# NOVEL USE OF A REMOTE LABORATORY FOR ACTIVE LEARNING IN CLASS

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Active learning engages students in the process of learning through activities and discussions in class; it emphasizes higher-order thinking and often involves group work.[1] This could provide a dynamic active learning environment in today's classroom. Engineers in leadership roles are required to have a great number of competencies to properly meet societal needs. To better educate the nascent leaders while they are working on their university studies, the learning infrastructure needs to be continually revamped and teachers' instructions adapted accordingly. Such a dynamic learning environment is essential for a sustainable society. This means ensuring that graduates are able to apply theoretical knowledge to industrial problems and possess theoretical comprehension, understanding of the concept,[2] creativity and innovation, teamwork, technical aptitude, and business skills.[3]

There is a tendency for educational institutions to seek better ways for developing the competencies and skills students require for their professional future.[3,4] The remote laboratory (RL) project is part of a larger instructional improvement program at the Tecnológico de Monterrey in México, which is part of a new university model that incorporates greater interaction with industry.[4]

To achieve the aforementioned goal in engineering education, the incorporation of demonstrations and hands-on applications of concepts and processes is crucial. However, there are practical limitations regarding the schedule and space available to carry out laboratory experiments. The incorporation of remote laboratories into a lecture class provides a solution to this predicament.

An RL demonstration is the application of a distant automated operating process system by a classroom instructor

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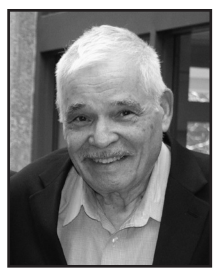

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who controls the presentation for the students. The RL allows the students and instructors to have a real-time image of the experiment; students and teachers can simultaneously see, via experiments, the application of lecture principles and theories. Because the demonstration is completely automated, remote equipment can be operated all day, seven days a week, unless the equipment is being used by someone else, allowing for the flexibility to schedule laboratory demonstrations that directly complement classroom lectures. There is an Internet system with which one hour can be reserved for the use of the RL. This is all possible because of the current advantages of audio and video streaming via the Internet.

The main advantages of using the RL instead of a live demonstration are: (1) it provides a unique opportunity to incorporate "real" demonstrations into an active classroom/active learning environment (allowing all students to watch and participate actively during class time), (2) it saves the time needed to carry the equipment to the classroom, (3) it would be difficult to build a tank with water coming in and out to demonstrate transient state that was big enough for everybody to see the details in a large class (30–60 or more students), and (4) when projecting the RL on the classroom screen, it is easy to zoom in and focus on the details of the process. Above all, the expected impact of RL demonstrations into traditionally theoretical courses is that students and teachers can simultaneously see, via experiments, the lecture principles and theories during the class time. This adaptation to classroom learning should achieve a better understanding of concepts by students. Comprehensive studies have been published regarding the need for active learning for university introduction and how to implement active learning in the classroom.[1,5,6] Furthermore, the use of experimental activities as part of the course activities motivates and engages the students in an active learning[1,7] environment, improving the experience during the teaching-learning process.

The RL demo approach is an educational innovation that allows interaction with an experiment at the same time the teaching-learning process takes place in the classroom. In this way, the teacher is able to connect theory with real practice (by having remote access to the laboratory using cameras) in his or her own classroom. In addition to using the laboratory apparatus at the same time as learning the theory, students conduct experiments remotely as part of their homework assignments.

This paper describes an RL demonstration for Material Balance classes for the development of competencies of engineering students. Although the demonstration was originally designed for a specific engineering class, it can also be extended to other courses, other disciplines, and other universities. The current article is a significant extension and enhancement of Ramirez and Macias[2] that adds a brief summary of active learning, results of administering the Index of Learning Styles in conjunction with the remote laboratory, and examples of how a remote laboratory is used in the classroom. Sections 1. "Remote Laboratory presented," 2. "Remote Laboratory description," and 4.3 "Analysis of the perception of students regarding their own learning using this educational model" are essentially the same as the previous article.

## BACKGROUND ON REMOTE LABORATORIES

Engineering is a practical discipline; it is a hands-on profession for which doing, and consequently learning by doing, is a very effective teaching method. In this sense, common laboratory course goals are to relate theory with practice and to provide motivation, either to continue in the study of engineering or to follow a particular course of study.

