AC 2007-1010: STUDENT-LED DESIGN, BUILD, TESTING AND USAGE OF IN-COURSE EXPERIMENTAL LABORATORIES

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Student-Led Design, Build, Testing and Usage of In-course Experimental Laboratories

Abstract

Laboratory components of engineering courses are traditionally designed and assembled by either course instructors or laboratory technicians. Student's involvement is most often passive owing to a detailed recipe style set of instructions and frequently recipe style report preparation in which even the relevant axes of figures have been predefined. Mass Transfer Operations (ENGG*3470) is a course that was introduced into the Environmental Engineering curriculum at the University of Guelph in 1998. A lack of facilities initially meant the course started without an appropriate laboratory component. Over the past four years the course has evolved through student designed, built and tested experiments as an integral component of their coursework. Currently, the students are responsible for choosing a mass transfer topic, selecting compounds involved in the mass transfer process, identifying most appropriate analytical techniques, designing, building and trouble-shooting the required apparatus, performing a minimum of two experiments and synthesizing the data in form of a laboratory report. Additionally, the students prepare a laboratory manual that is then used by other students to conduct the particular experiments. Our experience over the past five years indicates that such an approach is not only manageable but also provides the students a unique opportunity to sharpen their design, research as well as communication skills while learning the fundamentals of mass transfer operations.

This paper describes the evolution of this approach within the third-year mass transfer course and provides an assessment of its effectiveness on student's learning.

Introduction

It is now generally agreed that involving the students in the process of learning and knowledge construction promotes more in-depth understanding, better retention of concepts, increased interest on the subject matter among the students, and stronger problem solving skills. Several approaches have been practiced by educators to ensure meaningful participation of students in learning including problem-based learning[1], "learning by doing"[2], and "project-oriented education"[3] to name a few. All these approaches emphasize a "learner-centered approach" and a move from a "content-based" to a more "context-based" education[4].

In addition to sharpening student's laboratory skills, most undergraduate lab-based courses are used to promote some type of hands-on learning. In conventional laboratory course students are provided with detailed instructions on how to perform the work and, in many cases, how to analyze the data. The experimental setup is typically fully laid out by laboratory technologists or graduate teaching assistants and analytical equipment is checked, troubleshoot and calibrated with little or no input from the undergraduate students. In most cases such an approach to undergraduate laboratory experiments is driven by the need to move a large number of students through a lab with limited resources and within a prescribed time period.

There are several limitations with the conventional approaches to laboratory exercises in undergraduate courses. Conventional in-course laboratories do not encourage student enquiry and sense of discovery. The students are not provided the opportunity to apply known concepts and skills in solving problems. Little to no experimental design work is involved in performing these laboratories and students are not given much insight in the thinking process involved in scientific research. In addition, the majority of students do not take ownership of the assigned laboratory and the generated outcome. Several approaches have been attempted to help address the limitations of conventional in-course laboratories. Most involve challenging students to design experimental protocols to solve particular questions or problems.[5,6,7,8] Another approach requires students to conduct research on particular topics (e.g. conducting literature review) and design experiments (e.g. hypothesis formation, sample size estimation and randomization), prepare proposals, and analyze data using computerized data acquisition systems.[9] In general, these approaches seem to have enhance some aspect of student learning experience and help develop important problem solving skills.

Mass Transfer Operations (ENGG*3470) is a course that was introduced into the Environmental Engineering program at the University of Guelph in 1998. This paper describes the process of integrating student-led laboratories in to this third-year engineering course and the evolution of this approach over the past 9 years.

Background

The University of Guelph offers fully accredited engineering programs in Biological, Systems and Computing, Environmental, and Water Resources. Each program at Guelph is a multidisciplinary blend of traditional engineering disciplines with an emphasis on design. Guelph's Environmental Engineering program was launched in 1989 with a graduating class averaging about 40 per year. Mass Transfer Operations was a new course introduced as a requirement component of the program in 1998.

