Solving Material Balance Problems at Unsteady State using a Remote Laboratory in the classroom

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In Chemical Engineering education, material balances at unsteady state is a difficult topic for the student to understand, as it involves mathematical modeling without being able to see what is actually happening in the real process. The difficulty of differential equations is not high, but students have trouble understanding their conceptualization through a problem using just the blackboard.

The aim of this paper is to describe the experience of teaching material balances at unsteady state (or transient state) by having access to a remote laboratory experiment from the classroom at the same time. With the support of the online experiment, the instructor is able to go through the mathematical modeling of the situation while observing in real time what is going on in the process. This allows students to conduct experiments and calculations from their desks.

This remote laboratory could be used to explain, by means of different options, the concept of unsteady state processes. In addition, the impact of this teaching class’ dynamics could enhance the understanding of the concept, process and applications of mathematics towards problem solution.

Another advantage is that, by using remote laboratories in the classroom, the instructor is able to help a larger number of students, instead of bringing the students to the lab every time it is needed. There is also a matter of cost and equipment limitation. The experimental lab unit consists of a simple vessel equipped with all the necessary instrumentation to allow remote access, but the real impact on the learning processes for future engineers takes place in the classroom.

We are dealing with a new generation of engineering students; they are now more accustomed to see, touch, and experience by themselves than the students of ten years ago. They were born in the technology era and they are highly motivated when it comes to things they can see and understand. The results of this study show some of these statements, but, beyond that, the teacher is able to keep the students happily engaged and experiencing meaningful learning.

Introduction

Remote laboratories allow students to conduct practical laboratory exercises with real equipment without being physically present at the lab site. This is different to simulated laboratories, which don’t actually use real equipment. Furthermore, the inclusion of remote laboratories while teaching engineering classes involving mathematics problems allows students to have a holistic understanding of the concept, ensuring a natural and painless integration, having a potentially dramatic effect on the quality of learning.
The aim of this paper is to explain how a remote laboratory was built and used to teach engineering students in a Material Balances with transient state class. This paper also shows the students perception of the experience and the results in their final exams.

**Teacher’s experiences using the Remote laboratory in the class**

**Before using the Remote Lab**

In engineering education the teacher has a tendency to fill most of the time of the class with lecturing and writing on the board, especially with a subject as difficult as material balances with transient state. In the last few decades we have witnessed an inclusion of different techniques to help students learn better: problem based learning, active learning and project oriented learning, among others. However, there is still a gap between the concepts (abstraction) in the classroom and their application (real processes), mainly because the students only have their imagination to see and connect to the real thing during classes.

Stice (1987) writes that one of the problems is that students retain 10 percent of what they read, 26 percent of what they hear, 30 percent of what they see, 50 percent of what they see and hear, 70 percent of what they say, and 90 percent of what they say and do. Because of this, we can only engage a small percentage of the students during an average class. The other problem is that instructors, when teaching mathematics only by writing and lecturing on the board (for example, in this case, applying transient state to engineering problems, which means applying differential equations), most students fail to see the meaning of the equations: they just memorize the method and learn it in a sequential way, without a full understanding of the whole concept and its real world applications.

**The idea of the Remote Lab**

Laboratories are often used to demonstrate theoretical concepts in practice, but these activities usually take place asynchronously in relation to the class session. Therefore, the proposal of this study was to link theory and practice at the same time in the classroom by using a specifically designed Remote Lab experiment. Remote labs have the potential to offer some valuable educational advantages not available in traditional hands-on labs; remote access mode transforms the learning experience offering options like increased time and ease of recordkeeping. To achieve the technique’s full potential, it is important that its abilities and limitations are widely understood.

The idea of building a Remote Lab for the class of Material Balances aimed to introduce a real lab that could be controlled by the instructor and projected in the classroom at the same time, in a way that the instructor could be explaining the problem and solving it on the blackboard. With this technological aid, the instructor has the possibility to have three teaching tools at the same time: 1) the blackboard, to solve the equations and do the mathematics; 2) the Graphical User Interface (GUI), which shows the process; and 3) the Audio and Video Interface of the real
equipment of the lab. Using all these elements, the learning experience in the classroom is highly increased, allowing the students to interact with real world applications of the concepts they are learning about.

