WIP: Mobile Experiments for an Enhanced Engineering Learning Experience

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***Abstract*— This work-in-progress research-to-practice paper describes the development and fabrication of pilot-scale mobile experiments and their use in classroom demonstrations to enhance the practical learning experience of chemical engineering students.**

We recently renovated the undergraduate teaching laboratories in the chemical engineering department at the University of Texas at Austin, our main objective with these renovations was to update and improve the content, teaching effectiveness, and general learning experience offered by our laboratory sequence. As we progressed in our renovation efforts, we noticed that our students had limited opportunities to experiment hands-on with real applications of concepts discussed in their courses before the junior year. Thus, we recognized it was a priority to provide these opportunities earlier in our program to improve learning and enhance engagement. To this end, we have developed four pilot-scale flexible experimental stations that are custom build, modular, and on wheels for easy transport to classrooms (i.e., mobile experiments). The experiments are created to be used in demonstrations and they cover a wide area of engineering concepts and applications. In this work, we propose that the use of mobile experiments in engineering classes offers advantages over traditional engineering instruction: they can deliver a more tailored learning experience, they can be easily modified and updated to explain concepts, and they can promote an enhanced student-centered educational experience that invites discussion. By this work-in-progress, we take the initial steps to answer the following research question: *Does the development and utilization of hands-on flexible experiments that can be transported to classes to demonstrate engineering concepts result in improved classroom learning and an enhanced engagement with the major?*

In this paper, we describe the development of one experiment and we highlight how mobile experiments can contribute to an enhance learning. We detail their proposed applications in core courses, their use in laboratories, and their advantages in demonstrations. We present preliminary data on student perception; this feedback suggests that the use of these experiments can enhance engagement and contribute to the learning and understanding of engineering concepts. We conclude by summarizing our future work to study the benefits of the use of pilot-scale mobile experiment demonstrations in lecture-based engineering courses.

Keywords—chemical engineering, laboratory, experiential learning, active learning.

I. INTRODUCTION

The engineering profession can be defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs [1]. Intrinsic to this definition is the practical application of scientific knowledge to ideate solutions and create value. Nonetheless, the practical application of knowledge by engineering students can be challenging inside the classroom [2]–[4], there can be a disconnect between the engineering curriculum and the professional practice of engineering [5],[6]. In traditional engineering instruction, lecture time is typically allocated to the introduction of new topics, the learning of concepts, the application of theoretical deductions, and the development of solutions that involve mathematical problems [7]. There is often little time dedicated to the practical demonstration of real-world engineering applications. Indeed, multiple studies have highlighted the common difficulties associated with teaching the physical phenomena inherent to the application of engineering concepts inside the classroom [2], [3], [7]–[9].

To improve the learning of these concepts, previous studies have suggested an approach that embraces experiment-based learning as an effective tool in the development of engineering skills [10]. The inclusion of laboratory work to complement theoretical work can be effective in the improvement of classroom learning and can help cement fundamental concepts in engineering students [7]. However, it is often impractical to create a laboratory class for each core course in the engineering curriculum [11], [12]. In the particular case of chemical engineering programs, the undergraduate curriculum usually requires the completion of 1 to 3 undergraduate laboratory courses to help solidify student knowledge, strengthen understanding of concepts, and facilitate the application of these concepts in the solution of practical problems [11]. These laboratory courses are normally scheduled during the Junior and Senior years of the chemical engineering undergraduate degree.

We have recently renovated the undergraduate teaching laboratories in the chemical engineering department at the University of Texas at Austin. Our main objective with these renovations has been to update and improve the content, teaching effectiveness, and general learning experience offered by the junior and senior year undergraduate chemical engineering laboratory sequence. A summary of these renovation efforts has been published elsewhere [6]. As we progressed in our renovation efforts, we noticed our students had limited opportunities to experiment hands-on with applications of concepts discussed in their courses before their first chemical engineering laboratory in the junior year of their studies. Thus, we recognized it was a priority to provide earlier opportunities to improve learning, showcase engineering applications, and enhance student engagement. To help create these opportunities, we have focused on the use of experimental hands-on classroom demonstrations.

The use of hands-on demonstrations in the classroom has been previously presented as an alternative to laboratory classes to introduce students to the practice of engineering concepts in lecture-based courses. These hands-on classroom demonstrations promote an increased engagement through the practice of engineering fundamentals [4], [7], [9]. As such, demonstrations have been utilized to facilitate the assimilation of concepts in multiple engineering related disciplines: fluid mechanics, mechanics of materials, engineering dynamics, and statistics, among others [2]–[4], [8], [9], [13], [14]. It is well documented that the simultaneous visualization of concepts and their applications contributes to an enhance learning [4], [7], [15]. Nevertheless, most studies reported in the literature have focused on the use of small-scale desktop equipment to demonstrate concepts rather than on the real-world application of concepts. Hence, we propose class demonstrations using pilot-scale equipment – typical in undergraduate chemical engineering laboratories – can be an effective alternative to showcase connections between concepts and engineering applications in lecture-based courses [10], [16], [17]. Furthermore, we believe the use of pilot scale equipment connecting concepts to real-world applications can help students create more effective links to the practice of the profession [10].