Mass Transfer Operations covers fundamentals of mass transfer including diffusive, convective and interphase mass transfer, mass transfer in porous media, as well as transport in natural system including bioconcentration and the usage of fugacity in multi-media modeling. In addition the course details the design and optimization of major mass transfer unit operation involve in environmental engineering including absorption unit processes, gas transfer processes, adsorption unit processes (activated carbon and ion exchange) and membrane separation.

Student evaluation is based on one midterm or several quizzes (15%), a final exam (35%), and student-designed labs (50%). There are no assignments, however, several problem sets are provided to the students who are encouraged to work through them during weekly tutorials. The course normally receives one graduate teaching assistant (GTA). The student-designed lab component consists of two parts. Part one is to design, construct and operate one mass transfer lab (35%). Part two is to conduct five short mass transfer labs (15%) that have been designed by other student groups. The entire laboratory components of this lab is designed and built by the students. The instructor's role is to provide guidance throughout the design process and ensure that each team is able to complete the design project in time. In general, a class of 40 students will consists of 8 groups of 5 students and therefore a total of 8 labs will be designed. The labs are conducted by students outside the class time and students are responsible for arranging for lab space and time with the help of lab technicians.

The rationale for student-led experimental laboratories

It is common for introductory mass transfer courses to include a number of laboratory experiments. The purpose of such experiments is to provide the students with hands-on training in operating mass transfer units and collection and analysis of mass transfer related data. Although such experiments have merit, the approach suffers from several limitations.

1. The experimental design, setup and instrumentation are normally put together without input from students and as such the students do not gain experience in design, setup, and trouble shooting of laboratory and pilot-scale facilities.
2. Detailed experimental procedures, including data collection, monitoring and often analysis, are provided to the students in advance of the experiments. Students therefore, do not sharpen their skills in designing laboratory experiments.
3. The students, in general, are not provided with an opportunity to enhance their research skills including literature review, proposal development, and development of research methods.
4. Few students take ownership of the experimental work and little sense of pride of the final product is engendered.

Another aspect of traditional laboratory experiments is that they place considerable burden on the departmental resources and require sufficient space and equipment and extensive involvement of laboratory technicians. Small programs with limited resources will find the implementation of such experimental laboratories overtaxing. A lack of resources (laboratory space and technician time) was one reason for incorporating the student-led experimental laboratories in the third-year mass transfer course.

Inclusion of the student-led experimental laboratories in the mass transfer course was also a natural extension of the underlying engineering education philosophy of the School of Engineering at the University of Guelph. A great deal of emphasis is placed on incorporating design in as many engineering courses as possible. To complete their degrees, all students take four design courses (one per year) culminating with the capstone design course in the final year. In addition, design is integrated into a number of program specific courses. For Environmental Engineering students they have significant design experiences incorporated in at least five other courses.

The evolution of the Student-design in-course laboratories

In 2003, the student-designed laboratory component was introduced as a small component of the course. This first effort involved the entire class working collectively on the design and fabrication of a small, pilot-scale gas-liquid contacting tower. The approach was successful in engaging the majority of the class. They enjoyed the degrees of freedom available to them in the design, the role and challenge in purchasing decisions and the hands-on fabrication experience.

However, the single collective system did permit a small number of students to stay on the sidelines.

In 2004, the laboratory component of the course was expanded considerably. Groups of 5 students were required to design, build and operate specific mass transfer unit operation experimental laboratories chosen from a suggested list. The first topics included: absorption (scrubbing), gas stripping, activated carbon adsorption (both gas and liquid phases), aeration and ion exchange. The students were also encouraged to present other topics of their choice. A 2-page handout provided necessary directions for initiating the project was provided to students during the second week of the class. Aside from providing the rationale for the exercise and the suggested topics, the handout provided the following guidelines:

> "Each group is responsible for design, construction, and testing of one laboratory-scale unit. Each group must research and collect relevant information regarding their mass transfer unit process. The choice of dimensions, materials and mode of construction and operation is entirely up to each group however, smaller apparatus is preferred as it is easier to modify and operate. In addition, each group must choose an appropriate compound(s) that would be involved in mass transfer and used for testing the mass transfer unit. The selected compounds must have low toxicity and must be readily available. In addition, it should be possible to adequately monitor the specific contaminant in the School of Engineering laboratories or other laboratories on the Campus."