Figure 1. Experiencing the Remote Lab in class
Building the Remote Lab: Interconnection structure for the remote laboratories

By integrating client-server applications running on a computer, data acquisition cards, image acquisition hardware, and a scale model of an industrial process with modern internet technologies, a remote laboratory, similar to a traditional laboratory, can be deployed. Thanks to audio-visual feedback, it is possible to operate and monitor the entire system through the network without having to be physically present in front of the experiment.

It is also possible to create an adequate and efficient connection interface for control and operation of the system via a web interface or a stand-alone application, which, in turn, connects to a scheduling system database to ensure proper access to the equipment and control its usage. Furthermore, through the use of efficient image capture hardware with compression algorithms and a robust network connection, it is possible to provide the user with a very-close-to-real-time audio-visual feedback, essential for automation experiments.

When the entire system is connected to the network, it is controlled and accessed through an user-friendly graphical interface capable of running on any machine (via a web browser or a stand-alone execution runtime), also providing all the necessary elements for the control and reconfiguration of the experiment, as well as the audio-visual feedback display, all in real time for the user.

Currently, a remote station consisting of a network accessible controller, a server computer, a scale model of an industrial process, and two network cameras, have been set up to work remotely through proprietary, remote, stand-alone GUIs. Figure 2 shows the interconnection scheme proposed.

![Interconnection scheme for the Remote Lab](image)

*Figure 2* Interconnection schemes for the Remote Lab
Lab Access Interface

The Lab Access Interface is used as a work tool for the teacher and students to interact with the process and verify their operation. The Lab Access Interface is divided into two different interfaces: the Graphical User Interface (Figure 3) and the Audio & Video Interface (Figure 4). The Graphical User Interface serves as the “hands” of the user inside the laboratory, and will help him modify and examine the process state. The Audio & Video Interface are the “ears and eyes” of the user inside the laboratory, and allows him to look at the actual state of the process and check its responses after manipulating it with the Graphical User Interface. Figure 5 shows the real site for the lab equipment.

![Graphical User Interface](image)

*Figure 3 Graphical User Interface*
Figure 4 Audio & Video Interface 1 and 2

Figure 5 The physical laboratory with the two cameras
**How is the Remote lab actually used in the classroom?**

Next are presented some examples of the activities performed in the classroom using the Remote Lab technology. Each activity takes approximately 20 minutes:

**Exercise 1**

The student gets to know the equipment via the audiovisual interface, in which he can zoom the camera in to observe all the system’s details: the tank, the tank’s entry pipe, the exit pipe, the pump that transports the fluid to the tank, the control valve and the system’s control loop. Next, he or she calculates the tank’s dimensions and finds its total volume, also calculating its mass maximum capacity. The student then checks the system via the Graphical User Interface, and sees that only the entry flow to the tank can be controlled, which has a maximum capacity of 4 Kg/min. He also discovers that there are no controls on the tank’s exit pipe, so the exit flow occurs using gravity. The students perform some tests using the Remote Lab in order to observe how is it turned on, the waiting times and the graphical behavior displayed, which could be based on level, mass and volume.

**Exercise 2**

Once the students have become acquainted with the process, as if they were working on a “real” plant, the teacher then gives them calculation exercises. The first question is: How long does it take for the tank to fill up if there is maximum entry flow? The students must answer this question by doing the calculations first and then by conducting a practical experiment. A discussion session is held afterwards to explain the concept of: \( E - S = A \). This activity takes approximately 15 minutes.

**Exercise 3**

Next, the students are presented with the question: ¿How long does it take to empty the tank if the system’s intake is zero and the exit is completely open? Once again, they must perform the calculations and then check with the Remote Lab. The students get to find out that the tank empties in a shorter time than it takes it to fill up, and then they observe how the exit flow can be regulated using an equation. However, first they must conduct a series of tests in order to arrive to the exit’s function and properly calculate the correct time.

