Playing with Fire: Chemical Safety Expertise Required

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ABSTRACT: Over the past 20 years 164 children and educators have been reported as injured in demonstrations using flammable solvents. The injuries were the result of flash fires, flame jets, and projectiles which occurred once control was lost by the presenter. “The rainbow demonstration” using methanol as the solvent has by far been the most problematic. Numerous stakeholders and concerned individuals have sounded the alarm for years in an effort to increase awareness in the educational community about the substantial risks associated with performing demonstrations using solvents, but reaching the target audience has proved difficult. Punitive damages such as monetary awards for those injured and job terminations have held schools and teachers accountable, but more effective safety training and substantive safety education in the K–12 preteacher curriculum is also needed. This article seeks to present the totality of issues surrounding the problem and create a reference document that can be easily disseminated to support ongoing efforts in preventing future incidents.

KEYWORDS: General Public, High School/Introductory Chemistry, Curriculum, Demonstrations, Safety/Hazards, Hands-On Learning/Manipulatives, Elementary/Middle School Science

Humans are fascinated by the power of fire as a force of nature, and most of us have enjoyed observing colored flames in fireworks and fireplace colorant products. Fireworks, developed in China between 600 and 900 A.D., initially consisted of confined mixtures of chemicals burned in bamboo tubes. It was not until much later, that color producing chemicals were introduced into the mixtures by the Italians. Today, modern fireworks are engineered to produce specific colors by combining metal compounds with elements such as aluminum and magnesium.

Chemists have also learned to skillfully manage fire hazards in the classroom for educational purposes. Numerous activities have been developed to demonstrate atomic electronic transitions by burning different metal salts which produce emissions in the visible spectral range. In January 2018, an article in this Journal reported that, “The flame test is a longstanding demonstration in chemistry classrooms. From 1928 to 2015, the Journal has published 32 different procedures for conducting flame test demonstrations. One flame test, known as the “the rainbow demonstration”, involves igniting a mixture of solvent and metal salts in shallow dishes. In the demonstration a row of dishes (each containing a different salt) will produce a flashy display of multiple flame colors simultaneously, thus emulating the color order of a rainbow. Variations of this demonstration include the following: spraying methanol/salt solutions into a flame, the “green fire tornado”, the “whooshier bottle”, and alcohol-fueled rockets.

As a hands-on experiment, students can observe the colors produced when Nichrome wires are dipped in salt solutions and held in a Bunsen burner flame. Emission lines from many metals can be observed using inexpensive handheld spectrosopes or gratings. Student participation in the experimental version allows for greater pedagogical opportunities to explore concepts such as the Bohr model of the atom, wavelength and color, the electromagnetic spectrum, and the Rydberg constant, etc. In both the demonstration and the experiment, the hazards must be recognized and assessed so controls can be implemented to reduce risks. One obvious hazard from these activities is having an ignition source in the presence of a flammable solvent. The inhalation hazard is more insidious if there is inadequate ventilation. In the controlled environment of a laboratory, risk can be minimized in the experiment by using aqueous solutions, making sure the students tie back their hair, allowing the Nichrome wire to cool before dipping it in the aqueous solution to minimize spatter, burning the salts on lab benches which have table top hoods, wearing eye protection, and working with a partner to hold the wire in the flame. The hazards are more difficult to control in a classroom setting when presenting the demonstration.

WHAT IS THE PROBLEM?

Flame test activities can be safely used under controlled circumstances by instructors who understand the hazards of flammable solvents. However, using accelerants in classroom demonstrations has proven to be too high risk when educators have limited science background and/or chemical safety
education, do not have training on how to present the science safely to an audience of children, do not have (or use) appropriate emergency equipment, or who are working in an inappropriate venue. As a result, many children and adults have been injured over the past 20 years primarily during demonstrations in classrooms and outreach venues.\textsuperscript{15,14} Table 1 chronicles 32 documented events which occurred between 1998 and 2017 with 164 injuries reported.\textsuperscript{15}

Despite those who would suggest that serious incidents in schools are isolated and rare events, the data in Table 1 indicate that fires involving flammable solvents occur all too frequently in teaching venues to be dismissed.\textsuperscript{77} These events have left safety professionals, school administrators, and the legal system wondering where the educational safety system is failing. Seeing the events in one place should highlight the magnitude of the problem to the reader—especially if one considers that some incidents and many near misses may go unreported. The visual impact of seeing the events in one place is very impactful for dissemination purposes.

