

Opinion

# A Call to Prioritize Safety in STEM and CTE: Addressing Overcrowded Classes and Other Critical Safety Issues

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**Abstract:** Authentic hands-on learning experiences are paramount for applying content and practices in science, technology, engineering, and mathematics (STEM) and career and technical (CTE) education. Such learning experiences are foundational for preparing P-12 students for future post-secondary and workplace opportunities. However, valuable hands-on learning opportunities often involve some level of potential safety hazards and resulting health and safety risks. While progress has been made in some aspects of STEM education and CTE safety, numerous safety issues and barriers remain. This article provides a detailed overview of some of the most pertinent health and safety issues from the literature and recent studies (e.g., overcrowding and occupancy load). Moreover, this article provides important information for policy makers, state departments of education, teacher preparation programs, school systems, school administrators, curriculum directors, educators, and other stakeholders to make data-informed decisions to improve safety in P-12 STEM education and CTE programs.

**Keywords:** overcrowding; occupancy load; safety and risk management; liability; health and safety; science education; technology and engineering education; career and technical education; STEM education; makerspaces



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## 1. Accident Cases from Schools: Safety Affects Everyone

Safety does not discriminate nor is any instructor, teacher, or visitor immune from potential hazards and resulting health and safety risks inherent in science, technology, engineering, and mathematics (STEM) and career and technical education (CTE) instructional spaces. Hence, legal safety standards, better professional safety practices, appropriate and consistent safety policies, properly working engineering controls, adequate safety training, and direct supervision among other safety actions are critical for reducing risk and making STEM and CTE instructional spaces safer. Unfortunately, these facilities and instructional practices can only be made safer and not 100 percent safe. Accidents can still occur to anyone when they least expect it, like the following examples that occurred in the United States.

### 1.1. Science Education Accident

In December of 2023, a science class experiment that went wrong sent two high school students near Atlanta to the hospital. The two female students suffered chemical burns during a routine lab experiment that involved sulfuric acid and magnesium. The accident was believed to have resulted from a dangerously high concentration of sulfuric acid used in the experiment. This caused the chemical reaction to occur more abruptly than expected. Fortunately, the students were wearing personal protective equipment (PPE) consisting of aprons and safety goggles. Immediately following the incident, students throughout

the school were kept in their classrooms while medical attention was provided to the two injured students. Both of the students were later treated at a hospital and released. This accident prompted the superintendent and the school district to review their laboratory safety protocols with the science department to limit future safety incidents [1]. This case illustrates the importance and requirement of appropriate PPE and emergency procedures. Had the students not been wearing PPE and the school had not isolated the students for immediate medical attention, the severity of the accident could have been much worse.

This accident also reiterates the importance of administrative legal responsibility to ensure that legal safety standards (e.g., Occupational Safety and Health Administration (OSHA) Laboratory Standard 29 CFR 2910.1450 [2]) and better professional safety practices (e.g., National Science Teaching Association (NSTA) safety position statements [3]) are being followed. This includes mandated safety training for laboratory teachers and students, teacher review of appropriate safety protocols prior to all laboratory activities, appropriate chemical labels, appropriate chemical use, appropriate chemical storage and disposal, easy to read direction sheets for students, and an appropriate frequency of direct administrative supervision of teachers. These safety practices can help to reduce, or in some cases prevent, horrific accidents and limit loss. While this prompted the review of safety protocols for science classes across the school district, this type of review and other measures like safety training updates and hazardous chemical inventories should be occurring at least annually to comply with federal or state-adopted OSHA standards, along with the daily implementation of better professional safety practices.

### *1.2. Technology and Engineering/CTE Accident*

In November of 2023, an accident occurred from spontaneous combustion in an Indiana high school. The combustion was caused by rags with some type of stain or oil base on them that ignited in a paint booth. The fire investigator ruled the fire accidental and concluded that the fire resulted from the spontaneous combustion of the rags, which then ignited items within the paint booth and the workbench directly next to the paint booth. Smoke filled the room and eventually traveled to the outside hallways where the smoke detectors were activated as designed. Fortunately, the fire and heat damage was contained to these two areas. The superintendent noted that the school district was grateful nobody was harmed and they would use it as a teachable moment to reiterate the importance of safety in school laboratories and the workplace [4].

There are also a number of other lessons to be learned from this case. This example emphasizes the importance of having properly operating engineering controls in place (paint booths, smoke detectors, etc.). It also highlights the importance of direct administrative supervision to ensure teachers and students follow appropriate clean-up procedures, such as disposing of paint or stain rags in a fire-resistant oily waste can. Following this safer practice may have potentially prevented the fire, since oily waste cans limit oxygen, which fuels combustion. Disposing of the rags in an oily waste can may have also contained the fire from causing additional damage to the paint booth, workbench, and the room. In general, handling oily rags poses a fire hazard due to the potential for spontaneous combustion. National Fire Protection Association (NFPA) 30: Flammable and Combustible Liquids Code [5] and NFPA 1: Fire Code [6] are two relevant legal safety standards and better professional safety practices that may address the proper disposal of oily rags and are required to be enforced by the administration. Some jurisdictions or codes require the daily removal of oily rags from approved disposal containers to minimize the risk of spontaneous combustion. Administrators have the ultimate responsibility to check with the local fire marshal's office, or the local authority that has jurisdiction, to obtain the most accurate and current information specific to their location. Accidents like this do occur in schools and industries for a number of reasons, but, in many cases, they could have been proactively addressed or prevented to limit costly accidents and losses.