**Exercise 4**

The last activity requires a good understanding of the previous exercises. It consists of filling half of the tank and then asking the students: If the entry valve is kept shut and the exit valve is opened, how much mass will the system drop in a minute? Once again, the student must first perform the calculations and then verify them using the Remote Lab.
The impact of the Remote Lab on students learning

In order to assess the effect of the Remote Lab on student learning, three actions were taken after introducing the Remote Lab to the class: I) an online survey was conducted to analyze students’ feedback regarding their perception on their learning style; II) another online survey was conducted with open-ended questions about the students’ learning within the Remote Laboratory context; and III) a written final exam was applied to measure the students response to practical engineering problems including Transient State.

I) Students’ perception of their learning style

According to Felder (1988), a student’s learning style may be defined by answering five questions:

1) What type of information does the student preferentially perceive: sensory (external) sights, sounds, physical sensations, or intuitive (internal) possibilities, insights, hunches?
2) Through which sensory channel is external information most effectively perceived: visual, like pictures, diagrams, graphs and demonstrations, or verbal, like audible words, sounds? (Other sensory channels, like touch, taste and smell, are relatively unimportant in most educational environments and will not be considered here).
3) With which organization of information does the student feel most comfortable: inductive, (facts and observations are given, and underlying principles are inferred), or deductive (principles are given, consequences and applications are deduced)?
4) How does the student prefer to process information: actively (through engagement in physically activity or discussion), or reflectively (through introspection)?
5) How does the student progress through understanding: sequentially (in continual steps) or globally (in giant jumps, holistically)?

The Remote Lab presented in this paper was used in the class of Material Balances (belonging to the Chemical Engineering Department) during the August-December 2012 semester, at the Tecnologico de Monterrey, Campus Monterrey, specifically in three focus Chemical Engineering sections with 35, 33 and 32 students in each class, respectively. The survey for the students’ perception of their learning style was applied online to the total of these 100 students, of which 94 participated. Each learning style was explained to them and, after that, they were asked to answer each of the questions assigned (see Figure 6). The goal of the survey was to gather information about how the students feel and perceived they learn best. This survey was based on the theory proposed by Felder (1988), with the addition of question number six.

The results showed that the learning style the students like the most is visual (86.2 %); this means that they remember best what they see rather than what they hear. The results also showed that the students like to learn actively (71.3%) rather than in a reflective way. Active experimentation involves doing something in the external world with the information acquired. Engineers are more likely to be active learners5. Active learners do not learn much in situations
that required them to be passive, like most lectures are. Last, but not least, the results also show that students preferred to learn using technology (87.2%).

<table>
<thead>
<tr>
<th>Question</th>
<th>Preference</th>
</tr>
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<tbody>
<tr>
<td>1. What type of information do you preferentially perceive?</td>
<td>54.4% sensory</td>
</tr>
<tr>
<td></td>
<td>43.6% intuitive</td>
</tr>
<tr>
<td>2. Through which sensory channel do you most effectively perceive external information?</td>
<td>86.2% visual</td>
</tr>
<tr>
<td></td>
<td>13.8% verbal</td>
</tr>
<tr>
<td>3. Which organization of information are you most comfortable with?</td>
<td>48.9% inductive</td>
</tr>
<tr>
<td></td>
<td>51.1% deductive</td>
</tr>
<tr>
<td>4. How do you prefer to process information?</td>
<td>71.3% active</td>
</tr>
<tr>
<td></td>
<td>28.7% reflexive</td>
</tr>
<tr>
<td>5. How do you progress through understanding?</td>
<td>69.1% sequentially</td>
</tr>
<tr>
<td></td>
<td>30.9% globally</td>
</tr>
<tr>
<td>6. How do you prefer to learn?</td>
<td>87.2% with technology</td>
</tr>
<tr>
<td></td>
<td>12.8% without technology</td>
</tr>
</tbody>
</table>

*Figure 6* Survey applied for the students’ perception of their learning style and the results. The relevant numbers are indicated in red.

