Bridging Theory and Practice on a Budget: A model for delivering practical knowledge through partnership with an on-campus facility

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***Abstract*—Presented in this Research to Practice Work in Progress paper is a model for utilizing on-campus facilities to cost-effectively incorporate impactful, experiential learning into the engineering curriculum. Within the engineering curriculum, courses designed for hands-on engineering practice traditionally utilize benchtop educational units; whereas, real-world experiences are proven to promote more impactful active participation; developing the notoriously difficult to teach traits desired by industry such as critical thinking, troubleshooting ability, and foundational soft skills. Unfortunately, the purchase, setup, and maintenance of large, pilot-scale units within a teaching laboratory is often not feasible due to increased financial requirements.**

This article specifically highlights the development and implementation of a partnership with Tulane University's Power Plant as part of the junior-level Unit Operations Laboratory in the Chemical Engineering curriculum. The Power Plant experiments presented here are relevant to a wide range of engineering disciplines, and the general proof of concept is broadly applicable. Equipment available at the University's Power Plant includes a large-scale co-generation unit, chillers, water purification system, and cooling towers; with associated experiments demonstrating practical applications of heat and momentum transfer, engineering economics, process control, unit operation optimization, and collection and analysis of data from the field and control room floor. This was also the first opportunity for many students to interact with plant operators and engineers—exposing them to practical skills, fostering teamwork, managerial skills, and communication.

Student self-assessment of ABET student outcomes showed an increased level of attainment after implementation of the Power Plant experience. These results support the need to provide students with real-world laboratory modules to increase attainment of knowledge and enhance the overall engineering education experience. The partnership demonstrated here achieves this without the burden of additional expenditure: providing students with a unique opportunity to step outside of the lab and work with full-scale industrial equipment on-campus. Moving forward it would be of interest to transition the entire UO Lab experience over to multiple real-world facilities.

Keywords—Unit Operations Laboratory, large-scale equipment, experiential learning

I. INTRODUCTION

The role of the Unit Operations Laboratory (UO Lab) in the Chemical and Biomolecular Engineering Department's (CBE) curriculum at Tulane University is to reinforce the principles of the discipline through hands-on practice. Therefore, the junior-level lab is unique and invaluable in that it provides students with the opportunity to develop a skillset not emphasized in other courses. The lab is the first time in the CBE curriculum where students design, plan, and perform detailed experiments; collect, correlate, and interpret data; and write technical reports in a team environment. Due to this, the junior-level lab addresses many of the ABET student outcomes, Table 1.

Tulane's UO Lab traditionally covers the concepts of heat transfer, reaction kinetics, and fluid mechanics using small bench-scale units, and an expository instruction style—the instructor defines the topic to be investigated and provides all necessary resources to complete the experiment [1]. Although more traditional, this "cookbook" approach has minimal positive impact on student output, motivation, and the development of skills desired in industry [2]. Whereas, more real-world experiences have been proven to promote active participation, critical thinking, and troubleshooting due to a shift of learning from the teacher to the student [3]. When our alumni are surveyed regarding which topics should receive greater emphasis in the curriculum, the consensus is always hands-on, practical industrial applications, teamwork, open-ended projects, and professional communication. These responses are not unique to our program [4,5]. Additionally, the drift away from faculty members with industry experience further limits student exposure to practical industry knowledge [6].

TABLE 1. ABET STUDENT OUTCOMES SATISFIED BY THE UNIT OPERATIONS LABORATORY

a) an ability to apply knowledge of mathematics, science, and engineering
b) an ability to design and conduct experiments, as well as to analyze and interpret data
d) an ability to function on multidisciplinary teams
e) an ability to identify, formulate, and solve engineering problems
g) an ability to communicate effectively

The need to implement a more real-world experience into our UO Lab was the driving-force behind this research. Chemical engineering teaching labs typically meet this objective through the purchase of larger pilot-scale units; but the in-lab setup and maintenance of these units carry a hefty price tag (capital investment, staff salaries, costly reagents, etc.). This work asks the question, "can the Unit Operations Lab experience be updated in a way that instills the critical thinking and troubleshooting skills desired by industry without the purchase of large-scale educational equipment?". The solution identified here was through partnership with an on-campus facility.

II. TULANE UNIVERISTY'S UNIT OPERATIONS LABORATORY

The UO Lab is offered during the spring semester to junior CBE undergraduate students. Class size averages 25 ± 3.7 (n=6) students per year, and teams are randomly assigned with three to four members each. The first three sessions include laboratory safety presented by the University's Office of Environmental Health and Safety, an instructor guided session on technical report writing and presentation skills, and a module on Aspen HYSYS® including a tutorial and homework. The remaining course is divided into nine experimental modules which each team rotates through, shown in Table 2.

