AFTERMATH Firefighters investigate Biery's chemistry classroom at Western Reserve Academy after the 2006 fire that injured her and others.

TEACHING SAFELY

CLASSROOM FIRES that injure students prompt calls for safety assessments of demos, plus teacher training

JYLLIAN KEMSLEY, C&EN WEST COAST NEWS BUREAU

"ONE OF THESE DAYS, someone is going to die" from injuries sustained in a chemistry classroom fire, Calais Weber Biery says. "I almost did."

In 2006, when Biery was 15, her chemistry teacher set up a "rainbow" flame test demonstration of several metal salts that the teacher dissolved in methanol then set alight. One of the flames appeared to die down, so the teacher grabbed the stock bottle of methanol to add more. The classroom erupted with fire.

Biery suffered third- and fourth-degree burns over 48% of her body. "I had the rest of my childhood taken away," she says. She spent two-and-a-half months in the hospital. After returning to school, she spent every break undergoing medical treatments. By her junior year of college, she decided that she'd had enough. Her remaining scars prompt stares or questions from strangers when she wears shorts or a bathing suit, she says.

Less obvious than the scars on Biery's skin is her posttraumatic stress disorder. Although her symptoms have eased with time, the smell of something burning or the sound of people screaming still triggers anxiety, and she has what she calls "fire dreams" every few months.

What disturbs Biery just as often is that she's not alone: Similar alcohol-fueled fires from educational demos occur with alarming frequency, injuring at least 72 people since 2011, according to 18 incidents tracked by C&EN, the U.S. Chemical Safety & Hazard Investigation Board, and the blog Chemjobber. Most recently, five students and a teacher were injured in an alcohol-fueled flame demo gone awry at W.T. Woodson High School in Virginia on Oct. 30, according to local media reports.

Despite her experience and concern for others, Biery agrees with safety and teaching experts that demonstrations and hands-on experiments by students are essential for science education. Biery herself returned to school to take Advanced Placement biology, followed by general and organic chemistry in college. But she thinks that chemistry teachers must take a step back to assess what they're doing and how, and that states and school districts should provide teachers with training and equipment to do hands-on science safely.

Biery is not alone. "Kids need to experience phenomena if they're going to be engaged and develop understanding," says Joseph S. Krajcik, a former high school chemistry teacher who is now a science education professor at Michigan State University. "But I don't think instruction should be driven by 'splashiness,' either," Krajcik adds. Instead, teachers must stay focused on their educational goals and be clear about how a particular demo or experiment will meet those aims, then determine the safest way to achieve the objectives.

TO HELP WITH finding the safest way, the National Fire Protection Association (NFPA) updated its standard 45 on "Fire Protection for Laboratories Using Chemicals" this year to add a chapter on educational and instructional laboratory operations, including specific guidance for conducting demonstrations. NFPA 45 also covers topics such as laboratory design, fire protection, fume hoods, personal protective equipment (PPE), and chemical storage and handling.

When an NFPA committee convened to update the standard, "it was really clear to us in light of the number of student injuries from demos with flammable materials that we needed to include requirements to protect students," says committee member Barbara Foster, who is director of laboratory safety for the chemistry department at West Virginia University.

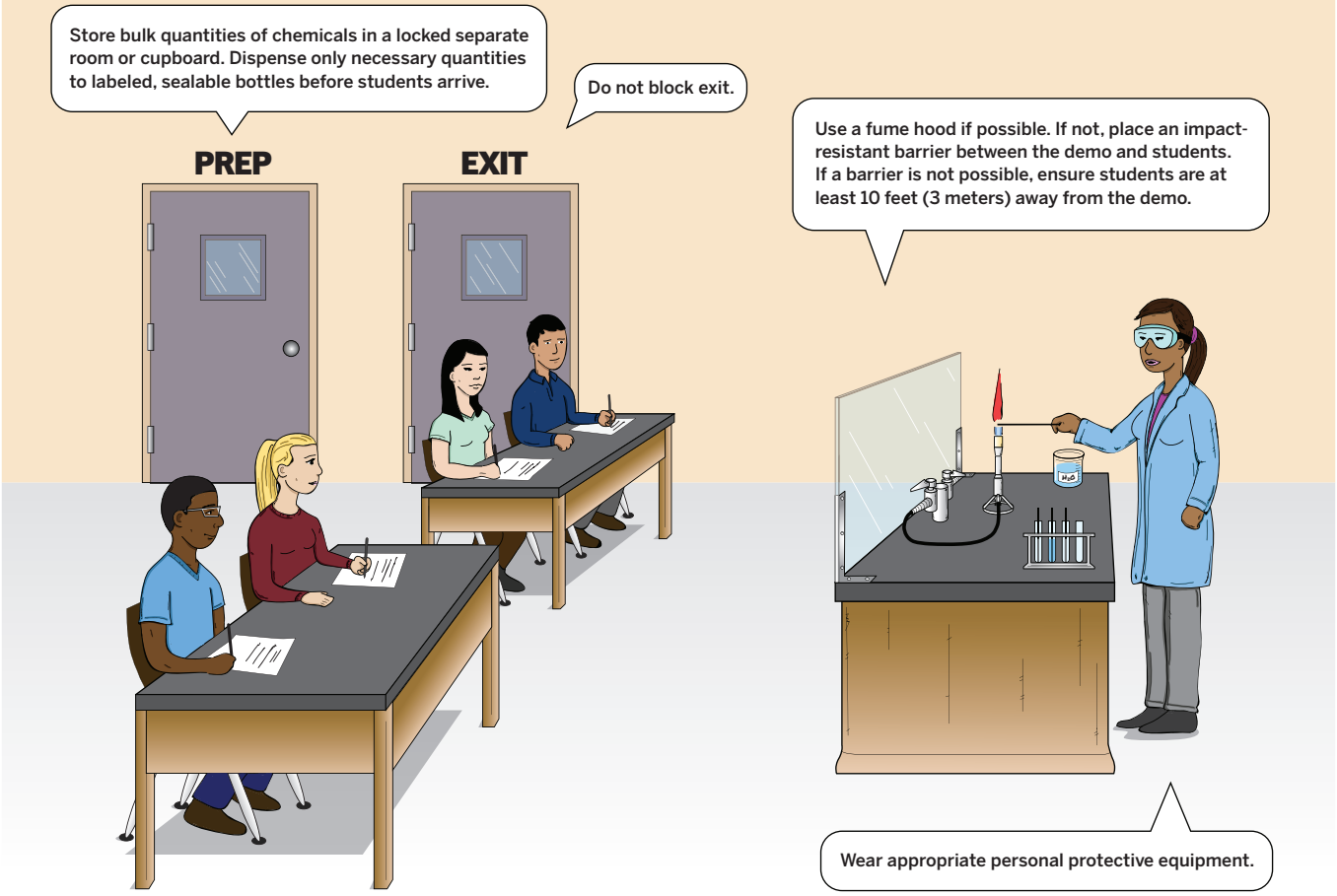
The committee wasn't just concerned about flame demos, adds committee chair Andrew Minister, who is chief fire protection engineer at Pacific Northwest National Laboratory. "Whoosh bottle" demos in which alcohol vapor is ignited also frequently go wrong, as do demos

