RESEARCH ARTICLE

Demonstrating the importance of cleanliness and safety in an undergraduate teaching laboratory

Safety and cleanliness are often-overlooked components for the success of chemists in any type of environment. Today's undergraduate chemists are often not fully prepared to enter the work place because they are not equipped with the necessary skill, knowledge, and attentive safety attitude for jobs in the laboratory. This article proposes a new, hands-on method of teaching laboratory cleanliness to undergraduate students via an organic laboratory experiment. A survey was given to participants who performed this laboratory experiment and to a control group to evaluate how completion of the experiment affected the following: (a) development of a greater appreciation of laboratory cleanliness, (b) understanding of the concept of thin-layer chromatography (TLC), and (c) development of a greater appreciation of common laboratory techniques.

By Luke A. Gallion, Michael J. Samide, Anne M. Wilson

Luke A. Gallion *is affiliated with the Department of Chemistry, Butler University, Indianapolis, IN 46208, United States.*

Michael J. Samide *is affiliated with the Department of Chemistry, Butler University, Indianapolis, IN 46208, United States.*

Anne M. Wilson *is affiliated with the Department of Chemistry, Butler University, Indianapolis, IN 46208, United States (e-mail: amwilson@butler.edu). Tel.: +3179409048; fax: +3179408434.*

BACKGROUND

Cleanliness and the safety impacts of cleanliness in the laboratory are crucial for the success of chemists in any type of environment. A new culture of concern for laboratory safety has developed with increasing knowledge of chemical hazards and risk management.[1] The American Chemical Society Committee on Professional Training has adopted a statement indicating that laboratory safety skills are essential components of any chemistry curriculum and has clearly defined the emphasis areas for these components.[2]

Fair, Kleist, and Stoy recently sought to identify what topics of chemical safety industry deems most important.[3] The study found that the two highest ranked safety items were identified as "maintain proper PPE" and "accident avoidance." Employers may be required to give site-specific safety training, but they should not be expected to educate new employees on common safety practices. Chemical educators are responsible for creating a safe environment in the laboratory while instilling in students the necessity of safety in the laboratory to ensure that students are ready to enter the work force. Many university curricula, though, do not include safety education around the component of laboratory hygiene.[4,5]

A review of the literature reveals that safety issues are seldom raised in general chemistry or organic chemistry curricula even though this is a strong recommendation by the American Chemical Society.[6] Curricula that do contain safety education around the component of laboratory hygiene tend to focus on house-keeping at the completion of the laboratory.[7–10] A standalone laboratory safety course has also been described.[11] Our proposed modification to Butler University's organic laboratory sequence provides a hands-on approach that SHOWS students the importance of laboratory safety WHILE performing the experiment. This is different from other approaches in that students are able to perform an experiment first-hand and visualize contamination.

Chemists at Butler University sought a method of incorporating a hands-on method of teaching laboratory cleanliness in the performance of an introductory foundational laboratory experiment. An existing laboratory experiment was modified so that undergraduates in the organic chemistry laboratory sequence would realize the importance of cleanliness in the laboratory and, as a result, implement hygienic laboratory practices.

PROJECT DESIGN

Our Traditional Laboratory Sequence

The traditional organic chemistry laboratory sequence began with a simple

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fermentation experiment than spanned two three-hour laboratory periods. In the first laboratory period, students initiated a fermentation reaction (aqueous sugar and yeast). In the second week, students used the full three-hour period to filter the solution and perform fractional distillation on the filtrate. In the third week of the laboratory sequence, students used melting points, thin layer chromatography, and mass spectrometry to identify an unknown compound.[12] This experiment took students approximately two hours to complete.

Modification to the Laboratory Sequence, Adding Chemical Hygiene

Modifications were made in week one and week three of the laboratory sequence, adding components to demonstrate correct chemical hygiene. After the fermentation apparatus was assembled in week one, students poured TLC plates. They suspended silica and a fluorescent indicator in water and poured onto a microscope slide (see full experimental details in the following section). Upon completion of preparation of the TLC plates and the students had "cleaned up" the laboratory, the laboratory lights were turned off and the laboratory instructor used a black light to examine the laboratory.

During the third week of the laboratory sequence, students performed thin layer chromatography using both the TLC plates that they poured and commercially available TLC plates. An anonymous survey was administered at the end of the laboratory period (see supplemental information for a copy of survey, $n = 33$ for the modified laboratory and $n = 18$ for the traditional laboratory).

Procedure for Student-Prepared Thin-Layer Chromatography Plates

To a 20 mL disposable scintillation vial equipped with a stir bar, silica (1.2 g), calcium sulfate (0.1 g), and fluorescence indicator green 254 nm (0.003 g, Zn_2SiO_4–manganese doped)[13] were suspended in 2.7 mL distilled water and stirred for ten minutes. The mixture was poured on a frosted microscope slide and allowed to air dry for two weeks.

RESULTS/DISCUSSION

Quantitative Results

Survey results in Table 1 showed that students who performed the modified laboratory are now more cognizant of the importance of cleanliness in the laboratory. Assuming a significance level of 0.10, which is appropriate for our human subject sample size, we have found statistically significant evidence that students who poured their own TLC plates were more aware of their lack of cleanliness before this laboratory as a result of the completion of the modified sequence (see Table 1, Question 1). The assessment also indicated a statistically significant difference in the proportion of students that changed their perception of laboratory cleanliness between students who performed the modified laboratory and students who completed the traditional experiment. We found that students who performed the modified laboratory changed their perception of laboratory cleanliness more so than students who completed the traditional experiment (see Table 1, Question 2). Another important item to note was that although students did not wear gloves when performing the experiment, even after being reminded to maintain proper PPE in laboratory and lecture, 100% of students wore gloves the following week and throughout the rest of the semester.

Survey results also indicated that completing the modified experiment significantly impacted student appreciation of common laboratory techniques. Students who poured and used their own TLC plates indicated that it was very worthwhile to purchase commercially available TLC plates, while students who did not pour their own TLC plates did not appreciate the convenience of having commercially available TLC plates (see Table 1, Question 3). This likely arose because many student-poured plates cracked, did not dry evenly, or were too fragile to be used effectively. When asked to include any additional comments on the laboratory, students included such comments as the following:

- "*It was helpful to see how the plates are made/work. However the homemade plates were a lot more difficult to use and I didn't get any data for one of my compounds.*"
- "*Homemade TLC plates, in my opinion, don't work as well as pre-made TLC plates.*"
- "*Home-made plates are extremely fragile and therefore not reliable as*

Table 1. Comparison of Survey Responses of Students Who Participated in a Modified Laboratory Sequence Versus Students Who Participated in the Traditional Laboratory Sequence.

Survey Statements for Response	Mean Scores, 1 = "Not Clean," "No Impact," "Not worthwhile"; 6 = "Very Clean," Strong Impact," "Very Worthwhile"		
	Students that Performed Modified Laboratory	Control Group Students	*p* values, significance
How would you have rated your lab cleanliness before this laboratory?	4.45 ± 1.15	4.93 ± 1.03	0.0817, significant
Indicate how this laboratory affected your view on lab cleanliness.	4.42 ± 1.36	3.47 ± 1.55	0.0266, significant
Now that you know how a TLC plate is prepared, how worthwhile is it to purchase commercial plates?	5.19 ± 1.07	3.60 ± 1.68	0.0016, significant