To this end, we have developed flexible pilot-scale experimental stations that are custom build, modular, and on wheels for easy transport. The experiments have been created to be used in laboratory courses and in classroom demonstrations; moreover, they are designed to cover a wide area of engineering concepts and applications. To the best of our knowledge, no other studies have focused on the use of pilot scale experiments to demonstrate engineering concepts and showcase real-world applications in chemical engineering lecture-based courses.

As an initial step to the completion of this study, we have developed four mobile experiments on five main areas of chemical engineering: fluid flow, separations, process optimization, materials engineering, and sustainability. In the following sections of this work-in-progress, we describe experiment development and we highlight how mobile pilot-scale experiments can contribute to an enhance learning. We detail proposed applications in engineering courses and their observed advantages in demonstrations. Furthermore, we present preliminary data on student perception on the use of mobile experiments to demonstrate concepts and applications in chemical engineering courses.

II. MOTIVATION AND RESEARCH QUESTION

As described in the aforementioned, we have identified the creation of mobile experiments on wheels as an alternative to introduce our students earlier to the hands-on practice of chemical engineering. By the utilization of these experiments in demonstrations and the completion of this study, we will answer the following research question:

Does the development and utilization of hands-on flexible experiments that can be transported to classes to demonstrate engineering concepts result in improved classroom learning and an enhanced engagement with the major?

III. EXPERIMENTAL DEVELOPMENT

To develop this study, we have focused on the design and acquisition of experiments that cover a wide area of engineering concepts and chemical engineering applications. Thus far, we have developed, designed, and built two units within our department (membrane separations and pressure swing adsorption), we have acquired the parts to assemble one experiment station (polymer processing), and we have received a full experiment station donation from an industry partner (process control). A short detail of the experiments currently available in our department is presented in Table 1.

TABLE 1. Mobile flexible experiments currently available.

Experiment	Experiment Description
Gas Separation Membranes (GSM)	This experiment evaluates the performance of hollow-fiber membrane modules to separate gas mixtures. Students can study gas flow through several membrane configurations to optimize separation performance.
Process Control	This process control unit allows for the modification of process variables (e.g. temperature, level, flow) and the study and application of process engineering methods.
Pressure Swing Absorption (PSA)	This system studies the adsorption properties of gas mixtures under different process conditions. Students can modify adsorption cycles to optimize the separation.
Polymer Processing	This experiment is composed of multiple units (e.g., extrusion, injection molding, etc.) to study the characterization and processing of polymers and composite materials.

This work-in-progress manuscript focuses on the use of the GSM experiment. The PSA experiment has also been built internally in collaboration with industry partners; however, this newly developed experiment has not been used yet in any of our courses or demonstrations. The polymer processing and process control experiments are not described either as these experiments were acquired externally. We plan to use all 4 experiments in future class demonstrations.

GAS SEPARATION MEMBRANES (GSM) EXPERIMENT

The GSM experiment was funded by and designed internally in our department and it was constructed in collaboration with students, faculty, and staff. The experiment was fully built by departmental staff, and the laboratory manual was created by doctoral chemical engineering students in consultation with faculty associated with the courses. In our senior laboratory, the experiment provides a high degree of flexibility to study various process parameters of interest in gas separation processes in membrane systems: permeability, selectivity, stage cut, optimization of process conditions, and design of process configurations [18].

The experiment pictured in Figure 1 can be utilized for any gas separation process at gas feed pressures up to 225 psi (i.e., as long as the gas mixture is compatible with the membrane material). In a typical experimental procedure, mid-pressure building air (i.e., up to 95 psi) or mid-pressure compressed air (i.e., up to 120 psi) is purified with a commercial filter system and regulated with a pressure gauge before it enters the system through flow meters. Students can utilize any of the 4 membranes modules and 4 flow configurations (i.e., membranes in series or in parallel) available by opening and closing the different valves in the system. As the gas permeates through the membrane, the separated permeate and retentate flow rates are measured via the flow meters on the right end of the experiment (labeled RET1, RET2 and RET3). Pressure drops across the membranes (i.e., the driving force for the separation) are recorded through the two digital displays (labeled P1 and P3). The degree of separation is measured using a gas analyzer and the retentate flow rate and pressure drop can be controlled using the Retentate Flow Valve (i.e., metering valve). An optimized air separation process in this system can produce nitrogen concentrations higher than 99% in the retentate stream from building air containing 79.1% nitrogen.

