A Safety Study on Educators of Technological and Engineering Design-Based Instruction in K-12 STEM Related Courses

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Abstract

Fostering experiential learning experiences that allow students to apply their design thinking skills is important for developing technological and engineering (T&E) literacy. However, K-12 schools must ensure that educators providing these experiential T&E experiences are adequately prepared and supported to maintain a safer teaching and learning environment. Therefore, this study examined the safety characteristics of 191 K-12 educators from the northeastern United States (U.S.) who were teaching core T&E disciplinary standards and practices within various science, technology, engineering, and mathematics (STEM) contexts. Analyses revealed there was a significantly higher proportion of accident occurrences in northeastern STEM related classes compared to other regions of the U.S. Further analyses identified 10 risk factors that were significantly associated with increased accident occurrences, and two protective factors that were significantly associated with decreased accident occurrences. Moreover, there were significant differences in the types of safety training completed by educators in the northeast compared to educators from other regions of the U.S. Taking all of this into account, it was discovered that when controlling for significant safety risk factors, safety protective factors, and completion of undergraduate coursework that covered safety topics, the odds of an accident occurrence decreased by 83%. This research has the potential to assist educators, administrators, school systems, state education departments, teacher preparation programs, and others with identifying safety areas of concern and to provide safer T&E teaching and learning experiences. Additionally, this research could inform efforts to help students develop safer habits, which they will carry into higher education programs and the workplace.

Keywords**:** Laboratory Safety, Technology and Engineering Education, Integrated STEM education, Experiential Learning, Safety Training, Risk Management

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Introduction

Hands-on, making and doing learning experiences have been engrained in technology and engineering (T&E) education curricula and teacher preparation programs dating back to its manual arts and industrial arts roots (Love, 2019). These experiences, with a more recent focus on design-based learning and interdisciplinary connections, continue to be one of defining characteristics of T&E education as evidenced throughout the *Standards for Technological and Engineering Literacy* (STEL) (ITEEA, 2020). Prior to the STEL, the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) placed an emphasis on teaching student-centered engineering practices within science education courses. While this increased the emphasis placed on engineering practices it also raised concerns from science and T&E educators regarding safety issues associated with providing design-based T&E instruction (Love, 2022b; Love, Roy, & Sirinides, 2023). Contributing to these concerns is the growing number of alternatively licensed and out of content educators tasked with providing hands-on T&E learning experiences (Williams & Ernst, 2022) despite limited to no training on safer T&E pedogogy and supervision practices that are a core component of T&E teacher preparation program coursework (Love, 2022b; Love et al., 2022; Love & Love, 2023; Love & Maiseroulle, 2021; Reed & Ferguson, 2021). These concerns provided the rationale for this study - to explore the safety characteristics and safety factors associated with accident occurrences in science, technology, engineering, and mathematics (STEM) related courses where educators are providing hands-on, T&E design-based instructional experiences.

Literature Review

Recognizing the foundational importance of safety in T&E education, and the increasing concerns pertaining to alternatively licensed and out of content area educators being tasked with delivering design-based T&E instruction, there was a strong emphasis intentionally placed on safety concepts and practices throughout the STEL (Love et al., 2020). This emphasis on safety is also reflected in state standards and safety guides recently developed by states in the northeastern United States (U.S.). Massachusetts published a safety guide and facility design resources in 2018 which presented a unique interdisciplinary focus aligned with recent integrative initiatives from science and T&E education (Massachusetts School Building Authority, 2019). This was one of the first state approved safety guides that provided guidance on complex safety topics emerging from makerspaces and other interdisciplinary laboratory learning environments. In 2021 Pennsylvania released a new safety guide for career and technical educators which featured a strong focus on accident prevention practices, safety attitudes, safety instructional practices, educator responsibilities, and many other critical safety topics that applied to T&E

education as well as other laboratory-based STEM courses (PDE, 2021). A year later Pennsylvania released new T&E education standards that built upon the STEL. Like the STEL, the Pennsylvania document also included a strong emphasis on safety concepts throughout the standards and benchmarks. This prompted the Pennsylvania Department of Education to initiate the development of an interdisciplinary safety guide for K-12 science and T&E instruction aligned with the new state standards (Love, Hutzel, & Brusic, 2023). As states continue to place an increased focus on interdisciplinary and collaborative learning experiences, further research will be needed to address the safety issues that arise.

