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Improving Understanding and Motivation in Learning Transient State by Using a Remote Lab*

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The purpose of this study is to show how a remote lab (RL) is used to supplement theoretical courses for first- and second-year engineering students. This is an exploratory study. The study centers on their learning and motivation in using an RL to learn about the transient state. The main concern of the study is that students at this stage are not yet familiar with the equipment. The specific objectives of this study are as follows: (1) to demonstrate that using a remote lab as an aid in class during lectures about the transient state improves students' understanding and application of the concept; (2) to establish that it also motivates students while they learn. This study uses a mixed-methods approach. The quantitative part of the study employed statistical analysis (ANOVA) using a pre-test and a post-test to evaluate the learning of the following three groups: (1) with a traditional method (control group); (2) with a remote lab; (3) with a group using only a traditional lab. In the qualitative part of the study, data were collected to determine the students' motivations. The instruments used included a survey, observation (photographs), and classroom note-taking and recording. With this information, an analysis of categories was conducted to gather and triangulate the data. The results showed that the students were more motivated to learn and performed better when they used the RL. Supplemented by RL experiments during class time and as homework, effectively designed activities could improve the understanding and application of some engineering concepts.

Keywords: improvement in the understanding of concepts; motivation; transient state; remote lab

1. Introduction

The learning of undergraduate engineering students has evolved from traditional classroom lectures to active learning using modern technology like smartphones, computers, and tablets. Such devices have promoted the ubiquity of various software and social networks. In their first two years, engineering students take several theoretical courses. Then, in the third and fourth years, this experience is reinforced by experimental activities in a laboratory. However, for second-year engineering students, several topics present a challenge because the theoretical approach alone is insufficient. In the case presented in this study, second-year engineering students have to apply mathematics to solve problems that are in a so-called transient state. Hence, these students have to apply derivative and integral equations because this kind of problem (the so-called transient state) involves systems where the mass that enters the system is not equal to the mass that leaves the system. Therefore, there is a change in the mass in the system against time. Because of the mathematical applications that are needed to achieve a solution, students at this stage have difficulty understanding this concept.

Some studies demonstrated that modern tools, such as remote laboratories (RL), could help students to understand challenging topics [1], which could be the case in teaching the transient state in a mass balance. Cyber-learning, for example, includes key components such as technological innovation, student-centered learning, and teamwork [1]. These authors described a remote laboratory where the students created a real-time collaborative network using technology. They provided a statistical analysis of the students' satisfaction with regard to several topics related to the use of remote labs. Others studies elucidated a hybrid structure of hands-on, virtual, and remote laboratories called Trilabs [2]. In one report, the authors [2] concluded that the students tended to favor authentic experiments. However, a combination of authentic experience and a Trilab might enable the maximization of their learning outcomes. Researchers previously reported other combined systems. For instance, Bruns et al. [3] demonstrated a structure that merged on-site and remote participation in a laboratory, the results of which showed that this interface aligned with students' varied learning styles while improving their skills. Karakasidis [4] provided a thorough literature review, outlining previous reports published on this topic. In this in-depth investigation, the author summarized keys to improving educational results with remote labs, including proper activity design as well as a combination of appropriate software and real labs. Other studies have reached similar conclusions [5–8].

Recently, several articles have focused on remote laboratories [9–14], most of which reported the use of remote labs mainly to support practical experience in control, computational, robotics, the web,