Laboratory exercises could help with student retention and student satisfaction. Another issue in the process of teaching engineering is that although engineering programs have become more theoretical, industry continues to require individuals who possess practical skills. By 1981, when IBM introduced its PC, it became a real breakthrough in computational power that changed laboratory instruction. "By the mid-1980s, engineering schools were developing laboratories that made more effective use of the computer in collecting and analyzing experimental data."(p. 124)[8] National Instruments developed a program called LabVIEW, which is a combination of software and hardware that turns a personal computer into a data-acquisition device and a set of simulated instruments. This can be used to control instruments remotely—meaning that students can not only simulate virtual outcomes of experiments, but can also control real instruments while they are located elsewhere.

While this level of automation might somewhat remove students from the direct process of the laboratory experience, it can be argued that it has also extended them into areas that are impossible to explore.[8]

In 1996, a network application developed at Oregon State University called "Second Best to Being There" (SBBT) was published. This network could provide remote laboratory users the opportunity to conduct experiments in a local laboratory. The goal was to make the already available equipment accessible to more students via the Internet. This was implemented using a User Datagram Protocol/Internet Protocol (UDP/IP). It was applied mainly for teaching controlled systems, and the experience gained is said to be the same as with the real equipment. "Many distance-learning applications involving classrooms emphasize the use of audio and video to create the sense of being present (telepresence)." (p. 321)[9] This SBBT replicates the local laboratory environment for the remote student. It is stated that a successful distance learning application should have three major components: (1) active learning, (2) data collection facilities, and (3) safety.[9]

Also in 1996 Jim Henry at the University of Tennessee, Chatanooga, (UTC) developed a ChE RL in controls. By 2003

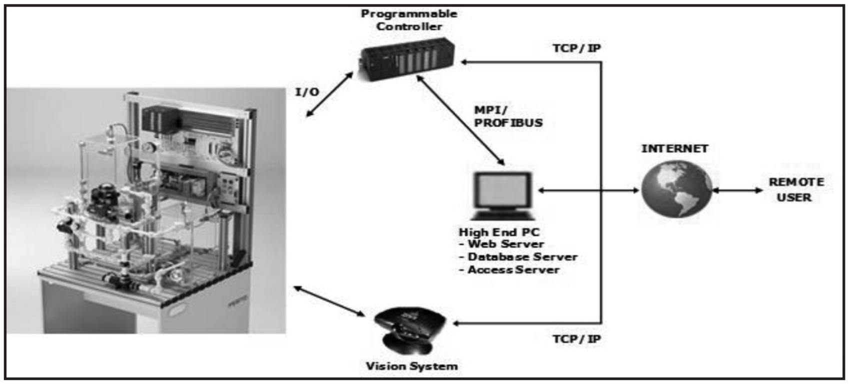


***Figure 1.*** *Interconnection schemes for the Remote Lab.*[2]

additional experimental stations were developed for conducting RL experiments. The students ran the experiments at any time from any location on the Internet. For chemical engineering students, the stations were operated in a manual mode to observe the equipment's typical operating characteristics. The stations developed were: Packed Column Absorption, Distillation, Heat Exchanger, Flow Through Porous Media, Batch Dryer, Pressure Swing Absorption, and Gas-Fired Water Heater. The desired learning outcomes for these students were achieved by using the remote controlled equipment. Some of these learning outcomes were: learn by doing, guided discovery, demonstrate by experiment the phenomena developed in lecture or textbook, design of experiments, collection of data, analysis of data, and presentation of data and results.[10]

The use of a remote laser laboratory experience in the area of laser engineering was discussed in 2012. One problem is that the laser can pose an immediate threat to an unskilled operator, and another problem is that having larger-sized groups working in the lab is not compatible with a clean environment and reproducible results. Therefore, the remote laser laboratory contributed to cost effectiveness and to overall safety.[11] Also in 2012, RL had brought practical sessions online and provided workbenches that were not constrained by geographical or time considerations for electrical and computer engineering education. RL also contributes to satisfying the role of laboratories in the current ABET engineering criteria (2012–2013). A student survey showed that students were very satisfied with the use of RL.[12] RLs provides an opportunity to make more use of the laboratories, not only those on site but also those that can be used online. In 2013, a new version of RL was introduced that did not require an expensive and proprietary software package, such as LabVIEW, to function. This universal laboratory (uLab) is not only open-source, but also is built entirely upon open source software and open hardware.[13]

The literature indicates that RL applications are not new; however, the authors of this article have not found any uses of RL to complement lectures for a Chemical Engineering Material Balance class that also promotes active learning

***The RL allows the students and instructors to have a real-time image of the experiment; students and teachers can simultaneously see, via experiments, the application of lecture principles and theories.***

while being in class. This technology could be easily extended to any university at any time. The university needs to have Internet access and LabVIEW installed and computers with Windows. The permission from the RL main administrator is available for sharing.