Related K-12 T&E Education Safety Studies

Threeton and Evanoski (2014) explored the structure of safety and health initiatives within K-12 technical education settings and determined there was need for concern related to the occupational safety practices promoted within these types of educational programming. Several years later, Love and Roy (2022a) provided an extensive overview of the status of T&E safety in K-12 STEM education programs in the U.S. Their study revealed that, compared to other regions, the northeastern states had a greater percentage of participants who: were teaching T&E literacy courses, were certified in their state to teach T&E education, had completed undergraduate coursework that taught about safer teaching methods, held a master's degree in T&E or STEM education, spent more time on average doing hands-on lab activities in class, had a full-time nurse in their school building, and had lower class enrollment sizes on average. Moreover, a lower percentage of northeastern STEM educators providing design-based T&E instruction had: comprehensive safety training experiences, safety zones taped or painted on the floor near potentially hazardous equipment, a personal protective equipment (PPE) policy from their school district, and annual safety audits conducted by their school district.

One of the most prevalent safety concerns throughout the K-12 STEM education literature is legal occupancy load limits (i.e., overcrowding). Numerous studies have found high occupancy loads to be significantly correlated with increased accident rates in K-12 science (West et al., 2003) and T&E laboratory courses (Love, 2022a; Love & Roy, 2023; Love, Roy, & Sirinides, 2023). Moreover, Love, Roy, and Sirinides (2023) found that when enrollments in K-12 classes involving design-based T&E instruction exceeded 24 students, there was a 48% increase in the odds of an accident occurring. Although the *NFPA 101 Life Safety Code* provides strict criteria for legal occupancy loads in K-12 school facilities where laboratory activities are being conducted, overcrowding continues to be a serious issue in K-12 STEM education learning spaces (Love & Roy, 2022a). Safety training is another factor that is commonly mentioned throughout the STEM education literature. Studies

investigating the influence that safety training has on participants from various STEM related content areas and grade levels, and differences according to mode of training delivery, have concluded that high-quality safety training can enhance educators' safety awareness and self-efficacy (Love, 2022b; Love et al., 2022). More importantly, educators delivering design-based T&E instruction who completed comprehensive safety training (which consisted of a series of pre-service and in-service safety training experiences), were found to be 49% less likely to have an accident occur in their classes (Love, Roy, & Sirinides, 2023). There remains a lack of safety training provided by school districts and completed by educators despite occupational health and safety standards, legal safety standards, and better professional safety practices requiring educators to be trained before teaching potentially hazardous design-based T&E lessons (Love & Roy, 2022a).

Previous studies have also identified a number of other safety factors to be significantly correlated with accident occurrences. Of note, multiple studies have found accident occurrences to increase with rises in: the percentage of time doing hands-on activities, the percentage of students with disabilities in a course, and course preparations (Love, 2022a, Love & Roy, 2023; Love, Roy, & Sirinides, 2023). Furthermore, these studies also found accident occurrences to decrease when teachers had: appropriate PPE for all students in their classes, a dust collection system connected to equipment, lockable flammables and storage cabinets, the SawStop table saw safety feature, master shut off switches for utilities, and other protective safety factors (Love, 2022a, Love & Roy, 2023; Love, Roy, & Sirinides, 2023). Recognizing some of the safety differences in the mid-Atlantic region from Love and Roy's (2022a) study, Love (2022a) further explored these differences though statistical analyses. He found that a significantly greater number of accidents occurred in mid-Atlantic states, and equipment/machinery was involved in a significantly greater number of accidents in comparison to other regions of the U.S. Additionally, requiring safety tests before any lab activity, requiring students to tie back long hair/sleeves/loose jewelry, and completion of an undergraduate safety teaching methods course by the instructor were all found to reduce accident occurrences in the mid-Atlantic region but were not significant in the national study (Love, 2022a).

Rationale and Research Questions

It is evident from the review of recent studies examining STEM education related safety topics that there are still a number of safety deficiencies that need to be addressed. Previous studies (Love & Roy, 2022a; Love, Roy, & Sirinides, 2023) have called for the need to more closely examine safety issues by region to provide more intentional and applicable safety recommendations tailored to design-based T&E instruction occurring in STEM courses in different regions of the U.S. As described in the review of literature, Love and Roy's (2022a) national study displays noticeable safety differences between teachers in the New England and mid-Atlantic regions (northeastern U.S.) in comparison to the rest of the U.S. Given this observation, the purpose of this study was to further examine the extent of these differences. The following research questions (RQ) were developed to guide this study:

RQ1: To what extent do T&E related accident occurrences in K-12 STEM education courses differ between northeastern states and other regions of the U.S.?

