Safety in Educational and Research Laboratories: Seizing the Opportunity

Administrators, faculty, staff, and students must recognize that teaching and research laboratories are fundamentally construction sites

by Kenneth C. Hover and Michael J. Schneider

Laboratory experiences are exciting and valuable components in the education of design and construction professionals, and they are essential for research that advances science and industry. Students look forward to lab work and well-planned projects, and experiments can be productive learning opportunities and great team-building exercises. But instructional and research labs in concrete materials and structural behavior present the same safety hazards as a typical construction site. Although lab work may be at a smaller scale, scale does not matter when there is a personal injury to an individual student or researcher.

Recognizing the industrial reality of safety hazards in our college and university labs focuses our responsibility to protect all persons working, observing, or just "passing through" those labs. Such recognition also provides a golden opportunity to use our lab experiences to teach professional, industrial-level safety philosophy and procedures with the goal of enabling our students to walk out of our labs and onto any construction site or fabrication shop prepared to identify hazards and able to protect themselves and others. Just as higher education prepares graduates for lifelong learning, our lab curricula can implant lifelong safety habits and a personal safety culture.

Nature of the Hazards

In almost all colleges and universities, well-established safety programs govern the use and disposal of hazardous materials in chemistry labs and safe operations in machine shops. However, few campus-safety guidelines truly embrace the full range of activities common in civil engineering labs, where the day-to-day activities can represent the full spectrum of safety challenges found on a typical construction site.

The challenges begin with the safe storage of cementitious materials,[1] admixtures, aggregates, form-release agents, and curing compounds (not all of which are clearly identified in campus chemical-safety procedures). During mixing of concrete, dust and fine particles may pose an inhalation hazard.[2] Addition of water triggers formation of calcium hydroxide and with it an increase in pH that can cause "first, second, and third-degree chemical burns."[3] The OSHA pocket manual for concrete manufacture[3] (a valuable reference for faculty and staff) therefore recommends wearing alkali-resistant gloves, coveralls with long sleeves and full-length pants, waterproof boots, and eye protection when working with concrete. PCA's guidelines[4] for working safely with concrete include recommendations to always wear hard hats, eye protection, waterproof gloves, and rubber boots high enough to prevent concrete from getting into them. (Given that students often equate lab wear with beach wear, complete with shorts, tank tops, and flip-flops or sandals, a strictly enforced laboratory dress code is essential to student safety, with the tone set by supervising faculty and staff.)

Most university policies stop short of requiring work boots, in favor of "closed-toe, substantial shoes." But even with commonly worn sneakers coupled with long pants, socks are required to protect exposed skin at the ankles. Work boots are the safest solution, and even expensive boots are cheaper than textbooks and way cheaper than a smashed toe. In setting policy, consider the fact that anything that can be lifted or carried can be dropped, and anything that can be dropped can hit a foot or toe.

Concrete and mortar mixers are common in college labs. As with any mechanical equipment, the moving parts create major hazards for users—even a small benchtop mixer with a planetary paddle can sever a finger. Contact with fresh concrete may cause skin or eye damage, and inhalation of the dust generated when cleaning forms or abrading or drilling hardened concrete can cause lung damage.[2] While each of these hazards are described in the handy OSHA pocket guide,[3] the guide will have no benefit if it is not opened and read.

After safe removal from molds or forms, test specimens and structural components must be safely lifted, transported, assembled, and precisely installed in the testing apparatus (and the testing frame itself may require fabrication and assembly). Loads are applied with actuators capable of inducing thousands of pounds of force in seconds, and destruction of the specimen is frequently the intended outcome. Safe, controlled testing is followed with the sometimes difficult task of safely removing and disposing of damaged and probably unstable specimens or assemblies. All this activity takes place in a three-dimensional space, and a wide variety of lifting devices are employed, ranging from manual labor ("Lift with your legs, not your back!") to forklifts and overhead cranes. Depending on the experiment, participants must climb a few steps or a few stories.

All of this is further complicated by the congestion common to many college labs. A large portion of total floor space is occupied by testing equipment and accessories, material storage, and archival specimens retained from previous experiments (with every expectation of further analysis at an unspecified time in the future).

Laboratory congestion forces students to work close together, increasing the likelihood of interference or collisions (a good reason for hard hats) and generating tripping hazards due to insufficiently cleared walkways. The handles of shovels and hoes, used to mix concrete and mortar, become dangerous "pokers" that can hit nearby students. And water, form-release agents, hydraulic fluid, fresh concrete, cement paste, or aggregates can pose slipping hazards on slick floors. When the placement exercise is complete, there can be a more intense exposure as students wash tools and equipment and properly dispose of or treat the leftover concrete and high-pH wash water. It is rare to have a lab with staff who "clean up the mess."