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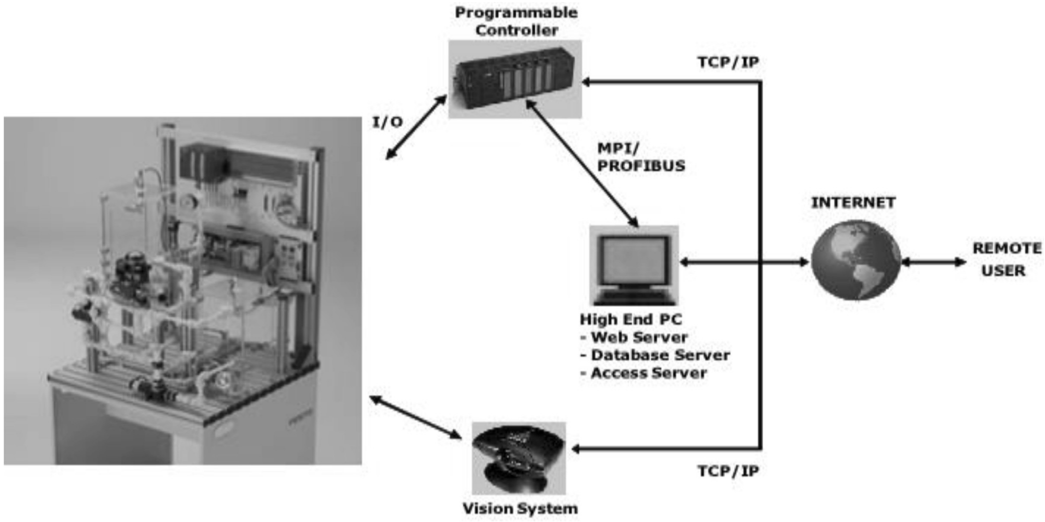

Fig. 1. The remote lab and its connections (modified from [4]).

and other related fields [9]. In recent years (2010–2015), studies have focused on innovative pedagogic methodologies for collaborative learning [12]. Studies on RL have showed that the students worked autonomously, thus breaking faculty-centered paradigms. Moreover, the facilities of RLs, such as access to remote equipment, are available 24 hours a day 7 days a week. RLs require lower investment and/or provide ease of access wherever students are, which implies that these labs can be used not only for improving skills but also for supporting conventional theoretical lectures in classrooms by ensuring user safety [12–14].

According to such studies [1–14], the best results occurred when remote technologies were combined with real laboratories. Several published studies applied the RL as a technique for improving real laboratory experiences. However, in the engineering curricula of some universities, the theoretical basis of this knowledge is reviewed separately by practical experiences. In a traditional theoretical class, time is very important because of the extensive amount of content to be learned. These theoretical explanations are often insufficient, requiring homework and other activities. With the RL, students can use the theoretical explanation without spending the time needed to cover the extensive list of other topics. In a previous study [5], some current researchers investigated the use of RLs by statistically analyzing students' perceptions and motivations. This previous report motivated the current study, which aims to evaluate the level of learning achieved when students used the RL for the specific topic of the transient state in a mass balance. The results showed that the simultaneous use of a remote lab in the classroom could improve the learning of theoretical topics such as the concept of transient state. This topic is notorious for being difficult, and new students find it extremely confusing. The sample used in this study comprised students that were currently taking a course in material balance. Although some students were in different engineering programs, some were local students, and some were foreign students, all participants had the same level of previous knowledge in this course. This criterion was important for measuring the learning performance with the combined model proposed in this study.

1.1 Transient state learning activities and the remote lab

In conventional courses on material balance, the instructor explains theoretical concepts in lectures (two 1.5-hour classes per week). Then the students apply the concepts in homework problems outside the classroom, which requires five hours per week. To assist the students' learning, sometimes the instructor provides real practice in the laboratory, which means an extra three hours of work each week. However, there is a time gap between the classroom and the laboratory. In other words, there is a gap between theory and practice.

The RL equipment comprises a tank interconnected by pipes in a closed circuit. The system is fully automated and connected to a network card, which allows for remote manipulation, as described in [5]. Fig. 1 illustrates this configuration.

The RL access interface is used as a work tool that enables the teacher and the students to interact with the process and verify its operation in real time. The access interface, which can be projected onto the whiteboard in the classroom, is composed of two parts: the graphic user interface and the audio-video interface, both of which are used to control and modify the process being conducted. The graphic user interface functions as "the hands" of the user in the laboratory. The audio-video interface is the "eyes and ears" of the user in the laboratory, enabling observation of the actual process and its behavior [5].