Media articles detailing these incidents often state or imply that the experiment went "wrong" or "awry" as if the fire was an unexpected or mysterious event.\textsuperscript{15,20,27,35,37,42,44,46} Inaccuracies reported at the time of the event are partially due to a lack of understanding by the media about science but can be exacerbated by an unwillingness of involved institutions to share details with the press for a variety of reasons (e.g., protecting the identities of potentially innocent parties and the injured). An investigation that completely describes the event (and lessons learned from it) takes much longer to finish, and final reports are rarely (if ever) shared with the public. Information from inaccurate and/or incomplete reporting at the time of an emergency is not as helpful for preventing similar incidents from occurring in other locations.

Leaving the solvent stock container in the area during a demonstration enables the presenter to add more fuel to a hot or still burning dish when a flame diminishes. This can lead to the vapors flashing back into the stock bottle, creating a torch fueled by the contents of the container. This phenomenon, known as "flame jetting", is well-described and totally preventable.\textsuperscript{48} Reviewing the articles written about the incidents in Table 1 reveals that the active "cause" was often the result of having casual access to excess amounts (1–4 L containers) of flammable solvent in the work area.\textsuperscript{15,18,22,24,32,35,37,43,44} The fires that result are not examples of unavoidable or happenstance occurrences—they are a predictable (and therefore preventable) consequence of a demonstrator working with a flammable solvent without fully understanding the chemistry of combustion and conditions for fires.\textsuperscript{15,18,20,22,24,27,35,37,43,44}

Basic safety precautions say that one should never attempt to add solvent to a previously ignited demonstration. Even if the flame is out, there may be sufficient heat present to ignite the vapor and flash back into the solvent container producing a flame jet.\textsuperscript{38} Demonstrations may be necessary in classroom situations where the equipment and chemicals are limited or too...
hazardous for hands-on participation, but the pedagogical value should not be secondary to the “wow” factor.

To help readers visualize hazard, risk, and controls in a flame jetting risk scenario, a “bowtie” diagram is shown in Figure 1. Bowties are visual communication and risk assessment tools. The hazard one is trying to control is placed at the top center of the diagram with the point at which control is lost, or top event, located directly below. Threats (Figure 1, blue boxes) and consequences (Figure 1, red boxes) are then determined. Barriers that would prevent or control the severity of the threats fan out to the left, while procedures and activities that would mitigate undesirable consequences are on the right.

![Figure 1. Basic bowtie diagram for flammable solvent demonstrations.](Image)

**WHY THE PROBLEM CONTINUES**

Experience tells us that when a group of grade school students are asked to describe what a chemist does, at least one answer of “they blow stuff up” will be given. Indeed, in many outreach demonstrations, that will be the first question we get, “Are you going to blow stuff up?” The visual excitement of burning chemicals during demonstrations is engaging, and the allure of “wowing” a class of students is very tempting for educators and teachers today. The temptation to recreate activities seen on the Internet is also powerful. However, with video sharing platforms such as YouTube the chemistry of fire and explosions is communicated to all by anyone regardless of their level of chemical or chemical safety knowledge.

Students in the 21st century have been raised using devices that provide high visual stimulation and show fantastic possibilities—without including real-world consequences. A search on YouTube for “rainbow fire” returns an undetermined number of videos showing how “beautiful” flames can be produced by burning salts in solvents. One particularly disturbing YouTube video is entitled, “5th grade science project rainbow flame”. This video (uploaded in 2012) shows a child performing the activity on the kitchen table with no personal protective equipment (PPE). What is clear from watching the video is that the child does not understand the chemistry.