None of these challenges are unique to the academic laboratory environment. An experienced construction worker would immediately recognize a structures and concrete laboratory as a construction site. Those with less construction experience could miss this fundamental realization, misled by the physical size of most college labs, the cramped quarters, the short duration of experiments, the indoor environment, or the relative inexperience of the students. But the specialist in construction safety would immediately see that the hazards and risks in an educational laboratory are fundamentally the same as those encountered on a typical construction site (which can also be indoors and in a tightly confined space).

The construction professional is also likely to observe that the students working under these lab conditions may be less accustomed to the tasks, less aware of the hazards, and less familiar with safety procedures than their counterparts working in construction. Further, in contrast to a construction superintendent, lab supervisors, instructors, or teaching assistants may be unprepared to quickly react according to a well-developed emergency action plan.

Typical Academic Approaches

Educators accept responsibility for safely conducting educational and research activities in their laboratories, although they may not realize their personal, legal liability in case of an incident.[5] A survey at one academic institution indicated that researchers and their supervising faculty generally felt that the work environment was safe.[6] An independent study of academic and industrial lab workers[7] reported that 90% of the academic respondents felt safe, while 95% of their industrial counterparts felt safe. However, **feeling safe** doesn't always correlate with **being safe**—being secure in the face of well-understood hazards and consequences with an acceptably low risk. Most victims of so-called accidents feel safe (and confident) up until the moment before impact. If they had felt otherwise, they would have changed their behavior.

In a civil engineering lab, a supervisor could probably get an inexperienced college student to perform an unsafe task that a construction specialist would not attempt, simply because the willing, enthusiastic yet inexperienced student does not yet recognize the risk.* Do we have to teach students to recognize danger? Do we need to teach them to be afraid? While one adage states that "Ignorance is bliss," another warns against "Learning the hard way."† Although one may feel perfectly safe in a dangerous situation, such confidence should come from training and preparation, not because of naïveté, inexperience, and the invulnerability of youth.

College and university administrations impose overall lab-safety policies (generally aligned with OSHA regulations[8]‡), to which faculty and laboratory supervisors add special requirements appropriate for specific experiments and demonstrations. Safety training ranges from instruction by specialists from environmental health and safety offices, to hands-on training and practice under the watchful eye of an experienced staff member, to on-the-job training. Online safety training is often used for convenience, but it has been shown to be less effective than face-to-face safety training. In some cases, online training has been shown to be "worthless."[6,9] Educators discuss lab safety in their lectures; and they provide briefings before each lab session, sometimes emphasizing protective gear to satisfy lab-safety rules, without describing hazards, consequences, ways to reduce risk, and, finally, reasons for wearing the safety gear. (We

*"There are old blasters, and there are bold blasters, but there are no old, bold blasters." (after E. Hamilton Lee)

†It has also been said that: "Confidence is that feeling you have before you fully understand the situation." (attributed to Woody Allen)

‡Literally invoking OSHA regulations can elicit debate in the teaching-lab environment because those regulations specifically apply to "employers," and one might argue that students are not employees.

wear hard hats to protect a student's most valuable asset: his or her brain—not just because the rules say so. The challenge is to get the students to want to protect their brains.) Educators not only provide the personal protective equipment but also often assign people to monitor and enforce safe behaviors during lab activities (with frequent safety reminders to lab users).

The Typical Approach to Lab Safety Is Problematic

Institution-wide safety policies are broadly disseminated but less broadly assimilated. Within any given academic unit there can be inconsistency in safety awareness and expertise among those persons responsible for overseeing lab activities. Occasionally, routine lab exercises may be supervised by inexperienced staff members. Although the principal hazards would have been identified during course development, and although associated protective measures would have been optimized during early lab sessions, an inexperienced instructor or safety monitor could unknowingly negate those efforts. Further, it can be difficult to build a tradition or culture of safety in the university setting, given the frequent turnover of lab instructors and assistants. The safest lab supervisor is often the one who has seen the most unexpected incidents, but institutional memories of risks, incidents, and near-misses can be short lived.

Safety problems can be more acute in research projects. Laboratory procedures used during research may be complicated, and some procedures will be unprecedented (that is, of course, the fundamental nature of basic research). Original research brings new safety-related problems requiring new safety solutions. One comprehensive survey reported that: "Approximately 5 to 10% of researchers [graduate students and staff doing the lab work] feel that their workplace is not safe," and that their supervising research faculty "are not concerned about safety, or that there is pressure to finish work even though safety is compromised."[6] The same study reported that research supervisors were generally more positive when evaluating lab safety than those who were doing the work, and there were indications that some research supervisors were somewhat detached from lab activity.