The first attempt at inclusion of these laboratories required students to build and troubleshoot their apparatus, write a detailed laboratory manual, conduct at least two experiments and write a detailed laboratory report. In addition, each group was asked to make two presentations during the term; the first to provide background information and their plan of action to other students and seek feedback; and the second at the completion of their experiments to present and discuss their results. A separate handout later in the term provided guidance on preparation of laboratory manuals and reports. The student evaluation was based on two midterms (40% total), experimental laboratories (25%) and the final exam (35%).

The feedback from the students with respect to the laboratory components was overall quite positive and little was changed for the subsequent year (2005). The larger number of students (38 vs. 25 in 2004) posed several challenges in terms of space, but this was overcome by moving some of the groups to a teaching lab space not used during the term. Additional topics were either added by the instructor or the students included distillation, membrane separation, and contaminants transport through soil.

A discussion meeting was arranged at the end of the term with the students to solicit their feedback regarding the course. Most students felt that presentations were not providing them with sufficient insight into labs designed by other students. They generally agreed that it would be more beneficial to perform some of the experiments designed by other groups. As the result, the course was modified for the subsequent year (2006) to allow each group to perform several labs designed by other groups. The experimental laboratory outline was modified to incorporate this change.

> "In addition, each group will prepare a one-page laboratory sheet to be used by other groups who will operate the laboratory equipment. The lab sheet should include a brief description of the lab, simple instructions on how to operate the lab, and three to five questions that must be answered (on the same sheet) by those who conduct the lab. The group who has designed the lab and prepared the lab sheet should also provide the answer to these questions to the GTA.
>
> Each group will perform 5 of the labs developed by other groups (total of nine groups). These labs must be performed during the period of March 17 to April 7. Once each group completed a lab, the completed lab sheet will be submitted to the GTA for marking."

2006 saw the largest number of students (45) in this course resulting in 9 groups and additional laboratory topics. Volatile organic compounds (VOCs) separation using non-porous membranes was added to the list. In addition to its own laboratory, each group completed five additional labs during the last three weeks of the term. This created a few problems as students were quite busy during that period and scheduling proved to be somewhat difficult. The overall consensus of the student was that performing five labs during the last three weeks of the term placed unnecessary stress on student during an already stressful time. Student evaluation was also modified from previous years to reflect the addition of five laboratories. Student evaluation was based on one midterm (15%), laboratory design (30%), other labs (15%) and the final exam (40%).

For winter 2007 the course is unchanged from the previous year except for a drop in the number of labs required from five to three. The evaluation scheme has also changed slightly, placing more emphasis on the laboratory design (35% from 30%) and less on the final exam (35% vs. 40%).

Evaluation of the overall project

In general most students took strong interest in the design of laboratory experiments. The instructor's experience was that most of the students were unprepared to take the challenge of designing experimental laboratories. At the beginning, the students were indecisive, nervous and unsure of where to start. Their choice of compounds was often unrealistic and sizing and arrangement of their apparatus impractical. However, with the help of the instructor, the GTA and lab technicians, the students began to feel more confident and took on the challenge with more vigour and zest. There was a noticeable difference between the student's ability to design and build as well as perform the experimental laboratories. Some were more adapt to building (more hands-on), other were better at the experimental design and yet others more skilled in laboratory work. There seemed to be a reasonably good mixture of individuals with various talents within each group. This was another benefit of this project as each student was not only able to enhance their overall experimental design skills, but also to learn additional skills from other group members.

