PROJECT-BASED LEARNING IN EDUCATION

Through an Undergraduate Lab Exercise

Donald D. Joye, Adam Hoffman, Jacqueline Christie, Mayo Brown, and Jennifer Niemczyk
Villanova University • Villanova, PA 19085

Project-based learning, student-centered learning, and a host of other innovative teaching/learning styles have been promoted, discussed, dissected, and advocated in the pages of this journal and others.[1-3] Oftentimes innovative teaching experiences just happen, because the circumstances demand or suggest them. What we did, described herein, may not fit precisely into categories suggested by Felder and his coworkers,[1,2] but it is certainly in the spirit of their advocacies and had a significant payoff in students' lives. It was a unique experience that could never be replicated in typical lecture-style methods or even undergraduate research activities.

In the last decade biotechnology has made significant inroads into chemical engineering departments across the country, even to the extent that some have changed their names to include this new specialty area. Our department decided that creating a lab experiment required of all junior chemical engineers and focusing on one important biochemical application would greatly increase the exposure of biotechnology at the undergraduate level. This would broaden students' horizons and increase their value for potential employers. Other institutions have done similarly.[4-6]

Donald D. Joye *is a professor of chemical engineering at Villanova University, where he has spent 29 years, after three years experience at Lafayette College and two years at Lehigh University. His B.S.E. is from Princeton University, 1967; his M.S. and P.hD. are from Lehigh, 1969/'72. He has five years full-time industrial experience with several different companies, including Sherwin-Williams, Engelhard, and Hercules, Inc. His major interests are in fluid mechanics, heat transfer, mass transfer, polymer science, rheology, process engineering, and education.*

Adam Hoffman *earned his B.S. ChE at Villanova University in 2009. Adam is from Lebanon, N.J. His major interests are in biofuels and alternative energy. He is presently in the M.S. graduate program at Villanova with a research project in biodiesel processing. He plans to go on for the Ph.D. and seek, ultimately, an academic position.*

Jacqueline Christie *earned her B.S. ChE at Villanova University in 2009. Jackie is from Matawan, N.J. Her major interests are in biotechnology, and she is presently employed at Centocor, Inc. R&D, Malvern, PA.*

Mayo Brown *earned his B.S. ChE at Villanova University in 2009. Mayo is from Milton, Mass. His major interests are material science, biotechnology, fuel cells, and engineering education. He is presently seeking employment and considering graduate school.*

Jennifer Niemczyk *earned her B.S. ChE at Villanova University in 2009. Jen is from Seaford, N.Y. Her major interests are biotechnology and sustainability. She is presently doing environmental work with a company on Long Island and about to re-enter college for a degree in teaching.*