## DEVELOPMENT

### 1. The Remote Laboratory presented (RL)

The RL was designed for an engineering class from the Department of Chemical Engineering and taught to third-semester students studying chemical engineering, industrial engineering, food engineering, sustainable development engineering, and biotechnology engineering. On average, 300 students take this course each semester at Tecnológico de Monterrey in México. The material balances topic for which the laboratory is mainly used is transitient operations, wherein differential equations are needed and used to solve practical process problems. Given how diverse the students' profiles are, the remote laboratory can be of great help to comprehend the topic.

Prior to the use of RL demonstration, the teaching-learning process of material balances had been mainly traditional, just lecturing only to passive students. This process has undergone recent modifications, with teachers introducing examples with their computers as well as active learning techniques.[14,15] However, none of these teaching methods in the classroom had implemented the visualization of a system with inputs and outputs to a process vessel. Transient operations can be controlled and observed in the classroom simultaneously while the teacher explains (or answers student questions about) the basic concepts of material balances in real time.

### 2. Remote Laboratory description

The RL is 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 (Figure 1).

The RL access interface is used as a work tool so the teacher and students can 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. The Graphic User Interface functions as "the hands" of the user in the laboratory, and it is used to control and modify the process being carried out[2] (Figure 2). The Audio-Video

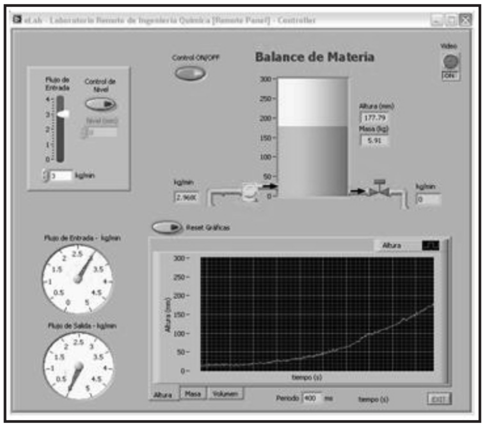


*Figure 2. Graphic User Interface..*

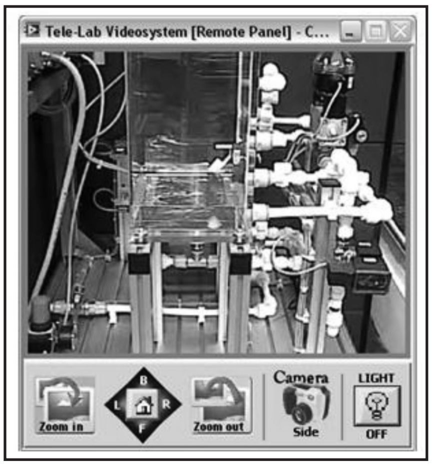


*Figure 3. Audio-Video Interfaces.*

Interface (Figure 3) is the "eyes and ears" of the user in the laboratory, and it is used to observe the actual real process and check its behavior.[2]

### 3. Use of remote laboratory in the classroom

First, the teacher performs a virtual tour of the laboratory via a live feed projected onto a screen in the classroom using the Audio-Video Interface, while the equipment's components are described. This is how students observe and familiarize themselves with the details of the system. The teacher can use the camera to zoom in so students can observe the tank and pipes, the intake and outtake sections of the tank, the flow, the control valves, and the entire water transport circuit of the process.

Afterwards, students calculate the tank's dimensions to obtain its total volume. Based on water density they can determine the tank's maximum capacity of water in mass (10 kg). Then, the students use the Graphic User Interface to observe that only the input mass flow can be constant and controlled (with a maximum capacity of 4 kg/min) and there is no output flow control for the tank because it is assisted by gravity. The outlet valve can be controlled only for opening or closing the system, but there is no mass flow control. The teacher proceeds with various exercises:

- ***Exercise 1.*** The teacher projects on the classroom´s screen the Audio-Video Interface (so the students can watch the processes) and the Graphical User Interface, sharing on the blackboard the material balance equation: $dm/dt = m_{in} - m_{out}$. The question that follows is: If I keep the outlet valve closed and the inlet valve open at the maximum flow rate, how long will it take to fill up the tank with water? (Total tank capacity = 10 kg). The students then start experimenting with the RL and with a chronometer in hand to take the time, after which they do the math to calculate the time by solving the transient state model previously presented by the teacher. They then compare the results (experimental vs analytical).

