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Safety Factors and Accidents in P-12 Pre-Engineering and Engineering Design Courses: Results from a National Study (Fundamental)

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Abstract

Developing and constructing solutions for engineering design challenges can pose inherent legal and ethical safety responsibilities that school systems and educators cannot ignore. While safety concepts are emphasized throughout P-12 engineering education standards [1,2], studies have documented a continued lack of safety in regard to awareness, training, supervision, practices, facility characteristics, inspections, and engineering controls [3,4]. For example, national studies in 2002 and 2022 found that only 81% and 83% of educators respectively had the appropriate eye protection for all students engaged in science and engineering activities in their courses [4]. Furthermore, a national study published in 2022 by the International Technology and Engineering Educators Association (ITEEA) in collaboration with the American Society for Engineering Education (ASEE) and the National Science Education Leadership Association (NSELA), discovered a number of alarming safety deficiencies among P-12 programs and educators providing engineering instruction in the United States (U.S.) [3]. Further analyses found that teachers who had completed comprehensive safety training experiences were 49% less likely to have had an accident occur in their courses [5]. However, of greater concern are the broader impacts of safety deficiencies modeled for students in P-12 since research suggests that students often implement these safety habits in post-secondary programs and the workplace.

Utilizing data from a national safety research project involving 718 P-12 educators from 42 states in the U.S. [3], this study examined results from a subsample of 381 educators who specifically reported teaching pre-engineering or engineering design (PE/ED) focused courses. The goals of this study were to examine how PE/ED courses differed in terms of accident occurrences in comparison to other P-12 engineering courses (manufacturing, etc.), and what safety issues were significantly associated with accident occurrences in PE/ED courses. Analyses revealed that educators teaching P-12 PE/ED courses reported a significantly lower rate of major accident occurrences during a five year span in comparison to educators teaching other types of engineering courses. Numerous safety issues were found to be significantly associated with accident occurrences in P-12 PE/ED courses. Additionally, PE/ED courses were found to have significantly more accidents involving hot glue guns, but significantly fewer accidents involving equipment and machinery.

This study contributes to the limited research on safety in P-12 engineering education by identifying safety issues that are linked to accident occurrences. This research not only has implications for improving the health and safety of P-12 engineering education students and educators, it can also help reduce exposure to potential safety hazards and resulting risks. In addition, it can save schools money resulting from potential legal safety issues involving students and/or teacher accidents. Furthermore, this research can help post-secondary engineering education programs and industry partners focus their safety efforts on areas where the data indicates incoming students and young workers will need the most support. Post-secondary engineering education programs, P-12 engineering education programs, and industry partners should collaborate to address the critical safety gaps identified in this study. Addressing these gaps can help develop greater safety awareness and safer habits among prospective engineers and our future workforce.

Introduction

Safety is an ethical and legal responsibility that engineers must consider during all design, manufacturing, and testing decisions. The critical role that safety plays among all engineering disciplines illustrates why it is essential for P-12 engineering educators to develop students' safety knowledge, understanding, and practices prior to their transition into post-secondary engineering programs and engineering careers. Research has shown that the safety skills students learn in their P-12 courses are often emulated at home and in the workplace [6]. This further demonstrates why it is important to help P-12 students develop safer engineering knowledge and practices, especially when examining data on the safety of young workers. The National Institute for Occupational Safety and Health (NIOSH) found that the rate of work-related injuries among workers under the age of 24 was 1.5 times greater than that of older age groups [7]. As educators prepare students to enter post-secondary engineering programs and engineering careers, they should prioritize safety in P-12 engineering curricula and instruction.

Despite the prevalence of accidents among young workers, safety has long been a component of manual arts, industrial arts, technology education, and science education curricula and instruction, which served as the foundation for current P-12 engineering education programs [1,8]. However, studies have shown that limited progress has been made toward addressing key safety issues in P-12 science, technology, and engineering education [4]. Therefore, this study was conducted to gain more insight about safety issues that are most prevalent in P-12 engineering education programs, specifically related to pre-engineering and engineering design (PE/ED) focused courses. The overarching goal of this study was to enhance the safety awareness, understanding, and efforts of those involved with P-12 engineering teaching and learning, providing implications for potentially improving student safety practices as they enter post-secondary engineering programs and the workplace.