The classroom activities that can be done with the RL are diverse. Students can fill and measure the tank and the time needed to complete this process. They may do the same when they drain the tank and perform measurements of time and calculations. These activities take place during class time while the teacher is explaining the concept of the transient state. The teacher accesses the RL and projects the real process on the whiteboard by remote control using the lab equipment. It is also possible to solve extremely difficult problems, such as leaving the tank half-empty and calculating how much water exits it at certain time intervals. Students can also build a mathematical model of the outlet mass flow rate as a function of time while draining the tank. Hence, the RL enables students to learn the concept and watch the real process at the same time. A previous paper regarding this use of the RL provides a detailed description of these activities [5].

2. Methodology

This research used a mixed-methods approach [10] that combined quantitative data with a unique qualitative case methodology. This approach is an exploratory research because of the new idea of students using the RL while a lecture is given. This design has allowed investigating a new situation without prior information. In the quantitative section, a test instrument is applied in two parts: the first part includes questions related to the understanding of concepts having to do with unsteady state (or transient) processes, whereas the second part involves the application and the solution of problems involving the unsteady state. This test was applied before and after teaching students about the transient state in order to compare previous learning and post learning. The same test was applied in both cases. In the qualitative part, date was collected about students' perceptions and motivation. The instruments used included a survey, observation (photographs), and note-taking and recording in the classroom. The instruments and data analysis are described in sections 2.2 and 2.3.

2.1 The selected sample

A sample was taken from seven groups in the material balance course given during the semester from January to May 2016 at the Engineering School of the Tecnologico de Monterrey. Three of these groups were chosen for participation in this study in order to maintain the same grading policy and the same teacher. This decision was not random because there was no control of the groups that were not selected because the teachers of the latter did not know how to use the RL in this innovative approach. However, when the groups were selected, there was a random selection of which of the three groups would be (a) without the RL and using the traditional method, (b) with the LAB meaning that the go to the physical lab, and (c) with the RL. In addition, to ensure consistency in the sample of students, it was necessary that the three groups were similar in the number of students per group and, more importantly, in their previous knowledge. The purpose of the study was to compare previous and post achievements in the results of the students' learning. A demographic survey of the three groups was then conducted.

Table 1 illustrates the results of the demographic analysis of the sample, which were used to validate that the three groups were similar: no group had an advantage or disadvantage at the beginning of the course. The traditional method (TM) group was taught about the transient state using a traditional method (lecture). The so called "LAB group" also learned about the transient state but with the addition of one practical experiment in the lab. Finally, the RL group was taught simultaneously with the RL in the classroom while doing exercises in class. The results of the demographic survey showed that although one group differed in terms of gender, it was not important for the purposes of the present study. The important variables were the students' semester and average grade at the time of taking this class. The other groups did not differ significantly in terms of gender. Almost all students in the three groups were of the same age, and they were all at a similar point in their studies. The students' average grades at the university at the time of this investigation were also similar in all three groups.

There were further similarities among the selected groups. All three groups comprised students in

Table 1. Demographic study of each group

	Gender		Age			Semester			Average Grade			
Group	F	M	Median	Mode	Mean	Median	Mode	Mean	Median	Mode	Mean	SD
TM	9	15	20	20	19	4	4	4	84	81	84	0.20
LAB	2	11	21	21	21	5	4	5	81	81	81	0.23
RL	11	10	20	20	19	4	4	4	84	80	84	0.18

different fields of engineering education: chemical engineering, industrial engineering, food industry engineering, biotechnology, and sustainable development engineering. Despite their different areas of focus, all students had studied material balances at the same academic level. All three groups included students from different cities and countries (not all of them were local students). Almost 60% of each group was from Monterrey, while approximately 5% was from other countries. Another important aspect of these groups is that all students reported having taken the derivatives and integrals course, so they (100%) were familiar with applying this mathematical methodology when solving the problems in material balances in the transient state.

2.2 *The instrument (pre/ post-test)*

The instrument, which was used in all three groups in order to measure the results of previous and post learning about the transient state, was applied in a questionnaire that had two sections of questions. Both sections were related to the transient state. The first section included questions that required the participant to demonstrate the understanding of the concept by analyzing the following general material balance equation: "input – output + production – consumption = accumulation." The second section included questions about the application and solution of a problem related to the transient state. The participants had to apply mathematics (derivatives and integrals) to solve the problem. The questions in both sections were graded either correct or incorrect.

