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# Introduction to Laboratory Safety for Graduate Students: An Active-Learning Endeavor

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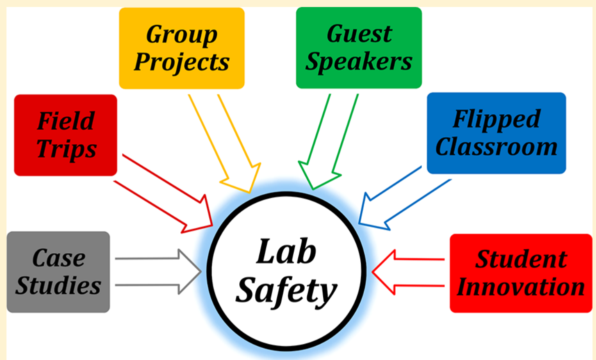
*Supporting Information*

**ABSTRACT:** A laboratory-safety course has been developed that is designed to introduce first-year graduate students to the array of dangers associated with research in the chemical sciences. We describe the challenges of creating an impactful course that seeks to convey practical laboratory-safety information in a classroom setting for students with a diverse array of interests. In particular, we have found that a flipped-classroom model highlighting case studies creates a concrete experience that actively engages course participants. In addition, the introduction of various pedagogical tools, including active-learning techniques (field trips, role-playing games, and group projects), were triggered in large part by recommendations from the students themselves.




**KEYWORDS:** *Graduate Education/Research, Upper-Division Undergraduate, Safety/Hazards, Collaborative/Cooperative Learning, Laboratory Management*

## ■ INTRODUCTION

Laboratory safety in an academic setting has received a great deal of attention because of a series of recent deaths,[1−3] dismemberments,[3,4] and fires.[5,6] Universities and science departments have responded by committing resources to improve lab safety on campus, including training, the development of safety plans, and ready access to online information.[7] However, rules, regulations, and resources are but abstract substitutes for the highly technical laboratory environment. Laboratories contain scores of hazardous chemicals and biologics that can act as carcinogens, irritants, corrosives, allergens and sensitizers, asphyxiants, explosives, toxins, and flammables. The dangers associated with lab equipment include exposure to extreme temperatures, explosions or implosions due to high or low pressures, moving parts (e.g., centrifuges and vacuum pumps), and high voltage. In short, a typical chemistry or biochemistry lab is replete with perils that run the gamut from the mundane to the exotic. In spite of these dangers, until recently graduate students at the University of North Carolina at Chapel Hill (UNC) only received a single afternoon of lab-safety training prior to serving as teaching assistants. All subsequent training in lab safety was typically performed on an ad hoc basis in research laboratories. The latter practice, which is subject to the vagaries of individual laboratories and mentors in those laboratories, has been in place for decades in academic settings.

The uneven safety training received by young scientists is a long-recognized problem that has received significant attention in this *Journal* and elsewhere. Publications have appeared over the course of the past half century that have discussed the shortcomings of academic safety,[8−12] accidents and their causes,[13−17] courses devoted to lab safety for high school[18] and undergraduate[19−21] students, strategies for establishing a "culture of safety",[22−24] and lab-safety skills.[25] In response to the recent spate of serious academic-laboratory accidents, the faculty in the Department of Chemistry at the University of North Carolina at Chapel Hill unanimously voted in 2012 to create a 1 unit, 1 semester "Introduction to Laboratory Safety" graduate-level course (CHEM 701) that meets once a week. This is the only course offered by the Department of Chemistry that is required of all incoming chemistry graduate students (~60 students per year). In addition, graduate students in the Division of Chemical Biology and Medicinal Chemistry in the UNC Eshelman School of Pharmacy (~5 students per year) are likewise required to successfully complete CHEM 701. Described herein are the challenges associated with creating an introductory graduate course devoted to laboratory safety, the evolution of the course

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**Table 1. Course Organization**

| | Class | Description | Guest Speakers, If Any | Case Studies |
|---|---|---|---|---|
| 1 | Introduction | Course organization, PPE, and library services | Librarian science-information services | Nickel hydrazine perchlorate detonation |
| 2 | Lab Emergencies | Chemical spills, leaking gas cylinders, and fires | Chapel Hill Fire Department | Tianjin explosion |
| 3 | Chemical Hazards | Chemical-hygiene plan, SDS, and chemical hazards | None | Mishandling of a fire, acid piranha explosion, and metal in an MRI room |
| 4 | Inspections and Compliance | Ordering and receiving chemicals and the role of EHS | EHS representative | Accidents at UNC |
| 5 | Field Trip | Lab tours in the students' chosen fields of interest | Graduate student safety officers of UNC laboratories | None |
| 6 | Chemicals, Part 1 | Storage, transfer, and transport of chemicals and fume-hood use | None | Elevator chemical spill, pharma chemist death, and academic chemist death |
| 7 | Chemicals, Part 2 | Flammables, explosives, compressed gases, and cryogenics | None | $LiAlH_4$−THF fire, Na−$H_2O$ conflagration, $O_2$−$H_2$−$CO_2$ explosion, and mishandling of a dewar |
| 8 | Waste Handling | Collection, storage, and pickup of chemical and solid wastes | None | Waste explosions and fires and solvent housekeeping and storage |
| 9 | Lab Equipment, Part 1 | Hazards associated with lab equipment | None | flooded laboratories and equipment fires and explosions |
| 10 | Lab Equipment, Part 2 | Laser hazards and control measures | Graduate-student led | Eye- and skin-damage case studies |
| 11 | Nanomaterials | Nanomaterial properties, handling, and waste | Graduate-student led | Nanoparticle immunogenicity and uptake and HF death |
| 12 | UCLA Incident | Incident, its causes, and aftermath | None | Devoted entirely to the UCLA Incident |
| 13 | Lab Safety in Industry | Strategies used to access risk in industry | Industrial-chemist led | None |
| 14 | Special Topics | Varies by year | None | Varies according to topic |