The designs were of varying quality and the generated data and reports covered a wide range from excellent to mediocre. The quality of the projects however, was not directly proportional to the students' academic performance in other courses. Some students with average academic standing performed extremely well, perhaps partly due to the hands-on nature of the project.

Yet, other relatively good students found the project challenging and too open-ended and struggled to perform adequately.

In general, more effort and one-to-one interaction was required from the instructor to ensure the success of the exercise. However, we feel that the additional effort has been worthwhile, judging form the comments received form the students. One of the students commented:

> "The lab project allowed us to learn about topics we were most interested in which meant that we would spend more time reading up on the topic, rather than doing enough to get by. I know for a fact that I will remember and use the information we were taught more than any other class this semester."

Description of some of the experimental laboratories

As indicated earlier, up to nine experimental laboratories (depending on the number of students each year) were designed by the students in this course. A brief description of each experimental laboratory is presented below.

Absorption (scrubbing)

This experiment involved the design of a packed column to remove chlorine gas or CO_2 from an air stream. Packing material were plastic beads which filled a 38 mm plastic column. The impact of packing height, gas and liquid flow rates on the removal of chlorine or CO_2 was evaluated.

Gas stripping

This lab investigated the removal of ammonia from water using a 38 mm plastic packed column. The impact of pH, packing height, gas flow rate in stripping ammonia was evaluated.

Activated Carbon Adsorption (liquid phase)

Removal of methylene blue from water using three different types of activated carbon was investigated. The experiment involved conducting adsorption isotherm tests to select the most effective carbon and preparation of breakthrough curves for the selected carbon. A schematic of their apparatus is shown in Figure 1.

Activated carbon adsorption (gas phase)

This experiment involved removal of toluene from air using a 25 mm diameter activated carbon column. The experiment involved conducting adsorption isotherm tests and preparation of breakthrough curves for the activated carbon-toluene system.

Membrane separation (liquid phase)

This experiment involved evaluation of the impact of temperature and fouling on membrane flux and transmembrane pressure. Figure 2 shows the schematic of the setup for this project.