However, and despite all the technology and how visual and active students are today, they still prefer to learn sequentially than globally (69.1%). This means that most of them prefer to be taught in typical formal education, involving the presentation of material in a logically ordered progression. Sequential learners follow linear reasoning processes when solving problems. However, the remote lab allows both sequential and global students to learn thanks to the activities the instructor is able to perform in the classroom.

Research has shown that learning styles affect learner performance at university. The recommendation is that lecturers should be aware of the potential problems and needs of students with different learning styles, and plan accordingly the learning opportunities they provide. Teaching transient state by using a remote lab experiment simultaneously provides with the opportunity to enhance the learning process by giving students a variety of conditions that fit most of the different learning styles. This way, most of the activities can be visual, verbal, inductive, deductive, active, sequential and global.

The learning styles that resulted almost similar by the surveyed students’ preference were: 54.4% sensory/ 43.6% intuitive and 48.9% inductive/ 51.1% deductive. The implementation of the Remote Lab will allow these types of learning style to develop, as students can enjoy both kinds of activities in their learning process.
II) Students’ perception of the Remote Lab

In order to provide a scope for a richer feedback, and to gather information regarding the students’ thinking on their own learning by using the remote lab, another survey with open-ended questions was applied to the same group of 100 students, where 94 students answered the questions. This survey consisted of the following 4 questions:

1. Did the use of the Remote Lab help you to understand the subject? Why?
   95.5% of the students answered yes. All the comments about the Remote Lab were positive. Some of the students’ comments were:

   “There are complex industrial processes that you don’t need to imagine because, with the Remote lab you’re watching them!”

   “It’s much easier to see a simple process in real time than to conceptualize an image”.

   “You can watch it in reality and not just imagine it, because I don’t know industrial processes”.

45 out of the 94 students’ answers were related to the word “imagine”. This is indicative of how important it is for students to be able to see things as part of their learning process. Moreover, when teaching an engineering discipline where students do not know most of the equipment and industrial environments, it is more difficult for them to use their imagination. Some representative answers follow:

   “It helps to remember”.

   “It helps to gather information about a process”.

   “I got to understand how processes’ equipment works”.

   “It relates the theory with the practice”.

   “At the same time we were seeing it on our notebooks we were doing it on the real lab at the classroom”.

   “It is more fun with the Remote lab”.

   “It helps to really know the equipment that we were told about in class”.

   “You can see how the mass changes in relation to time in a process and not just because someone said it does”.

   “Since the tank is transparent you can observe what happens inside during the process”.
“Usually we aren’t familiarized with the processes, and the Remote lab helps us to understand the formulas we use”.

“Because it shows in a graphic way what is happening on the process”.

2. Did you learn more than you expected with the use of the Remote Lab?
   80.7% of the students answered yes. All the comments towards the Remote Lab were positive. Some of these comments were:

   “I did understand easily”.

   “I got to see how the process equipment works”.

   “It was a real application”.

   “I can have a better idea of how the equipment works in the industry”.

   “We did practice more in less time”.

   “It makes the class feel with better interaction than with no Remote Lab”.

   “We were watching physically the phenomenon while the teacher was explaining the math”.

   “The presence of the lab makes me want to learn”.

   “I paid more attention”.

   “It is much easier to learn chemistry processes when you can see them”.

   “I could watch how the valves, controls, the pumping system and other things really work”.

   “I learned the importance of the calculus on its applications before making real tests”.

3. Did the remote lab motivate you to pay more attention and participate during class?
   88% of the students answered yes. All the comments towards the Remote Lab were positive. Some of the students’ comments were:

   “It is really interesting”.

   “Yes, because it is real”.

   “Yes, because it makes the class less monotonous and I like to work at the lab.”
“It helps to promote more activities”.

“It is novel and fun”.

“I would like to see a real complete plant in this version of lab”.