content since 2013, and a discussion of key learning objectives and outcomes. In addition, course material from the 2017 fall semester is available for download in the Supporting Information.

## COURSE DEVOTED TO LABORATORY SAFETY: CHALLENGES AND OPPORTUNITIES

There is little doubt that the greatest challenge associated with a course of this nature is attempting to convey practical laboratory-safety information in a classroom setting. It is akin to learning how to play baseball by reading the rulebook. However, an online survey (in 2013) of Chemistry Department safety-related training resources suggested that a rulebook-based approach to safety training serves as the primary introductory mechanism for graduate students. We performed a subsequent survey in 2017 of Safety Officers at 10 institutions to determine the method of delivery of lab-safety content.[26] Training is generally but not exclusively limited to online exercises and one-time, in-person instruction at graduate-school orientation.[26]

Three practical challenges surfaced during the design and rollout phases of the course: course scheduling, course content, and student engagement. UNC's Department of Chemistry has a comparatively large first-year graduate class that is composed of students with interests that align with one or more of the six divisions in the Department: Analytical, Biochemistry & Chemical Biology, Inorganic, Organic, Physical, and Polymer/Materials. Students from the School of Pharmacy's Chemical Biology and Medicinal Chemistry Division add to the size and scientific diversity of the class. Given the array of time commitments imposed upon first-year students (courses, teaching assignments, lab rotations, etc.), it proved challenging to identify a time and day that accommodates all students. These constraints require that the course be offered at 8 a.m. on Monday mornings. However, even at this time of day, graduate students are occasionally asked to proctor exams in large undergraduate courses. The Department's commitment to lab safety excuses first-year students from this duty so that they can attend the lab-safety course. Course content proved to be an additional challenge given the range of scientific interests among class members. For example, the complexities of working with *t*-BuLi is pertinent to only a small fraction of students in the class. However, because this particular reagent has had a profound impact on the importance of lab-safety training in academia, its properties and proper handling are nonetheless discussed. Ultimately, the challenge of scientific relevance has been addressed by combining general elements of lab safety with opportunities for students to focus on discipline-specific material. Finally, student engagement is an extraordinarily difficult challenge because the course topic is not perceived to be intellectually stimulating. In the first year the course was taught (2013), class sessions were generally organized using a traditional lecture-style approach that emphasized proper laboratory procedures in the abstract. All students received a binder containing nearly 500 pages of lab-safety information, which included the (1) syllabus, (2) lecture content, and (3) more than a dozen appendices describing rules and regulations. The one exception to the conventional lecture style was a class period devoted to the death of Sheharbano Sangii.[1] The latter was presented as a case study, and the conversation that ensued with the students went well past the allotted class time. End-of-semester student evaluations indicated that, although the course content was understood to be important, it was felt to be too abstract and broad to be relevant. Several students suggested that more case studies be introduced. The course content was "flipped"[27] in the subsequent years, and students now receive, prior to each class, assigned background reading focusing on rules. In general, class periods offer a brief-to-moderate overview of the reading assignment, and the remainder of in-class time is devoted to case studies. There are a few exceptions to this


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lecture format, which are noted in the Course Content section below.

Although the expressed purpose of the course is to introduce first-year graduate students to the wide variety of safety concerns associated with a laboratory environment, the course setting offers a number of additional opportunities. First, it helps to establish a department-wide safety culture. Second, it is the only setting that includes all first-year graduate students, which ensures that even nonsafety departmental-policy issues are uniformly conveyed and discussed. Indeed, by exposing students to fellow classmates outside of their immediate subdisciplines, cross-disciplinary safety- and nonsafety-related connections are established. Finally, guest lecturers not only introduce students to specific areas of lab safety, but they eventually serve as resources for information as the students progress through their Ph.D. studies.

## COURSE CONTENT

The following goals serve as the driving force for the design of the course and its contents: (1) provide a broad overview of safety issues commonly found in a typical laboratory setting, (2) offer discipline-focused safety content within the context of the student's specialization, (3) catalyze student engagement via active learning and case studies, and (4) establish the foundation of a safety culture within an academic setting. As noted above, the majority of lectures focus on case studies, which are presented within the flipped-classroom model. Classes I, II, and V are exceptions to this general model (Table 1).