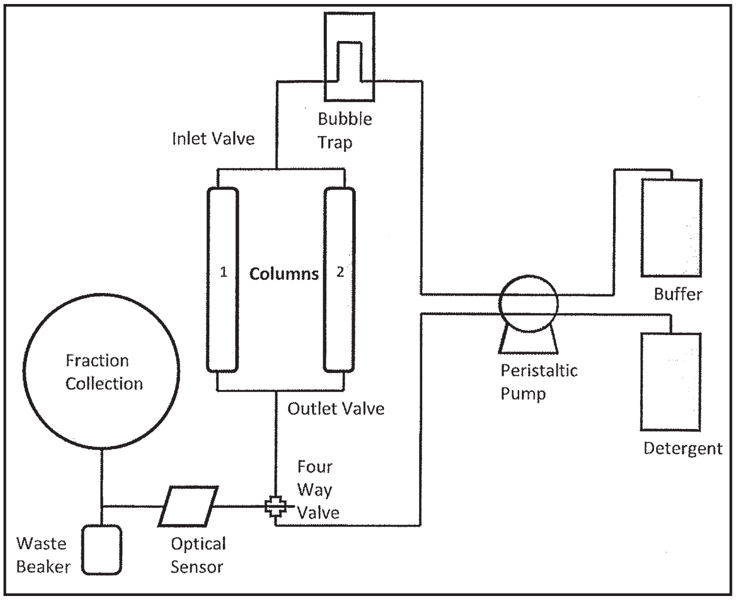

Figure 1. *Schematic diagram of the apparatus.*

The department had purchased the BE2 Chromatography Unit from Armfield—an English supplier of engineering laboratory equipment[7, 8]—that demonstrates the process of size-exclusion chromatography, an industrially important biotech operation. The unit (Figure 1) was purchased over the summer and commissioned by Adam Hoffman, one of the authors, who was at that time a rising senior.[9] Once the unit was up and running, it was decided to integrate the experiment into a junior-level laboratory course in the spring semester. To prepare for this, further development of the experiment was offered as a senior project, generally two semesters long and three credits each semester, that is a requirement for all undergraduate chemical engineering students to complete before graduating. Most seniors do technically related investigations—running equipment, building equipment, doing research, etc. By early fall, three students—Jacqueline Christie, Mayo Brown, and Jennifer Niemczyk, the other authors—expressed an interest in this opportunity for their senior project. One of them (JC) had actually done chromatography during her summer internship with a local biotech company. Because this was a new piece of equipment, the students used the fall semester to develop and test out various ways it could be used in the laboratory and develop the lab instructions. In the spring semester they functioned as teaching assistants on that unit for the junior lab class.

All three seniors had voiced an interest in pursuing the education profession at some time in their future, and this lab exercise was used to give them an opportunity to function as educators. All of them had voiced a strong interest, and so motivation was not an issue. Motivation and competence would be critical to the success of any endeavor like this, however. Their undertaking included commissioning the equipment, developing an experimental protocol suitable for a junior-level lab course, directing the educational delivery of the experiment to students (*i.e.*, lecturing, assisting in the calculations, preparation of chemicals), and grading the reports. The reports were re-graded by the faculty member prior to entering the grades formally. The students worked primarily on their own with close communication with their advisor. During the running of the lab itself, they functioned as typical TAs, primarily responsible for oversight and instruction of the students. As advisor, I checked in on them frequently but tried not to interfere. Their experiences were archived in a senior project report,[10] in which they shared their individual experiences and impressions. The TAs were evaluated on the basis of what they achieved and the quality of their final report. This proved to be a rather novel and interesting experience that combined real-world exposure, project-based learning, and peer interaction. Some of their reflections on the process are included herein.

This lab exercise was one of six experiments for a typical, junior-level, chemical engineering lab course. Other experiments included a pumps lab, a heat exchanger lab, a refrigeration lab (thermo), a pipes and fittings lab, and a distillation lab used mostly for visuals. For us, it is the second lab course in a sequence of three. The biotech lab had to be at an introductory level, as it was intended to expose all chemical engineers, not just those with a biotech interest, to some practice-relevant activity in the biotech field. The calculations involved were relatively simple, but the principles were explained in more detail.

BACKGROUND

Chromatography is a very widely used separation technique in the chemical and biochemical engineering fields.[11-14] It is a highly selective process capable of separating components of closely similar physical and chemical properties. It is important both at processing and process analysis scales. Wikipedia, the popular online encyclopedia, has a good, readable article written by a college professor on general principles that closely follows the unit described herein and could be used by the students as an extra reference. Size-exclusion chromatography is also known as gel filtration chromatography and separates proteins and other biological compounds, and especially polymers, based upon the size of the molecule, or more precisely, the Stokes' radius, which is the effective radius a molecule has as it moves in solution, assuming it occupies a spherical volume. This is equivalent to the end-to-end distance of a polymer chain configuration.[15, 16] A long, extended molecule has a larger Stokes' radius than a compact molecule of the same molecular mass. For the purposes of this laboratory experiment, the Stokes' radius is assumed proportional to the molecular weight.

In size-exclusion chromatography a porous, cross-linked gel is used to separate compounds of different sizes that have been dissolved in an aqueous solution. The gel sits in a tube, and liquid containing the dissolved compounds is passed through. Large compounds pass straight through the column, between the individual beads of gel, because they are too large to fit into the pores. A smaller compound will take longer to elute, because it diffuses into the pores of the gel and has higher retention time in the column. There is a direct correlation between the size of the molecule and the time it takes to elute through the column. Typical for chromatographic techniques, the sample containing the mixture of compounds is injected into a flowing stream of aqueous solvent (the buffer solution), and their travel through the column is hindered by the relative size of the molecules. In this unit, the recommended species to be separated had red and blue colors, so the process was dramatically visual. One could see a bluish-grayish region and a reddish-yellowish region move through the column. The details of the experimentation were described in the manual that came with the unit, but references could be used to supplement and expand on that.

The absorbance plot, which detects the species, can be used to calculate the eluted volume of a compound Ve by measuring the time corresponding to a peak height and knowing the pump delivery rate. Using these values and Vo and Vt, a partition coefficient, K_{av}, can be calculated for each compound in the sample.

$$K_{av} = \frac{Ve - Vo}{Vt - Vo} \quad (1)$$

Here Vt is the volume of liquid that flows through the column in order to elute all the compounds. This could be taken as the end of the last peak. Vo is the volume of liquid that passes through the column just before the first sample is eluted. This could be taken as the beginning of the first peak and should be equivalent to the void volume in the column. There are somewhat different ways to represent the partition coefficient also. If the compounds being separated have a similar shape, a plot of K_{av} vs. the logarithm of the molecular weight will give a linear relationship, or calibration curve, that can be used to estimate the molecular weight of an unknown. Obtaining the calibration curve was the goal of the experimentation for the juniors doing the lab.