Chemical educators also compete with Hollywood productions. For example, the spray bottle version of the rainbow demonstration was sensationalized in the pilot episode of “Breaking Bad” in 2008. The picture featured on the show Web site, depicts Walter White “performing” the spray bottle version of the rainbow demonstration with no PPE in use, no emergency equipment visible nearby, and what appear to be solvent bottles on the lab bench. This variation of the demonstration was published in this Journal and in the fifth volume of the Shakhashiri series.

In addition to videos, television, and movies, there are numerous sources of easily available instructions for chemistry demonstrations—in print and on the Internet. As noted previously, this Journal has published many activities that were developed and tested by the authors with the safety information required by journal policy at the time of publication. The Shakhashiri series of demonstration books is very popular and has always stressed in the introductory material that a certain level of chemical knowledge and understanding of chemical hazards is required to reproduce the demonstrations in the books.

However, even the best written procedures, peer reviewed for the chemistry, often lack complete risk assessment of the hazards. Additionally, over time new hazard information is established, waste handling methods evolve based on new regulation, and best practices change based on new knowledge—all potentially rendering materials obsolete for best safety practices. A level of chemical competency must be assumed by authors, but a student or novice educator who understands the chemistry conceptually may erroneously also assume they have the level of chemical safety knowledge required and accurate safety information.

In his blog posting, James Grimmelmann noted that the credibility of safety information and resources available to teachers and the public varies widely. His review of published articles states, “I would like to think that these articles are reaching an audience capable of recognizing the remarkable danger of such demonstrations and taking appropriate precautions. The frequency with which students and teachers are burnt in methanol flame tests suggests otherwise.”

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Figure 2 gives a graphical snapshot of the incidents from Table 1 by year and anecdotally indicates how Internet videos, media, and the ease of obtaining “how to” information may be impacting the number of occurrences, particularly since 2010. While YouTube debuted in 2005, the earliest video found in a cursory search for “rainbow fire” was from 2010.

RECTIFYING THE PROBLEM

Reducing the occurrence of solvent-fueled incidents will take attacking the problem on several fronts. This section presents some actions which have already occurred and, over time, have the potential to reduce the incident frequency.

Corrective Actions and Penalties

We all want to think that if people are informed and aware of these incidents, they will do the right thing. However, when things go “awry” and best practices have not been followed, educators and school districts must be held accountable. It can be very difficult to find out what the legal consequences of a specific event are and what, if any, actions were taken. Legal teams must meet a high threshold and show proof of gross negligence to overcome governmental immunity. Figure 3 shows a reenactment still used by one legal team to demonstrate the flame jetting that occurred in their client’s case.

Dissemination to educators about known negative consequences may help prevent future incidents by either acting as a deterrent or ensuring they have correct controls in place if solvents are used. Some known examples of punitive actions follow.

Monetary Awards.

(1) In 2008 an $18.9 million settlement was reached with Western Reserve Academy for the injuries sustained by Calais Weber [Biery] and Cecilia Chen in the 2006 fire. According to the settlement report, “The families say that the teacher acted negligently because she did not implement safety measures when conducting the experiment. The family’s Ohio personal injury lawyer says that the teacher should have conducted the experiment at least 10 feet away from the students, as well as used a safety shield and vent system.”

(2) In 2016, lawyers for the student burned in the 2013 incident in Georgia were able to overcome immunity issues and obtain $1.5 million for their client.

(3) In 2017, a school board in Florida awarded a student burned in the Tallahassee, FL 2015 incident $125,000.

(4) Beacon High School (New York, 2014) was cited with eight violations by the fire department. Additionally, the families of the most severely injured students have filed multimillion lawsuits naming the city, the department of education, and the teacher.

Personal Consequences.

(1) Daniel Powell, the teacher in the Reno, NV incident, was fired and charged with misdemeanor crimes of third-degree assault and being negligent.

(2) Asia Moses, the teacher who poured rubbing alcohol on a student’s hand and lit the solvent with a lighter was fired and charged with “neglect of a dependent resulting in bodily injury and criminal recklessness” for this incident.
Broader Actions.