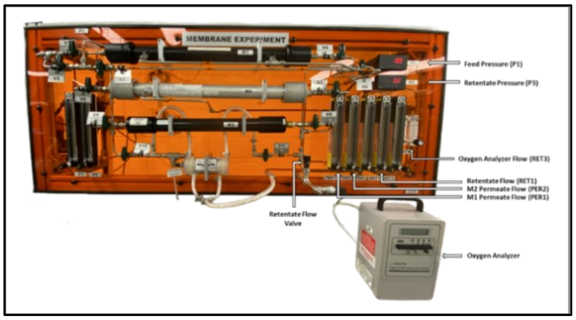

Figure 1. Diagram of Gas Membrane Separation Set-up. The gas analyzer in use will vary depending on the separation being performed.

The experiment was originally designed to be stationary in the laboratory space; nonetheless, we decided to modify the experiment to be mounted in a mobile table and to scale down the experiment to dimensions that would fit inside regular sized building elevators and classroom doors. In addition, we equipped the system with a quiet gas compressor that provides air pressures up to 120 psi. We also acquired multiple gas sensors that can be connected via USB to a computer and projector to show the changes in gas concentration as a function of time as the process is modified and optimized inside classrooms.

IV. IMPLEMENTATION

To further explore the potential use of the GSM experiment and mobile experiments in lecture-based courses, we conducted a GSM demonstration in the course "Separations and Mass Transfer". Separations and Mass Transfer is a junior year core course in the chemical engineering program. The course focuses on the design and analysis of equilibrium and mass transfer operations based on separations such as absorption, chromatography, crystallization, distillation, extraction, and membrane-based processes. The course is typically taken by students in the Spring semester of their junior year. Thermodynamics and Transport Phenomena are the two main prerequisites.

The demonstration was completed during the last week of classes in the Fall Semester 2023 (i.e., after all concepts were covered in the class). The demonstration was completed in about 30 minutes during the regular lecture time (total lecture time is 50 minutes). First, the course instructor reviewed concepts on membrane separations discussed during the previous week, subsequently, the instructor introduced the experiment to students while discussing applications of gas membranes in the purification of air streams to produce nitrogen.

After an overview of the system and its capabilities, student volunteers were invited to operate the equipment. Pressurized air was feed to the system utilizing the quiet compressor. All experimental results were shared with the class through a classroom projector. Every section of the demonstration was utilized to show connections to concepts previously discussed in the course. The demonstration explored membrane properties and detailed how different membrane configurations can be used to target a particular degree of product purity while optimizing a process. As the experiments were performed, the instructor asked questions to the class on the expected results as conditions, configurations, and materials were changed. The concepts discussed were reinforced with experiments. The instructor reserved a few minutes for discussion and additional questions at the end of the class session.

V. RESULTS AND DISCUSSION

After the demonstration and discussion was completed, we conducted a survey to collect data and student feedback on this classroom experience. We believe data to be representative of overall student perception as the course has a combination of students in the junior and senior years as well as students that have completed our Junior Year laboratory course (i.e., the course is a prerequisite to the Senior Year Laboratory). The end goal of our survey was to understand whether the demonstration was helpful in solidifying student understanding of concepts and facilitating the visualization of engineering applications. We were also interested in understanding whether these demonstrations could be effective at integrating practical experiences to chemical engineering courses to increase student engagement.

The survey was administered in Qualtrics. The survey contained three Likert-scale questions and one open-ended question to provide further feedback. Likert-scale questions surveyed students on their overall perception of the experience using a 5-point scale: "1=Strongly Disagree," "2=Somewhat Disagree," "3=Neither Agree nor Disagree," "4=Somewhat Agree," and "5=Strongly Agree." Student were surveyed on the following questions:

- Q1 –Perceived contribution to the understanding of concepts, systems, and processes discussed in class (Question: The experiment brought to class was helpful to understand better concepts, systems, and processes described in this course?).
- Q2 – Increased visualization of chemical engineering applications in the classroom (The experimental demonstration helped me visualize better applications of class concepts to chemical engineering).
- Q3 – Perceived interest, class engagement, and relevance of the experience class concepts (Question: The demonstration was engaging and relevant to this course).

A total of 71 students participated in the demonstration and survey in Fall 2023 (96% of the 74 students registered in the course). No other identifying characteristics were recorded; the goal of the survey was to understand the perceived class understanding and engagement of all students rather than that of a particular group of students. To further simplify data visualization, we grouped answers to these questions in three categories:

- Positive perception if students strongly agree (5) or somewhat agree (4)
- Neutral perception if students neither agree nor disagree (3)
- Negative perception if students somewhat disagree (2) or strongly disagree (1).

Figure 2 summarizes the survey results.