### Class I: Introduction to Laboratory Safety

There is no preclass assigned reading material or quiz for the first lecture of the year. Rather, this is a traditional lecture-style presentation that

- introduces the course,
- provides an overview of personal protective equipment (PPE),
- presents an example of a case study, and
- introduces the first of several guest speakers throughout the semester (Supporting Information, syllabus).

In this particular case, a representative of Science Information Services of UNC's Kenan Library spends the second half of the lecture discussing available online resources (lab safety and others).

Following the lecture, students are provided with electronic handouts on PPE and a case study describing a nickel hydrazine perchlorate explosion that resulted in serious injuries to a graduate student[4] (Supporting Information, reading assignments).

### Class II: Laboratory Emergencies: Chemical Spills, Gas-Cylinder Leaks, and Fires

Preclass assigned reading material is focused on the steps to take in the event of laboratory emergencies (chemical spills, leaking gas cylinders, and fires) and how to assess risk (Supporting Information, reading assignments). Students are also provided with

- an Employee Accident Report, which must be completed in the event of an accident
- an Air Products "Safetygram", which discusses the emergency procedure for handling a leaking gas cylinder; and
- a first-person account of an HCl cylinder leak.

An overview of the assigned reading material is presented in the first 5 min of class. However, rather than discuss case studies, this particular lecture is turned over to a Captain of the Chapel Hill Fire Department. The discussion focuses on what transpires when the fire department arrives at a laboratory building. In the event of a true emergency, graduate students are taught how to identify the on-scene commander, the importance of knowing precisely which chemicals are involved, and the critical role of Safety Data Sheets (which are further discussed in Class III).

### Class III: Chemical Hazards

The preclass assigned reading material describes

- the Chemical Hygiene Plan and Safety Data Sheets (SDS);
- the variety of toxic, flammable, reactive, and explosive hazards typically encountered in a lab (Supporting Information, reading assignments); and
- handling of lab emergencies, which was introduced in Class II and remains an important theme in this class on chemical hazards.

A key learning objective for the students is to recognize that emergencies often elicit an incorrect response that can magnify the seriousness of the situation. A simple example of this tendency is shown using a YouTube video of a chemistry instructor who initially attempts to douse a small fire with a nearby flammable solvent.[28] Additional learning objectives include the steps to be taken as a first responder on an accident scene and the importance of providing explicit and clear instructions to trainees in order to mitigate accidents. Case studies involving an acid piranha solution explosion[29] and an accident in which an oxygen cylinder was mistakenly brought into an MRI exam room[30] are used to emphasize the significance of these learning objectives.

### Class IV: Lab Inspections and Compliance

The preclass reading material describes

- ordering and receiving chemicals at UNC;
- the history of occupational safety and environmental laws in the United States; and
- the roles, responsibilities, and organization of UNC's Environment, Health, and Safety Department (EHS; Supporting Information, Class IV reading assignment).

A guest speaker from EHS leads the majority of this session, which provides the students with the opportunity to interact with a key member of the team that supports the research enterprise at UNC. The majority of this session is devoted to accidents that have occurred in the Chemistry Department at UNC, thereby emphasizing the immediacy of laboratory-safety issues.

### Class V: Field Trip

A course that provides an overview of safety for the various subdisciplines in chemistry will, at any given time, not be relevant to all students. The issue of relevance was addressed by introducing "field trips" in order to provide students with a glimpse of the safety issues associated with their chosen subdiscipline. Students, on the basis of their anticipated interests, are assigned to groups that tour two different laboratories over the course of an hour in one of the following specialties: Analytical, Chemical Biology, Inorganic, Organic, Pharmaceutical Sciences, Physical/Material/Polymer. The students receive a 20−25 min presentation from the graduate



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student safety representative in each lab, who describes the unique safety issues that their lab contends with.

### Class VI: Managing and Working with Chemicals. Part 1

Assigned reading material for this class focuses on (1) proper storage, transfer, transport, and general handling of chemicals as well as (2) appropriate use of fume hoods (Supporting Information, reading assignments). The case studies include

- the improper transport of allyl alcohol, resulting in an elevator spill (an unpublished UNC incident);
- the death of Roland Daigle, a pharmaceutical chemist at Sepracor, due to a nonoperating fume hood;[31] and
- the death of Dartmouth's Professor Karen Wetterhahn due to dimethylmercury poisoning.[32]

### Class VII: Managing and Working with Chemicals. Part 2

Part 2 of Managing and Working with Chemicals focuses on specific safety concerns associated with flammables, explosives, compressed gases, and cryogenics. The widespread online availability of Standard Operating Procedures for individual chemicals is emphasized in both the preclass readings and the in-class discussion (Supporting Information, Class VII reading assignment). The case studies include

- a $LiAlH_4$−THF fire (and the use of an inappropriate fire extinguisher);[33]
- the contact of a small amount of Na with $H_2O$, which triggered a series of increasingly destructive events;[34]
- an $O_2$−$H_2$−$CO_2$ gas explosion that resulted in severe injuries (including the loss of an arm) to a postdoctoral fellow;[35]
- the transport of a 230 L liquid $N_2$ dewar down a flight of stairs;[36] and
- the consequences of interfering with the pressure-relief device on a compressed-gas cylinder.[37]

