Incorporating Aspects of the Ohio REEL Program into the Organic Chemistry Laboratory: The S_N1 Reaction of Bromotriphenylmethane

Janet L. Marshall and William Comminos
Miami University Middletown

Abstract

At Miami University Middletown, second-year, organic chemistry students perform a classic S_N1 synthesis reaction to prepare an ether from the reactants bromotriphenylmethane and ethanol. The published experimental procedure of monitoring the reaction progress by measuring the pH of the reaction vapor was unreliable; therefore, an alternate method for executing and following the course of the reaction was needed. Drawing upon concepts inherent to the Ohio "Research Experiences to Enhance Learning (REEL)" program (NSF funded; 15 participating Ohio institutes including Miami University), students in the fall 2010 course designed and performed a series of experiments to develop an alternate method for the execution of this reaction. Subsequent refinement and further testing has led to an improved experimental procedure which is now incorporated into the laboratory course. The collaborative and cooperative design of these experiments, as well as the application of REEL concepts to the process, is described.

Background

Second-year, organic chemistry students typically perform a synthesis experiment towards the end of their first-semester laboratory course. At Miami University Middletown, this is often an S_N1 substitution reaction whereby bromotriphenylmethane, $(C_6H_5)_3CBr$, is reacted with ethanol, CH_3CH_2OH, to form an ether, ethoxytriphenylmethane, $(C_6H_5)_3COCH_2CH_3$.

$$(C_6H_5)_3CBr\ (s)\ +\ CH_3CH_2OH\ (l)\ \rightarrow\ (C_6H_5)_3COCH_2CH_3\ (s)\ +\ HBr\ (g)$$

The reaction yields a white, crystalline product which can be readily characterized and affords students the opportunity to apply both lecture concepts and laboratory skills taught during their first semester of organic chemistry. The published experimental method directs students to follow the course of the reaction by monitoring the pH (acidity) of the reaction

vapor (Lehman, 2009). At best, only a few students are able to actually sample or observe acidic vapor which usually leads to the instructor letting the students know when to stop the reaction, based on prior experience; this isn't particularly instructional or intellectually satisfying to the students or to the instructor.

Objective

Since this S_N1 reaction is well-suited for an introductory organic synthesis experiment, an alternate method for executing and monitoring the course of the reaction was sought. Instead of having the instructor independently revise the lab, students in the fall 2010 laboratory course were asked to participate in the planning and execution of a set of experiments to help develop an improved method, incorporating aspects of the Ohio REEL program in their approach.