RQ2: What safety factors are significantly associated with T&E related accident occurrences in northeastern K-12 STEM education courses?

RQ3: To what extent do T&E related safety training experiences differ among educators in northeastern states and those teaching in other regions of the U.S.?

RQ4: What influence does occupancy load and select safety training experiences have on T&E related accident occurrences in K-12 STEM education courses when controlling for significant safety factors?

Method

The research design employed in this study was a non-experimental, quantitative approach intended to explore the relationships between safety issues, accident occurrences, and training experiences associated with K-12 STEM education courses teaching design-based T&E concepts. The study analyzed a subset of the data collected by Love & Roy (2022a). A link to the Technology and Engineering Education - Facilities and Safety Survey (TEE-FASS) (Love & Roy, 2022b) was distributed by national and state K-12 science and T&E educator associations. This resulted in responses from 718 K-12 educators across 42 U.S. states who were teaching design-based T&E concepts. Among those 718 participants, this study analyzed the 191 who taught in the northeastern states (Connecticut, n = 34; Maine, n = 7; Massachusetts, n = 26; New Hampshire, n = 5; New Jersey, n = 28; New York, n = 22; Pennsylvania, n = 67; Rhode Island, n = 1; and Vermont, n = 1). This study utilized descriptive statistics to analyze participant demographics, number of accident occurrences, and accidents according to safety training experiences completed. Mann-Whitney U tests were used to compare the occurrence of accidents between

northeast states and the rest of the U.S. Polychoric correlational analyses were conducted to examine safety risk and protective factors from the TEE-FASS that were significantly associated with accident occurrences. Next, z tests for two independent proportions were used to compare different forms of safety training completed by participants in the northeast and rest of the U.S. Lastly, a series of binary logistic regression models were utilized to examine the influence that safety risk and protective factors had on the odds of an accident occurring.

Instrumentation

The TEE-FASS includes of series of demographic and Likert-scale questions to collect data pertaining to demographics, experience, teaching conditions, facility characteristics, safety training, safety practices, and accident occurrences. To make the instrument more user-friendly due to the large volume of questions, responses reflected ordinal and nominal data (Love, Roy, & Sirinides, 2023). This was also helpful because of the type of information that respondents had to recall (e.g., how many accidents occurred in their courses within the past five years). In this study the term accident referred to water or chemical spills, slipping/tripping, broken glass, excessive fumes, small fires, projectiles, or other accidents that occurred during K-12 design-based T&E instruction in STEM course activities that may or may not have required medical attention from a school nurse or doctor. Love, Roy, and Sirinides (2023) provide details about the reliability and validity of the TEE-FASS. The full instrument can be accessed from the URL provided in the 2022b Love and Roy reference.

Participants

Table 1 displays key demographic information about the full national sample and participants from the northeastern subsample. The northeastern sample, like the national sample, consisted of predominantly White males who taught design-based T&E concepts at the secondary level and had more than eight years of teaching experience. A greater percentage of northeastern participants received state certification to teach K-12 T&E education. Additional demographic information about the national sample and the northeastern participants (New England and middle Atlantic regions) can be found in Love and Roy (2022a).

Table 1

Participant Demographics

Characteristic	Regions		
	N. East n = 191	Other n = 527	Full U.S. n = 718
Gender			
Male	73%	74%	74%
Female	27%	26%	26%
Ethnicity			
White	95%	88%	90%
Bachelor's Degree Area			
T&E education	34%	26%	30%
A professional engineering field	9%	7%	7%
State K-12 T&E teaching certification	85%	75%	78%
Grade Level Taught			
6-8	30%	28%	29%
9-12	51%	56%	55%
6-12	11%	12%	11%
Years of P-12 teaching experience			
0-8 years	20%	33%	30%
9-25 years	55%	45%	48%
>26 years	25%	22%	23%

Note. T&E = technology and engineering education.