### Class VIII: Waste Handling and Housekeeping

The preclass reading material includes the environmental rationale for the proper characterization, collection, storage, and handling of chemical and solid (glass, cylinders, etc.) wastes (Supporting Information, assigned readings). UNC's pickup procedures for assorted waste types are outlined in the reading material as well. The class-discussion case studies encompass both waste handling as well as proper housekeeping:

- waste-bottle explosions in undergraduate laboratories,[38,39]
- the attempted disposal of Na resulting in a large fire,[40]
- recrystallization performed in a fume hood containing excessive quantities of organic solvents,[41] and
- the collapse of a solvent-storage shelf and the resultant conflagration.[6]

### Class IX: Laboratory Equipment. Part 1

Reading assignments discuss the hazards associated with equipment employing electricity, water, low and high pressures, low and high temperatures, and moving parts (Supporting Information, assigned readings). The class hour focuses on case studies describing

- flooded laboratories,[42]
- an oil-bath fire,[43]
- a blast from a pressurized reaction vessel,[44]
- a centrifuge explosion due to the use of an improper rotor,[24] and
- the death of an undergraduate working alone with a lathe.[45]

A significant challenge associated with discussing safe laboratory practice is the difficulty of adequately demonstrating physical hazards in a lecture setting. In this regard, we make use of the YouTube platform in class presentations in an effort to highlight accidents relevant to scientific hazards. For example, the perils associated with operating a lathe are significantly more tangible upon viewing a lathe accident:[46] the inappropriate dress of the operator (loose clothing, no safety googles), the swiftness of the accident, the helpless condition of the victim caught in the lathe, and the improper decision making of the first responders (an initial rush to grab the victim instead of turning off the machine).

### Class X: Laboratory Equipment. Part 2

This laser-safety session is the first of two classes run by a senior graduate student in the Department of Chemistry. The decision to have students preside over two sessions of the course was based on our desire to establish a safety culture that is embraced by and expected of all graduate students. The preclass reading material includes a description of laser components, classification, exposure limits, hazards, and control measures (Supporting Information, assigned readings). Case studies[47] describe eye damage due to

- reflections off of equipment,
- poor beam-alignment practices,
- a modified polarizing-beam splitter,
- the absence of appropriate safety glasses, and
- a malfunctioning light shutter.

### Class XI: Microfabrication and Nanomaterials

This graduate-student-led session is devoted to the hazards associated with nanotechnology. The properties, diversity, safety concerns, safety practices, and waste handling of nanomaterials are described in a preclass handout (Supporting Information, assigned readings). In-class case studies include

- the exposure of a formulation chemist to a Ni nanoparticle powder and her resultant sensitivity to Ni-containing jewelry;[48]
- a death due to HF exposure;[49]
- the presence of carbon nanotubes in the lungs of Parisian children (analogous to and possibly derived from the nanotubes associated with vehicle exhaust);[50] and
- the presence of magnetite nanoparticles, which is a pollutant associated with Alzheimer's Disease, in the frontal cortex of human-brain samples.[51]

### Class XII: UCLA Incident

A preclass reading assignment is not provided for this particular session. In every year this course has been offered, the overwhelming majority of students acknowledge (by a show of hands) that they are aware of the death of Sheharbano Sangji in a chemistry laboratory at UCLA. The in-class material is derived, in large part, from a series of articles published in Chemical & Engineering News,[1,52−58] and includes an in-depth discussion of the backgrounds of the principals involved, the experiment itself, the accident and possible causes, the immediate aftermath of the accident, and the impact that this tragedy has had on the academic community. A number of other sources were employed to tap into the breadth of opinion triggered by Sangji's death, the subsequent felony


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charges against the principal investigator of the lab, Professor Patrick Harran, and the legal resolution in terms of criminal charges.[59−61] In this particular instance, the “quiz” at the end of class is an opinion survey to gauge the attitudes of the students on the accident at UCLA and its ramifications. The results of the survey are shared and discussed with the students at the beginning of the subsequent class.

### Class XIII: Laboratory Safety in Industry

In a survey of scientists from academic, government, and industry laboratories, Schröder and colleagues found that the academic environment suffers from a less well-established safety culture (as exemplified by diminished PPE compliance) and a comparatively weak reliance on formal risk-assessment protocols relative to laboratories in government and industry.[62] Although the majority of the respondents in this study, irrespective of their work environment, perceived their safety training to be sufficient for the hazards to be encountered, the authors noted:[62]

> *Graduate students, especially in their beginning years, often do not realize that risks may be associated with their experiments when they change or scale up procedures. Postdoctoral fellows typically enter a new lab to expand their scientific expertise; therefore, postdocs similarly to graduate students are generally inexperienced in the experimentation in their new research field.*

This class session, led by an industrial chemist, focuses on the strategies used to assess risk (process safety review) and identify the causes of accidents (root-cause analysis).