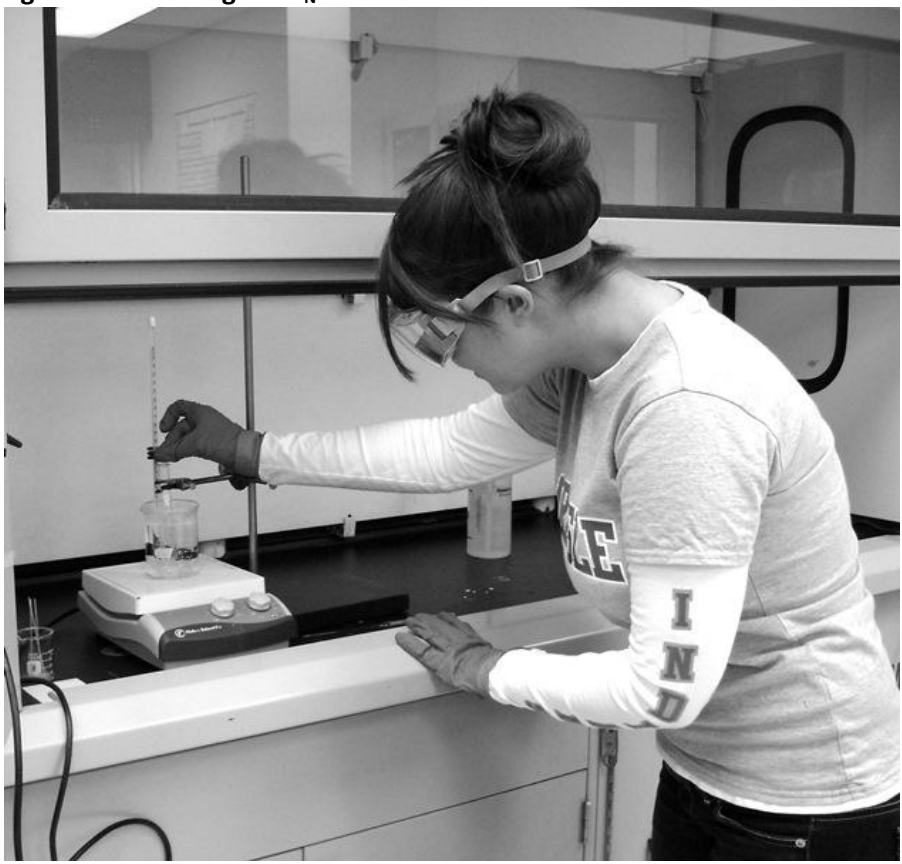
The Ohio REEL program, funded by the National Science Foundation (NSF), is a partnership of the chemistry departments of 15 educational institutions throughout the state, including liberal arts colleges, community colleges, university regional campuses, and research universities, who share the vision of introducing more realistic chemistry laboratory experiences to first- and second-year students. The major goals of REEL are to: (1) transform the chemistry curriculum to become more research-intensive, (2) increase the retention and graduation rates of students in STEM (science, technology, engineering, and mathematics) disciplines, and (3) generate new knowledge in the chemical sciences through multi-site, faculty-student collaborative research projects (Ohio REEL, 2005).

The experimental work the organic students were asked to undertake focused on the first goal. The intent was for the students to gain an appreciation of how laboratory experiments are designed and developed, to understand the need for controlling experimental variables, to apply newly-acquired laboratory techniques and skills, and to work cooperatively to solve experimental problems. Furthermore, by having students generate data and results, a large amount of information needed to modify the procedure, which directly factored in the inherent trials and errors of beginning experimentalists, could be obtained.

Accordingly, the students first performed the S_N1 synthesis experiment by following the published method of heating the bromotriphenylmethane reactant, $(C_6H_5)_3CBr$, in absolute ethanol, CH_3CH_2OH, which serves as both a reactant and the solvent. This allowed the students to become familiar with the techniques required, as well as

understand the inherent experimental shortcomings. Since the by-product of the reaction is hydrogen bromide (HBr), the reaction was conducted in a fume hood and the progress of the reaction was followed by monitoring the acidity of the reaction vapor using litmus paper (Figure 1). In theory, as the reaction proceeds, the vapor becomes acidic due to the evolution of gaseous HBr; when the reaction is "complete" the vapor is no longer acidic. In practice, students find it challenging to observe this, likely due to the draw of the fume hoods and/or a low concentration of HBr in the reaction vapor since this by-product is also soluble in the reaction solution.

Figure 1: Executing the S_N1 reaction in the fume hood.



After this initial experiment, the instructor and students discussed their observations and results, and the students were asked to develop a set of experiments to improve the procedure and to implement their ideas the

following week. Because of the challenges in measuring vapor pH, the students proposed using thin-layer chromatography (TLC) to follow the course of the reaction. TLC separates compounds on the basis of polarity and is often used to monitor the progress of an organic synthesis reaction (Lehman, 2009). Because of the significant difference in polarity between the bromotriphenylmethane reactant, $(C_6H_5)_3CBr$, (more polar) and the ethoxytriphenylmethane product, $(C_6H_5)_3COCH_2CH_3$, (less polar), this technique was a good choice for following the progress of the reaction. In addition, the students decided to control reaction variables such as temperature and time to avoid the formation of colored by-products which had been observed in the initial execution of this experiment. Accordingly, the students decided to run the reaction at two different temperatures (40°C and 65°C) for three different amounts of time (5, 10, and 15 minutes). A total of six conditions were tested, in duplicate, with each student responsible for the isolation and characterization of the ether product for a given reaction condition. When the experiment was performed this second time, several students also tried to incorporate methods to "capture" the reaction vapor in order to better sample its pH.

