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Flipped Laboratories in Chemical & Biomolecular Engineering

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Flipped Laboratories in Chemical and Biomolecular Engineering

Abstract

Important learning objectives for experiential, or hands-on, courses include (1) development of skills pertaining to statistical experimental design and analysis of data, (2) utilization of standard operating procedures (SOPs), and (3) understanding and employment of laboratory safety procedures. As the complexity of laboratory equipment increases, so does the length of written SOPs and safety considerations. Furthermore, students are often asked to follow these written standardized documents in a recipe-like format to acquire the aforementioned skills instead of utilizing inquiry-based learning techniques. This project seeks to improve upon standard laboratory-based instructional methodologies, with the overarching goal to enhance student understanding and operability of chemical engineering processes and equipment.

Introduction

There is a strong body of research on active learning and the benefits to engineering education.[1,2] The "flipped" or "inverted" classroom is one approach to creating a more active learning environment during class time. There has been a surge in literature in the last decade and a decent amount of web-based resources to assist instructors with the "flipping" process, as detailed in a recent review by Bishop and Verleger.[3] The simplest definition of a "flipped classroom" is that in which the "events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa." [4] Within the sciences and engineering, the "classroom" can also be a laboratory. Experiential learning complements lecture-based instruction and provides students with the practical knowledge of how to apply what they have learned in the classroom to a hands-on setting. Furthermore, industrial partners have emphasized the need for students to safely operate standard pieces of equipment and to possess the ability to apply theoretical concepts to new and challenging problems in the workplace.[5]

The objective of this study is to extend the principles of the flipped classroom to the laboratory. Thus, we propose that a "flipped laboratory" in chemical engineering is a pedagogical model that essentially inverts the instructor-to-student passage of information regarding operation of key pieces of chemical engineering equipment. Traditionally in our department, students are trained to use expensive and sophisticated pieces of equipment during one, or several, training sessions with the instructor. During these training sessions, the instructor tells (and shows) the student how to operate the instrument. A major limitation of this approach is that the students often forget how to do something by the next time they need to operate the equipment on their own because they are not in control on their own learning. Further, the time invested by the instructor on these initial training sessions, and on subsequent follow-up sessions, is significant. When needing to train multiple new users, this model quickly becomes unsustainable to the instructor. In the flipped laboratory model, we invert this training process. New users can control the time, place, and rate of training through access to a library of short videos (less than 5 minutes each) with narration that explains standard operating procedures and applicable safety protocols. Students can watch the videos multiple times and have access to them in the laboratory (on their laptop or tablet). Subsequently, instructors can meet with students to address higher-order concerns, such as troubleshooting tips and "what if" scenarios, especially regarding safety issues.

The overall goal of implementing flipped laboratories is to enhance student understanding and operability of chemical engineering processes and equipment.

Video Development & Impact

Dozens of tutorial videos have been developed for major pieces of equipment in both teaching and research laboratories within our department and are available on our YouTube channel (https://www.youtube.com/user/LafayetteChBE). Standards of practice have been established so that all videos share a similar archivable quality. In general, each procedural step is filmed as a short clip that can be edited more easily using editing software, such as iMovie or Camtasia, and audio is added later as voiceover from a written script. Title and credit slides have also been standardized with respect to font and branding banners.

The earliest videos were posted live to our YouTube channel in 2011 and have received thousands of views (as of time of writing, February 2016). Examples are summarized below:

- “Nikon Ti Eclipse Confocal Microscope – Fluorescence”: 8,903 views
- “Measuring size and zeta potential”: 5,438 views
- “How to change cell culture media”: 26,646 views
- “Trypsinizing cells”: 5,925 views
- “Thermophysical characterization – Bomb Calorimeter”: 3,233 views

Based on an average in-class laboratory size of 15 students per semester, we are demonstrating impact well-beyond our institution. Thus, there may exist a larger opportunity for archivable vSOPs beyond curricular instruction. These may include partnerships with research equipment technical staff or industrial partners looking to document procedures as their “baby boomer” workforce nears retirement. Anecdotally, we have heard from former students that these videos were helpful as they transitioned into industry. Students have watched them in their new jobs, drawing comparisons between the relatively simply operations in the laboratory and the larger plant-scale operations at their place of employment, usually big oil and gas companies.

Flipping CHE 322: Experimental Design II

Course Description and Video Development

CHE 322 is the second of four experiential courses in our curriculum. In CHE 312 (the first course) students are exposed to small, bench-scale equipment for thermophysical properties characterization (i.e. viscometer, spectrophotometer, calorimeter, etc.) and introduced to report writing and statistical design of experiments (DOE). In CHE 322, they operate much larger, pilot plant scale equipment (heat exchanger, packed beds, etc.) and are introduced to writing formal laboratory reports, using common analytical methods, and applying problem solving strategies. Although “the ability to design and execute simple unit operations experiments” is a course objective, the focus is on the DOE and not on the actual operation of the equipment itself. Thus, it is required that students learn how to safely operate their designated piece of equipment for a given lab period *prior to coming to lab*. This is precisely where the benefit of video SOPs and the flipped laboratory model can be realized.