Team are given three class sessions (4 hours/session) to complete each module. Typically, the first two periods are devoted to experimental design, data collection, and experimentation; while the third period is devoted to data analysis, re-collection of data, and report writing. The instructor is present during each class session to provide guidance and facilitate group interactions. The lab handouts for each module present any necessary information needed for the students to begin designing and planning the experiment such as experimental objectives, process overview, instrumentation documentation, manufacturer provided spec sheets, and P&IDs. Additionally, to better manage each module, teams are required to develop a work breakdown structure. This ensures all team members consider the entire scope of the module and allows the team leader to delegate responsibilities along with due dates.

Final written reports are due one week after the last laboratory session. The report has typical lab report format and students are most heavily assessed on presentation of experimental procedure and apparatus, thorough data analysis, thoughtful discussion of results, and recommendations. In addition to experimental modules, each team gives a community-based presentation following the format developed by Mitchell and Law [7].

TABLE 2. EXPERIMENTAL MODULES IN THE UO LABORATORY

Relief Valve Sizing using the Advanced Reactive System Screening Tool
Introduction to Process Control
Heat Exchanger Design and Construction using the Makerspace
Head Loss through Piping Network and Pump Curves
Polymerization of Acrylamide
Pilot-Scale Methanol Distillation
*Cooling Tower Performance**
*Cogeneration Economics**
*Chiller Efficiency**
*included in the PP Experience

III. IMPLEMENTATION OF THE POWER PLANT EXPERIENCE

The Power Plant (PP) experiments presented here are relevant to a wide range of engineering disciplines, and the general proof of concept is broadly applicable. The experience provided students access to full-scale industrial equipment providing real-world applications of heat and momentum transfer; an introduction to unit optimization, economics, and process control; and collection and analysis of data from the field and control room floor. The PP experience was also the first opportunity for many students to interact with plant operators and engineers, exposing them to practical skills, fostering teamwork, managerial skills, and communication.

The Tulane University Power Plant operates equipment to produce electricity, steam, and chilled water in order to provide the heating and cooling to campus. The experimental modules associated with the PP experience required teams to visit the PP during seven sessions throughout the semester and work closely with operators to determine efficiency of a cooling tower, optimize the performance of a chiller system, and investigate the economics of installing a cogeneration system. The open-ended nature of the module handouts were created to challenge the students and required them to design the experimental procedure and plan for data collection—which was approved by the course instructor before their first visit to the PP. Students were encouraged to seek out information from additional sources including plant engineers and operators, and students were accompanied by plant engineers during all data collection, Fig. 1. Students had the opportunity to actively monitor equipment and collect real-time data utilizing the PP control system computer interface. The three examples presented here only

Fig.1. Students collecting data with PP personnel

scratch the surface of potential experiments utilizing an on-campus power plant facility.

A. Cooling Tower Efficiency

To evaluate the performance of the main cooling tower at the PP, teams acquired data manually, as well as from the plant control room software interface across three days. Before arriving to the first session, students were assigned relevant readings on both cooling tower theory and practice. The final technical report required teams to generate a detailed material balance around the main cooling tower, estimate the amount of makeup water required, and calculate the cooling tower efficiency from three different daily atmospheric conditions. Students were able to provide comparisons of their experimentally determined values to data obtained from the control room. Additionally, each team provided recommendations to increase cooling tower efficiency to the PP personnel.

B. Chiller Optimization

For this module, teams determined the optimal operating conditions for the centrifugal compressor chillers at the PP. Before arriving to the first session, students were required to read a design brief on chiller plant efficiency to prepare them for the task, as well as a module handout outlining the theory and requirements for the session. The final technical report required teams to analyze performance data by two methods. First, students were given performance data for one of the six chillers at the PP, and were tasked with determining a relationship for chiller efficiency as a function of part load, and condenser input/evaporator output water temperature. Students then obtained experimental data from the PP control room, Fig. 2, over the three experimental sessions. The final technical report required teams to report actual tons of cooling, heat rejection rate, and chiller efficiency. Each team then provided recommendations to the PP team for the optimal chiller mode of operation.