Observations and Results

Overall the follow-up synthetic experiment went very well. The students collaborated on the experimental design and agreed on a common method for controlling reaction variables. Students paired up to run the six experimental conditions, but each student ran his or her own reaction in order to obtain data in duplicate. Each student followed the reaction by TLC and isolated and characterized his or her product by melting point, as directed in the published procedure. Product yields were also determined (Figure 2).

Figure 2: Student partners documenting experimental observations and results.

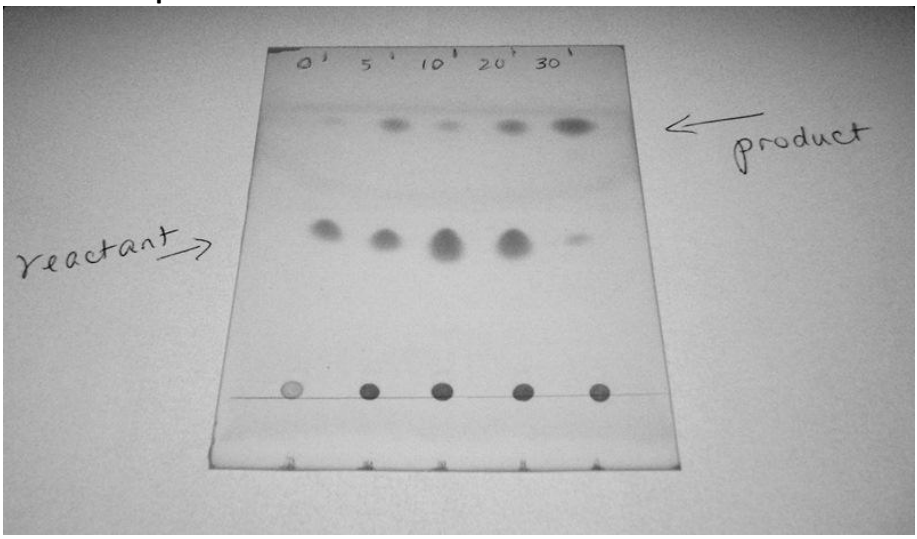
The key observations/results were:

- Product was produced quickly at both temperatures; however, the product produced from the reactions performed at 40ºC was often impure as observed by a lower and broader melting point. For example, one student's impure product was observed to melt over a 73-77°C temperature range vs. 80-81°C for pure $(C_6H_5)_3COCH_2CH_3$ product.
- TLC monitoring of the reaction at both temperatures clearly showed the rapid conversion of the bromotriphenylmethane reactant to the ether product (within 5-10 minutes), with product continuing to be produced as a function of reaction time (Figure 3). (TLC conditions: silica gel plate with 85% hexane/15% ethyl acetate eluent.)
- Minimal yellow by-product(s) were observed since the reaction temperature was kept well below the boiling point of ethanol

(78°C). In the initial experiment, when students allowed the reaction solution to boil, the solution became yellow in color and the solid ether product was often discolored instead of bright white.

- Attempts to better monitor the vapor pH by inverting a funnel over the top of the reaction test tube did not improve the ability to track the progress of the reaction.

Figure 3: Monitoring the reaction progress by thin-layer chromatography. From left-to-right, the reaction time was 0, 5, 10, 20, and 30 minutes at a reaction temperature of 65ºC.