### Class XIV: Special Topics

At least one class each semester is set aside to explore alternative strategies to deliver meaningful lab-safety experiences. The West Africa Ebola outbreak in early 2014[63] served as an opportunity to discuss laboratory biosafety practices. In 2017, a case-study-based session was introduced to explore ethics with a focus on fabrication, falsification, and plagiarism.[64,65] It has been argued that ethics is an integral component of lab safety, particularly with respect to an organization’s expectations, values, and integrity.[66] Finally, we have explored educational strategies that promote active student participation while encouraging creativity. For example, the class, divided into interest groups, developed presentations (from serious to amusing) on a lab-safety topic of their choosing. In addition, interest groups have been tasked with generating narratives for role-playing games that examined decision-making scenarios under emergency or hazardous laboratory conditions.

### Course Grades

A single final exam in the 2013 inaugural year of the course was used to assign student grades. However, class attendance plummeted as the semester progressed. In the following year, quizzes at the end (or beginning) of each class were introduced to ensure strong class attendance. There is a natural tendency among chemistry faculty to pose intricate questions that challenge a student’s ability to apply first principles to novel problems. We have resisted this temptation and have, instead, employed straightforward, conventional multiple-choice quizzes (assessing a basic understanding of lab safety) as well as nonconventional (opinion survey) quiz formats. Nonetheless, it is essential that students understand the importance of this course. Consequently, a student who misses more than one quiz is assigned an incomplete grade. The student must then attend the lectures they missed in the subsequent academic year. Failure to do so results in the conversion of an incomplete grade to a failing grade and the student is then dismissed from graduate school. Finally, in addition to quizzes, the students are given the following final exam: “Propose one or more changes to the Lab Safety Course that can improve its relevance and/or impact to future students who take the course. Please provide enough detail to enable execution of your ideas.” Several of the proposed ideas were subsequently incorporated into the course, including safety skits, field trips, and role-playing games.

## ■ COURSE EVALUATION

Student assessment of the course was derived from two sources: (1) a standard online course evaluation that is administered through UNC’s Office of Institutional Research and Assessment and (2) proposed changes in course content offered by students in their final-exam essays. The generic nature of the questions associated with the online evaluation do not explicitly address the various pedagogical elements employed but do furnish an overall appraisal of student satisfaction with the course itself (Table 2). For example, on a scale from 1 (strongly disagree) to 5 (strongly agree), the students agree with the statements that “The instructional techniques engaged me with the subject matter” and “The course material helped me better understand the subject matter”. Furthermore, an unexpected surprise was the response of students to what is arguably the most challenging statement in the online survey, “The course was very exciting to me intellectually”, which significantly improved from 2.66 (2013) to 3.54 (2016).

**Table 2. Comparative Summary Data from Online Course Assessment**

| Course Characteristic Statements for Student Response | Mean Scores[a] by Year (Number of Respondents)[b] | | | |
|---|---|---|---|---|
| | 2013 (43) | 2014 (36) | 2015 (48) | 2016 (47) |
| Overall this course was excellent. | 3.02 | 3.51 | 3.56 | 4.00 |
| The course challenged me to think deeply about the subject matter. | 2.98 | 3.64 | 3.53 | 4.15 |
| This course was very exciting to me intellectually. | 2.66 | 2.83 | 3.08 | 3.54 |
| The instructional techniques engaged me with the subject matter. | 3.29 | 3.97 | 4.15 | 4.23 |
| This course material helped me better understand the subject matter. | 3.79 | 4.00 | 4.00 | 4.29 |

[a]The scale for the scores has a range of 1−5, with 1, “strongly disagree”; 2, “disagree”; 3, “neither agree nor disagree”; 4, “agree”; and 5, “strongly agree”. [b]Response rate varied from 65 to 75% for each year.

In contrast to the generic questions posed by and the anonymity associated with the online survey, the non-anonymous final exam explicitly sought ideas to improve the course for future students. Chief among the proposals were pleas for more subdiscipline-specific learning opportunities. For example, one student wrote, “there are a lot of different safety hazards for the different groups in the class, and so not all lectures/class periods were applicable to everyone. To deal


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with this, I think that some group work may be useful for the next years of this class." This comment, along with others of a similar nature, lead to the development of field trips with a focus on safety issues in specific subdisciplines. Group-based activities, such as the design of role-playing-game scenarios, were introduced as a consequence of comments that focused on decision-making under emergency conditions: "it would be interesting if you proposed to groups an emergency and then allowed them to brainstorm ways to act to control the situation." In addition, group skits were developed as a result of proposals that the course be made "more interactive [in order to] force students to participate more during lecture." However, group projects do have the potential disadvantage of uneven workload distribution among members, particularly when the group size balloons to more than 5 students. Indeed, this problem was subsequently noted by several students in the written section of the online course survey. Consequently, a key challenge in a course of this nature is to create experiences that maximize student participation while covering lab-safety topics that have both broad and narrow appeal.

In summary, we have developed a once-a-week full semester "Introduction to Laboratory Safety" (CHEM 701) course that is required of all first-year Chemistry and Chemical Biology & Medicinal Chemistry (Pharmaceutical Sciences) graduate students. Although the course initially employed a traditional lecture-style format emphasizing rules, we found that the flipped-classroom model highlighting case studies and using various active-learning techniques creates a more concrete experience that better engages course participants. Nonetheless, the classroom serves as an imperfect environment for demonstrating and experiencing safe laboratory practice. We anticipate that by tapping into student creativity and engagement, the course will continue evolve as we seek to create more impactful in-class exercises that are relevant to hazards present in a laboratory setting.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.8b00774.