Table I below is the laboratory schedule for the course, which is divided into four blocks, increasing in complexity. The Blocks are:

1. Sequential Experiments I and II (Fluidized Beds)
2. Gas Chromatography (GC), Pump Performance, and Flow in Pipes and Valves
3. Packed Bed, Vapor Liquid Equilibrium (VLE), and Heat Exchanger
4. Process Control I, II, and III (Twin-column Distillation Unit)

Table I. CHE 322 Laboratory Schedule of Experiments

Week of	**Group**		
(Monday)	**A**	**B**	**C**
January 26th	Sequential Experiments I		
February 2nd	Sequential Experiments II		
February 9th	GC	Pumps	Pipes
February 16th	Pipes	GC	Pumps
February 23rd	Pumps	Pipes	GC
March 2nd	Block II Presentations/Intro to Block III		
March 9th	Packed Bed	VLE	Heat Exchanger
March 16th	**Spring Break**		
March 23rd	Heat Exchanger	Calculations	VLE
March 30th	VLE	Packed Bed	Calculations
April 6th	Calculations	Heat Exchanger	Packed Bed
April 13th	Block III Presentations/Process Control I (Intro)		
April 20th	Process Control II		
April 27th	Process Control III		
May 4th	Wrap Up/Block IV Presentations*		

The main objectives of Block I are to extend the knowledge and usage of statistical DOE and write formal laboratory memos. Students use a fluidized bed filled with polyethylene powder to carry out a fractional factorial design and a central composite design for coating metal tags. Deliverables are short individual memos.

In Blocks II and III, students analyze simple unit operations by comparing theoretical principles learned in other core chemical engineering courses (i.e. CHE 311 Transport Phenomena, CHE 323 Fluid Phase and Reaction Equilibria) to experimental data collected in the laboratory. For each piece of equipment, each group will have different objectives, some of which will require information from previous groups. For example, the first group using the “Pumps” apparatus (week of Feb. 9, see Table I) is expected to calibrate all flow meters and develop a pump curve for the centrifugal pump. The second group (week of Feb. 16, Table I) is expected to spot check all calibrations and use a different impellar size to generate a pump curve. The third and final group (week of Feb. 23, Table I) is expected to generate a pump curve with the final impellar size and synthesize all previous data into a report analyzing the effect of impellar size and flow rate on pump head. Using this experimental approach, it is critical that students have a similar understanding of the operability of each piece of equipment to maintain consistency in data collected over the three week period. Further, if students try to familiarize themselves with the equipment *during* the lab period, they will not be able to complete the experiments and analyze the data. Data analysis within the lab period allows students to compare their data to previous groups and optimize protocols as needed. Tutorial videos afford students the opportunity to learn the safe operation of the equipment prior to coming to lab and the videos also ensure that students are receiving the same exact information.

In Block IV, students gain experience in understanding the dynamics of different control loops in the Twin-column Distillation Unit in the Unit Operations Laboratory. The projects allow students to integrate their coursework in CHE 324: Process Controls into a laboratory setting. Students must determine appropriate tuning parameters for one of four control loops (cooling water flow rate to the tray OR packed column and feed flow rate to the tray OR packed column). The Custom Separations Technologies twin-distillation plant is the single most complex piece of equipment in the department, valued at $1M and commissioned in Spring 2014. There are currently 11 different tutorial videos on the distillation unit, ranging from pre-startup safety procedures to priming the feed pump to operating the packed electric configuration. Although students do not fully operate the columns in CHE 322, they must have an understanding of the function and operation of the different components in order to work with a given control loop. Students fully operate the column in the third laboratory course in the experiential sequence, CHE 412: Integrated Chemical Engineering.

Table II summarizes the videos that were created to enable the flipping of CHE 322. As a note, the videos posted on June 25, 2015 have not yet been used in class by our students. Thus, the significant number of page views generated to date further demonstrates the utility of the videos to users outside of our own institution.

Table II. Tutorial Videos posted to YouTube for use in CHE 322

Video Title	Map to CHE322 Schedule	Post Date	Views
Minimum Fluidization Velocity Determination	Block I, Fluidized Bed	25-Jun-15	430
Fluidized Bed Video SOP	Block I, Fluidized Bed	25-Jun-15	92
Pipes Video SOP	Block II, Pipes experiments	25-Jun-15	17
Pumps Video SOP and Rotameter Calibration	Block II, Pump experiments	25-Jun-15	31
Agilent 7890A GC Video SOP Software and Method	Block II, Gas Chromatography	25-Jun-15	173
Heat Exchanger Video SOP	Block III, Heat Exchanger	25-Jun-15	99
Packed Bed Video SOP	Block III, Packed Bed	25-Jun-15	81
Vapor Liquid Equilibrium Video SOP	Block III, VLE	25-Jun-15	831
Getting to Know the Lafayette College Distillation Plant	Block IV, Controls	25-Mar-14	1208
CST Distillation Plant: Pre-Startup Procedure	Block IV, Controls	12-May-14	278
CST Distillation Plant: Data Logging	Block IV, Controls	12-May-14	82
CST Distillation Plant: Safety and Emergency Shutdown	Block IV, Controls	12-May-14	281
CST Distillation Plant: Packed Column Cooling Water SOP	Block IV, Controls	7-Mar-14	313
CST Distillation Plant: Tray Column Cooling Water SOP	Block IV, Controls	7-Mar-14	213