Results

Research Question 1

We first examined if there was a difference in the number of T&E related accidents that occurred in K-12 STEM courses within northeastern states compared to the rest of the U.S. over a five-year span beginning in 2015. Participants reported accident occurrences as ordinal responses (e.g., How many accidents occurred within the past five years? Response choices: 0, 1-5, 6-10, 11-15, or >15). Percentages provided in Table 2 help display the occurrence of accidents reported by northeastern educators in comparison to educators from other regions of the U.S. These descriptive statistics revealed that a greater percentage of participants in the northeast had 6-10, 11-15, and >15 accident occurrences over five years. This led us to investigate if the number of accident occurrences were significantly higher in northeastern states compared to other regions of the country.

Table 2

Accident Occurrences Over a Five-Year Span

Region(s)	n	Number of Accidents				
		0 (%)	1-5 (%)	6-10 (%)	11-15 (%)	>15 (%)
Northeast	191	11	43	20	17	9
Rest of U.S.	527	17	51	18	8	7

A Mann-Whitney U test was utilized to determine if there was a significant difference between the number of T&E related accidents occurring in STEM courses in northeastern states versus other regions of the U.S. This test was deemed best suited for analyzing the data due to the ordinal (accident occurrence categories = 0-4) and nominal (binary northeastern state or rest of the U.S.) nature of the data. The Mann-Whitney U test analyzes the mean difference in rank of responses between two independent groups (Sheskin, 2011). The analyses indicated that the difference in reported accidents between the northeastern STEM educators and the other regions of the U.S. was significant at the $p < 0.001$ level (Table 3). From this analysis it was discovered that northeastern STEM educators reported having a significantly greater number of T&E related accidents than other regions during a five-year span (Table 3).

Table 3

Mann-Whitney U tests for Accident Occurrences Over a Five-Year Span

Region (s)	n	*Mdn*	*M* Rank	U	z	*p*
Northeast	191	1	404.20	41790.50	-3.721	< 0.001*
Rest of U.S.	527	1	343.30			

Note. * = $p < 0.05$

Research Question 2

Following the examination of differences among T&E related accident occurrences according to region, the second research question investigated what safety factors were significantly associated with T&E related accident occurrences in northeastern STEM education courses. Similar to Love, Roy, and Sirinides (2023), an exploratory correlational analysis was implemented. These correlational analyses estimated the independent associations of various safety factors from the TEE-FASS with the occurrence of accidents over a five-year span. Associations were estimated as polychoric correlation coefficients, which

are an alternative to the Pearson *r* used when variables represent a continuous measure. However, since the data were organized in an ordinal manner (i.e., accident occurrence categories) it was determined that polychoric correlation analyses were most appropriate (Rigdon & Feguson, 1991). For each safety factor the p-value for the likelihood ratio test was reported along with the polychoric correlation coefficient (Tables 4 and 5). These analyses indicated the direction of the correlations, where 12 risk factors were found to have a positive correlation with T&E related accident occurrences, of which 10 were statistically significant at the $p < 0.05$ level (Table 4).

Table 4

Polychoric Correlations of Risk Factors Associated with Accident Occurrences Over a Five-Year Span in Northeastern U. S. STEM Courses

Risk Factors	Accident Occurrences	
	ρ	*p*
Course Characteristics		
>60% of class time doing hands-on activities^	0.32	***
Course enrollment >24^	0.31	**
Course with increased hazards#	0.25	*
>15% of students in courses taught have a disability	0.10	
>3 course preps	0.02	
Facility Characteristics		
Facility included a lab area	0.56	***
Separate finishing room^	0.34	**
Room square footage	0.29	**
Sink in lab area^^	0.20	*
Lab Practices		
Table saw used in lab	0.41	***
Welding activities conducted in lab^	0.23	*
Circuit breakers tripped	0.22	*

Note. # = Courses classified with increased hazards Love, Roy, & Sirinides (2023), ^ = Significant factor in this study but not in national study, ^^ = Risk factor in this study but protective factor in national study (Love, Roy, & Sirinides, 2023), *** = $p < 0.0001$, ** = $p < 0.01$, * = $p < 0.05$.

Additionally, 18 protective factors had a negative correlation with T&E related accident occurrences; however, only two of those protective factors were statistically significant at the $p < 0.05$ level. Four of the 18 protective factors were marginally significant at the $p < 0.10$ level (Table 5).