- ***Exercise 2.*** The students have the tank filled and the inlet valve closed, but the outlet valve is open and the students have to determine the time it takes to empty the tank. They first do the experiment with the RL and then with the calculations, using the previously used mathematical model (the material balance). They realize that the mass flow rate is leaving the tank faster than when the experiment was done with the mass flow rate entering the tank. The students discuss in class what is happening in a transient state real process, its parameters and limitations.

- ***Exercise 3.*** In this exercise (with the tank half-full) the inlet valve is kept at a maximum mass flow rate (4 kg/min) and the outlet stream is open, and because the flow rate for the inlet and outlet streams are not equal, the students must calculate the time it will take to reach some level of mass in the tank. Again, students first do the experiment and then the calculations.

- ***Homework.*** To continue doing experiments outside the classroom, students have to access the RL lab (with their computers or tablets from home or anywhere with Internet connectivity). Students make different experiments at home. They build a graph that could help them create a mathematical model of the outlet stream behavior: $m_{out} = f(t)$. This homework is done individually and then in teams of three.

Students then perform different tests with the equipment to analyze its operation, waiting times, and behaviors observed on the graph (the Graphic User Interface, which could be used to measure the level, mass, or volume against time). Additional examples are conducted this way, experimenting in the classroom until there is a full understanding of the concepts and application of the topic. The laboratory is also used to explain other basic topics: flow diagrams, industrial equipment, steady state, etc.

### 4. Analysis and discussion of the results

Three specific actions were conducted to evaluate the impact of the remote laboratory instruction mode on students' learning, namely: (1) analysis of variance of the applied exam, (2) evaluation of learning styles, and (3) surveying the students regarding their perception of their own learning.

### *4.1 Analysis of Variance (ANOVA)*

For this analysis, the samples were two groups of material balances students, both from the third semester of the engineering field. Fifty percent were men and 50 percent were women. The analysis of variance was applied on the third exam for both groups; one of the groups was the control with no use of the RL, and the other group was experimental with the use of the RL. This exam evaluates the learning outcomes expected for the subject of material balances with transient state and was exactly the same exam for both groups. The control group had 21 students (January–May 2014 semester) and the experimental group had 30 students (August–December 2014 semester). The teacher was the same for both groups with the same teaching material and strategy. The only difference was the use of the RL in one of the groups. With the purpose of proving that the group of students that used the RL performs better than the one that did not used the RL, the analysis of variance was applied using the SPSS (Statistical Package for Social Sciences) to compare the average grades obtained by both groups in the exam. From a statistical point of view, what has to be proven is that the statistical average from each group is different (see Table 1).

The average grades on the experimental group are clearly higher than in the control group, but this has to be proven statistically by means of the sample and not of the whole population. To prove this, the ANOVA was used to do the analysis of variance and the results are shown in Table 2. The null hypothesis was that the means of both groups were equal, meaning that the RL had no effect on student performance on the exam. This hypothesis has to be rejected ($\alpha$ must be less than 0.05). The results from the ANOVA showed that this hypothesis is rejected with $\alpha = 0.01$, which means that the significance is high for these data and that the use of the RL helped to increase the performance of the students' grades on their exams.

**TABLE 1**
**Learning results for Control and Experimental group average on test**

| Group | Average Score | Number of students | Standard Deviation |
|---|---|---|---|
| Control | 73.6 | 21 | 20.32 |
| Experimental | 88.5 | 30 | 10.52 |
| All | 82.4 | 51 | 16.86 |

### *4.2 Learning style analysis*

The research approach used to evaluate learning styles was quantitatively based, using a closed-ended questionnaire. The purpose of evaluating the tendency of some learning styles in students was to confirm that RL technology aids in the learning process. The sample used consisted of two groups of material balances students from the semester August–December 2014 (40 students were in each group; in one group, only 35 answered and in the other group only 30 answered. See Table 3.), and the test was applied before using the RL. These students were different than the ones in the ANOVA analysis because the author did not want the students to have prejudicial feelings toward the RL. The evaluation of the learning styles was conducted according to the method presented.[16] This method posits that a student's learning style can