(1) After the Washington, DC incident the Fairfax County, VA Superintendent proactively called for an immediate ban on all experiments using open flames in county schools. The ban was placed with the conditions that a review of the science curriculum would be conducted, guidance to science teachers on safety methods would occur, and there would be mandatory safety training for all county high school teachers. The ban was scheduled to be lifted when the training was completed.63,64,65

(2) To prevent additional incidents in New York City schools, Councilwoman Rosenthal introduced a resolution to review the use of the rainbow demonstration as well as ensure that teachers adhere to the N.Y. Department of Education (DOE) Science Safety Manual.66,67 The manual states to, “Make sure that all rooms containing chemicals are properly ventilated.” and, “There is to be NO FLAME in the room when using flammable, volatile liquids such as alcohol.”68 The resolution is still listed as “active” and in committee.66 Since the resolution was introduced, two additional incidents have occurred in NYC schools.41,46 Had the teachers adhered to the DOE Science Safety Manual, they would not have been presenting the rainbow demonstration or experiment.

Standard Change

In 2015, a revision of NFPA 45, “Standard on Fire Protection for Laboratories Using Chemicals” was published (available to read for free at NFPA Web site with registration).65 Of interest in the updated standard are the recommendations found in Chapter 12 which address working with flammable materials in educational laboratories (those that are K−12). Specifically, instructors must be knowledgeable about fire emergencies, PPE use, emergency planning, and hazard assessment. The revised standard (Chapter 12) also states that only instructors who are knowledgeable about using flammable liquids and open flames shall perform demonstrations and experiments using them.68

Interestingly, the 2015 NFPA 45 standard also states that when demonstrations are performed outside of a fume hood a shield should be used and that if a shield is not used, the students should be a minimum of 10 ft. from the chemicals. This premise appears to have been tested in court in the 2013 incident case.56 While not all jurisdictions adopt NFPA standards, there is now precedent supported by a legal settlement and best practices advocated by NFPA for how flammable solvents are handled in classrooms.

Advocacy

Some in the media have been sounding the alarm for over 15 years. In 2002, Tammy Webber posted an article that was picked up by the Associated Press. The article highlighted several incidents and talked about just how frequently all types of incidents with injury occur in schools.69 At least two other general articles have been published to alert the public about the hazards of alcohol-fueled activities.70−72 Students who have been impacted by these events often become strong advocates for safety education by telling their stories.73

Many groups have advocated publicly in hopes of preventing future incidents. In 2013, the U.S. Chemical Safety and Hazard Investigation Board (CSB) released a “video safety message” which was distributed to 60,000 subscribers.74,75 The video, “After the Rainbow”, presents a firsthand account of the classroom fire that occurred in 2006 as told by Calais Weber [Biery] who suffered the most severe injuries that day. Calais has also used her experience to advocate for better safety education for teachers and even established a safety program for chemistry teachers with part of her settlement.74 Today she still speaks publicly on the need for better training and education for teachers.75

Incidents continued to occur at an alarming rate and in 2014 six incidents were reported by the news media.86−88 In response, the American Chemical Society Committee on Chemical Safety (ACS CCS) Chairperson put out a “Safety Alert” which was published in Chemical & Engineering News.76 The CCS recommended that schools discontinue the rainbow demonstration with solvents and substitute with a safer version using wooden splints soaked in aqueous salt solutions.77,78

One 2014 incident occurred at a science museum injuring very young children and prompted the ACS CCS to issue a second, stronger alert stating that, “At no time should methanol be poured from an open bottle on an open bench top in the presence of a flame or source of ignition—the risk of a flash fire is very great.”77,78 The CSB Chairman also released a statement, shortly followed by a “Safety Bulletin”.80,81 Despite all efforts by these groups, by the end of October, two more incidents would be reported. Two additional incidents that year prompted the National Science Teachers Association (NSTA) to issue their “Safety Alert” which called for teachers to “immediately halt” the use of methanol demonstrations on open desktops.82