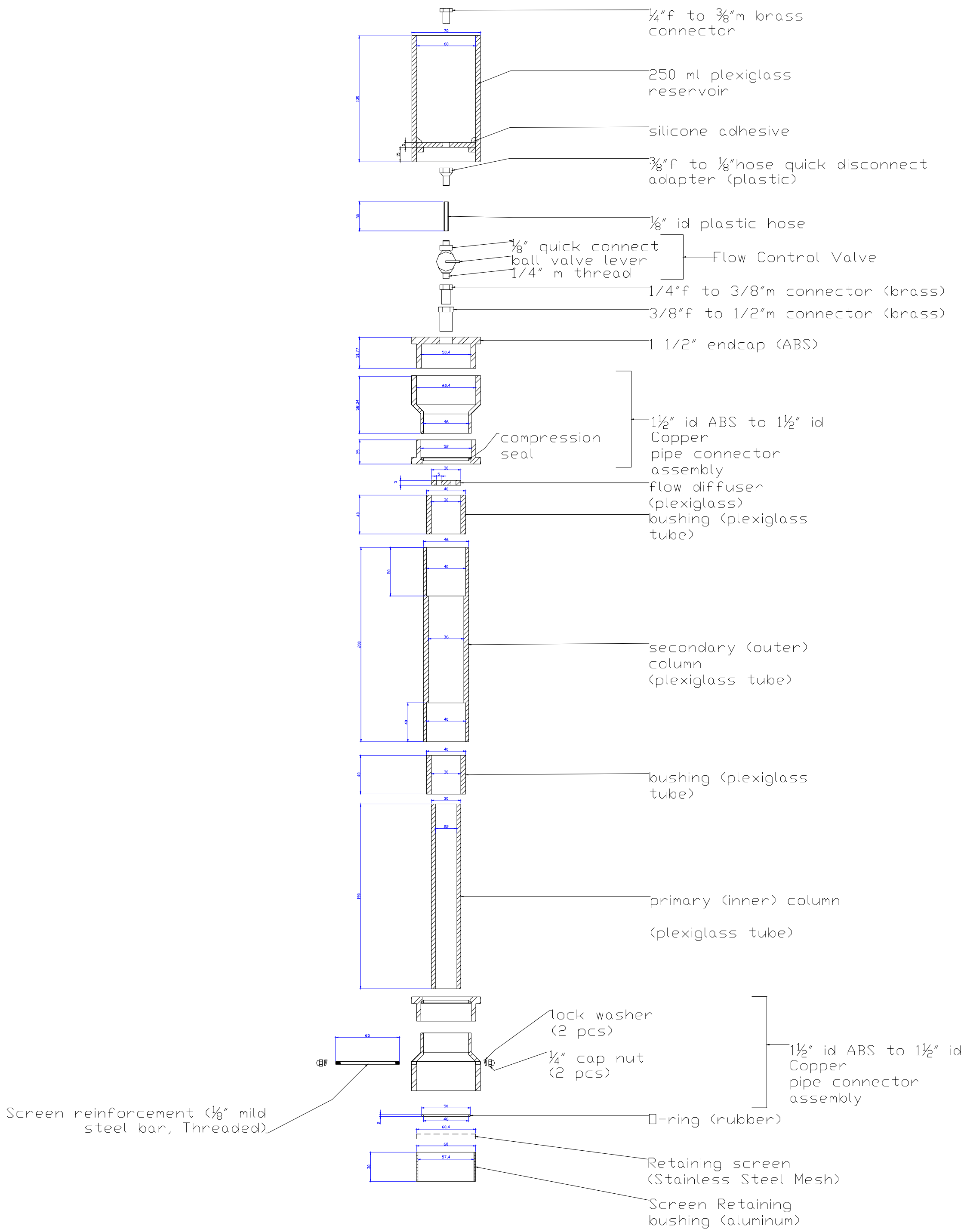

Figure 1. Schematic of the activated carbon column for the removal of methylene blue