Background

In 2014, the inclusion of engineering content and practices at the same substantive level as scientific inquiry in the *Next Generation Science Standards* (NGSS) [9-11] raised concerns from engineering educators [12-14]. Concerns reflected the limited preparation that engineering educators believed many P-12 science educators had to teach engineering concepts in great depth [12-16]. The NGSS also prompted concerns from both P-12 science and engineering educators regarding increased potential safety hazards and resulting risks that science educators would need to be prepared to address when tasked with delivering hands-on, design-based engineering instruction [1,4,5,11,14,17]. Moreover, the NGSS was criticized for its limited focus on key safety concepts related to science and engineering [1,11].

Six years after the release of the NGSS, the *Standards for Technological and Engineering Literacy* (STEL) [2] were published. The STEL placed a strong emphasis on engineering safety concepts across the standards, practices, and context areas [1]. Unlike many science teacher preparation programs, the literature indicates that P-12 engineering teacher preparation programs often require coursework addressing safety topics directly related to engineering education facilities and pedagogy [12,18-20]. Additionally, students in P-12 engineering teacher preparation programs frequently are introduced to engineering safety practices during their core engineering and technical courses [3,5,18,19]. However, due to the critical shortage of P-12 engineering educators across the United States (U.S.), there has been an increasing number of teachers hired to teach P-12 engineering education through alternative licensure routes [21-22]. This has also raised concerns as alternative licensure does not always require the completion of safety coursework like traditional P-12 engineering teacher preparation programs [4,19]. Additionally, this poses some potentially serious legal and safety concerns for the students, educator, school administrators, and school system [4].

Prior research on P-12 engineering education safety

Findings from previous P-12 engineering education related safety studies indicate there have been some concerning safety issues that need addressed and further investigated to make P-12 engineering teaching and learning safer [3-4]. One study that compared results from previous P-12 science and engineering education studies found very little improvement in national and state safety findings reported from 2002 to 2022 [4]. Moreover, a national P-12 engineering education safety study published in 2022 by the International Technology and Engineering Educators Association (ITEEA), in collaboration with the American Society for Engineering Education (ASEE) and the National Science Education Leadership Association (NSELA), offered an extensive overview of the status of safety in P-12 engineering education programs across the U.S. [3]. This study included 718 educators from 42 states who were teaching a broad spectrum of P-12 engineering related courses (see Love et al. [5, p. 5] for the full list of courses). This study found there was a major lack of personal protective equipment (PPE) policies among school systems, annual safety audits conducted by school systems, readily accessible safety data sheets (SDS), signed safety acknowledgement forms, non-skid strips and/or rubber matting near potentially hazardous equipment, and fully stocked first aid kits [3,6]. Furthermore, respondents reported that hot glue guns were the tool/machine/item most frequently involved in a safety incident, followed by power equipment or machinery, and hand or portable power tools respectively. Statistical analyses of this national sample found 17 protective items (e.g., ANSI/ISEA Z87.1 D3 rated safety glasses with side shields available for every student enrolled in their courses) and eight risk items (e.g., number of course preparations per semester) to be significantly correlated with accidents that occurred in the P-12 engineering related courses that participants' taught [5]. Moreover, it was discovered that among the 718 participants teaching P-12 engineering related classes, those with enrollments exceeding 24 students per class were 48% more likely to have had an accident. Additionally, participants who had reported completing comprehensive safety training were 49% less likely to have had an accident occur in the P-12 engineering related courses they taught [5].