Students and researchers may perceive inconsistency in safety policies from one lab, class, or supervisor to another. Part of this is the rational outcome of differences in the hazards associated with various activities conducted in the same general space. But another component of inconsistency can be lack of clarity on baseline safety provisions that always apply to all users of the facility, subject to more stringent requirements for special operations. Lab users who do not understand why there may be variable lab-safety policies may incorrectly infer that safety requirements are optional, discretionary, open to broad interpretation, and evidently a function of the personal risk tolerance or risk aversion of the person making up the rules for any given lab activity.

"Safety rules" (that is, "occupational safety regulations"[9]) communicated via policies, memos, posters, rote recitations, and frequent reminders, are as easily forgotten as they are declared—especially when the rules vary from week to week. (Nothing induces the "eyes-glazed-over" response like the weekly lab-safety sermonette.) Not only do educators need to find more impactful ways to embed safe behavior into students' lab and career habits but we also all need to recognize the limited effectiveness of rule- and reminder-based responses to hazards in the form of "When Hazard = 'X,' Wear 'Y.'" The challenge is to make the students **want** to be safe and to turn that desire into a **habit**.

Status Quo Woes

Olewski and Snakard[9] wrote that: "The focus of traditional occupational safety regulations is on personal protective equipment (PPE), which is important for protecting personnel in the event of an accident, but does nothing to reduce the likelihood of the incident occurring nor does it reduce the magnitude of the event." They reported further that "compliance with regulations … only sets the minimum requirement for safety and is often not sufficient to ensure a safe working place."[10,11] This focus on occupational safety can lead to a false sense of safety and does not engage the lab personnel in a critical assessment of hazards within the laboratory process, a critical first step in managing risk at any level.[9] More attention is required to consistently teach our students to identify hazards or prevent accidents and not just how to protect themselves from injury in the event of an accident.

For example, civil engineering educators teach students that design starts with assessing service loads, exposures, and boundary conditions, which is equivalent to starting by assessing the "hazards." Further, we teach our students that building codes set **minimum** standards, and it is the engineers' responsibility to recognize that with more intense loads or load combinations, the need for greater reliability or a more complex model of structural behavior are appropriate. These same lessons and thought processes should be applied to developing the students' capacities to analyze safety hazards in any given situation. (When we introduce the day's planned lab experience, how often do we ask the students in our care to identify or imagine the various risks to which they will be exposed, how best to eliminate those risks, and how to protect against risks that cannot be eliminated?)

Some academic labs may focus on personal protection to the exclusion of preparing students for how to respond when an incident occurs. What should be our first response to cement powder in the eye, regardless of whether eye protection was properly worn? Where are the eyewash stations, fire extinguishers, power switches, and first-aid kits? Where are the "kill switches" for mortar and concrete mixers? Where are the exits? (Lab supervisors cannot assume that all students are familiar with the lab, the building, or even that part of campus.) When an incident occurs, who do we call, and who does the calling? What should students do if the supervisor is absent, incapacitated, or injured? If injured persons need medical attention, how are they transported and who accompanies them? We have frequent fire drills in our academic buildings, but how often do we have lab-incident drills?

After an emergency situation has been stabilized, a lab-safety incident always triggers visits and meetings with safety officers and administrators at multiple levels. Reports are generated; proximate causes and responsibilities are discussed; and policy, equipment, or personnel changes are proposed. The most valuable lessons learned, however, can come from performing a root-cause analysis (RCA) to identify the main causes of problems. By rectifying those issues, we can avoid a recurrence.[12] The American Chemical Society has reported that "An important element of a strong safety culture is establishing a system for reporting and investigating incidents, identifying direct and root causes, and implementing corrective actions."[13]

Unfortunately, an RCA investigation is too often treated as a bureaucratic exercise rather than the result of an important and challenging rational process. Lack of motivation for an RCA may stem from misunderstanding the incident as a random occurrence. While the term "accident" implies that an event was uncontrollable, unpredictable, or random, accidents are no accident. As defined by Bierce,[14] an accident is "an inevitable occurrence, due to the action of immutable natural laws." Educators and research investigators are dedicated to linking various outcomes and behaviors to these same natural laws, and accident investigators are dedicated to finding how these natural laws combined to create the root cause of the incident in question. Neither the researcher nor the incident investigator would accept the hypothesis that "sometimes, these things just happen." Accidents happen for a reason, as academics are well prepared to understand. Academics know that once a cause-and-effect relationship is understood, desired effects can be stimulated and undesired effects, such as so-called "accidents," can be avoided. It's all quite scientific!