The sample was prepared and injected into the flowing buffer solution for the operation of the unit. Our samples consisted of a mixture of the following compounds: 0.2 mg of phenol red in 1 ml of buffer solution, 3.0 mg of blue dextran in 1 ml of buffer solution, and 2.0 mg of cytochrome c (colorless) in 1 ml of buffer solution. These samples were then mixed together in a weigh boat to a uniform green color. Then 300 μL of the mixture was drawn up into a micro-syringe, avoiding air bubbles. The pump is stopped for the injection procedure. The outlet valve of the column is closed, but the inlet is left open. The syringe is then inserted into the septum

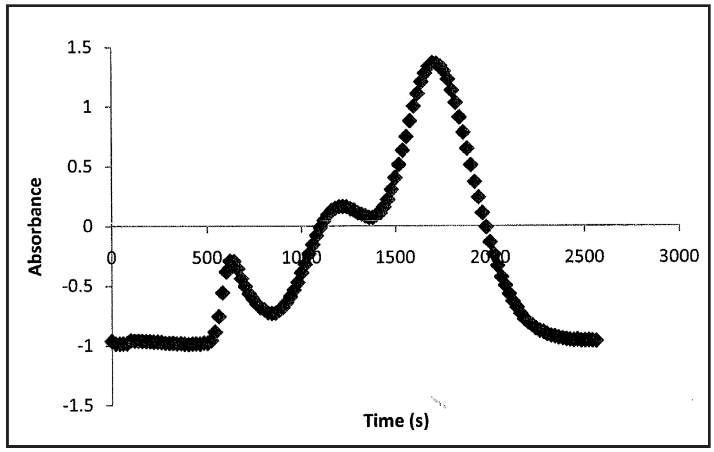

Figure 2. *Typical elution peaks from absorption data.*

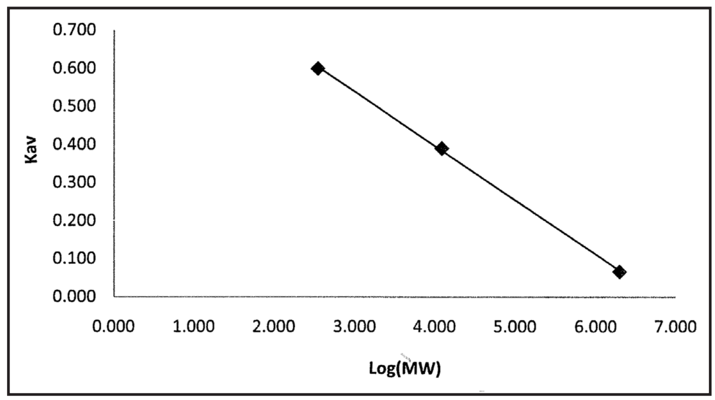

Figure 3. *Calibration curve for molecular weight using the partition coefficient, K_{av}.*

at the top end of the column, and 100μL is carefully injected into the column. Then, simultaneously, the outlet valve of the column is opened, the pump is turned on, and the green "GO" button on the computer is struck to start the data recording. The absorbance is sampled at the time interval selected previously (20 sec). Visible separation should be observed as the compounds move through the column.

RESULTS AND DISCUSSION

Regarding the lab results, Figure 2 shows the elution vs. time curve from which one can see three distinct peaks corresponding to the three compounds to be separated. Peak heights are clearly identifiable and the times at which they occur are also. This information is used along with the partition coefficient to obtain the calibration curve in Figure 3. These are the major results of the experiment. Students would then explain how to find the molecular weight of an unknown from the location of the peak and the calibration curve, or, given the molecular weight, estimate the elution time. The subsequent reports were a group effort, not individual.

As with all experimental equipment, there were several difficulties with this unit that had to be overcome for a successful operation. We had to try a number of different compounds for the separation, but eventually settled on the ones reported here, because the peak heights were distinct.

The junior students who took the lab were not formally polled as to their experiences with their peer TA "educators," but all of them got enough out of the experience to write an acceptably coherent short report, and ad-hoc conversations with some provided evidence they learned something valuable from the experience and enjoyed having seniors as their TAs.