**TABLE 3**
**Strengths of preferences of the learning styles**

| | Active-Reflective | | | Sensory-Intuitive | | | Visual-Verbal | | | Sequential-Global | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mod-Str Act | Mild | Mod-Str Ref | Mod-Str Sens | Mild | Mod-Str Int | Mod-Str Vis | Mild | Mod-Str Vrb | Mod-Str Seq | Mild | Mod-Str Glo |
| G1 | 51% | 29% | 20% | 71% | 23% | 6% | 77% | 14% | 9% | 57% | 29% | 14% |
| G2 | 43% | 30% | 27% | 53% | 33% | 13% | 73% | 13% | 7% | 63% | 33% | 3% |

G1_ Tecnológico de Monterrey, Campus Monterrey, Material Balance Student's, group 1, N= 40 (35)
G2_ Tecnológico de Monterrey, Campus Monterrey, Material Balance Student's, group 2, N= 40 (30)

**TABLE 2**
**Analysis of Variance (ANOVA)**

| | | | Sum of squares | df | Root mean square | F | Sig. |
|---|---|---|---|---|---|---|---|
| Grades from control group * comparing groups | Inter-groups | (Combination) | 2753.004 | 1 | 2753.004 | 11.766 | .01 |
| | Intra-groups | | 11464.643 | 49 | 233.972 | | |
| | Sum | | 14217.647 | 50 | | | |

be determined by answers to these five questions taken from Reference 16, page 675:

*(1) What type of information does the student preferentially perceive: sensory (external), such as sights, sounds, and physical sensations; or intuitive (internal), such as possibilities, insights, and hunches?*

*(2) Through which sensory channel is external information most effectively perceived: visual, such as pictures, diagrams, graphs, and presentations; or verbal, such as words and other audible sounds? (Other sensory channels, such as touch, taste, and smell, are relatively unimportant in the majority of educational environments and are not considered).*

*(3) Which type of organization of information is the student more comfortable with: inductive (facts and observations are given and the underlying principles are inferred), or deductive (the principles are given, but the consequences and applications are deduced)?*

*(4) In which way does the student prefer to process information: actively (through participation in the physical activity or debate), or reflectively (through introspection)?*

*(5) How do students progress through their understanding: sequentially (in continuous stages) or globally (in giant leaps, holistically)?*

Students answered a standardized questionnaire comprised of 44 questions and applied via the Internet. Results were determined automatically and feedback was nearly immediate (it took only a few seconds for the learning style to appear on screen). That is how students individually identified their own learning style.

The means to quantify LS, known as ILS (Index of Learning Styles),[17] is used mainly to understand the way each student learns. It has been proven that the ILS provides reasonable evidence for valid and reliable assessment of learning styles.[18-20] The results in this study indicated that the students are predominantly active, sensory, visual, and sequential. This is an indicator that RL aids in the learning process of our current students.[21,22] That is, it favors the current predominant learning styles.[23] Table 3 shows the comparison of the entire group in each category of the classification of learning styles.[19]

If one focuses on the main differences in Table 3, the RL helps the visual learners who were the majority of the students tested (see also Figure 4). "Including live demonstrations" allows efficient learning environments for the visual learning styles, but does not exclude the verbal learning style.[19]

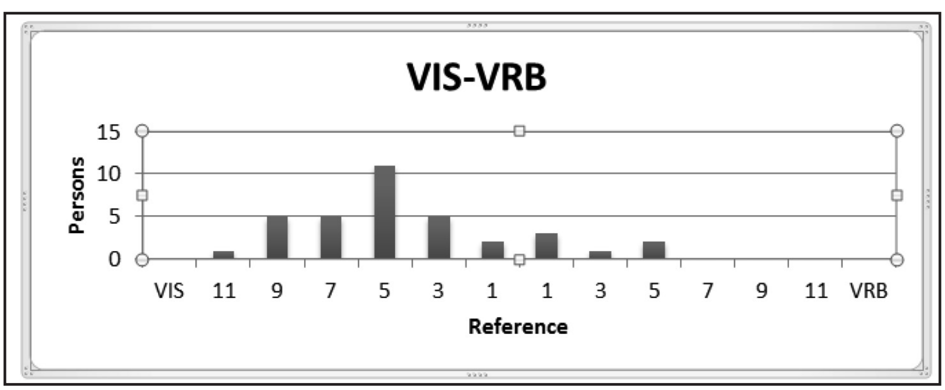


***Figure 4.*** *The distribution of the results of the ILS test for group 1, category of VIS-VRB.*

The graph of Figure 4 shows the distribution among the tendency to either be more visual (one extreme) or more verbal (the other extreme) as a learning style. The number 1 represents being low visual or low verbal and the number 11 represents a greater tendency to the specific learning style. The y axis represents the number of students that are in the specific category. The total number of students in this group is 35. Figure 4 shows there is a tendency for these students to be more visual than verbal.