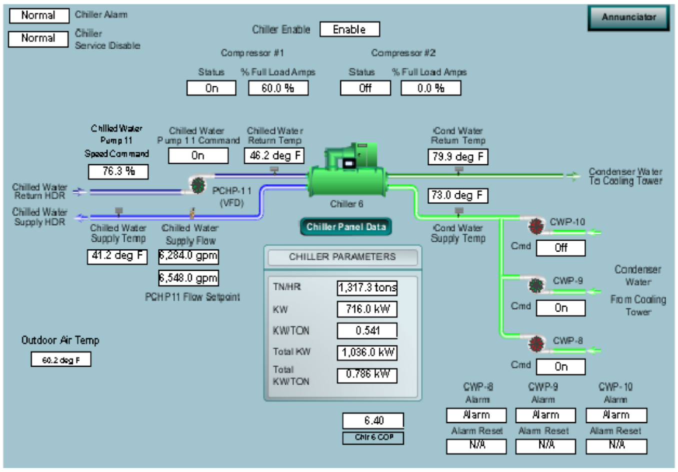

Fig. 2. Software interface of the chiller digital control system

C. Cogeneration Economics

In addition to a tour of the cogeneration unit at the PP, the cogeneration economics module made use of the Energy Sustainability Remote Laboratory (ESRL)—a set of modules designed for remote monitoring of systems with a focus on energy production and sustainability [8]. After students toured the cogeneration system (turbine, boilers, water purification) at the PP, they were given access to live monitoring of a comparable unit through the ESRL to obtain real-time cogeneration data, Fig. 3. Students were then required to conduct an energy balance around the system, generate a Sankey diagram, determine the total utility cost of the setup, and conduct a sensitivity analysis on the effect of fuel costs on the profitability of the system.

IV. ASSESSEMENT METHODS

The addition of the PP experience to the UO Lab was assessed through various mechanisms. Attainment of ABET

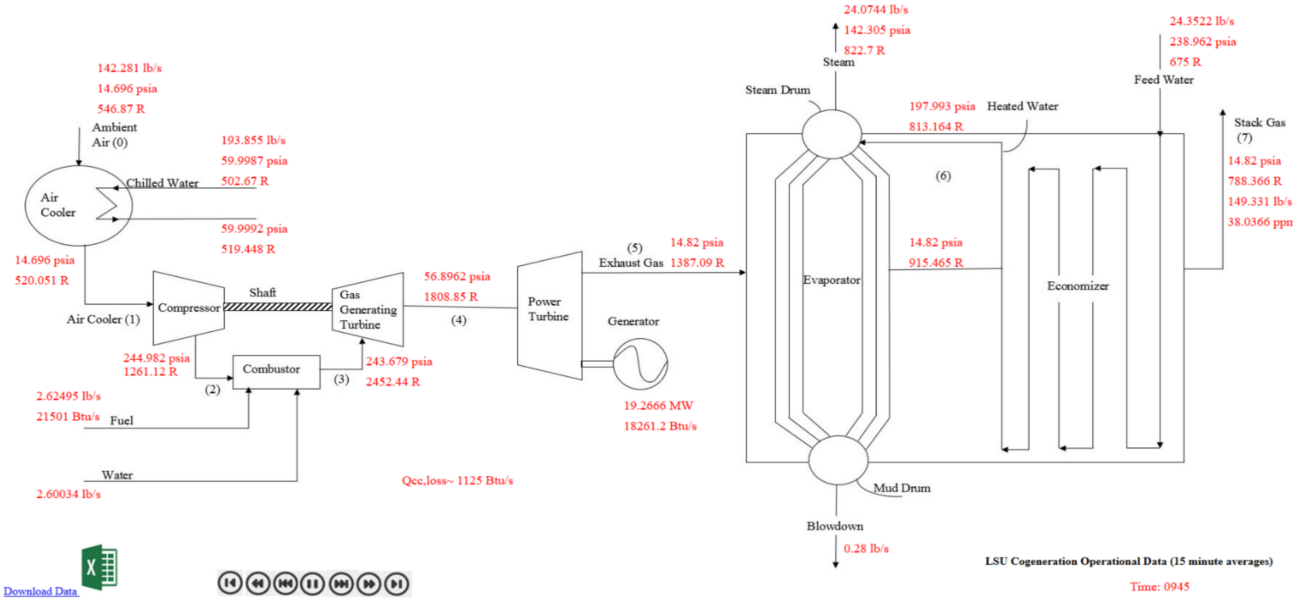

Fig. 3. Remote monitoring of Louisiana State University's cogeneration unit through the ESRL

student outcomes was determined through student self-assessment data from 1) anonymous course evaluations given at the end of the semester and 2) senior exit surveys administered one year later. Student performance was also assessed by the instructor at the end of each semester to quantitatively measure outcome attainment. Additionally, students were asked to provide any other comments after completing the course evaluation. Data for ABET outcome attainment from before and after implementation were averaged and analyzed with a two-tailed, two-sample Student's *t*-test. *P*-values of 0.05 or less were considered statistically significant.