Based upon the results generated by the fall 2010 organic students, subsequent work was completed to hone an improved experimental procedure for incorporation into the laboratory course. This included further understanding the dependence of product yield and purity on reaction temperature (40ºC to 65ºC) and time (5 minutes to 30 minutes). These experiments showed that product obtained from reactions performed at 40ºC was often impure due to undissolved (and therefore unreacted) bromotriphenylmethane, $(C_6H_5)_3CBr$. The experimental conditions were then refined. Students in the following summer and fall 2011 classes were asked to execute the reaction at either 50ºC or 65ºC for either 10 or 20 minutes, again monitoring the reaction by TLC, in order to acquire additional experimental data.

The compilation of data generated from these experiments showed:

- As in earlier experiments, TLC monitoring of the reaction proved to be a simple, reliable method for following the course of the reaction and allowed the students to apply a recently-learned analytical technique towards solving a practical problem.
- Product was produced quickly at both temperatures and was generally pure. However, care had to be taken to make sure the bromotriphenylmethane reactant was completely dissolved (especially at lower temperatures) to avoid impure product.
- The large difference in solubility between the bromotriphenylmethane reactant, $(C_6H_5)_3CBr$, and the ether product, $(C_6H_5)_3COCH_2CH_3$ facilitated the separation of the desired product. The ether product crystallized from the reaction solution and was easily isolated by vacuum filtration.
- Isolated product yields varied between 20% and 73%. Although, product yield increased as the reaction time was lengthened from 5 to 30 minutes, 10-20 minutes of reaction time was sufficient to yield product which could be readily isolated and characterized (Figure 4; Table 1).

Figure 4: Comparison of the amounts of crystallized product as a function of reaction time. From left-to-right, the reaction time was 5, 10, and 20 minutes at a reaction temperature of 50ºC.

Table 1: Isolated product yield as a function of reaction time and temperature (averaged student data).

	Temperature = 50ºC	Temperature = 65ºC
Reaction Time = 10 minutes	44%	55%
Reaction Time = 20 minutes	58%	51%

Conclusions: Experimental Lab Development and REEL

The compilation of observations, data, and results over three classes of organic laboratory students resulted in an improved method for the execution of this introductory S_N1 synthesis experiment. The reaction can be performed at moderate temperatures (50-65ºC) which minimize undesired by-products as well as loss of solvent. Pure product is obtained within relatively short reaction times, and the reaction progress can be

readily monitored using TLC. Since TLC is an analytical technique which is taught earlier in the first-semester laboratory course, students quickly get to apply it to a synthesis reaction. Building on the success of this work, additional problem-solving and collaborative-learning experiments utilizing this general S_N1 synthetic scheme are planned for future courses. These include varying the substrate (e.g., bromodiphenylmethane vs. bromotriphenylmethane) as well as the reaction solvent/nucleophile to probe several mechanistic aspects of the substitution reaction (Esteb, Magers, McNulty, Morgan, Tindell, and Wilson, 2009).

Importantly, all of the students who participated in the design, development, and execution of an improved experimental procedure for this S_N1 reaction were asked to move beyond "cookbook" or expository experimentation (Domin, 1999). The students had to apply knowledge gained in this course, as well as previous science courses, to solve an experimental problem without knowing the exact outcome. For example, when following the published method, students would often overheat the reaction mixture and run the reaction for longer than necessary. By monitoring reaction time and temperature and tracking the reaction via TLC in a systematic fashion, students realized pure product could easily be obtained under mild conditions rather quickly. Since these experiments were performed using an uncomplicated organic synthesis reaction, the control of reaction variables and means for evaluating the results were straightforward. This was especially helpful for students beginning to develop synthetic organic chemistry skills. In the process, the students also gained a new appreciation for process refinement and optimization, which are fundamental skills required of practicing scientists and engineers.