Video Implementation and Assessment

Since the majority of videos were created during the last offering of the course in Spring 2015, this current semester (Spring 2016) represents the first opportunity to utilize and assess the videos. A pilot study was conducted in Fall 2014 in CHE 312 on the Parr Bomb Calorimeter experiment. Students were given access to the “Thermophysical characterization – Bomb Calorimeter” video before their prelab assignment was due. Instead of meeting with the Instructor for a training session on how to operate the Parr 1341 Oxygen Bomb Calorimeter, students watched the video to develop their own SOP and to learn how to use the instrument. The video replaced instructor-led meetings, saving approximately 10 minutes per group for 11 groups, or approximately 1 hr and 50 minutes of one-way instructor-to-student passage of information on equipment operability. Students reviewed the videos favorably and the number of views reached an average of 4 per student, indicating their willingness to not only watch the video, but to use the video multiple times to control the pace of delivery. No formal assessment was completed during this pilot on the enhancement of student learning; the pilot simply affirmed that students were interested and excited to use this pedagogical technique.

In CHE 322 this semester, we will expand the study to assess the utility of videos in improving student understanding in equipment operability and safety. Based on the sequential nature of the laboratory assignments, it is critical that all students working on the same apparatus have access to the videos. For example, all students working on the “Pumps” lab will be able to access the videos. In this course, all students are expected to meet with the Instructor for a pre-lab meeting prior to the actual lab period. The objective of this meeting is for the students to learn enough information from the Instructor so that they can develop an SOP for the equipment. (SOPs are not provided to the students). Traditionally at this meeting, the Instructor goes over the lab objectives and gives the students an overview of the operating procedure for the given piece of equipment. Students usually ask few questions at this meeting, and instead return afterwards when they finally sit down to develop a written SOP and realize they didn’t understand something. In the past, this pre-lab meeting was not assessed and used as information-gathering only. Students then submit a written prelab with SOP 2-3 days later that is assessed before the lab period.

This semester, all students will instead be given a quiz at the end of the Instructor-led prelab “lecture” to assess their understanding. To maintain consistency between the “videos” and “no videos” groups, the Instructor will watch the videos and essentially read the transcript to the students in the “no videos” groups. In the flipped laboratory model, students will watch the video SOP for the equipment prior to attending the pre-lab meeting. At the beginning of the meeting, students will be asked to take the same quiz and results will be compared. It is anticipated that because students have access to the videos ahead of time, they will be able to watch them multiple times, potentially in front of the piece of equipment. It is hypothesized that student understanding and retention of information will increase.

Example quiz questions include:

- What the major safety considerations for this piece of equipment?
- Can you show me how to properly start-up this piece of equipment?
- Can you place the heat exchanger in a counter-current configuration?

- Can you divert water flow through the Venturi meter (in the given piping network)?
- What will happen if valve 153 is closed?
- Using a scale of 1 (lowest) to 5 (greatest), rate your confidence as the sole operator of this piece of equipment.

After the quiz, the Instructor will continue the pre-lab meetings by asking several troubleshooting scenarios (“what if” statements). It is anticipated that students that have watched the videos will have a better understanding of the equipment operation and therefore answer these questions in a more satisfactory manner. It is anticipated that video tutorials will standardize the information that each group receives about a piece of equipment, thereby minimizing differences in protocols and operation that make sequential experiments difficult to combine and analyze. It is hypothesized that students who have control over the mode of delivery will perform better on pre-lab quizzes. Focus groups will be conducted at the end of the semester to address the effectiveness of the videos and overall impact on the student learning experience and any challenges that may have been encountered with their implementation.

Instructors will also monitor the use of lab time between the “videos” and “no videos” groups. As the familiarity of equipment increases in the “videos” groups, it is anticipated that students will be able to complete the required set of experiments in a shorter amount of time. This would allow the learning objectives of the laboratory to increase. Due to present time constraints, students are unable to explore troubleshooting equipment in a robust fashion during the lab period. This very important skill would be a desirable learning objective to formally implement into the course after the successful integration of the video SOPs.

Summary

The objective of this project is to motivate and empower students to personally control hands-on learning through the development and implementation of flipped laboratories, with the overarching goal to enhance student understanding and operability of chemical engineering processes and equipment. A variety of video tutorials have already been developed to enable flipped laboratories in both pedagogical and research settings. Video usage reports from YouTube provide anecdotal evidence of their adoption and utility as a learning tool.

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