Table 5

Polychoric Correlations of Protective Factors Associated with Accident Occurrences Over a Five-Year Span in Northeastern U. S. STEM Courses

Protective Factors	Accident Occurrences	
	ρ	*P*
Coursework/Preparation		
Graduate certificate in an engineering field^	-0.52	~
Graduate certificate in STEM education^	-0.20	~
Graduate certificate in T&E education	-0.15	
Content Included in Safety Training		
First-aid procedures^	-0.41	**
Hazard communication plan requirements^	-0.30	*
Safer classroom management strategies^	-0.28	~
Safety data sheets (SDS)	-0.15	
Reading GHS chemical labels	-0.14	
OSHA requirements	-0.13	
School District Policies and Practices		
District was involved in lab accident litigation within the past five years^	-0.18	~
District restocks first-aid kits in labs each semester	-0.15	
District has a written PPE policy	-0.09	
District conducts annual chemical inventory for labs	-0.07	
District has a written safety policy	-0.04	
Facilities Characteristics		
Phone within 25 feet of lab area	-0.16	
Workspace ≥ 6 sq. ft. per student	-0.12	
Wheelchair accessibility	-0.11	
Lab Practices		
Appropriate welding face protection for all students in the lab area	-0.18	

Note. ^ = Significant factor in this study but not in national analyses (Love, Roy, & Sirinides, 2023). ** = $p < 0.01$, * = $p < 0.05$, ~ = $p < 0.10$.

These correlation coefficients revealed that as a risk factor was present (e.g., a binary variable of 0 indicated their students spent < 60% of their class time engaged in hands-on laboratory activities, whereas a 1 indicated >60% of class time involved hands-on laboratory activities) or as a risk factor increased (e.g., ordinal responses about the net square footage in their facility), the number of reported T&E related accidents also increased. Protective factors indicated that as a safety factor was present or increased, the number of reported T&E related accidents decreased.

Research Question 3

After identifying the risk and protective factors associated with T&E related accident occurrences in northeastern K-12 STEM courses, it was important to then examine the differences in safety training experiences completed by educators in northeastern states compared to those in other regions of the U.S. As highlighted in the literature review, previous studies have found certain safety training experiences can often reduce the odds of a T&E related accident occurring (Love, Roy, & Sirinides, 2023). Table 6 is provided to demonstrate the percentage of participants who did not report any T&E related accident occurrences within a five-year span according to different safety training experiences completed. Compared to educators from other regions, the northeast had a higher percentage of T&E related accident occurrences for each safety training category. This prompted us to question if these training experiences had a significant influence on the odds of a T&E related accident occurring like previous studies discovered (Love, Roy, & Sirinides, 2023).

Table 6

No Accident Occurrences Over a Five-Year Span According to Safety Training Experiences Completed

		Safety Training					
Region(s)	n	UG (%)	G (%)	DI (%)	UD (%)	UO (%)	Comp (%)
Northeast	191	7	13	15	13	5	15
Rest of U.S.	527	15	20	18	17	14	21

Note. UG = undergraduate course(s), G = graduate course(s), DI = school district initial safety training, UD = Update training(s) from school district, UO = Update training(s) from outside source, Comp = comprehensive safety training as defined by Love, Roy, and Sirinides (2023).

Before exploring the potential influence of safety training, we wanted to determine if there were T&E related safety training experiences more prevalent in the northeast than other regions of the country. To examine this, z tests for two independent proportions were used to determine if the proportion of northeastern educators who completed each T&E related safety training experience was significantly different than the proportion of educators from the rest of the country who completed that same experience. The z test for two independent proportions was deemed appropriate for this analysis given the nominal nature of the data (completed or did not complete the training) and

large sample size (Sheskin, 2011). The z tests for two independent proportions revealed that a significantly greater proportion of educators in the northeast completed T&E related safety training during their undergraduate coursework (Table 7). However, a significantly greater proportion of educators from other regions of the U.S. completed T&E related safety training from their district when initially hired, received safety updates from their school district within the past five years, and had a comprehensive safety training experience as defined by Love, Roy, and Sirinides (2023).