## 2. Background

Engaging students in transdisciplinary STEM instruction that is directly relevant to the world today requires authentic hands-on learning opportunities. Such experiential learning opportunities are the foundation of STEM and CTE courses that help prepare P-12 students for success in the workforce and postsecondary education [7–12]. However, these valuable learning opportunities do not come without potential safety hazards and resulting health/safety risks. While there has been progress in some aspects of safety pertaining to hands-on STEM and CTE teaching and learning, some barriers (e.g., class enrollment size, number of students with a disability in a STEM or CTE course without additional support, and number of course preps) remain after decades of research and calls for improvements [13]. Critical safety concerns like these must be addressed by school system administrators, curriculum directors, educators, and state departments of education due to the significant correlation with accident occurrences and serious legal implications.

## 3. Occupancy Load and Overcrowding: A Major Concern

Studies have continually found that the greatest safety concern reported by STEM and CTE teachers is overcrowding (referred to as occupancy load) [7,14,15]. This is not surprising given that Love and Roy's [14] recent national study found that 57% of participating educators teaching STEM or CTE courses reported having class enrollments exceeding the research-supported 24-student threshold, while only 26% of those educators were teaching in facilities that met the required net square footage to legally facilitate laboratory-based instruction for more than 24 occupants. When a STEM or CTE instructional area has too many students, there is a lack of individual workspace and/or an increase in the number of students a teacher has to supervise and assist to uphold safer learning conditions for everyone in the instructional space. The occupancy load for each lab activity room/area, which is determined by the size of the room, is specified on the architectural plans, and should be mounted on a sign at each entry door.

The Occupant Load Factor of the NFPA 101 Life Safety Code specifies that all "labs, shops, and other vocational spaces" [16] (p. 101-85) (e.g., STEM, CTE, and makerspace areas) in schools must provide 50 net square feet per occupant. However, research has found that even when STEM and CTE areas have the net square footage (>1200 net square feet) to facilitate more than 24 occupants, accident rates significantly increase once a student to instructor ratio of 24:1 is breached [15,17–19]. Specifically, when class enrollment surpassed 24 students, Stephenson et al. [15] found a significant increase in accidents. Love et al. [18] found the odds of an accident increased by 48% when enrollments in STEM and CTE classes exceeded 24 students per instructor. Moreover, another recent study found that when the enrollment in STEM courses exceeded 24 students per instructor, those courses were eight times more likely to have had an accident occur. Furthermore, this study also found when enrollment surpassed 30 students, those courses were 21 times more likely to have had an accident occur [17]. Yet, despite NFPA 101 Life Safety Code occupancy standards, and research findings linking overcrowding and high student-to-teacher ratios to increased accident occurrences, this issue continues due to a range of factors. In some countries, like the United Kingdom, there is a national limit on the maximum number of students (20) that can be placed in a Design and Technology-based STEM course "with one competent, qualified teacher" [20]. Within the United States (U.S.), approximately fifteen states currently have legislation regulating enrollment size in STEM courses, and only eight states have legislation limiting STEM course enrollment to 24 students or less [17]. For example, the Virginia Administrative Code 8VAC20-120-150 on Maximum Class Size limits enrollment in specific CTE and STEM courses to 20 students [21]. School systems and administrators also need to take into account the abilities of the enrolled students [14,18,22–24], types of activities to be conducted, and all potential hazards specific to each STEM and CTE course [25]. In some cases, this may warrant a student-to-teacher ratio lower than 24:1 [25,26]. For example, Love and Roy [25] discovered

that enrollments surpassing 20 students per instructor in secondary level construction courses were significantly correlated with accident occurrences.

Non-compliance by school systems and administrators that either knowingly or unknowingly continue to perpetuate overcrowding and dangerous occupancy load levels create situations that impede safer STEM and CTE learning [8,23,26–31]. Given current budget challenges and teacher shortages in P-12, this can present some major difficulties for school systems to find other courses for students, build or find the facilities to safely host additional sections of STEM and CTE classes, and find additional certified and safety-trained instructors to keep STEM and CTE class sizes at 24 students or less [17]. However, safety must remain at the forefront of all decisions as school systems and administrators would have shared liability for allowing unsafe class sizes or overcrowding to exist in the event of an accident that is found to be the result of overcrowding or the occupancy load.