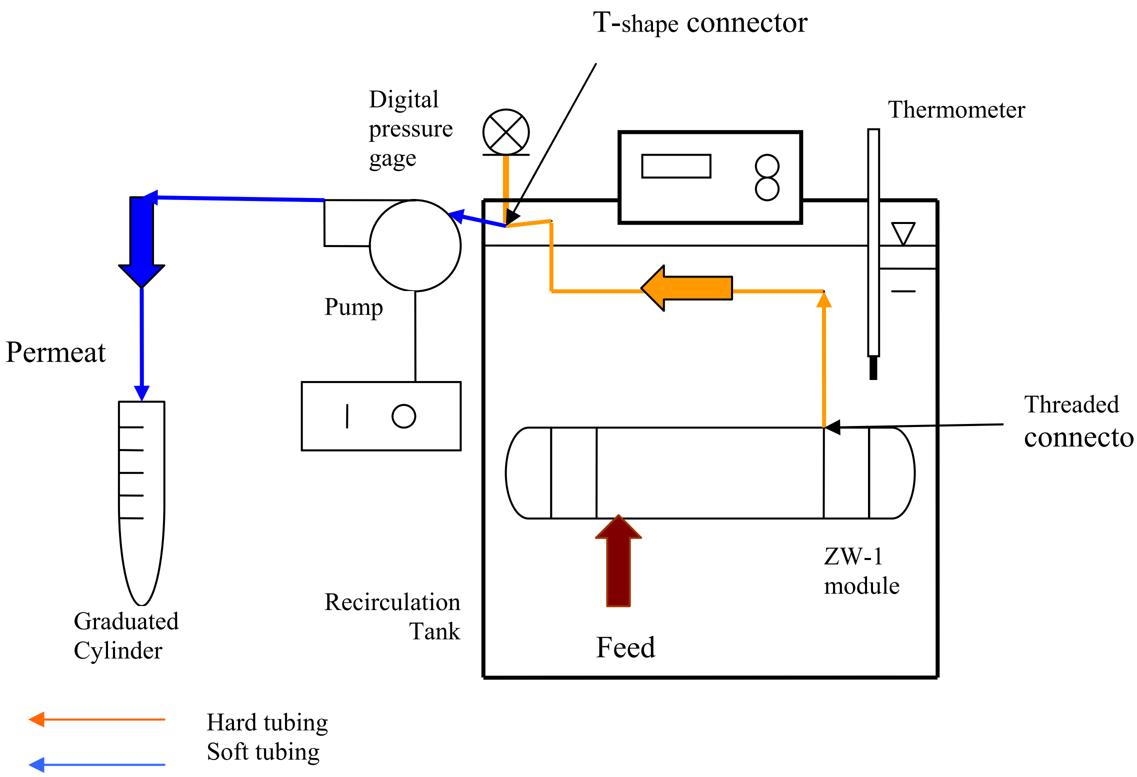

Figure 2. The schematic of membrane flux experiment

Membrane separation (gaseous phase)

This experiment evaluated the impact of membrane wall thickness and gas flow rate on the removal of VOCs using non-porous synthetic membranes. Experimental setup is shown in plate 1.

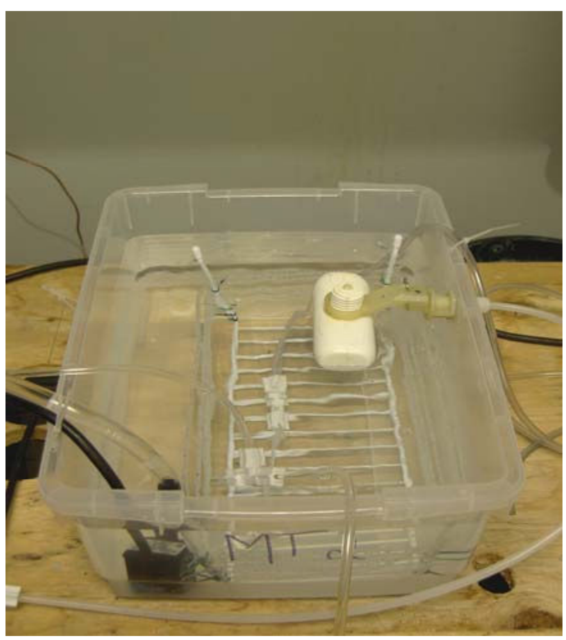

Plate 1. experimental setup for the Removal of VOCs using dense phase non-porous membranes.

Ion exchange

The purpose of this experiment was to remove hardness (approx. 400 mg/l as $CaCO_3$) from tap water using ion exchange. Zeolite was used as the ion exchange resin and sodium chloride was used to regenerate the resin. The experiment evaluated the overall performance of the system for the removal of total, calcium and magnesium hardness. A schematic of the setup is shown in Figure 3.

Distillation

This experiment evaluated the effect of column height on the removal of methanol from methanol-water system using distillation. In addition the diffusion coefficient of methanol in air was measured and compared with published values. Plate 2 shows the setup for this experiment.