Table 7

Z tests for Two Independent Proportions Regarding Forms of Safety Training Completed

	Northeast		Rest of U.S.			
Training Source	n	%	n	%	z	*P*
Undergraduate Safety Training	151	79	331	63	-4.096	< 0.001*
Graduate Safety Training	70	37	187	36	-0.288	0.773
District Initial Safety Training	27	14	203	39	6.187	< 0.001*
Safety Updates from School District within 5 years	80	42	319	61	4.443	< 0.001*
Safety Updates from Outside Source within 5 years	40	21	92	18	-1.065	0.287
Comprehensive Safety Training	26	14	148	28	3.999	< 0.001*

Note. Northeast n = 191, Rest of U.S. n = 527, * = $p < 0.05$.

Research Question 4

After identifying risk and protective factors significantly associated with T&E related accident occurrences and prevalent safety training experiences for northeastern STEM educators, a series of binary logistic regression analyses were conducted to examine what influence these safety factors had on the odds of an accident occurring. The dependent variable was whether an accident occurred (1) or did not occur (0) within the past five years. Among the northeast educators, 89% reported the occurrence of one or more T&E related accidents within their STEM courses over the past five years. Table 8 presents the logistic regression results as model estimates which can be converted to odds ratios as the inverse natural log (i.e., negative estimates are associated with lower odds of

an accident occurring while positive estimates are associated with increased odds of an accident occurring). Table 8 reports the *p* values for the Hosmer-Lemeshow goodness-of-fit tests which indicated each model was a good fit for predicting the occurrence of an accident. Additionally, while all model coefficients in Table 8 were significant at the $p < 0.05$ threshold, Model III demonstrated the lowest *p* value at < 0.001. This indicates the inclusion of the covariates and predictors increased the accuracy of the model in regard to predicting an accident occurrence.

Model I included risk and protective factors found to be significantly associated with accident occurrences from the polychoric correlation analyses in RQ2 and the literature (Love, Roy, & Sirinides, 2023). This model only included the risk and protective safety factor covariates, and had an estimated effect that courses with increased hazards ($\beta = 1.286$, $p = 0.017$, $OR = 3.617$) and a lab in or connected to the facility ($\beta = 1.660$, $p = 0.005$, $OR = 5.261$) were significant among the northeastern sample. We then added the covariate of occupancy load above 24 students in Model II based on the literature and findings from RQ2 that suggested occupancy loads are associated with increased accident occurrences in STEM courses. While the occupancy load covariate was not a significant predictor in Model II, when this covariate was added to the model the estimated effect of courses with increased hazards and a lab in or connected to the facility slightly decreased. Lastly, in Model III we added two safety training experiences found to be significant from RQ2 and the literature as predictors (safety training in undergraduate coursework and school district training on safer classroom management strategies within the past five years).

The intent of Model III was to see if the magnitude or precision of the covariates in the model changed with the inclusion of these safety training predictors. Model III indicates that receiving safety training during undergraduate coursework ($\beta = -1.746$, $p = 0.003$, $OR = 0.175$) reduced the estimated effect of having a lab in or connected to the facility ($\beta = 1.386$, $p = 0.029$, $OR = 3.997$). These safety training predictors also helped the model yield a higher Nagelkerke R square value (30.3%) in comparison to Models I (20.8%) and II (22%). This indicates that the safety training predictors increased the variability in accident occurrences explained by the covariates in the model. Furthermore, the area under the Receiver Operating Characteristic (ROC) curve was calculated for each model. The area under the ROC curve provides a measure of the model's ability to discriminate between those subjects who had an accident occurrence versus those who did not (Hosmer et al., 2013). Model I yielded acceptable (0.784) discrimination as did Model II (0.791), and Model III yielded excellent discrimination (0.821) (Hosmer et al., 2013). The increase in the area under the ROC curve values from Models I to III suggest that the inclusion of predictors such as occupancy load and safety training helped to improve the model's ability to predict the probability of an accident occurrence.

The findings from the models presented in Table 8 indicate that although safety training during an educators' undergraduate coursework is among one of many factors associated with the occurrence of accidents, it is an important safety factor to reduce the odds of a T&E related accident when also controlling for various risk and protective factors. Overall, the analyses revealed that after controlling for relevant risk and protective factors, teachers who received some form of safety training during their undergraduate coursework had an 83% reduction in the odds of a T&E related accident occurring within the STEM courses they taught.