- Syllabus (PDF)
- Reading assignments (PDF)
- Class IV reading assignment (PDF)
- Class VII reading assignment (PDF)

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### Notes

The authors declare no competing financial interest.

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## ■ REFERENCES


(1) Kemsley, J. N. Negligence Caused UCLA Death. *Chem. Eng. News* **2009**, *87*, 7.

(2) Van Noorden, R. A Death in the Lab. *Nature* **2011**, *472* (7343), 270−1.

(3) Kemsley, J. N. University of Hawaii fined $115,500 for lab explosion. *Chem. Eng. News*, Sept 23, 2016. https://cen.acs.org/articles/94/web/2016/09/University-Hawaii-fined-115500-lab.html (accessed Sept 7, 2018).

(4) *Texas Tech University Laboratory Explosion*; No. 2010-05-I-TX; U.S. Chemical Safety and Hazard Investigation Board, 2011. http://www.csb.gov/texas-tech-university-chemistry-lab-explosion/ (accessed Sept 7, 2018).

(5) Zurer, P. Fire guts University of Texas chemistry lab. *Chem. Eng. News* **1996**, *74*, 10−11.

(6) Schulz, W. G. Fighting Lab Fires. Explosion and fire at an Ohio State University chemistry lab highlight safety issues in academia. *Chem. Eng. News* **2005**, *83*, 34−35.

(7) Laboratory Safety. *University of North Carolina at Chapel Hill.* https://ehs.unc.edu/lab/ (accessed Sept 7, 2018).

(8) Johnson, J.; Kemsley, J. Academic lab safety under exam. *Chem. Eng. News* **2011**, *89* (43), 25−27.

(9) Kaufman, J. A. Safety in the academic laboratory. *J. Chem. Educ.* **1978**, *55* (9), A337.

(10) Landgrebe, J. A. Safety in academic departments with graduate and undergraduate programs. *J. Chem. Educ.* **1985**, *62* (12), A310.

(11) Pesta, S.; Kaufman, J. A. Laboratory safety in academic institutions. *J. Chem. Educ.* **1986**, *63* (10), A242.

(12) Stacy, G. W. Safety and health in the academic laboratory: Recommendations by the participants ACS tenth biennial education conference. *J. Chem. Educ.* **1979**, *56* (2), 91.

(13) Ozaruk, N. Lab safety: The case of the errant cylinder. *J. Chem. Educ.* **1976**, *53* (6), 373.

(14) Macomber, R. D. Chemistry accidents in high school. *J. Chem. Educ.* **1961**, *38* (7), 367.

(15) Hellman, M. A.; Savage, E. P.; Keefe, T. J. Epidemiology of accidents in academic chemistry laboratories. Part 1. Accident data survey. *J. Chem. Educ.* **1986**, *63* (11), A267.

(16) Steere, N. V. Identifying multiple causes of laboratory accidents and injuries - Part 2. *J. Chem. Educ.* **1973**, *50* (5), A287.

(17) Wilk, I. J. Chemical accidents in academic institutions - A critical commentary on accidents reported in the University of California system. *J. Chem. Educ.* **1977**, *54* (10), A415.

(18) Nagel, M. C. An innovative course in lab safety. *J. Chem. Educ.* **1982**, *59* (9), 791.

(19) Lowry, G. G. A university-level course in laboratory safety (Concluded). *J. Chem. Educ.* **1978**, *55* (6), A263.

(20) Lowry, G. G. A university-level course in laboratory safety [part one]. *J. Chem. Educ.* **1978**, *55* (5), A235.

(21) Huston, E. M.; Milligan, J. A.; Powell, J. R.; Smith, A. M.; Neal, D.; Duval, K. M.; DiNardo, M. A.; Stoddard, C.; Bell, P. A.; Berning, A. W.; Wipf, P.; Bandik, G. C. Development of an Undergraduate Course in Chemical Laboratory Safety through an Academic/Industrial Collaboration. *J. Chem. Educ.* **2018**, *95* (4), 577−583.

(22) McGarry, K. A.; Hurley, K. R.; Volp, K. A.; Hill, I. M.; Merritt, B. A.; Peterson, K. L.; Rudd, P. A.; Erickson, N. C.; Seiler, L. A.; Gupta, P.; Bates, F. S.; Tolman, W. B. Student Involvement in Improving the Culture of Safety in Academic Laboratories. *J. Chem. Educ.* **2013**, *90* (11), 1414−1417.

(23) Staehle, I. O.; Chung, T. S.; Stopin, A.; Vadehra, G. S.; Hsieh, S. I.; Gibson, J. H.; Garcia-Garibay, M. A. An Approach To Enhance the Safety Culture of an Academic Chemistry Research Laboratory by Addressing Behavioral Factors. *J. Chem. Educ.* **2016**, *93* (2), 217−222.

(24) Creating a strong safety culture. *C&EN Global Enterprise* **2017**, *95* (36), 31,.

(25) Stuart, R. B.; McEwen, L. R. The Safety "Use Case": Co-Developing Chemical Information Management and Laboratory Safety Skills. *J. Chem. Educ.* **2016**, *93* (3), 516−526.

