

Using Simulation of Apparatus Set-up to Improve Safety

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Received March 28, 2015; Revised April 06, 2015; Accepted April 09, 2015

Abstract There is increased focus on improving both safety and learning outcomes of undergraduate chemistry laboratory experiences. Incorrect setting and/or misuse of equipment occurs commonly and can even lead to accidents. This article describes how this was addressed by the development of pre-lab activities that require students to read a detailed step by step word document with instructions and appropriate diagrams describing the set-up of the apparatus, watch a video demonstrating the same and then demonstrating that they could set-up the apparatus by successfully completing an online simulated assembly of the apparatus. Following the pre-lab activities, students undertook the lab and were required to set up the apparatus on their own but to seek instructor's help as needed. It was observed that the class was able to set-up the apparatus within fifteen minutes. This is in contrast to the usual time of around one hour taken traditionally. The time saved was used to link the theory underlying the lab to a novel application of nanoparticles to accomplish distillation at room temperature. Students were also surveyed on their perception of the pre-laboratory activities. An overwhelming majority of the students felt that the pre-lab activities were valuable and better prepared them to set-up the simple distillation apparatus correctly and that similar pre-lab activities be developed for other laboratory exercises.

Keywords: flipped pre-lab, laboratory safety, organic chemistry, simulation, simple distillation

Cite This Article: Brahmadeo Dewprashad, and Colin Persaud, "Using Simulation of Apparatus Set-up to Improve Safety." *World Journal of Chemical Education*, vol. 3, no. 2 (2015): 36-39. doi: 10.12691/wjce-3-2-2.

1. Introduction

Chemistry laboratory experience is a valuable and integral part of chemical education but not without challenges. Safety is a major concern. Recently, a UCLA research student died from a lab accident and one of the reasons cited (for the accident) was that she "had very little experience" with the procedure she was using [1]. Although, undergraduate organic chemistry laboratories are much safer, mishaps can and do happen. In addition, many instructors and students feel that laboratory sessions are not meaningful learning experiences [2,3,4]. There is increased focus on improving both safety and learning outcomes from laboratory experiences. Methods intended to improve lab safety tend to focus on providing more information on safe practices and concerns such as having each student become familiar with the educational and governmental laboratory safety, or assigning each student to locate safety resources for a specific class laboratory experiment, or having students present on safety aspects of a lab [5,6]. Approaches to improving learning from laboratory exercises include use of inquiry based and project based laboratory exercises [7,8]. At the undergraduate level, particularly in organic chemistry, a student is required to set up and use equipment that he/she has never used or even seen before. Students attempt to do this by following a procedure outlined in a lab textbook (with instructors' help). The lab textbooks generally do

not provide detailed step-by-step instructions for setting up equipment. The authors assume that students can make certain inferences from what they read. This is often not the case. In addition, many students do not read the procedure before the start of a laboratory exercise. These problems are understandably heightened at community colleges where many students come academically underprepared and lead very busy lives-often holding down jobs and supporting families whilst taking classes. Undertaking pre-lab activities is not usually on their list of priorities.

Incorrect setting and or misuse of equipment happens commonly and can lead to accidents. As such, often the focus of instructors in laboratory sessions is on helping each of about twenty-five students with the correct set-up and safe use of the equipment. It was envisioned that providing students with detailed written descriptions and video presentations of the set-up followed by the experience of virtually setting up the apparatus before a lab, and ensuring that they have done so, would likely make them better prepared to undertake the actual set up without errors and in less time. Simulation is recognized as a valuable teaching tool and simulated experiments have been developed and used as substitutes for experiments [9]. However, this approach has not been embraced by the chemical education community as they see simulated experiments as poor substitutes for actual laboratory experiments. Although simulations and/or online videos of several undergraduate organic chemistry experiments (including simple distillation) have been done,

they do not include detailed instruction for set-up of the apparatus. In addition, There are no reported development or use of simulation of the assembly of the apparatus required for an organic chemistry experiment.