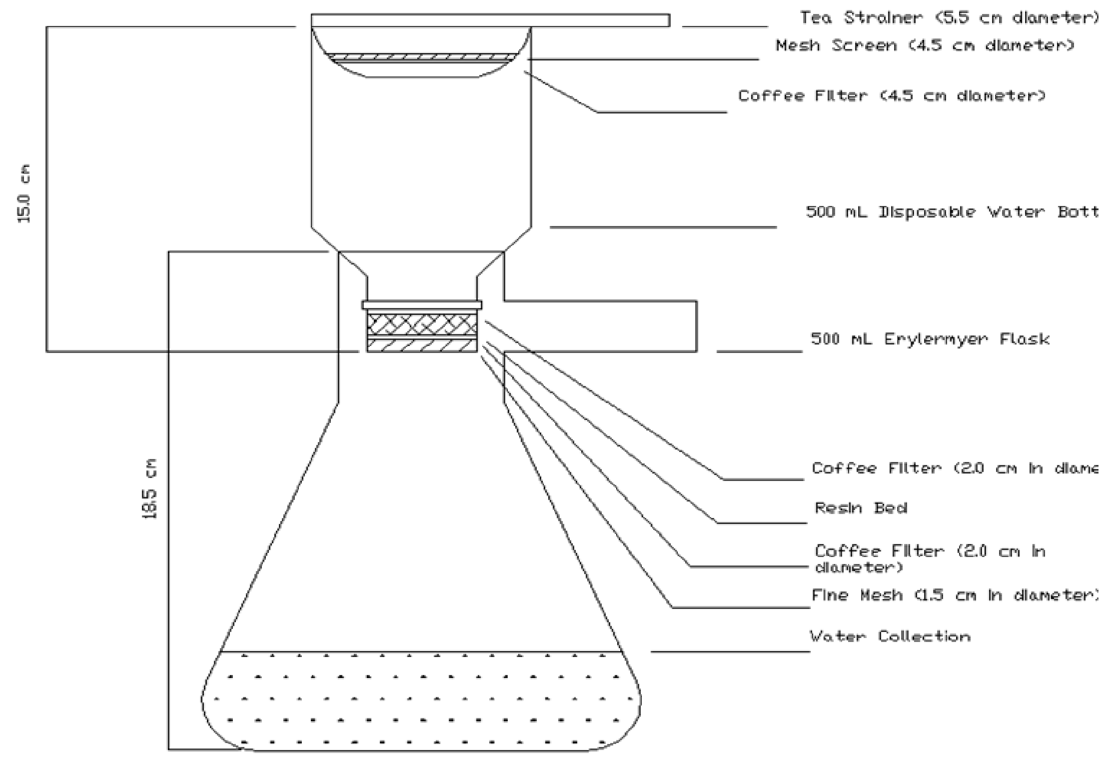

Figure 3. Schematic setup of the ion exchange apparatus for the removal of hardness