In 2015, the National Fire Protection Association (NFPA) published “Lab Fire Safety 101” tips for teachers advocating for, among other things, hazard assessment for experiments and demonstrations.83 To help spread the word more broadly and reach the correct audience, the ACS Division of Chemical Health and Safety (CHAS) recently posted a letter template which can be used to alert area K−12 administrators and fire marshals to the hazards associated with burning solvents in the open.84

- IMPlications FOR TEACHER EDUCATION AND FUTURE DIRECTIONS

Improving the Undergraduate Curriculum for Science Teachers

Advocating for change and holding educators to a standard duty of care are both necessary and useful, but preventing unsafe behavior in classrooms begins by educating K−12 science teachers how to work with chemicals. Others have suggested ways to reduce the number of incidents, but removing chemicals from classrooms is not a viable solution because most agree that students should be exposed to the excitement of chemistry, perform hands-on activities, and work with chemicals.71 Science teachers should have safety education in coursework in addition to training, and mentorship. All are needed to learn how to work safely with their chemical tools. Even Calais Weber [Biery] who was burned in 2006 acknowledges this. “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.”75

The undergraduate curriculum for those seeking K−12 teaching certification is very full, and any safety information or training is probably incorporated into an existing methods class. Even with certification, middle and high school science teachers may or may not obtain a strong background in the science they end up teaching. A newly placed science teacher can inherit a stockroom of chemicals, be assigned as the school’s Chemical
Hygiene Officer (CHO), or enter laterally into chemistry without receiving instruction or training. Including chemical safety and risk assessment in student portfolios (where applicable) in edTPA (formally known as Teacher Performance Assessment) has the potential to graduate teachers with better safety knowledge.88

A preservice science teacher may obtain some aspects of classroom safety such as emergency management during the certification process, but a newly certified science teacher is unlikely to have become proficient in chemical management, hazardous waste handling, risk assessment (required by NFPA 45, 2015), or chemical reactivity, all of which are needed to teach chemistry safely.68,85,86 While some preservice teachers do receive minimum safety training as part of their education program, as of 2014 only seven states required safety training as part of teacher certification.80 According to Webber,69 “… a high percentage of science teachers have never had safety training, and in some cases, the schools did not even own the necessary safety equipment, experts said. Gerlovich, the Drake University researcher, has found, for example, that more than 70% of North Carolina science teachers had never received safety training. He said surveys in 17 other states found an average of 55% to 65% of teachers have never been trained in safety.”

Even if a state certification program does include safety education and/or training, certified teachers in all schools is not a given. Charter schools often do not seek those who are state certified, opting for the ability to be flexible in hiring “experts” in fields other than general teaching.38,62 Hiring a teacher who has a chemistry degree might make them more knowledgeable about chemistry, but it does not guarantee they have a strong background in chemical safety.35 Some state certification programs and school systems do provide safety training, but that is not a substitute for increasing knowledge through safety education.47,71,85

In 2012, the National Science Teacher Association (NSTA) published updated Standards for Science Teacher Preparation.86 NSTA Standard 4: “Safety” gives guidance on what should be in the science teacher curriculum, but the specifics of implementation are left to the curriculum designers. More specific safety guidance (risk assessment, chemical management, and so on) in NSTA standards on what should be included in the curriculum for science teachers could prove useful to the designers.

Involving organizations such as the American Association of Colleges for Teacher Education (AACTE) in discussions may be a way to alert those who design courses for science teachers about the need to integrate chemical safety into the curriculum.87 For example, at Appalachian State University chemical safety concepts are integrated into the preservice teacher methods course. AACTE is leading the effort with others to implement a common evaluation system for licensing that is “…standards- and performance-based assessment of teaching effectiveness that would measure the classroom readiness of aspiring teachers and provide information for program improvement.”88 Including chemical safety and risk assessment in student portfolios (where applicable) in edTPA (formally known as Teacher Performance Assessment) has the potential to graduate teachers with better safety knowledge.88