(26) Triumph, T. F.; Lawrence, D. S. University of North Carolina at Chapel Hill, Chapel Hill, NC. Unpublished work, 2018.

(27) Persky, A. M.; McLaughlin, J. E. The Flipped Classroom − From Theory to Practice in Health Professional Education. *Am. J. Pharm. Educ.* **2017**, *81* (6), 118.

(28) PBS NewsHour. When Things Go Wrong in the Lab, 2013. *YouTube*. https://www.youtube.com/watch?v=JZ-cF2PYY70 (accessed Sept 7, 2018).

(29) Occupational Health & Safety Service. *Acid Piranha Solution: User Guidance*; HSD176C (rev 2); University of Cambridge, 2016. http://docplayer.net/50034708-Acid-piranha-solution-user-guidance.html (accessed Jan 2019).

(30) Bloom, D. Two hospital workers spend FOUR HOURS pinned to MRI machine by metal oxygen tank that was catapulted across room when device's giant magnet was turned on. *Daily Mail*, Dec 29, 2014. http://www.dailymail.co.uk/news/article-2890088/Two-hospital-workers-spend-FOUR-HOURS-pinned-MRI-machine-metal-oxygen-tank-catapulted-room-device-s-giant-magnet-turned-on.html (accessed Sept 7, 2018).

(31) Kemsley, J. N. Firm Fined For Chemist's Death. *Chem. Eng. News* **2011**, *89* (19), 15.

(32) Risk Management Services at the University of Alberta. Karen Wetterhahn's Story - Accidental Poisoning at Dartmouth, 2012. *YouTube*. https://www.youtube.com/watch?v=h049Hgfk-BI (accessed Sept 7, 2018).

(33) A Campus Laboratory Fire Involving Lithium Aluminum Hydride. *Stanford Environmental Health and Safety*. https://ehs.stanford.edu/reference/campus-laboratory-fire-involving-lithium-aluminum-hydride (accessed Sept 7, 2018).

(34) Lowe, D. Accident Report, or One Damn Thing After Another. *Science*, Oct 26, 2012.http://blogs.sciencemag.org/pipeline/archives/2012/10/26/accident_report_or_one_damn_thing_after_another (accessed Sept 7, 2018).

(35) Kemsley, J. N. University of Hawaii lab explosion likely originated in electrostatic discharge. *Chem. Eng. News* **2016**, *94* (28), 5.

(36) Measurements of Gravity Using Cryogens, 2006. *Arcane Gazebo*. http://www.arcanegazebo.net/2006/08/measurements_of_gravity_using.html (accessed Sept 7, 2018).

(37) Liquid Oxygen Cylinder Explosion. *eCLOSH*. http://www.elcosh.org/document/1676/d000585/Liquid%2BOxygen%2BCylinder%2BExplosion.html?show_text=1 (accessed Sept 7, 2018).

(38) Toreki, R. What Can Happen When You Don't Follow Safety Rules, 2015. *Interactive Learning Paradigms Incorporated*. http://www.ilpi.com/safety/explosion.html (accessed Sept 7, 2018).

(39) Office of the Vice President for Research. Failure to Segregate Waste Streams Mixes Nitric Acid and Organic Solvent, Causes Waste Bottle to Explode From Pressure Buildup; Written Procedures Did Not Reflect Current Procedures, 2015. *Texas Tech University*. https://www.depts.ttu.edu/vpr/integrity/lessons-learned/February-2015.php (accessed Sept 7, 2018).

(40) Zurer, P. Fire guts University of Texas chemistry lab. *Chem. Eng. News* **1996**, *74* (44), 10−11.

(41) WTHR Fire Feb 2004. *Purdue University Department of Chemistry*. https://www.chem.purdue.edu/chemsafety/news-and-stories/WTHR248FireFeb2004.php (accessed Sept 7, 2018).

(42) Vosshall, L. The Great Vosshall Lab Flood of 2014. *flickr*. https://www.flickr.com/photos/vosshall-lab/sets/72157644250561445/with/13980804731/ (accessed Nov 30, 2018).

(43) Lab Safety Fire Incidents. *American Industrial Hygiene Association*. https://www.aiha.org/get-involved/VolunteerGroups/LabHSCommittee/Incident%20Pages/Lab-Safety-Fire-Incidents.aspx (accessed Nov 30, 2018).

(44) Blast of Pressurized Reaction Vessel Injures Researcher. *UC Center for Laboratory Safety*. https://cls.ucla.edu/lessons-learned/lessons-learned-fire/173-lessons-learned-category-b (accessed Nov 30, 2018).

(45) Henderson, D.; Rosenfeld, A.; Serna, D. Michele Dufault '11 dies in Sterling Chemistry Laboratory accident. *Yale Daily News*, April 13, 2011. https://yaledailynews.com/blog/2011/04/13/michele-dufault-11-dies-in-sterling-chemistry-laboratory-accident/ (accessed Sept 7, 2018).

(46) Soto, L. Industrial Lathe Accident. *YouTube*. https://www.youtube.com/watch?v=3EdQq5iAGYs (accessed Sept 7, 2018).