Table 8

Multiple Logistic Regression Results

	Model I		Model II		Model III	
	χ^2	*p*	χ^2	*p*	χ^2	*p*
Hosmer-Lemeshow	8.879	0.353	4.594	0.800	6.577	0.583
Model Coefficient	20.983	0.007**	22.270	0.008**	31.330	< 0.001***
Area under ROC curve	0.784		0.791		0.821	
Nagelkerke R^2	0.208		0.220		0.303	
Safety Factors	β	*p*	β	*p*	β	*p*
Course with increased hazards	1.286	*	1.263	*	1.504	*
Lab in/connected to facility[#]	1.660	**	1.638	**	1.386	*
>3 course preps	0.579		0.650		0.628	
>60% of class time doing hands-on activities	0.092		0.070		0.226	
>1 Students With Disabilities	-0.055		-0.023		0.036	
Student workspace	-0.475		-0.345		-0.142	
District-wide Personal Protective Equipment policy	-0.515		-0.574		-0.772	
Occupancy load >24			0.657		0.575	
Training Factors						
Graduate Cert. (T&E Ed, STEM Ed, or Engrg. Field)	-0.957		-1.062		-1.098	
Safety training in undergrad coursework					-1.746	**
School district training on safer classroom Mgmt.					-0.673	

Note. Statistical associations calculated as logistic regressions in full analytic sample (n = 191). *** = $p < .0001$, ** = $p < 0.01$, * = $p < 0.05$. # = Type of facility with some form of lab/makerspace area; T&E = Technology and engineering.

Discussion

Although this study provides several important implications for improving T&E safety in K-12 STEM education, there are some limitations. This study included a high percentage of white and male participants; however, this aligns with national demographic findings from other studies involving T&E educators (Williams & Ernst, 2022). The results reflect voluntarily self-reported responses from educators in one region of the U.S. It is unknown if participants had increased interest in participating in this study due to their own safety experiences they felt compelled to share. The results may not be generalizable to every STEM teacher, program, facility, or state providing design-based T&E instruction. Additionally, caution must be exercised when interpreting the results as the correlational analyses indicate a relationship exists between the specified safety factors and accident occurrences, but this does not indicate causation.

The analyses indicated that there were an increased number of T&E related accident occurrences in northeastern U.S. K-12 STEM courses. Some of the safety factors that emerged as significant in this study mirrored similar findings to the national results from Love, Roy, and Sirinides (2023). In both this study and the national study, course enrollments greater than 24 students, percentage of students with a disability in a course, number of course preps, courses with increased hazards, and table saw usage were found to be significantly associated with T&E related accident occurrences. Love and Roy (2022a) and Love, Roy, and Sirinides (2023) discuss in detail the criteria specified by the *NFPA 101 Life Safety Code* and how educators can work with their school system to legally address hazardous overcrowding issues. Better professional safety practices also inform class size stipulations for safer STEM teaching and learning experiences. Additionally, the aforementioned studies provide detailed descriptions of working with the school special education department to get the required support to keep all occupants safer as required by federal and state occupational health and safety standards. As described by Love, Roy, and Sirinides (2023), occupancy load, percentage of students with a disability in a STEM course, and course preps are all concerns that have been found to be an issue in past studies. The findings from this study indicate they are still issues and need to be adequately addressed because of their association with increased T&E related accident occurrences. Some safety factors associated with T&E related accidents that were unique to the northeastern sample included facilities that had a separate finishing room, conducting welding activities, graduate certificates in engineering or STEM education, and training on first-aid procedures and safer classroom management strategies. These findings provide implications to better focus safety practices and training efforts in northeastern states to address these specific issues that were found to have a significant influence on the chance of an accident occurring. This is not to say other safety factors should be ignored as many of them are required by federal or state occupational and health standards.

Rather, the significant factors may provide a good starting point for school districts and teacher preparation institutions to focus on to have the greatest immediate impact.