Because the scope of the job can easily change, and the temptation of presenting demonstrations using household chemicals can be strong, all K−12 preservice teachers should receive basic chemical and fire safety principles as part of the preservice teacher curriculum. Additionally, secondary education preservice science teachers (regardless of subject area) should develop the following competencies:

1. a working knowledge of the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) which facilitates understanding all chemical hazards (physical, health, and environmental);89

2. an ability to perform a risk assessment based on the RAMP principle—Recognize, Assess, Minimize, and Prepare for Emergencies86 (the basic bowtie shown in Figure 1 could be used to start a discussion about risk assessment with teachers);

3. a working understanding of inventory management—including the ability to segregate, secure, and safely store chemicals in a stockroom based on best practices and hazard classes;

4. a thorough understanding of flammable solvents and combustion—including flash points, flammable limits, deflagration, vapor density, the fire tetrahedron, types of fires, and required extinguishing materials.91

5. the ability to read and understand a Safety Data Sheet (SDS)—including differentiating between a good and a poor one, understanding terms, and what to focus on for the chemical of interest;85

6. a working knowledge of PPE—including material types and fit;

7. a fundamental understanding of hazardous waste management—including labeling, storage, and the principals of reduction;

8. hands-on experience with common demonstrations and experiments including practice with identifying hazards and assessing risk.

Administrative Controls

Leadership should be provided by school board members, superintendents, and principals. Clear policy and standard operating procedures for allowed activities (such as limits on the amount of solvent that can be present in the work area) should be developed. Safety education and training should be required for all teachers regardless of the length of time they have been teaching. Mechanisms should be in place to review new procedures, and administrative controls should be monitored for effectiveness, updated as needed, and enforced. Professional development in safety topics should be encouraged and funded. Teachers should be empowered to begin discussions with their administrators about what is needed to teach science safely and effectively, and they should have access to local, trained CHO who can mentor them. Emergency response equipment should be inspected and problems immediately reported and corrected. Teachers also need be held accountable to those in authority and prepare hazard and risk assessments for their experiments and demonstrations. The caveat often heard after these incidents is, “I have done the activity numerous times, and this has never happened before” indicating that the teacher has previously been fortunate not to have experienced an incident.

Responsible Dissemination of Safety Information in Materials for K−12 Teachers

In 2017, the ACS enacted a new policy requiring authors publishing in their journals to address novel or significant hazards.92 Those who create materials intended for K−12 educators describing demonstrations and experiments, whether on the web or in text, must ensure that the hazards in the activities have been recognized and addressed in a meaningful way. It can no longer be assumed that the caveat “chemical expertise is required” is necessarily a sufficient warning. At a minimum, those creating new activities aimed at K−12 teachers should include risk assessment information along with any known reported incidents in the hazard section. It some cases,
perhaps author guidance should be “chemical safety expertise is required”.

Information from the Internet is particularly worrisome. For example, one procedure on the web for producing a colored fireworks demonstration (no solvent used in this one) calls for, “Each chemical used as an ingredient should be in finely ground form.” Several of the recipes call for potassium chlorate as an ingredient. The instructions say to grind the chemicals separately to avoid contamination, but there is no mention of the significant possibility of forming an explosive mixture if potassium chlorate is ground in a mortar with trace amounts of organic residue. No ventilation requirements are provided for burning potassium chlorate, which produces toxic fumes. The instructions do say, “This project is best performed by persons with chemistry expertise or pyrotechnics experience.” If this statement did not deter a teacher with access to the chemicals, it would be insufficient to control the level of hazard present.

Development of Educational Materials for the 21st Century within the ACS

Groups within the ACS are creating new guidance materials and updating others to have the best chemical safety information available for educators. The newly created staff position, “Manager of Safety Programs”, is coordinating with internal and external groups to ensure consistency of message. Materials are being developed based on risk-based safety ideas using the RAMP. Some recent ACS accomplishments are given here:

1. a centralized web presence which links to all safety resources mentioned and numerous others are available;
2. the establishment of the American Association of Chemistry Teachers (AACT), a professional community by and for K–12 chemistry teachers (2013);
3. a specific guidance booklet with student learning outcomes for K–16 educators, “Guidelines for Chemical Laboratory Safety in Secondary Schools”, and for college level educators, “Guidelines for Chemical Laboratory Safety in Academic Institutions” (2016);
4. the eighth edition of “Safety in Academic Laboratories” or SACL (2017), primarily providing information for students in the first two undergraduate years;
5. updated “Safety Guidelines for Chemical Demonstrations” (2016);
6. currently, development of a rubric that will assist teachers in evaluating the credibility of online videos with respect to level of risk vs pedagogical value (expected to be disseminated in 2018).