SUMMARY OF EXPERIENCES

The major educational goal of this work was to give senior students, who voiced an interest in joining the education profession at some point in their careers, a chance to do some hands-on learning of what that might be like. All three wrote of their personal experiences in their final senior project report, and their reflections are summarized here. All three had a unique take on their educational role, but they all agreed they wouldn't have traded their time on this project for anything else they did in college. It's a different view from the other side of the fence, and that was an eye-opening experience for them all. In retrospect, the benefits for the three seniors included project-based learning, an exposure to real-world teaching, and peer-learning experiences (seniors/juniors). An education-based senior project was a great way to realize this goal. The senior students had to develop and participate in the delivery of a new experiment for a course they had taken before. They had to develop learning objectives, refine the operation of the equipment so that it gave clear, instructive results, develop the procedure of the experimentation, explain the process to their peers, and assist their peers with the analysis and calculations, then read and grade the reports.

The students on the project speak for themselves in the following paragraphs, so that the readers can get an unfiltered insight into their reactions, frustrations, and joys, and to get an idea of what they took away from the experience.

Mayo Brown: "We, as a group, tried to keep the explanation of the unit the same to each group to prevent any inconsistencies or unfair advantage. The explanation was made assuming that students would read the lab experiment before their scheduled period and be somewhat familiar with the procedure to be performed that day. I found that many students failed to read the lab experiment handout before they came to lab. This hindered their understanding of the lab and resulted in them struggling while performing the lab.

"One aspect I enjoyed the most was the interaction I had with the students during both the experimental and calculation sessions. I personally got to know every junior chemical engineering student, which resulted in them feeling comfortable asking for help.

"My overall experience as a teaching assistant proved how difficult, yet exciting, it is to teach something that has never been done before. The hardest part of the whole experience was becoming comfortable with using the unit, as it takes patience and time. It was always discouraging when a part of the unit malfunctioned, but solving and fixing the problem always provided that extra 'push' to move forward. Overall, I really enjoyed this experience as it has motivated me to become an educator at some point in my life so that I may continue to inspire those younger than me to strive for their best."

Jacqueline Christie: "I enjoyed interacting with the students throughout my experience. I got to know the junior class and made some good connections. I was surprised at the lack of interest in some of the groups, as this lab was out of the ordinary for chemical engineers. Grading the lab reports was an experience in itself. It was easy to tell which groups were attentive and which were not engaged at all.

"From my experience as a teaching assistant I have learned how difficult it is for some professors to get through to some students. As I am very interested in the biochemistry aspect of chemical engineering, I liked sharing my knowledge of biochemistry techniques and chromatography with students who share my interest as well as those who may not have a great knowledge of biochemistry."

Jen Niemczyk: "Serving as a teaching assistant has been an interesting task. This was a great experience that has allowed me to learn things about myself, about my fellow classmates, and a little bit about being a teacher. Grading the lab came as a real surprise. I took this lab (course) two semesters ago and was always satisfied with the work my group turned in. Some of the lab reports that were submitted were awful (*to put this comment in perspective a bit, Jen graduated summa cum laude, and by the time these junior students are second-term seniors, their report-writing skills will have improved significantly*). Through this lab experience I was able to see a little more clearly some of the experiences that a teacher can have from day to day. It is very difficult to engage students if they are not really interested. It's also difficult to get them to understand when they are not entirely paying attention. The groups that experienced the most success were the groups that asked questions and made an effort to understand what was going on."

From a faculty perspective, perhaps the most significant insight our "educators" got was that not all students paid attention to their lectures (amazing!), and that not all students adapted well to the experiment. Some groups paid attention, and their work was very well done. Others barely lifted an eyebrow, showed no interest, did not pay attention, and their work was not well done (what a surprise!). The TAs actually failed one group. The TAs were also emotionally disappointed that some students seemed not to appreciate their efforts, but they were happy when groups showed interest in and grasp of the material, and they felt the fundamental reward of teaching, when they saw a clean transfer of knowledge from one mind to another. This was a big thrill for them, as it continues to be for us in the profession.

I (DDJ) was also happy to see that they used the full spectrum of letter grades, recognizing that the transfer of knowledge is rarely total, and that they could see the "shades of gray" for partial credit or items overlooked or incompletely described in the reports the student groups handed in.

CONCLUSIONS

A biotech lab experiment suitable for junior chemical engineers was created and successfully performed in order to give all chemical engineering students in the class an introduction to a biotech process. The more important educational objective—to use a senior project with an educational twist for those interested in the profession—was even more successful. This proved to be quite revelatory and an interesting and potent way to engage those who may be considering a career in academia at the college or high school level some time in their future. Others may consider doing something like this to encourage motivated people into the education profession.

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