Follow up studies that analyzed subsamples of Love et al.'s national data set [3,5] revealed similar safety deficiencies and safety items correlated with accidents according to individual states [23-25] and regions [3,26]. One of those studies found that in comparison to other regions of the U.S., equipment/machinery was involved in a significantly greater number of accidents in middle Atlantic (mid-Atlantic) P-12 engineering education courses. That study also found that manufacturing and construction focused classes taught by mid-Atlantic P-12 engineering educators had a significantly higher rate of accidents than the same course taught in other U.S. regions. However, there was no significant difference in the number of accidents that occurred in engineering design focused courses when comparing the mid-Atlantic region to the rest of the

U.S. [26]. These studies contributed valuable findings to the P-12 engineering education literature which was severely lacking empirical-based safety research to inform practices and recommendations [5,26]. Despite these contributions to the P-12 engineering education literature, none of these studies examined in detail how safety in PE/ED courses differed from other engineering related courses taught in P-12 education. This study aimed to address this gap to better inform the safety practices of educators teaching P-12 PE/ED courses. As school systems look to integrate more engineering content and practices in their curricula to align with science and engineering standards [2,9] and prepare more technological and engineering literate citizens [2,14], safety must remain a top priority. An emphasis on safer engineering practices has implications for improving young worker safety, safety in the workplace, and the safety awareness of students entering higher education engineering programs [3,5,6,26].

Research questions

After reviewing the limited number of empirical studies published on safety in P-12 engineering education, the following research questions (RQ) were developed to address the identified gaps in this area of the P-12 engineering education literature, and specifically examine how safety in PE/ED courses differed from other courses taught by P-12 engineering educators.

RQ1: How does the occurrence of minor and major accidents in P-12 pre-engineering/engineering design (PE/ED) courses over a five-year span differ from other courses taught by P-12 engineering educators in the U.S.?

RQ2: What safety issues are significantly associated with accident occurrences in P-12 PE/ED courses in the U.S.?

RQ3: How do the items involved in accidents differ among P-12 PE/ED courses and other courses taught by P-12 engineering educators?

Methods

This study analyzed data collected by Love and Roy [3] using the Technology and Engineering Education - Facilities and Safety Survey (TEE-FASS). The TEE-FASS included a series of demographic and Likert-scale questions examining participant demographics, teaching and informal experiences, teaching conditions, facility characteristics, safety training experiences, safety habits and practices, and information related to accident occurrences. Due to the large volume of questions and the type of information teachers had to recall (e.g., how many accidents occurred in their courses within the past five years), most of the data was collected as nominal and ordinal data to make it more user-friendly. This study used the following definitions for minor and major accidents as described by Love et al. [5, p. 5]:

Minor accident - Encompasses water or chemical spills, slipping on dusty floors, broken glass, excessive fumes, small fires, projectiles, or other accidents during course activities that either resulted in no injuries or required minor medical attention such as Band-Aids, minor first aid, or a visit to the school nurse.

Major accident - Resulted in an injury during course activities that required major medical attention with a visit to a doctor or hospital (stitches, etc.).

National and state level P-12 engineering educator associations advertised the TEE-FASS survey link to educators across the U.S. Participation in the survey was open to any educator who was teaching P-12 engineering education courses. This resulted in 718 responses from P-12 engineering educators across 42 U.S. states. More information about the reliability and validity measures of the TEE-FASS are described by Love et al. [5], and the full instrument can be accessed from Love and Roy [3].

Participants

Table 1 displays some key demographic information according to those who indicated they were teaching PE/ED courses, who were teaching other engineering education courses, and the full national sample. The PE/ED sample was slightly less diverse in terms of gender, with a higher percentage of participants identifying as males. The full sample and subsamples were predominantly White. The PE/ED sample had a slightly higher percentage of participants who earned their bachelor's degree in a professional engineering field and possessed certification from their state department of education to teach P-12 technology and engineering courses. Furthermore, the PE/ED sample had a greater balance of middle school and high school level educators. The full sample and subsamples included many participants who had been teaching more than eight years.

Table 1

Participant Demographics

Characteristic	PE/ED n = 381	Other n = 337	National n=718
Gender			
Male	70%	79%	74%
Female	30%	21%	26%
Race			
White	89%	92%	90%
Hispanic/Latinx	1%	1%	1%
Black	6%	3%	5%
Asian American	1%	0%	1%
Multiracial	3%	4%	3%
Bachelor's Degree Area			
T&E education	29%	29%	28%
Professional engineering field	10%	5%	7%
State P-12 T&E teaching certification	80%	75%	78%

Note. PE/ED = Pre-engineering and engineering design courses; T&E = technology and engineering education.

