solved using computing tools of programming, simulation and data analysis.
k3	Different technologic equipments are used in order to implement and validate the solution.

Table 6. Four Level Rubric used to assign the ABET Score in order evaluate the Document Report for each student-group in each lab-work modality

ABET Indicator	ABET Score Levels			
	0.0	1.5	3.5	5.0
a4	Nothing	The control theory is erroneously applied to solve the given problem.	The control theory is properly applied to solve the given problem but this is not verified with real results.	The control theory is properly applied to solve the given problem and this is verified with real results.
b5	Nothing	The modeling and design control validations are not consistent.	The modeling and design control validations are consistent but they are not justified.	The modeling and design control validations are consistent and they are justified with real results.
c1	Nothing	The specifications and constraints system are erroneously identified and described.	The specifications and constraints system are properly identified and described but they are not justified.	The specifications and constraints system are properly identified and described and they are justified with real results.
c5	Nothing	The performance of the control design is evaluated but it is not discussed.	The performance of the control design is evaluated and discussed but improvements are not proposed.	The performance of the control design is evaluated, discussed and improvements are proposed.
k1	Nothing	Only the identification of model is verified through simulation tool.	Both, the identification of model and the control design are verified through simulation tool.	Both, the identification of model and the control design are verified through simulation tool and the results are discussed with real data.
k3	Nothing	The proposed computers tools are used buy only to verify the identification of model.	The proposed computers tools are used to verify both, the identification of model and the control design.	The proposed computers tools are used to verify both, the identification of model and the control design, and the results are discussed with real data.

Table 7. Averages ABET Score obtained by each student-group for the associated Lab-work Modality

Lab-work Modality	Student-Group	Average ABET Score (Student-Group)	Average ABET Score (Lab-Work Modality)
RL	1	4,4	**3,9**
	2	3,3	
	3	4	
	4	3,9	
R@L	5	3,4	**3,4**
	6	3,2	
	7	4,1	
	8	2,8	
RL+R@L	9	4,1	**4,1**
	10	4,3	
	11	4,1	
	12	3,92	

modality. On the other hand, Fig. 3 shows the distribution of usage, in terms of time, associated to each lab-work modality as well. In this case, the distribution has been obtained considering the average time obtained from partaking groups while carrying out specific activities during their own lab-work schedule.

It can be observed that there are significant differences between the average time spent by various groups following a particular lab-work modality. In this way, and following the multivariate analysis for this set of data [8] the hypothesis below were formulated.

In the first place, it should be noted that the groups who worked on the Remote Lab Modality (R@L) spent less time doing the experiment than the groups working in the other two lab modalities.

Although the first set of groups tried to compensate for such (remote) activity by devoting more time to doing math calculations, they did not perform well when assessing the whole experiment carried out with this lab-work modality. Moreover, performance seems to worsen if we consider that the set of activities in question is closely connected with the exploration of the model as well as with the design and implementation of the appropriate controller. These results suggest that such activities were not carried out properly by the R@L student groups, yielding an ABET-SCORE that is lower than those obtained by the groups in RL and RL+R@L Modalities.

On the other hand, and following the distribution of usage of Fig. 3 (in terms of time), it can be observed that the groups working in Remote Lab Modality [R@L], particularly regarding the simulation analysis and doing the experiment activities, spent less time than the groups working according to the other two lab-work modalities. In contrast, these groups (R@L) put more effort into doing math calculations. This observation may suggest that the time spent in doing these activities, namely simulation analysis and experiment execution, results in higher scores according to the ABET-SCORE criteria, as observed in the RL and RL+R@L cases.

Also, it is worth mentioning that, although the groups that worked in Remote Lab Modality spent more time reading the instructions, doing the math calculations and writing the final report, their performance was not as good when compared to the ABET-SCORE obtained by the groups following the other two lab-work modalities. In fact, it can be inferred that the R@L Groups spent more time doing the final report because the results obtained doing the experiment were unsuccessful, leading to an extra work-load (doing more math calculations) in order to replace the real model (experimentally extracted) with an approximation of the physical experiment.

As a final hypothesis, and taking into account the same Distribution Usage Time Graphic, it appears that the Hands-On experience that is associated with the Hardware and Assembly Connection activity and that is inherent in Local (RL) as well as in Local plus Remote Lab (RL+R@L) modalities, has a significant impact on the full development of the laboratory practice. This suggests that the groups still need to be in contact with the physical experiment in order to explore the estimated model in greater detail. Such a model can be obtained by grasping the way the system actually works and not by relying on intuition to have a basic idea of its operation, which was basically what happened to the groups that only worked following the Remote Lab Modality.