2.3 *Validation and consistency of the instrument (pre/post-test)*

The validity of an instrument refers to the degree to which the instrument measures what it purports to measure. The reliability of the internal consistency of the instrument can be estimated by Cronbach's alpha [16]. The content of any instrument is valid if the expert on the subject is the one that makes the questions or problems for the instrument that is going to be used to measure. In the present study, the questions and problems were taken from the textbook that is used for this assignment. Although the author of this textbook is an expert, this test was reviewed by other colleagues that teach the subject to ensure the validity of its content about the learning results of understanding and applying transient state in order to solve problems. For consistency, Cronbach's alpha was applied in the following formula:

$$\alpha = (K/K - 1) * (1 - (\Sigma Vi/ VT))$$

where

α = Cronbach's alpha
K= Items' number
Vi = Variance of each item
ΣVi = Sum of variance of each item
VT= Sum of total variance

Self-assessment Post-Test

This is a self-assessment test that can give you feedback about your knowledge. It will also give you feedback about a research study in engineering education. If you agree to participate, please provide your name, signature, and date before answering the questions below.

Name: ____ **Signature:** ______________

Date: ___________________________

Please answer the following questions:

1. Balances are to be written for each of the quantities listed below for a continuous process. In each case, state the conditions under which the balance equation takes the simple form "input = output". * [15, p. 89]

1.1 Total mass.

1.2 Mass of species A.

1.3 Total moles.

1.4 Moles of species A.

1.5 Volume (The answer provides an indication of why volumes should be converted to masses or moles before balances are written).

2. Water enters a 2 m^3 tank, at a rate of 2 kg/s and is withdrawn at a rate of 3 kg/s. The tank is initially half full. * [15, p. 155]

2.1 Is this process continuous, batch, or semi-batch?

2.2 Is it in a transient or a steady state?

2.3 Write the mass balance of the process. Identify the terms of the general balance equation presented in your equation and state the reason for omitting any terms.

2.4 How long will it take the tank to drain completely?

Fig. 2. Self-assessment post-test. The questions were adopted from [15].

According to Huh et al. [17–18], in exploratory research, the value of reliability must be equal to or greater than 0.6; in confirmatory studies, it should be between 0.7 and 0.8. In the present study, because it is an investigation of an innovative approach to apply RLs in class during lectures, the acceptable range of α should be between 0.6 and 0.7. The results of the pilot study using three groups showed that $\alpha = 0.63$. However, only the first section of the instrument (1.1–1.5) showed a result of an average $\alpha = 0.70$. Because this is an exploratory research, these results indicated that the instrument has validation and consistency at this stage.

2.3.1 Statistical analysis of the quantitative section

In the instrument pre/post-test, section 1 had a value of 50%, and section 2 had a value of the remaining 50%. This test was applied as a quiz before and after the students started to learn this subject (pre-test and post-test). The test was evaluated by using a scale from zero to 100. After grading each test, a statistical method was applied in order to determine if the two sets of data (before and after and between each group) were significantly different from each other (pre- and post-test). Because there were three groups to compare with the pre- and post-test, the statistical F test was applied using the software, the Statistical Package for Social Sciences (SPSS). In this study, the hypotheses were as follows:

Null hypothesis (H_o) = There is no difference in students' performance when learning about the unsteady state when using an RL during class time.

Alternative hypothesis (H_1) = There is a difference in students' performing when learning about the unsteady state when using an RL during class time.

In order to compare the difference and the significance between the results of the pre-test and post-test, we performed an analysis of variance (ANOVA). In its simplest form, the ANOVA provides a statistical test of whether the means of several groups are equal, therefore generalizing the "*F statistical treatment*" with more than two groups. Finally, the SPSS was used to analyze the results to enable comparisons of the differences in learning achievement among the three groups in the study.

2.3.2 Analysis of the qualitative section

In the qualitative section, the instruments used were observation, note-taking during the entire teaching/learning experience, and a learning perception survey of only the students who used the RL. This survey had two open questions (see Table 4). The data were analyzed as follows. All the answers to the survey were gathered, and this information was reduced to sentences that represented the main ideas expressed as the students' perceptions. This was done by counting the number of repetitions of words and similar sentences [11]. This process helped to understand the students' perceptions at the time the survey was conducted. The qualitative results were validated by triangulation of the observations, the teacher's notes, and the analysis of the opinions that were repeated.