Table 1 (continued)

Participant Demographics

Characteristic	PE/ED n = 381	Other n = 337	National n=718
Grade Level Taught			
6-8	39%	18%	29%
9-12	49%	61%	55%
6-12	9%	14%	11%
Years of P-12 teaching experience			
0-8 years	33%	25%	30%
9-25 years	45%	51%	48%
>26 years	21%	24%	23%

Note. PE/ED = Pre-engineering and engineering design courses.

As presented by Love et al. [5, p. 5], teachers from the national sample reported the following engineering related courses as their primary area of teaching responsibility (n): PE (117), ED (264), CAD/architectural design (42), electronics (57), power and energy (19), manufacturing (132), construction (20), biotechnology and science fields (13), elementary STEM (12), and a few other small areas. To determine what qualified as an engineering related course, the authors deferred to the classification of engineering education according to each participants' state department of education. Analyses have found that some states classify a broad range of courses, like those mentioned above, as engineering programs of study within their division of career and technical education (CTE) [3,5]. The broad spectrum of engineering courses reported by participating educators reflects the diverse nature of P-12 engineering education across the U.S. and aligns with the various engineering contexts that are highlighted in current P-12 engineering education standards [2,14]. Moreover, to aid educators in making the most appropriate selection between PE and ED courses, the TEE-FASS provided examples of potential PE (e.g., Project Lead the Way) and ED courses (e.g., Engineering byDesign). Additional demographic information pertaining to the national sample can be found in Love and Roy [3] and Love et al. [5].

Results

Research question 1

The first research question examined if there was a significant difference in the number of minor and major accidents that occurred over a five-year span in PE/ED courses compared to other P-12 engineering courses in the U.S. Participating educators reported accident occurrences as ordinal data (e.g., How many accidents occurred within the past five years? Response choices: 0, 1-5, 6-10, 11-15, or >15). Percentages are provided in Table 2 to help display the occurrence of minor and major accidents reported in PE/ED courses compared to other P-12 engineering education courses taught in the U.S. These descriptive statistics indicate the PE/ED courses had a higher percentage of minor accidents in the 1-5 occurrence range, but also a higher occurrence of no major accidents reported as well as a lower percentage of 1-5 major accident occurrences.

This led the researchers to question if there were significant differences between the occurrence of accidents in PE/ED courses and other P-12 engineering education courses.

Table 2

Accident Occurrences Over a Five-Year Span

Courses	Number of Accidents 0 (%)	1-5 (%)	6-10 (%)	11-15 (%)	>15 (%)
Minor Accidents					
PE/ED	14	52	19	9	6
Other	17	45	18	11	9
Major Accidents					
PE/ED	72	27	0.5	0	0
Other	64	36	0	0	0

Note. PE/ED = Pre-engineering and engineering design courses; PE/ED n = 381; Other n = 337

Next, the researchers conducted Mann-Whitney U tests to examine if there was a significant difference in the number of minor and major accidents that occurred over a five-year span within PE/ED courses compared to other P-12 engineering education courses. The Mann-Whitney U analysis was deemed appropriate to test for significant differences among two samples with ordinal (accident occurrence categories = 0-4) and nominal (binary PE/ED or other courses) data. This type of analysis tests for the mean difference in rank of responses between two independent groups [27]. These analyses revealed that while there was no significant difference between the two groups regarding minor accident occurrences, there was a significantly lower occurrence of major accidents in PE/ED courses compared to other P-12 engineering education courses during over the past five-years (Table 3).