Finally, it can be observed that the average time spent by students doing the whole work (total time equals the sum of all time averages for each modality) is minimum for the RL+R@L modality as shown in Table 8.

Considering the hypothesis presented above, and acknowledging that there are particular differences (in terms of time distribution) between the Remote Lab Modality and the other two, further and clearer

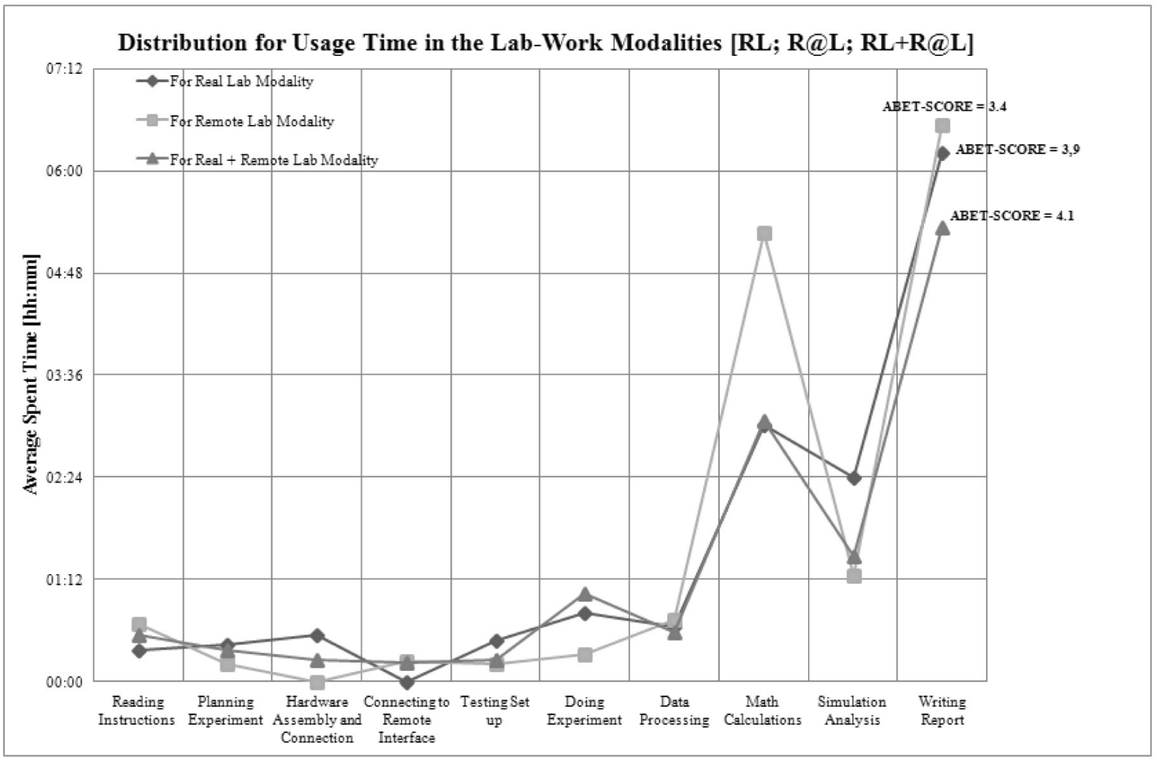

Fig. 3. Distribution for Usage Time in the Lab-Work Modalities [RL, R@L and RL+R@L].

Table 8. Total Mean Time Spent by Student-Group during the Lab-Work; ABET Score and Standard deviation for each modality [RL, R@L and RL+R@L]

Group Lab-Work Modality	Total Spent Time	ABET MEAN/ S.D
RL	14:55	3.88/0.8
RL + R@L	13:08	4.1/0.51
R@L	15:26	3.4/0.59

exploration of our analysis included a statistical treatment based on one-way ANOVA [19, 28] and Descriptive Statistics [13].

These statistics took into account the ABET-SCORE obtained for each laboratory modality as the final results of the quality of work presented by partaker student-groups regarding specific lab-work modalities. Table 9 shows the results obtained from the Analysis of Variance technique (ANOVA) when applied to the ABET-SCORE data set. Around this data set, interpretation of the previously presented hypothesis, based on such arguments, becomes more reasonable. The group modality represents the factor level and the ABET score is the variable of interest in our statistical model (the normality of the data for each group was verified through Shapiro-Wilk test and the homogeneity of variances—also called homoscedasticity—was checked through Bartlett test).