The experiment for which the pre-lab activities were developed is a "Comparison of Simple and Fractional Distillation". It is a standard experiment that is done nationally at the beginning of organic chemistry courses as it introduces students to the equipment and process of distillation, a procedure that is used in several subsequent experiments in Organic Chemistry I and II. In addition, this experiment requires students to correctly assemble sixteen different components and this has proven to be a challenge to many students in the experience of one of the authors.

2. Materials and Methods

Pre-lab activity whereby student are required to read a detailed step by step word document, with instructions and appropriate diagrams, describing the set-up of the apparatus, watch a video demonstrating the same, and then completing an online simulated assembly of the apparatus, was developed.

The word document describing the apparatus set-up and the video were placed on the course website so that students could access and use at their convenience. The interactive simulation of the apparatus was set up in the computer lab in which lectures were held and students were allowed to complete during a class session. In the following semester, in response to students' feedback, a new version of the program was developed using pictures and drag selection areas twice as large as those in the first version. This interactive simulation was placed in an open computer lab and students were required complete the activity in their own time but before undertaking the laboratory exercise.

The apparatus set up simulation was done by creating a windows computer application consisting of four modules: Mechanical, Electrical, Distillation Flask and Condenser. Pictures were taken of each component of the distillation apparatus before and after setup. The before and after pictures of the distillation apparatus were assigned to the appropriate modules. A form for each of the modules was created, and the before and after pictures of each module were integrated within each form. The after pictures on each module's form were hidden until the correct steps were completed within that module. The module forms were coded into the program and activated via icons and menu items. Additionally, menu items were created and coded for logins and student results. The Electrical menu was visible upon program startup and when this module was completed, the Mechanical menu became visible. Subsequently, the Distillation Flask menu and the Condenser menu became visible once the preceding modules were successfully assembled. The modules were required to be setup in the above listed order and upon successful completion of each; the student was instructed to proceed to the succeeding module. On successful completion of all of the modules, a completion status message was displayed and a student's log consisting of the setup date and time, duration and completion status was written to the database. The student could then choose

to restart the simulated process of setting up the apparatus again.

This windows computer application was written in the C# (.Net framework) programming language with a Microsoft SQL Express Server 2005 database on the backend. It was fully unit tested and system tested to ensure that all functionality is within specification before being made accessible to students. The database used to store the user login and data was housed in a secure server within the College Computing Center. This application was coded in the .net environment and used Microsoft (MS) SQL Server Express 2005 database. This environment and database are produced by Microsoft and are used by a large install base of companies for business applications [10]. The program is simple to code and could be done by someone with rudimentary knowledge of C# programming, SQL programming and Relational databases.

The students' apparatus setup data was collected by the instructor for evaluation purposes. The apparatus setup data consisted of all students' setup attempts including date, setup duration and status. No students' personal data such as social security numbers, or addresses was collected or stored in the application or database. The instructor maintained a hard copy of all students' login credentials and stored securely in his departmental college facility. The apparatus setup data was compared with the student list to determine the students who used the application to attempt the setup. Following the pre-lab activities, students undertook the lab and were required to set up the apparatus on their own but to seek instructors help as needed.

3. Results

An analysis of the times taken by students to complete the interactive exercise indicated that the times ranged from 2 to 38 minutes with an average time of 14 minutes and median time of 11 minutes. It was observed that the classes were able to set-up the apparatus in the laboratory within fifteen minutes. This is in sharp contrast to the usual time of around one hour taken traditionally. It was observed that the classes (that undertook the flipped pre-lab activity) were able to set-up the apparatus in the laboratory within fifteen minutes. This is in sharp contrast to the usual time of around one hour taken traditionally. The time saved was used to link the theory underlying the lab to a novel application of nanoparticles to accomplish distillation at room temperature [11]. Researchers have shown that when solutions of carbon nanotubes are exposed to sunlight, the vapor pressure above the solution rose as a result of steam generation. In addition, it was shown that water-ethanol mixtures can be quickly separated by distillation using sunlight when nanomaterials are added to the mixture, resulting in 99% pure ethanol. Absorption of light by the nanoparticles excites surface electrons and causes a rapid temperature rise in the vicinity of the nanoparticles and these results in shells of steam around the nanoparticles. These steam shells coalesce and form bubbles which then rise to the top of the liquid and escapes as steam. Class discussions centered on: (a) students' ideas for modification of the simple and fractional distillation experiment such that

sunlight can be used instead of heating as an energy source, (b) would distillation occur at the same temperatures observed in the experiment with their suggested modifications and, (C) applications of the described research developments to affordable solar-powered water purification systems and more efficient electricity generation.