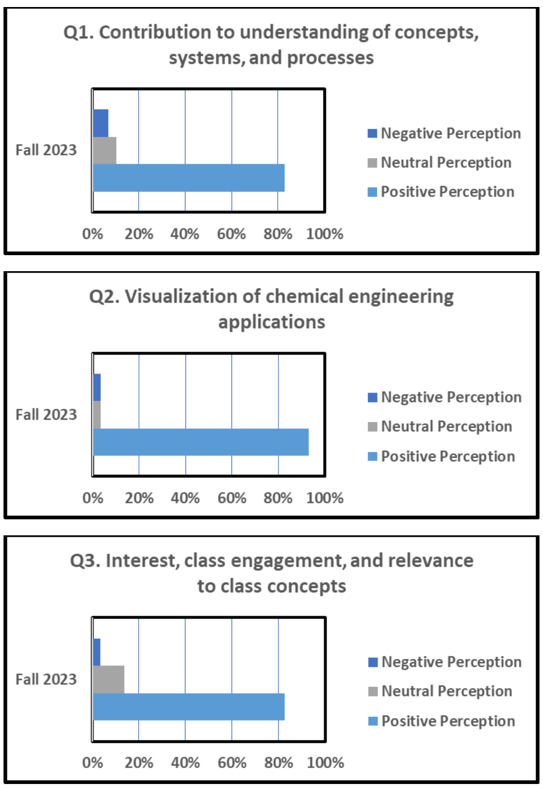

Figure 2. Membrane separations demonstration survey results Fall 2023.

As depicted in Figure 2, students had an overall positive perception of the demonstration and its benefits to their learning. Our survey results indicate that most students perceived the demonstration as helpful to their understanding of concepts, systems, and processes presented in class (>82%). In addition, more than 93% of students considered the demonstration to be helpful in the visualization of applications in the professional practice of chemical engineering. Figure 2 also indicates a majority of students perceived the demonstration as interesting, engaging, and relevant to concepts previously discussed during class (>82%). We hypothesize that the relatively lower number of students (i.e., the number is still high) perceiving positively the contributions explored in questions 1 and 3 (i.e., as compared to question 2) is due to the slight disconnect between the demonstration and the applications and concepts discussed during lecture. We believe this perception can potentially increase by enhancing the synergy between class demonstrations and course lectures in the future. Furthermore, all survey results suggest that in-class demonstrations have the potential to effectively contribute to the learning, engagement, and visualization of practical applications of class concepts. We hypothesize that such demonstrations in other courses, especially lower-division courses, can result in enhanced engagement and can invite more student participation.

Our survey also captured feedback through one open-text question requesting additional student comments on the use of mobile experiment in courses. Student comments were analyzed and divided into categories to explore areas for improvement. It is important to note that only 14% of participants (10 students total) provided additional feedback (i.e., positive or negative). Percentages presented in this section are out of the 30 students providing an answer to the open-ended question. We summarize these categories as follows:

Positive – Increase in class engagement: 40% of students perceived the experience as a potential way to enhance learning and increase class engagement:

- "It has potential, seeing things helps me understand better."
- "I'd like to see more experiments in classes to help understanding."

Positive – Application of demonstrations in other courses: 30% of students suggested the use of such demonstrations in other core chemical engineering courses:

- "I am intrigued by the possibility of using experiments like this to visualize what we learn in class."

Improvement – Demonstration and course synergy: 30% of students suggested that it would be beneficial to create more synergy between the concepts covered in lecture and the class demonstration:

- "It was hard to connect visualization to exactly what we learned […] Maybe a diagram on the board before would have helped."

As a result of the feedback received from students, we plan to find further ways to customize the demonstration to each class concept covered. It is important to note that the author of this manuscript is not the instructor for the course where the demonstration was completed. It would be beneficial to meet in advance with the course instructor or teaching assistant to devise a strategy to make the demonstration more effective to course learning. We also plan to complete demonstrations in other courses and explore student understanding of concepts through quizzes and surveys pre and post experience.

In future demonstrations, we will complete surveys and pre-demonstration and post-demonstration quizzes to further assess whether these experiments enhance student learning of chemical engineering concepts. In addition, we will compare quiz results between students in two course sections (i.e., the demonstration will be completed in just one section) to evaluate student learning and gauge increase in engagement with the courses.

VI. CONCLUSION

We have created and utilized pilot-scale mobile experiments on wheels to enhance learning and demonstrate the application of concepts in the engineering classroom. We performed one classroom demonstration that captured feedback on student perception. The survey and feedback collected suggest that the use of these experiments in the classroom can enhance engagement and contribute to the learning and understanding of engineering concepts. Based on our observations during this implementation, we believe the use of mobile experiments in engineering classes offers advantages over traditional engineering instruction: they can deliver a more tailored learning experience, they can be easily modified and updated to serve class concepts, and they can promote an enhanced student-centered educational experience that invites discussion and participation.

VII. ACKNOWLEDGMENT

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