As shown in Table 9 for the ABET-SCORE, there is a significant effect across group modalities. This effect is associated to the proposed Academic Evaluation Protocol (AEP) taking into account that a Pr (>F) value of 6.01e-5 was obtained when running the ANOVA TEST over this small set of data.

Moreover, and based on Fig. 4, it is worth noting that the maximum difference, in mean and variance, obtained from this test occurred between the groups following the R@L and RL+R@L modalities. From this observation, first of all it can be said that the R@L lab-work alone, for the particular context of the present study, would not be a good option in order to attain the proposed pedagogical objectives of this evaluation; secondly, the Local (RL) lab-work modality seems to be a point of reference for the other two lab-work modalities. Additionally, the RL with R@L lab-work modality

Table 9. Results obtained from the ANOVA TEST applied to the ABET-SCORE achieved in the Lab-Work Modalities

	Df	Sum	Sq Mean	Sq F	Value Pr(>F)
ABET-SCORE	2	9.448	4.724	11.28	**0.0000601**
Residuals	67	28.067	0.419	—	—

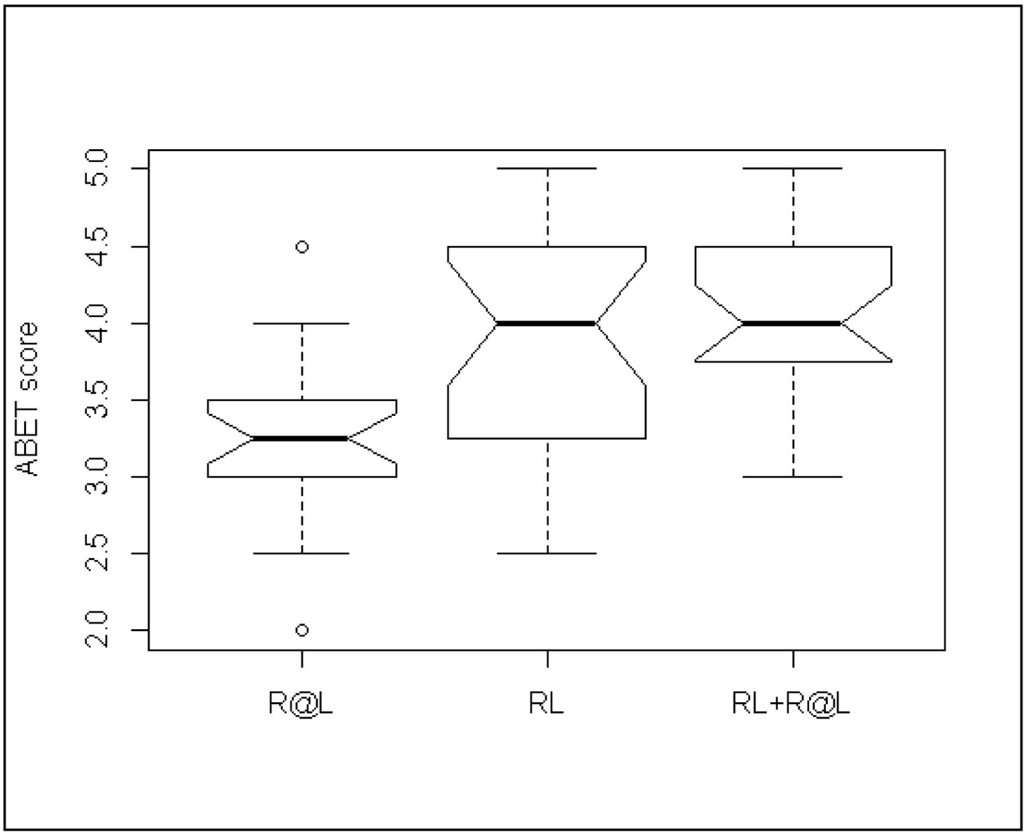

Fig. 4. Results obtained from the Descriptive Statistics based on ABET-SCORE given by the Lab-Work Modality.

(RL+R@L) seems to increase the amount of students who perform well if we consider that the mean for this lab modality rises slightly while the standard deviation decreases (to a lower value than that of the other two modalities).

In order to explore how the statistical differences change regarding quality of work between the three (3) laboratory modalities (changes in ABET-SCORE obtained for each modality), a Student's Test [20] (also called "t-test") based on this set of data was conducted, also starting from the hypothesis explained below, where it was suggested that a R@L modality alone seemed not to have an impact on the performance of the corresponding student-groups in order to properly carry out the proposed work.