“It is didactic”.

“It helps not only to listen but to do and observe”.

“I was fascinated by it”.

“It makes the class more dynamic”.

“It is a change of the daily routine of the class”.

“You can watch the application of what I’m learning”.

4. Write your comments about the remote lab.
   This was the last question of the survey and only one student out of 94 commented on the preference of having learned the theory first:

   “I prefer to learn the theory first and then have the practical experience, not the other way around”.

On the other hand, the other 93 students that answered the survey commented with enthusiasm about it. Some of these relevant comments were:

“I loved it”.

“It was a great experience because we first saw the real process, and then we learned the theory”.

“What we saw mainly on the remote lab was that in reality the systems do not work as you expect them to work, sometimes there is an accumulation of material inside the tank, not everything that comes in comes out at the same time. Also, sometimes it takes a while to start the processes, which causes the filling time to be slower in the tank”.

“It is an excellent way to understand the theory”.

“If we go to the lab we waste a lot of time; instead, here we can see the teacher explanation and the real process with the remote lab all at once in the classroom time”.
III) **Students’ achievement on their final exam**

Since August 2011, and with the specific purpose of being able to improve the teaching methods and to compare the students’ learning results on the transient state material balances, the author has tried different activities and teaching methods. During August 2011 a difficulty on student’s comprehension of the subject was detected and, starting January 2012, a variety of teaching methods were applied to help students with this subject, obtaining some favorable results. During the summer of 2012 the same methods were applied, while also taking the students to the lab for a practical experience. However, a significant difference on students’ achievement was observed in their final exam when the teacher included the use of the remote lab during the August-December 2012 semester, compared to the previous one. Figure 7 shows the percentage of students that solved correctly the exam’s problem (96.67 %), in comparison to the previous semester (63.89 %). This final exam was applied to the 100 focus group students. Although it is important to conduct further research on this matter to validate this statement, there is a considerable increase in students’ achievement on their final exam when using different activities and the Remote Lab.

![Figure 7](image)

*Figure 7 Students’ achievement on final exam compare to the previous semester.*

**Benefits and recommendations for best practices**

For better results it is recommended to introduce remote labs while teaching the class, not before and not after the theory, but simultaneously when explaining an example. The instructor has the knowledge and the power to design different activities and examples that, designed with the use of remote labs in mind, can complement the class. Instead of drawing on the blackboard or projecting pictures or photographs of industrial equipment, the instructor could show the real thing by having a close up with the cameras while doing the activities.
Conclusions and remarks

Studies documenting the impact of sophisticated technology systems, like Remote Labs, have shown increased teacher-student interaction, cooperative learning, and, most importantly, interaction with the equipment, and performing analysis on experimental data\textsuperscript{10}. This can also provide a proper environment for cultivating communities of practice in engineering education, according to the theory of cultivating communities of practice proposed by Wenger (2002)\textsuperscript{11}.

It is generally agreed that practical laboratory and workshop activities offer engineering students an opportunity to advance their learning through the linking of theory with the real world\textsuperscript{12, 13}. Some of the additional benefits associated with the inclusion of the Remote Lab, and according to the students’ opinion, are: it helps to remember and to gather information about a process, it can be fun, students are able to see the changes in the process against time as the teacher explains the mathematical equations in the blackboard, and students can see graphically the mass flow changing against time at the Graphical User Interface, while they see the change in the tank on the audio-video interface, all this by remote control.

Motivation is another important issue that contributes to enhance students’ learning. It is probably one of the most important things that an instructor has to keep in mind at all times while teaching. In this regard, and according to the students’ opinions, the Remote Lab provided motivation to the class because it was new, interesting, real, fun, didactic, easy to watch and understand, dynamic and practical. Because all of this, the students believe they learn more while having fun.

All of the above benefits the Remote Lab provides to the teaching-learning processes could lead to a teaching style that is both effective for students and comfortable for teachers, which could evolve not only into a more suitable learning environment, but also a more meaningful one.
References