The instructor compared the number of instances of incorrect apparatus set-up in a class in which the pre-lab simulation was used and found only two instances. This compares favorably with the results from another class that was used as a control where the number of instances of incorrect set-up was twelve.

The assessment of students' perception of the effectiveness of the pre-lab activities and the results are shown as follow. An overwhelming majority of the students felt that the pre-lab activities were valuable and better prepared them to set-up the simple distillation apparatus correctly and that similar pre-lab activities be developed for other laboratory exercises. In addition, students indicated that they found the discussions on using nanomaterials to accomplish distillation at room temperature and its application very interesting and educational.

Results of Student Survey

1. After reading the document describing the steps involved in the set-up of the apparatus, watching the video of the same and completing the interactive simulation of the apparatus set-up, I _____ guidance from the instructor to correctly set-up the apparatus in the lab.

Did not need any: 6 Needed minimal: 9 Needed some: 3 Needed much: 2 (fall 2013)

Did not need any: 10 Needed minimal: 8 Needed some: 5 Needed much: 1 (spring 2014)

2. The _____ was most beneficial in preparing me to set up the apparatus correctly.

Document: 2 Video: 7 Interactive simulation: 10 A combination of the video, word document and the interactive simulation: 10 Video and document: 1 (fall 2013)

Document: 2 Video: 13 Interactive simulation: 1 A combination of the video, word document and the interactive simulation: 6 Video and document: 2 (spring 2014)

3. I would recommend that similar Pre-lab activities be designed for each of the experiments in this course

Strongly agree: 10 Agree: 9 Disagree: 1 Strongly disagree: 0 (fall 2013) Strongly agree: 9 Agree: 9 Disagree: 4 Strongly disagree: 2 (spring 2014)

4. I feel that the pre-lab activities better prepared me to set-up the simple distillation apparatus correctly

Strongly agree: 8 Agree: 10 Disagree: 2 Strongly disagree: 0 (spring 2013)

Strongly agree: 10 Agree: 10 Disagree: 3 Strongly disagree: 0 (fall 2014)

Any Additional Comments (fall 2013)

Interactive simulation should be less sensitive than current system that requires that components be connected at exact points: 4

Interactive simulation hard to use: 2

The interactive simulation is a great way to assess student's knowledge of lab set-up: 1

The video and document were easier to use and follow: 1

Any Additional Comments (spring 2014)

Interactive simulation was very helpful: 1

The electrical practice was not beneficial, but the video was: 1

The interactive software was very confusing on how to use doesn't let you choose the steps you wanted it will only allow the steps in order registered to the program: 1

The idea of the program to see the video and practice it is nice. But the program itself did not work properly: 1

The computer did not work properly the whole time: 1

I was unable to complete the interactive activity, but watched the video and have in the past, set up the distillation apparatus: 1.

4. Conclusions

The pre-lab activities whereby student are required to read a detailed step by step word document with instructions appropriate diagrams describing the set-up of the apparatus for the simple distillation experiment, watch a video demonstrating the same and then demonstrating that they could set-up the apparatus by successfully completing an online simulated assembly of the apparatus was a success. Students were able to correctly set up the apparatus in record time. The time saved was used to link the theory underlying the lab to a novel application of nanoparticles to accomplish distillation at room temperature and its practical applications. Technology was effectively used to improve safety and learning in the chemistry lab. Similar flipped pre-lab activities can be developed and used effectively in other STEM classes to improve safety and facilitate learning.

Acknowledgements

We would like to thank the students who participated in this study and BMCC for support of this work in the form of a BMCC Faculty Development Grant permission to publish this work under IRB 606485-1.

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