(47) Barat, K. Laser Safety: Little Mistakes with Big Consequences. *Photonics Media*. https://www.photonics.com/Articles/Laser_Safety_Little_Mistakes_with_Big/a25167 (accessed Nov 30, 2018).

(48) Journeay, W. S.; Goldman, R. H. Occupational handling of nickel nanoparticles: a case report. *Am. J. Ind. Med.* **2014**, *57* (9), 1073−6.

(49) Muriale, L.; Lee, E.; Genovese, J.; Trend, S. Fatality due to acute fluoride poisoning following dermal contact with hydrofluoric acid in a palynology laboratory. *Ann. Occup. Hyg.* **1996**, *40* (6), 705−10.

(50) Kolosnjaj-Tabi, J.; Just, J.; Hartman, K. B.; Laoudi, Y.; Boudjemaa, S.; Alloyeau, D.; Szwarc, H.; Wilson, L. J.; Moussa, F. Anthropogenic Carbon Nanotubes Found in the Airways of Parisian Children. *EBioMedicine* **2015**, *2* (11), 1697−704.

(51) Maher, B. A.; Ahmed, I. A. M.; Karloukovski, V.; MacLaren, D. A.; Foulds, P. G.; Allsop, D.; Mann, D. M. A.; Torres-Jardón, R.; Calderon-Garciduenas, L. Magnetite pollution nanoparticles in the human brain. *Proc. Natl. Acad. Sci. U. S. A.* **2016**, *113* (39), 10797−10801.

(52) Kemsley, J. N.; Torrice, M. Preliminary hearing for Patrick Harran in #SheriSangji case: Day one. *Chem. Eng. News*, Nov 19, 2012. http://cenblog.org/the-safety-zone/2012/11/preliminary-hearing-for-patrick-harran-in-sherisangji-case-day-one/ (accessed Sept 7, 2018).

(53) Kemsley, J. N.; Torrice, M. California Deal Tightens Lab Safety. *Chem. Eng. News* **2012**, *90* (33), 34−37.

(54) Kemsley, J. N. Myths of the #SheriSangji case. *Chem. Eng. News*, June 24, 2014. http://cenblog.org/the-safety-zone/2014/06/myths-of-the-sherisangji-case/ (accessed Sept 7, 2018).

(55) Kemsley, J. N. Lab Death Legal Defense Cost University Of California Nearly $4.5 Million. *Chem. Eng. News* **2014**, *92* (44), 9.

(56) Kemsley, J. N. Lab Death Legal Cases Resolved. *Chem. Eng. News*, 2014. http://2014.cenmag.org/lab-death-legal-cases-resolved/ (accessed Sept 7, 2018).

(57) Kemsley, J. N. Systemic Failures Cited In Lab Death. *Chem. Eng. News* **2012**, *90* (5), 10.

(58) Kemsley, J. N. Learning from UCLA. *Chem. Eng. News* **2009**, *87* (31), 29−31.

(59) BREAKING: Professor Patrick Harran and LADA reach agreement: community service and fine, no jail, no trial contingent on meeting agreement, 2014. *CHEMJOBBER*. http://chemjobber.blogspot.com/2014/06/breaking-professor-patrick-harran-and.html (accessed Sept 7, 2018).

(60) Kemsley, J. N. Charges dropped against UCLA chemistry professor Patrick Harran for death of Sheri Sangji after lab fire. *Chem. Eng. News*, Sept 14, 2018. https://cen.acs.org/safety/lab-safety/Charges-dropped-against-UCLA-chemistry/96/web/2018/09 (accessed Jan 2019).

(61) Lowe, D. Blowups Happen. *Science*, May 22, 2009. http://blogs.sciencemag.org/pipeline/archives/2009/05/22/blowups_happen-2 (accessed Jan 2019).

(62) Schröder, I.; Huang, D. Y. Q.; Ellis, O.; Gibson, J. H.; Wayne, N. L. Laboratory safety attitudes and practices: A comparison of academic, government, and industry researchers. *J. Chem. Health Saf.* **2016**, *23* (1), 12−23.

(63) Coltart, C. E.; Lindsey, B.; Ghinai, I.; Johnson, A. M.; Heymann, D. L. The Ebola outbreak, 2013−2016: old lessons for new epidemics. *Philos. Trans. R. Soc., B* **2017**, *372* (1721), 372.



DOI: 10.1021/acs.jchemed.8b00774
*J. Chem. Educ.* 2019, 96, 652−659

(64) Committee on Science Engineering and Public Policy. *On Being a Scientist: A Guide to Responsible Conduct in Research*, 3rd ed.; The National Academies Press: Washington, DC, 2009.
(65) Noyori, R.; Richmond, J. P. Ethical Conduct in Chemical Research and Publishing. *Adv. Synth. Catal.* **2013**, *355* (1), 3−8.
(66) Robbins, J. Is Lab Safety An Ethical Issue? *Inside Higher Ed*, Oct 24, 2012. https://www.insidehighered.com/blogs/sounding-board/lab-safety-ethical-issue (accessed Sept 7, 2018).



DOI: 10.1021/acs.jchemed.8b00774
*J. Chem. Educ.* 2019, 96, 652−659