Table 10 shows the results when running the t-test over this data sample, for which the pairs of the three (3) analyzed lab-work modalities are regarded as nominal variables and the ABET-SCORE as the measurable variable. The purpose was to clearly explore whether or not significant statistical differences occur between such modalities for the aforementioned hypothesis.

According to these results, which have been analyzed regarding the obtained p-value column as in [9], one can conclude that, the student-groups who worked only on the local plant (RL) perform better than the students who worked on the remote plant (R@L) only; students who worked on the local +remote plant (RL+R@L) perform better than the two others. However, the statistic results indicate that the maximum effect on the students' ABET-SCORE is due to the work on the local plant, indicating that there is no significant difference between working at the local laboratory (RL) and working at the local + remote laboratory (RL+R@L).

In other words, it can be said that working on the remote system (R@L) only is the worst case and

Table 10. Results obtained from the t-test applied between ABET SCORE reached in the three (3) Lab-Work Modalities

t-test	W Data	p-value
Between ABET R@L and ABET RL + R@L	116	**0.000302**
Between ABET RL and ABET RL + R@L	245.5	**0.3758**
Between ABET RL and ABET R@L	388.5	**0.03529**

according to the analysis performed, there is no statistical difference between working at the Local Laboratory (RL) or at a Local plus Remote Laboratory (RL+R@L). Therefore, the use of the remote system combined with the local one does not improve significantly the ABET score, ruling out the idea that by placing special interest in using only the remote system, an improvement in students' comprehension is achieved. However, the standard deviation of the ABET score for the "RL+R@L" group is quite low, which suggests that better results can be obtained for a larger number of students (a more homogenous group).

Even though for the application of the AET a few group samples were available, these were organized according to academic performance features representative of each of the participating groups. The purpose was to keep uniform profiles to be evaluated by running the test in such a way that the employed sample be kept as homogeneous as possible.

Considering the results obtained from the application of the Academic Evaluation Protocol, it was possible to examine some functional differences between a Local and a Remote Laboratory stemming from the way activities (to be performed in each of the proposed modalities) were carried out, indicating that, the groups who work with the local plant and then with the remote system (RL+R@L) are those who perform better than the groups carrying out the full experiment through the remote laboratory only.

These findings suggest that the Hands-On stage within the whole practice plays an important role in the development process associated to this kind of academic activity. This assessment considers the fact that the AET was applied over a control course usually accustomed to working at local physical-processes labs only.

On the other hand, based on the ABET results obtained from the presented evaluative test, it was possible to validate the significant working effect that occurs within the analyzed laboratory modalities, whose results (after applying the ANOVA test and the Descriptive Statistical method) show that a remote laboratory with no direct involvement in a local work modality is not a good choice since the local (physical) part still seems to be a point of reference for work in order to properly understand a particular experiment during this kind of academic activities.

7. Conclusions

The proposed Academic Evaluation Protocol (AET) has allowed analyzing significant differences between three types of laboratory modalities that can be employed in order to carry out an automatic control laboratory academic practice. Certain hypotheses have been presented taking into account two main points of analysis, first, how the activities to be developed, following the proposed lab-work modalities, are performed in time; and second, what the final quality of work is after an evaluation using ABET Indicators for each one of the presented lab-modality setups.

In this context, an automatic control laboratory using servo drive systems was successfully structured in order to analyze the differences between Local Real Laboratory (RL), Remote Laboratory (R@L) and a combination of both (RL+R@L). These differences were identified by modeling the dynamic distribution of the time devoted to each of the activities that constitute the various lab-work modalities as well as by the score of the final pieces of work. Such an assessment was based on the final ABET-SCORE obtained for each of the lab-work modalities in question whose results, once the ANOVA test and the Descriptive Statistical method are applied, show that a remote laboratory with no direct involvement in a local work modality is not a good choice since the local part still seems to be a point of reference for work in order to properly understand a particular experiment during this kind of academic activities.

Concerning future work perspectives, a more ambitious scope involves applying the presented Academic Evaluation Protocol (AET) to a control course from other national universities as well as to courses from an international institution, such as École des Mines de Nantes—France—where the results of this test could be cross-compared and analyzed.

Also we would like to explore the main differences that may be observed when implementing the proposed AET with student-groups from one university combined with student-groups from another university (e.g., Universidad de los Andes and École des Mines de Nantes). In order to accomplish this task, prior examination of result-cross-analysis methods or techniques is expected so that results between the dedication in time for each lab activity and the final results obtained from the quality-of-work assessment can be properly compared. This may lead to a more efficient design of tools to improve the learning process at a remote laboratory, making these experimental practices more similar to a local-lab experience.

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