The data indicates that a greater proportion of STEM teachers in the northeastern region completed a course during their undergraduate studies that covered safer T&E teaching methods. This study did not analyze if this was related to the percentage of participants who completed a traditional T&E teacher preparation program or if it was related to the percentage of alternatively licensed educators in the northeast region. Those may have been confounding variables that influenced the findings on safety training source. Teacher preparation programs and state education departments in regions outside of the northeastern U.S. should examine if there is a lack of safety training occurring in undergraduate T&E and STEM teacher education related coursework in their state. Furthermore, a lower proportion of educators in the northeastern U.S. had received T&E related safety training from their school district upon their initial hire, safety update training(s) from their school district within the past five years, and a comprehensive safety training experience. This lack of T&E related safety training reflects similar findings from decades of K-12 STEM education safety research (Love et al., 2022; Love, Roy, & Sirinides, 2023). This is extremely alarming given comprehensive safety training experiences have been found to reduce the odds of a T&E related accident by 49%! As Love and Roy (2022a) and Love, Roy, and Sirinides (2023) described, federal and state occupational safety and health standards (along with legal standards and better professional practices) require employers (school districts) to provide safety training to employees (educators). Safety training should be occurring at all three phases: in one's teacher preparation or certification coursework, upon initial hiring by a school district, and annual safety updates. In not providing these trainings, school districts could potentially be deemed negligent, if not reckless (Love & Roy, 2022a).

The important influence of significant safety factors from the literature and this study was evident in the logistic regressions. As the analyses demonstrated, occupancy load had an impact on the occurrence of T&E related accidents when other safety factors were considered. Most notably, when safety training factors were added to the model, not only did the effect of occupancy load decrease, but the model's ability to predict the probability of an accident increased. This demonstrates the complexity of research on K-12 STEM laboratory safety topics, especially when trying to isolate or address specific factors to improve safety. As other variables are added, the predictability of the models will change. The factors included in the models in this study suggest that when considering these various safety issues and factors, safety training can help reduce the effect of some risk factors (e.g., course preps) and increase the effect of some protective factors (e.g., district-wide PPE policy).

Conclusions and Implications

This study was conducted to investigate differences in safety factors reported by K-12 educators providing hands-on, design-based T&E instruction within STEM courses in the northeastern U.S. compared to educators in other regions. From this study emerged a number of critical findings. The northeast region of the U.S. had significantly more accidents than educators in the rest of the U.S. Ten safety risk factors and two safety protective factors were found to be significantly correlated with accident occurrences. Consistent with previous literature, it was discovered that as occupancy load exceeded 24 students per instructor, accident occurrences significantly increased. Training on first-aid procedures and hazard communication plan requirements were associated with significantly lower accident occurrences. Compared to the rest of the U.S., a greater proportion of northeastern educators received safety training in their undergraduate studies; however, a lower proportion received initial safety training and safety updates from their school district. The series of logistic regression models revealed that when accounting for prevalent safety risk factors, receiving safety training during undergraduate coursework reduced the odds of an accident occurrence by 83%. Some findings reiterated concerns that have been raised in the STEM education literature for over two decades and continue to persist (e.g., occupancy load), indicating the need for studies like this to provide data that supports educators' and school districts' requests for additional resources and policy changes. This study also contributes some unique findings to the K-12 STEM education safety literature. The safety factors that were not significant in the national analysis but significant in this study provide implications for educators and school systems in the northeastern U.S. to more closely examine these issues in their schools to make hands-on, design-based T&E teaching and learning safer.

This study also has broader implications. Given the influence of undergraduate safety training and training on safer classroom management strategies, state education departments, teacher preparation programs, and school districts should work to provide and require these types of training experiences for any educator teaching hands-on T&E lessons. This would be applicable to out of content teachers tasked with teaching T&E concepts (e.g., science educators teaching engineering activities involving power tools). This would also legally benefit a school district in the event of an accident. School districts have a legal obligation to follow federal or state occupancy load requirements and better professional safety practices. Schools would be wise to address overcrowding issues as this study and the literature presents evidence that overcrowding significantly increases the odds of an accident. It would also be wise of school districts to address the other significant safety factors from this study and the literature (Love, 2022a; Love & Roy, 2023; Love, Roy, &

Sirinides, 2023) in a good faith attempt to decrease the odds of an accident. Making these changes can model safer practices to students who will transfer their safety habits into post-secondary programs and the workplace. Addressing the safety issues highlighted in this study must occur through collaborative efforts between teacher preparation programs, state education departments, school districts, administrators, and educators. Given the unique safety factors found to be significant in the northeast region, additional analyses focused on significant safety factors in other regions of the U.S. are warranted. Further research is also needed to examine potential changes in accident occurrences as stakeholders address these factors.

Ethics approval

This research was approved by the Office for Research Protections at The Pennsylvania State University.

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