It is important for chemical safety and chemical education researchers to develop and disseminate safer visually stimulating alternative demonstrations. For example, the ACS created and produced a video and graphic (Figure 4) depicting a low risk classroom demonstration to show electronic transmission. While an expensive initial purchase, another option is to use a transformer, emission tubes, and spectroscopes or gratings to show electronic transmissions.

■ CONCLUSION

If the point of demonstrations is to promote the “wonder of chemistry”, one never wants to do anything that could impact their audience negatively. Even the students who were not directly injured in the incidents in Table 1 will carry scars of the event forever. We can never know for sure, but these incidents may have driven students away from studying chemistry because they now perceive it as “too dangerous” and thus the demonstration would have had the exact opposite effect of what was intended.

As incidents were reported, those affected likely believed they were experiencing an isolated event, not realizing until later just how frequently they occurred. Safety professionals and others who were paying attention knew better. With every news report, we saw another solvent-fueled fire injuring children and teachers at schools, museums, or social events. Numerous concerned organizations and advocates have worked to raise awareness and prevent the next incident, but incomplete reporting of incidents and near misses limit the completeness of this study and make correcting the problem more difficult.

Flame jetting is a well-defined phenomenon and not just confined to educational settings. Each year, hundreds of people are injured and/or killed when flammable liquids unexpectedly ignite. This article seeks to raise educator awareness, provide a comprehensive overview of an ongoing problem, and aggregate information in one place to facilitate dissemination. We urge those reading to pass the information on to curriculum developers, superintendents, principals, fire marshals, teachers, law makers, and parents. A dedicated Web site at Interactive Learning Paradigms Incorporated (http://www.ilpi.com/safety/demosafety.html) is being created to maintain up-to-date information on incidents, new guidance information, regulations, and legal corrective actions. The need to keep this information publicly available is great as evidenced by the fact that in the time it took to prepare and publish this article two additional incidents occurred. Both were apparently solvent-fueled flame tests.

Finally, three particularly relevant points from Roberts’ guidance document are offered for working with flammable liquids: Flammable liquids can be handled safely if they are handled properly. Flammable liquids are dangerous when mishandled.

Figure 4. Graphic representing a safer classroom demonstration of electronic transmission. Reprinted with permission from C&EN (cemn.ag/labdemo). Copyright 2016 American Chemical Society.
“Users do not deliberately cause fires and explosions. On most occasions users are unaware of the severity of the hazards. Miss-handling [sic] is typically the result of a lack of knowledge, not willful destructive intent.”

“It is users’ responsibility to continuously strive to become better informed, and more adept at identifying and controlling hazards.”

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■ REFERENCES


(9) Shahkashi, B. Z.; Shreiner, R.; Bell, J. A. Chemical Demonstrations: A Handbook for Teachers of Chemistry; The University of Wisconsin Press: Madison, WI, USA, 2011; Vols. 1 − S.


(55) Grimmelmann, J. Don’t Try This At School. Laboratory, Jan 5, 2014; http://laboratory.net/archive/2014/01/05/dont_try_this_at_school (accessed July 2018).


(93) Potassium chloride. TOXNET Hazardous Substance Database, CAS RN: 3811-04-9; https://toxnet.nlm.nih.gov/cgi-bin/sis/search2?rdbs+hsdb@term+@rn+@rel+3811-04-9 (accessed April 2018).


(98) Guidelines for Chemical Laboratory Safety in Academic Institutions. Committee on Chemical Safety (CCS) Task Force for