Regarding the results of this study (Table 3), most of the students were sensing and active. In this sense, the RL could help to provide a learning environment in the class where the students have the opportunity to participate by making the calculations of real processes in real time, and to experiment with their curiosity regarding the equipment and the way it works. This does not substitute for the practical lab, meaning the space where students go and do experiments with the real equipment on site, but it is a handy instrument in the classroom that allows teachers to introduce some of the ideas regarding how future engineers are going to work. Also, they have the graphical interface in which they can see the changes of the mass in the tank against the changes of the time during the experiment.

### *4.3 Analysis of the perception of the students regarding their own learning using this educational model*

A questionnaire was conducted with the purpose of gathering information on how the students feel regarding this learning model. This was applied after the students used the RL. After the first application of the RL in class (during lectures) occurred during the August–December 2013 semester, a survey was applied to 100 students. The questionnaire included four questions and the results follow:

Question 1: Did the use of the RL help you to better understand the concepts? Why?

All the comments regarding the remote laboratory were positive. Thus 95.5 % of the students answered "yes." Some of the comments were as follows: "There are some industrial processes we don't know, but the remote laboratory can give us an idea of how they work," or "It's simpler to watch a tank fill up and empty out in real time than having to imagine it all."

Also, 48% of the students mentioned the word "imagine" in a context in which it appears as a limitation to understand the unfamiliar industrial processes. This can be indicative of how important it is for students to be able to "visualize" what they are learning. Furthermore, when teaching an engineering discipline to students who are not yet familiar with industrial equipment and environments, it is hard for them to use their imaginations because it is something they have never seen before. Some answers pertinent to this issue were: "It helps me to remember," "You can relate the theory with the practice," and "Using the remote laboratory is more entertaining."

Question 2: Did you learn more than you expected using the RL?

Of the students, 80.7% answered affirmatively. All the comments were positive, including: "I was able to understand more easily," "We practiced more with the equipment in less time," "I paid more attention to the problem," "It's easier to understand chemical processes when you are observing them," and "I learned of the importance of calculations in real applications."

Question 3: Did the RL help you become more engaged and participative in class?

With respect to this question, 88% of the students answered affirmatively. All the comments in relation to the RL were positive. Some of the comments were as follows: "It helps because it makes the class less monotonous and more engaging," "It helps us to be able to do more activities," "I would like to see a real full industrial plant in this version," and "It helps us not just to listen, but also to observe and practice."

Question 4: Write your comments regarding the RL.

This was the last question, and there was only one negative comment by a student, who wrote: "I prefer learning the theory first." On the other hand, the other 93 students who answered the questionnaire mentioned only positive aspects of using the laboratory. Some of the comments were: "I loved it," "It was a great experience, because first we learned with the real thing and then the practice," "If we go to the lab we waste a lot of time; instead, here we can see the teacher's explanation and the real process with the remote lab all at once in the classroom time."

## CONCLUSIONS

Engineering students better comprehend material balance concepts by visual RL demonstrations in an active learning class. This conclusion was evaluated and assessed during different semesters that included laboratory practices and workshops. These class activities favor student learning by visualization, since they provide an opportunity to connect theory with real-world practice and have a more meaningful learning process. This is the age of technology; we only need to imagine and to think how to use it to enhance learning.

In addition, motivation is another important aspect of active learning. It allows students to be engaged in their education. Student motivation is probably one of the most important aspects that these professors nurtured. In this regard, applications of a remote laboratory were new, didactic, and easy to observe and understand in class; students felt they were having fun, yet learning.

## RECOMMENDATIONS

This kind of educational model could pioneer a beneficial teaching-learning style and practice in class. Teachers and students can evolve not only into a learning environment more appropriate to our age, but also more meaningful. Future projects could include evaluation of long-term retention of fundamental concepts and new demonstrations of principles. Because this study is new, in future projects we plan to apply the RL to a large number of students, and to test student performance before and after using it.

## ACKNOWLEDGMENTS

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