#### 4. Other Prevalent STEM and CTE Safety Issues

In addition to occupancy load, studies have documented other safety issues that were significantly correlated with accident occurrences in STEM and CTE courses. Engineering controls, such as ventilation systems, patented SawStop table saw safety technology, fire protection equipment (e.g., fire extinguishers), eyewash stations, master shut-off switches, lockable flammable cabinets, non-skid strips and/or rubber matting on the floor near machines, and safety zones around potentially hazardous machine operator zones and laboratory activity areas, were each significantly correlated with accidents [18]. PPE, such as appropriately sanitized eye protection for all occupants (e.g., safety glasses with side shields or indirectly vented safety goggles as appropriate meeting the American National Standards Institute/International Safety Equipment Association (ANSI/ISEA) Z87.1 D3 standard), has also proven to be a safety feature lacking in many STEM and CTE courses in the U.S. [14]. Love et al.'s [13] comparison of national P-12 STEM education safety studies found that 81% of STEM teachers reported having appropriate eye protection for all students within their instructional space in 2002; however, in 2022, that percentage only increased to 83% (it should be 100% to comply with federal and adopted state plan OSHA standards, as well as statutes in many states). This highlights the ongoing need for monitoring and improving safety in P-12 STEM and CTE programs. Additionally, teacher course overload, that is, requiring an instructor to teach more than two distinct courses per semester, has been linked to increased accident occurrences and should be taken into consideration by administrators for safer STEM and CTE instruction [18].

##### *Safety Training*

Another commonly cited safety issue among STEM and CTE teachers is student misbehavior, or lack of following safety directions [7,14,15]. Helping teachers to develop the skills and provide the support needed to address this issue is a shared responsibility among teacher preparation programs and school systems. For example, one study discovered that educators who completed coursework covering safety topics and safer pedagogical methods during their undergraduate teacher preparation experience were 83% less likely to have had an accident occur in the STEM courses they taught [18]. Training on safer classroom management strategies provided by school systems has also been shown to help improve safety. For example, studies have discovered that in-service educators who completed training on safer STEM and CTE classroom managements strategies provided by their school system had significantly fewer accident occurrences in their courses [19,25]. However, only 54% of STEM and CTE educators reported receiving safety training or learning about safety topics in their undergraduate coursework, only 32% received safety training when initially hired by their school system, and only 56% received safety training updates within the past five years (these updates should be occurring annually) [18]. Further illustrating the shared safety training responsibilities among teacher preparation programs and school systems, Love et al. [18] revealed that a comprehensive safety training experience (consisting of a combination of pre-service and in-service safety training experiences) helped to reduce the

odds of an accident occurrence by 49%. Employers (school systems) are legally required to provide safety training to their STEM and CTE teachers under federal OSHA standards and most state occupational safety and health plans [14,30–32]. One way school leaders, school systems, educators, and teacher preparation programs can collaboratively encourage safer decisions and behaviors from students is to emphasize safety instructions that clearly articulate what students need to know on the first day in each STEM or CTE course. Such instructions might include the following: (a) specific directions on how to safely exit the room and exactly where to go when exiting the building, (b) where the emergency cut-offs are for electricity, (c) where and how to correctly use the eyewash station, and (d) other emergency information presented following the “just-in-time” industry model.

## 5. Conclusions

Research results about the significant association between safety factors mentioned in this paper and accident occurrences need to be carefully reviewed and addressed by policy makers, state departments of education, teacher preparation programs, school systems, administrators, school curriculum directors, school counselors, and educators. Ignoring these better professional safety and instructional practices published by reputable STEM and CTE safety scholars in top-tier peer-reviewed journals places stakeholders at risk of potentially being negligent or reckless in the event of an accident. Trying to save money in lieu of safety should never be an option (e.g., overcrowding to save from hiring another teacher). Making every effort to ensure students leave school without life-altering injuries should be the top priority of all P-12 school systems and school leaders as they provide transdisciplinary STEM learning opportunities that help prepare students with the skills they will need to solve the problems of the future.

Authentic, hands-on experiential learning experiences are critical for higher order thinking in STEM and CTE courses [9,11,17,19], and this must remain a key component in STEM and CTE curricula. However, these learning experiences must be provided while following data-informed safety practices, such as those discussed in this article. Safety is a shared legal and ethical responsibility among teacher preparations programs, state education departments, school systems, administrators, educators, students, and others directly or indirectly involved in STEM and CTE instruction. In the end, each of these parties could find their name listed in a lawsuit for negligent or reckless behavior [12,33,34] that is not aligned with legal safety standards and better professional safety practices found in the research cited throughout this article.

## 6. Helpful Resources

In addition to the references list, the following open access resources provide excellent information to improve STEM and CTE safety in school systems:

- National Science Teaching Association (NSTA) safety website [3].
- International Technology and Engineering Educators Association (ITEEA) safety website [35].
- Association for Career and Technical Education (ACTE) High-quality CTE Facilities, Equipment, Technology and Materials website [36].
- *Your CTE Safety Program: Safe Students, Safe Workers* guide published by the University of California, Berkeley’s Labor Occupational Health Program [37].
- State Department of Education Safety Guides/Documents. These will vary by state. Please contact the STEM education, CTE, or related office at your state’s Department of Education to obtain all applicable documents and resources.

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