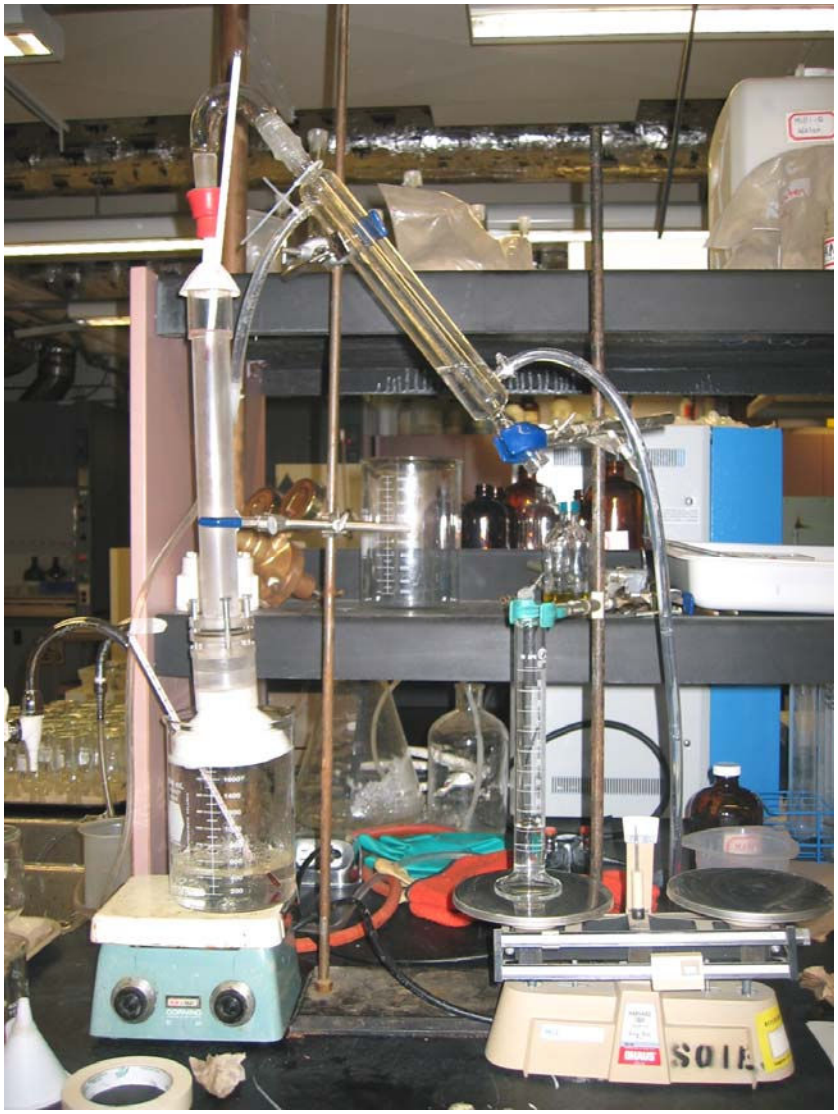

Plate 2. The distillation apparatus

Conclusions and Recommendations

The authors feel that overall the inclusion of student-led design and build of experimental laboratories has been a successful exercise. Students have repeatedly commented on the effectiveness of this method of learning. Many students commented that the labs helped them retain the knowledge and learn experimental design skills not provided in any other course.

We feel that there is a limitation in terms of number of students with this method and recommend to cap the student numbers to 50. Availability of additional space would certainly help the implementation of the labs so would a dedicated budget for students to purchase some of the required material.

Acknowledgement

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Bibliography

1. Haworth, I.,S.; Eriksen, S.P.; Hikmat Chmait, S.; Matsuda, L.S.; McMillan, P.A.; King, E.A.; Letourneau-Wagner, J.; and Shapiro, K. (1998). A Problem Based Learning, Case Study Approach to Pharmaceutics: Faculty and Student Perspectives, American Journal of Pharmaceutical Education Vol. 62(4): 398-401.

2. Carlson, L. and Sullivan, J. (1999). Hands-on Engineering: Learning by Doing in the Integrated Teaching and Learning Program. Int. J. Engng. Ed. Vol. 15(1): 20-31.

3. Eyerer, P.; Hefer, B.; and Krause, D. (2000). The Reformation of Technical Education through Project-Orientated Education (TheoPrax®), Global J. of Engng. Educ., Vol.4, No.3.

4. Dong, Z.Y. (2005). Improving Learning in Undergraduate Control Engineering Courses using Context-based Learning Models Int. J. Engng. Ed., Vol. 21, N0. 6, 1076-1082.

5. McNeal, A.,P.; Silverthorn, D.U.; and Stratton, D.B. (1998). Involving Students in Experimental Design: Three Approaches. Advan Physiol Educ 275:28-34.

6. Hanson, J. and Hoyt, T. (2002). Unknown Gases: Student-Designed Experiments in the Introductory Laboratory. JChemEd.Chem.Wisc.edu. vol. 79, No.7.

7. Arce, J.; Betancourt, R.; Rivera, Y. and Pijem, J. (1998). The Reaction of a Food Colorant with Sodium Hypochlorite A Student - Designed Kinetics Experiment
8. Journal of Chemical Education • Vol. 75 No. 9.

9. George, C. (2004). In Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, Salt Lake City, Utah.

10. Marcella J. Myers and Ann B. Burgess. (2003). Inquiry-based Laboratory Course Improves Students' Ability to Design Experiments and Interpret Data, Advan. Physiol. Educ. 27:26-33.