3. Results and discussion

3.1 Quantitative results

The pre-test and post-test, which were given to the students before and after learning the transient state, respectively, included basic questions about the concepts and the application of mathematics to solve a related problem. The pre-test and post-test included questions and problems that were adopted from textbooks in the literature that are well known in teaching material balances. In this case, we used the information from [15]. As shown in Table 2, the SPSS software was used for the statistical analysis of the results of the pre-test and post-test.

The results showed that the LAB group had the lowest grade (average) in the pre-test, and the TM and RL groups had the same average grade. As

Table 2. Grade averages from the pre-test and post-test (N = Number of items = 9, total items to analyzed = 18, Number of students per group that answered the test = 23 per each group)

Test		Group TM	Group LAB	Group RL
Pre-Test	Average	34.33	29.33	34.33
	N	9	9	9
	Typical Dev.	20.025	23.000	17.769
Post-Test	Average	54.22	48.22	62.89
	N	9	9	9
	Typical Dev.	26.466	27.087	21.450
Total	Average	44.28	38.78	48.61
		18	18	18
	Typical Dev.	24.961	26.242	24.103

expected, the results showed that the average grades after the lecture and the related activities were improved in all three groups, but the improvement was better in the RL group than in the others. However, unexpectedly, in the post-test, the LAB group had the lowest average grade. This unexpected result could be explained from different points of view. The student performance of the LAB group had been the lowest compared to the other groups before the test was applied, so probably this group had been since the beginning of this study the group with lower academy achievement students. Another issue is that when students go to the lab only once (as in this case) as an extra activity for a theoretical course, it is probably not enough to enable understanding of the subject, which usually requires more time. The comparison between the RL and the LAB groups is complex because other parameters could affect the results. The main purpose of this study is not to compare the learning of the RL group with the learning of the LAB group but to investigate and recommend more effective tools for teaching engineering students during classes. In order to obtain the significance (SIG.) of the differences in the results of the pre-test and post-test for each group, the analysis of variance (ANOVA) was applied by using the SPSS.

Table 3 illustrates the statistical results, which confirm the alternative hypothesis (H_1): There is a difference in students' performance when learning about the unsteady state when using a RL during class time. The hypothesis is confirmed because the grades obtained by the RL group had a higher "F treatment" (9.459) and were significantly different at SIG = 0.007, which was statistically consistent at 99.3%. In this analysis, significance (SIG) must be less than 0.05.

As previously discussed, the demographic data of all groups did not reveal additional information about performance. One or more of the three groups sometimes showed a particular behavior that could have affected the results (e.g., motivation or the students' conformation in a study team). These features were not evaluated here.

As previously noted, the students in the LAB group needed more time in the lab to improve their understanding and problem solving with regard to the transient state. This finding does not imply that the physical lab is not beneficial for students. Instead, it indicates that in teaching a theoretical course, it might be less beneficial to take students to the lab because of the amount of time needed to achieve a minimum understanding of the concept.

3.2 *Qualitative results*

We conducted a survey to gather information about how the students felt about their learning of the transient state. This survey was given to the three groups (TM, LAB, and RL). There was an open-ended question in the survey: "What would you like to see included in class time while learning about the transient state that would motivate you more?" We analyzed the answers by placing them in categories according to similar meanings. The results are shown in Table 4. It is important to note that there was another open-ended question in this survey, but it was applied only to the students in the RL group: "What did you like about the remote lab?" We placed all comments within categories by selecting some of the most frequently repeated sentences. These results are shown in in Table 4.