V. RESULTS AND DISCUSSION

Fig. 4a shows student self-assessment of ABET outcome attainment from course evaluations both before (n = 38) and after (n = 56) the PP experience was implemented. Similarly, Fig. 4b presents results from the senior exit survey before (n = 42) and after (n = 31) implementation. Of note was that both sets of data showed an increase across the board in ABET student outcome self-assessment after implementation. ABET outcome G was statistically signification compared to self-assessment data from before implementation: 4.65 ± 0.07 compared with 4.90 ± 0.10 ($p < 0.05$) after. Students performance was evaluated by the instructor at the end of each semester and is shown in Fig. 4c before (n = 52) and after (n = 67) implementation. Interestingly, there was no statistically significant increase in outcome attainment after implementation. This is likely due to the already high attainment levels before implementation. In addition to quantifying outcome assessment, the course evaluations provided student feedback. Student feedback with respect to the experience was generally positive, and overall, students appreciated the addition of real-world equipment and the interaction with the PP staff. Representative feedback is shown in Table 3. This initial attempt at instilling the critical thinking and troubleshooting skills desired by industry into our students on a limited budget revealed promising results through partnership with an on-campus facility.

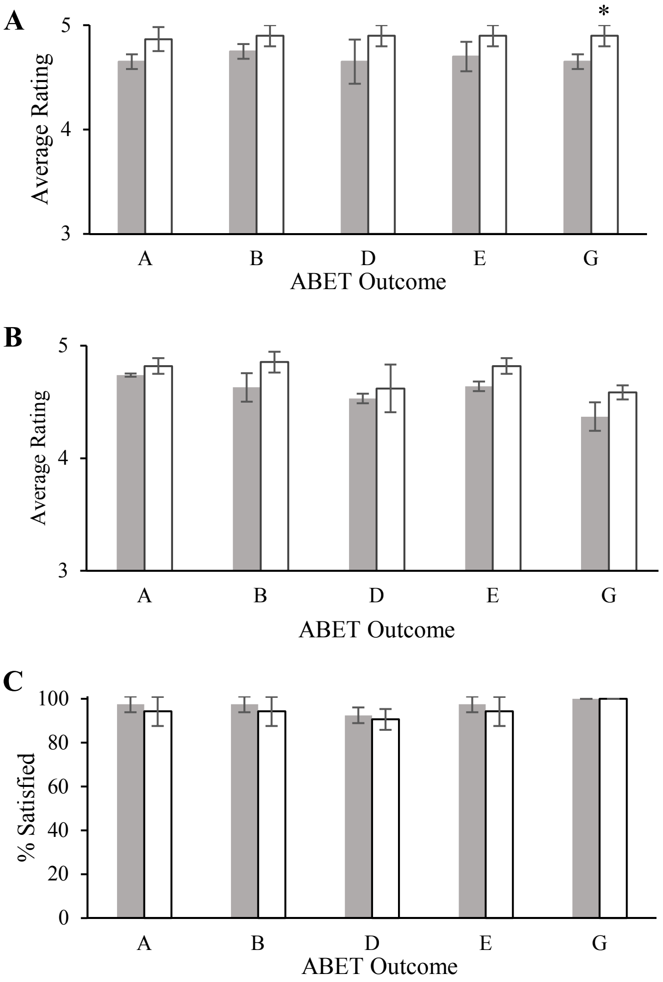

Fig. 4. ABET outcome assessment from student course evaluations (A), senior exit interviews (B), and instructor evaluation (C) before (grey) and after (white) implementation

TABLE 3. FEEDBACK FROM STUDENT COURSE EVALUATIONS

BEFORE IMPLEMENTATION

"Many of the experiments required a lot of trails and a lot of sitting around."

"I think students designing more experiments given an overall objective would be more meaningful that just following written instructions. It would be meaningful to do more "design" and less of just "conducting" experiments"

AFTER IMPLEMENTATION

"The strongest aspect of this course was that each lab was based on an actual piece of equipment that we were able to visit and get data from to perform the analysis. This helped give me an understanding of how each piece of equipment worked and it allowed me to prepare for things I may face in industry in the future."

"The interactive nature of the course brought our coursework to real-world application."

"I really enjoyed being able to do hands-on engineering and get to see how the material we're learning in class works in the real world."

VI. CONCLUSION

Integration of the PP into the junior-level UO Lab provided students with a unique opportunity to deviate from the traditional bench scale laboratory experience by working with industrial equipment and PP personnel. Additionally, students demonstrated an increased level of attainment in the difficult to teach engineering skills desired by industry. The main drawback to this approach was that coordination with the often busy PP operators and engineers was difficult at times, but the pros outweigh the cons. Although this current study only modified three of the nine lab modules, the results are promising. Moving forward it would be of interest to transition the entire UO Lab experience to real-world facilities.

ACKNOWLEDGMENT

The author would like to acknowledge the operators and engineers at Tulane University's Power Plant for their generous support, devotion to our students, and patience throughout the development of the partnership outlined in this article.

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