Experiencing and reacting to a safety incident is often followed by a temporary increase in safety consciousness that quickly decays back to preincident normalcy. This cycle is so common that Hudson[15] and Gibbs[16] described an organization with a "Reactive" Safety Culture as looking "for fixes to accidents and incidents after they happen," characterized by the mantra: "Safety is important; we do lots of it after every accident." The unfortunately common post-accident decay of safety awareness is a measure of the sincerity of the organization's true commitment to safety. In some organizations, heightened concern for lab safety decays with a half-life of only a few weeks after an incident.

Opportunities Abound

We propose that the responsibility to keep students safe in the lab brings a tremendous opportunity. Not only can educators protect their students on campus but they can also prepare those same students for the realities of safety management and hazard identification and prevention in their post-academic careers. Although the topic of "safety" is often institutionalized via university- or college-level safety regulations in the lab, and by federal, state, and corporate regulations on the jobsite, the injuries that we are all trying to prevent are intensely personal events: A blade hits a finger, a

vibrator burns skin, cement powder burns an eye or is inhaled into lungs, the handle of a rake collides with a skull, an individual suffers a partial loss of hearing due to intense and prolonged noise, or a back is twisted by poor lifting technique.

Injuries do not know or care whether the site is a commercial or educational enterprise (but the injured persons, insurance companies, lawyers, and administrators certainly care). When it comes to safety in the college laboratory, we would set a more appropriate or meaningful tone by talking about "construction safety applied to the laboratory environment," rather than talking about "laboratory safety."

But in the longer term, just as contemporary physical and health education prepare students for lifelong wellness, and general education prepares students for lifelong learning, laboratory safety can set the stage for career-long safety at work and at home. Our goal is a lifelong, 24/7 lesson and mindset that matures into a long-term asset for our alumni and their families. We want students and research assistants to be able to think beyond safety rules to identify hazards, recognize risky behaviors, and think through procedures and protective measures to mitigate the risk. This is particularly important given that construction in the future will incorporate new materials, processes, equipment, and skills—all generating new hazards and risks that will be mitigated only by the ability to recognize and identify hazards and to imagine new solutions. In-depth reports[8,13,17,18] contain powerful strategies for developing an effective safety culture in university laboratories.

We believe that administrators, faculty, staff, and students associated with laboratory facilities, courses, and research must adopt a contemporary and industrial-scale level approach to safety. By adopting an affirmative safety culture—an organizational mindset that goes beyond mere recitation of safety hazards and giving students reminders to "wear hard hats and eye protection"—colleges and universities will convey at least three benefits to their students, the design and construction sector, and society at large:

- Everybody benefits when institutions, faculty, staff, and students "up their game" regarding laboratory safety in ways that translate into safe field practices. But first we have to protect our students so they can live the bright futures for which we are preparing them. Everybody benefits from the identification and mitigation of hazards. Paraphrasing U.S. Federal Safety Regulations,[19] students and research assistants have the right to safe and healthful working conditions; and they have the right to receive information and training about hazards, methods to prevent harm, and the safety standards that apply to their workplace. As OSHA requires, the training must be done in a language and vocabulary (that is, a mode of communication) that undergraduate and graduate students, research assistants, and staff members can understand and will heed;
- Taking a professional, industrial approach to safety in the teaching and research laboratory will prepare students for the workplace. This is valuable for the short-term, when students report for summer jobs, internships, and co-op assignments, and it is essential for developing career habits that will protect themselves and the people for whom they will be responsible. This applies to those who go into

construction careers and to those whose professional duties take them to construction sites; and

- The design and construction sector at large will benefit because our students (the future design and construction professionals) will learn to accept responsibility for construction safety, from the identification and reduction of hazards to the protection of themselves, the public, and the people for whom they will be responsible. Our industry needs professionals who are not only trained to comply with and enforce baseline protective measures but also thinking individuals who can identify hazards associated with new or complex situations, operations, materials, or conditions, and are able to plan safe operations accordingly. Most of all, we want people who **want** to be safe.

Background on establishing an affirmative safety culture and suggestions for better preparing our students for career-long engagement in safety in the workplace will be included in a following article.

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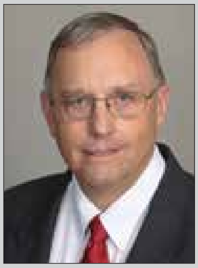

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