Table 4 provides a comparison of the students' perceptions about learning the transient state concept while using a lab (physical or remote). The results shown in Table 4 indicate that most students felt that they needed to see the process in order to learn the concept even though they had just learned about it in a lecture. The results also showed that the students that used the RL were more eager to learn and understand the concept when they had the experience of learning while simultaneously watch-

Table 3. Analysis of variance (ANOVA) applied to the three groups using SPSS comparing pre- and post-test

		Sum. of Squares	**D.F.**	**Root Mean Square**	**F**	**SIG.**
Group TM	Inter-Groups					
	(Combined)	1780.056	1	1780.056	3.232	0.091
	Intra-Groups	8811.556	16	550.722		
	Total	10591.611	17			
Group LAB	Inter-Groups					
	(Combined)	1605.5561	1	1605.556	2.543	0.130
	Intra-Groups	10101.556	16	631.347		
	Total	11707.111	17			
Group RL	Inter-Groups					
	(Combined)	3669.389	1	3669.389	9.459	0.007
	Intra-Groups	6206.889	16	387.931		
	Total	9876.278	17			

Table 4. Results of the qualitative analysis

"What would you like to be included during class while learning about the transient state that could motivate you more?" (question asked to all groups)	"What did you like about the remote lab?" (question asked only to the group that used the RL)
"*Go to the lab and analyze the process while watching*" (29%) "*We need more real-life examples*" (23%) "*Videos, they help me a lot*" (11%)	"*I liked that we were able to witness a real-life example*" (33%) "*We could see how a process works*" (24%) "*Very easy to understand*" (19%) "*I understood the process we did in paper*" (14%) "*It's new, different, and entertaining*" (10%)

Table 5. Students answered this question: "What could motivate you to learn more about the transient state in class?"

Groups	TM	LAB	RL
Without a remote lab	30%	25%	22%
With a remote lab	70%	75%	78%

ing the real process. This finding is very important for engineering education because students in the third semester are just starting to become familiar with industrial equipment. Therefore, they find many concepts difficult because they cannot connect the theoretical mathematics with the real process (e.g., material and energy balances). According to the results of the present study, it did not seem to matter that they had learned differential equations and calculus before encountering material balances. With regard to the RL, it has the advantage of being used at the same time that the teacher is explaining the concepts on the blackboard. Therefore, it is possible to showed a real process in class while doing the calculations due to the RL.

Finally, the survey included a closed question: "What could motivate you to learn more about the subject of transient state while learning in class: (a) traditional class (lecture) or (b) access to a remote laboratory (real process) from the classroom?" All three groups were asked this question. Table 5 provides the results.

Most students answered that they would prefer to have a RL to learn these concepts even though some of them had not used the RL. Therefore, the results shown in Table 5 demonstrated the importance to engineering students of the practical application of their calculations in order to achieved a better understanding of the balance of materials in the transient state.

4. Conclusions

Three groups were evaluated using pre- and post-tests to assess their learning of the transient state in the mass balance course. Each group used a different approach to learning the transient state in material balances. The quantitative results showed that the remote lab (RL) improved the learning process in a theoretical course for engineering students to a greater extent than in the two groups that did not use the RL. The results of the statistical analysis showed that the RL group was significantly different ("better" in their learning improvement) compared with the TM and LAB groups with a statistical significance of 0.007 (99.3% consistency). Moreover, the qualitative results showed that the students were more motivated because RLs are the technology of the new age and are able to show them the real equipment while learning. In addition, the time used for the practice in class was no longer than that required for a traditional lecture.

There is no conclusion regarding the "real" lab in this study. However, to complement classes with practice in a physical lab is important; there is no question about its usefulness. However, it is impossible to conduct a theoretical course if students are in the lab all the time. Hence, the RL can provide an effective supplement to the traditional lecture. Using the RL while teaching the transient state allows the teacher to keep students motivated and engaged in their learning. The RL allows the users to perform experiments in the classroom by using the internet and following simple indications. In only a few minutes, the students can learn to operate the equipment, and they can even repeat the experience at home using their computers or their tablets.

Effectively designed activities supplemented by RL experiments during class time and in homework could improve the understanding and application of some engineering concepts. The RL could be useful in augmenting both theoretical lectures and laboratory courses.

The present exploratory study focused on the use of RLs during lecture classes. Future research could further explore the use of innovative technology such as RLs to encourage the active learning of engineering students. The use of technology such as the RL could be helpful in teaching and learning not only in the engineering field but also in other educational fields.

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