"Universities and colleges don't seem to be preparing teachers to do what they need to do safety-wise."

HOW TO DO A LAB DEMO SAFELY In response to recent accidents in the classroom, here is a guide for performing experiments or demonstrations involving open flames, fire, or the use of flammable, reactive, toxic, or corrosive chemicals.

Preparing for demos or experiments:

- Determine educational goals and how the activity will meet them.
- Perform hazard and risk assessments.
- Provide a safety briefing to students.



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NOTE: Instructors in teaching labs shall be trained and knowledgeable in fire safety procedures, emergency plans, the hazards present in the lab, the appropriate use of personal protective equipment, and how to properly conduct a hazard risk assessment.
SOURCE: National Fire Protection Association Standard 45, 2015 Edition

involving oxidizing sugar with potassium chlorate or potassium nitrate.

NFPA has no legal authority itself, but some jurisdictions adopt its standards as regulatory or legal requirements. West Virginia incorporated the updated NFPA 45 into its fire code in June. New York City—where a "rainbow" demo gone wrong injured two students in January 2014—is doing similarly, with fire code updates to take effect in January 2016. But even where NFPA 45 isn't adopted, it still represents good professional practice.

For educational and instructional laboratories, NFPA says that instructors "shall be trained and knowledgeable in fire safety procedures, emergency plans, the hazards present in the lab, the appropriate use of PPE, and how to properly conduct a hazard risk assessment." For instructor-led demonstrations or experiments done by students, instructors must review hazards, assess risks, provide safety briefings to students, and use or provide appropriate PPE.

NFPA also says that bulk quantities of chemicals must be locked in a separate room or cabinet. Before students arrive, instructors should dispense only the minimum amounts necessary for the activity. Demos involving open flames or flammable, reactive, toxic, or corrosive chemicals should be done in a fume hood if possible. If a fume hood is not available, instructors

& VIDEO ONLINE View a video of a safer procedure for the "rainbow" flame test, find links to free resources for teachers, and download a pdf of this story and infographic at cenm.ag/labdemo.

should place an impact-resistant barrier between the experiment and students, or ensure that students are more than 10 feet (~3 meters) away.

THE NFPA guidance largely echoes recommendations issued last year by the Chemical Safety Board in a safety bulletin, "Key Lessons for Preventing Incidents from Flammable Chemicals in Educational Demonstrations."

Beyond the NFPA guidance, teachers need to practice demos or experiments ahead of time, recommends Donald J. DeCoste, a chemistry professor at the University of Illinois, Urbana-Champaign, and adviser to the school's master's degree in the teaching of chemistry program. Even if an activity is something that an instructor has done before, "if you think it needs to be bigger, or you change some variable, then you need to think about that and practice it on your own before doing it in front of students, because you're just not sure how it's going to go," he says.

And as schools embrace more inquiry-based learning in which students may construct their own experiments, teachers need to stay closely involved. "You don't just send students into the storeroom and say, 'Go,'" DeCoste says. If students are mixing various solutions, for example, then teachers need to be certain in advance that all combinations are safe. If there are safety concerns, then students can plan out their procedures, but the teacher must check the procedures before experiments begin.

But to accomplish all of this, teachers need better lab safety training and resources. The training needs to start before they're in a classroom on their own, says Ken Roy, director of environmental health and safety for Glastonbury Public Schools in Connecticut and chief science safety compliance adviser to the National Science Teachers Association. "With some exceptions, universities and colleges don't seem to be preparing teachers to do what they need to do safety-wise," Roy says. Then, once teachers are in the classroom, they also need ongoing in-service training, and states and school districts need to allocate the resources for that—as well as for equipment such as eyewashes, fume hoods, impact-resistant barriers, and PPE.

"There are a lot of chemistry teachers who are very safety conscious and very careful," comments Deanna M. Cullen, a chemistry teacher at Whitehall High School in Michigan and an associate editor of the *Journal of Chemical Education*. "At the same time, I've been teaching for more than 20 years, and nobody's really ever checked on my safety. Early on, following my mentors, I did things that I didn't realize weren't okay. I feel like I'm lucky that something bad didn't happen in my classroom." ■