This laboratory development experience illustrates a basic goal of the Ohio REEL program. By taking a traditional organic synthesis lab and asking students to apply their scientific training towards solving an experimental challenge, elements of problem-solving and collaborative learning were incorporated into the first-semester organic chemistry course (Browne and Blackburn, 1999). The students were asked to be creative and to work together to design experiments in which the answer was not predetermined.

Although, the experimental work undertaken to improve this synthesis lab would not be considered a classic chemistry "research project" in which new information is learned or discoveries are made, the cognitive skills required by this exercise, such as independent and open-ended thinking, application of the scientific method, and cooperative

experimentation, are exactly those needed for success in chemical research. An early introduction to these types of experiences, which the Ohio REEL program is designed to foster, can certainly lead to student interest in both pure and applied research and retention of students in STEM disciplines (OSU Chemistry REEL Program, 2011).

References

Browne, L.M. & Blackburn, E.V. (1999). "Teaching Introductory Organic Chemistry: A Problem-Solving and Collaborative-Learning Approach." *Journal of Chemical Education.* 76(8): 1104-1107.

Domin, D.S. (1999). "A Review of Laboratory Instructional Styles." *Journal of Chemical Education.* 76(4): 543-547.

Esteb, J.J., Magers, J.R., McNulty, L., Morgan, P., Tindell, K., & Wilson, A.M. (2009). "A Flexible Solvolysis Experiment for the Undergraduate Organic Laboratory." *Journal of Chemical Education.* 86(7): 853-855.

Lehman, J.W. (2009). *Operational Organic Chemistry*, 4th ed. Upper Saddle River, N.J.: Pearson Prentice Hall.

OSU Chemistry REEL Program (2011). Retrieved August, 26, 2012 from http://research.chemistry.ohio-state.edu/reel/

Research Experiences to Enhance Learning (REEL) (2005). Retrieved August, 26, 2012, from http://ohio-reel.osu.edu/

Acknowledgments

The authors thank Dr. Richard Taylor (Miami University - Oxford) and Dr. Ted Clark (Ohio State University – Columbus) for an introduction to the Ohio REEL program. They also thank the Miami University Middletown Center for Teaching and Learning for financial support to attend the Pearson "Strategies for Success" workshop at OSU (April 2009). The fall 2010 organic chemistry laboratory students who completed the initial work on the improvement of the "S_N1 Reaction of Bromotriphenylmethane" experiment are: Jacqueline Baker, Diedrea Barker, Danielle Begley, Steven Comminos, William Comminos, Jessica Everage, Ryan Gaston, Aaron Hirsch, Ashleigh Kincaid, Robbie Laubenstein, Kristen Monroe, Bryan Osinski, and Jesse Powell.

Biographical Information

Janet L. Marshall, Ph.D., is a lecturer in the Department of Chemistry and Biochemistry at Miami University Middletown. She teaches sophomore-level organic chemistry and a one-semester introductory general, organic, and biochemistry course at the Middletown campus during the academic year. During the summer, Janet teaches organic chemistry at the Oxford campus. She also serves as the Miami University faculty liaison for the teaching of dual enrollment/dual credit organic chemistry lecture (CHM 241/242) at Centerville High School. Janet is currently developing an introductory course in food chemistry to be offered at Miami University Middletown in the spring of 2013.

William (Bill) Comminos is a senior at Miami University majoring in Microbiology and Medical Laboratory Science with a minor in Computer Science. He spends time on both the Middletown and Oxford campuses taking courses in the sciences as well as computer software/technology courses. He also works part-time in the Middletown chemistry stockroom and in IT Services on these two campuses. Bill plans to start a one-year internship to complete his Medical Laboratory Science degree upon graduation in May, 2013.

Correspondence concerning this manuscript should be addressed to Janet L. Marshall, Department of Chemistry and Biochemistry, Miami University, 4200 N. University Blvd., Middletown, OH 45042. Electronic mail may be sent to: marshaj@muohio.edu. Telephone correspondence: 513.727.3398.