Table 3

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

Courses	Median	Mean Rank	U	z	*p*
Minor Accidents					
PE/ED	1	364.56	62270.5	-1.114	0.265
Other	1	353.78			
Major Accidents					
PE/ED	0	345.94	59031.0	-2.319	0.020*
Other	0	374.83			

Note. PE/ED = Pre-engineering and engineering design courses; PE/ED n = 381; Other n = 337; * = $p < 0.05$

Research question 2

Following the examination of differences in minor and major accident occurrences according to courses taught, RQ2 investigated what safety issues were significantly associated with accidents that specifically occurred in P-12 PE/ED courses. Using methods applied in previous P-12 engineering education safety studies [5,24,26,28], exploratory correlational analyses were conducted to estimate the independent associations of various safety issues (reported in the TEE-FASS) with the occurrence of minor and major accidents over a five-year period. Associations were estimated as polychoric correlations, which is an alternative to the Pearson *r*. Polychoric correlation analyses are used when variables represent a continuous measure but the data is organized in an ordinal manner (i.e., accident occurrence categories) [29]. Table 4 reports the p-value for the likelihood ratio test along with the polychoric correlation coefficient for each safety issue. These analyses indicate the direction of the correlations, which are reported in Table 4 as safety risk issues (positive correlation) or protective safety issues (negative correlation). Six safety risk issues and three safety protective issues were found to be significantly associated with reported minor and/or major accident occurrences. These correlations indicate that as a potential safety hazard and resulting risk issue was present (e.g., a binary variable of zero indicating their average class enrollment was ≤ 24 or a variable of one indicating average enrollment was >24) or as a potential safety hazard and resulting safety risk issue increased (e.g., ordinal responses about the average percentage of students with disabilities (SWD) in their courses), the number of reported accidents also increased. Conversely, protective safety issues indicated that as a safety issue was present or increased, the number of reported accidents decreased. Due to the amount of safety issue questions included in the TEE-FASS, only those factors which were found to be statistically significant were reported in Table 4.

Table 4

Polychoric Correlations of Safety Issues Associated with Minor and Major Accident Occurrences Over a Five-Year Span in PE/ED Engineering Courses

Significant Safety Issues	Minor Accidents		Major Accidents	
	ρ	*p*	ρ	*p*
Risk Issues				
Independent student use of table saw[+]	0.37	***	0.32	***
Lab in/connected to facility	0.25	**	0.11	
Percentage of SWD per course	0.16	**	0.10	
Student access to storage area(s)^	0.14	*	0.19	**
Percentage of class time doing hands-on activities	0.22	*	0.24	~
Course enrollment >24	0.15	*	0.10	
Protective Issues				
Department has copies of all SDSs^	-0.25	***	-0.08	
School district policy for PPE^	-0.13	*	-0.05	
Housekeeping practices^	-0.08		-0.18	*

Note. ^ = Significant issue in this study but was not a significant issue in national analyses [5]; [+] = based only on the number of participants that reported having a table saw in their lab (n = 254). SWD = student with disabilities; SDSs = safety data sheets; PPE = personal protective equipment; *** = $p < 0.0001$; ** = $p < 0.01$; * = $p < 0.05$; ~ = $p < 0.10$.

Research question 3

The second research question investigated associations between safety issues and accident occurrences in P-12 PE/ED courses in the U.S.; however, it did not specifically examine the tools/items that were involved with accidents during the reported five-year span. The third research question examined this, determining if there was a significant difference between items involved with accidents in PE/ED courses compared to other P-12 engineering courses taught in the U.S. Once again Mann-Whitney U analyses were used due to the nominal (binary item involved or not involved, binary PE/ED or other courses.) nature of participants' responses. These tests revealed that hot glue guns were involved in significantly more accidents within PE/ED courses compared to other P-12 engineering education courses over the past five years. Furthermore, equipment/machinery (drill press, CNC, miter saw, belt/disc sander, etc.) were found to be significantly less involved in accidents that occurred in PE/ED courses in comparison to other P-12 engineering education courses (Table 5).

Table 5

Mann-Whitney U tests for Tools/Items Involved in Accidents over a Five-Year Span

Items and Courses	Involved n (%)	Median	Mean Rank	U	z	*p*
Hot Glue Guns						
PE/ED	191 (50)	1	404.47	47064.5	-7.363	<0.001*
Other	79 (23)	0	308.66			
Equipment/Machinery						
PE/ED	67 (18)	0	340.63	57009.5	-3.565	<0.001*
Other	97 (29)	0	380.83			
Hand/Power Tools						
PE/ED	80 (21)	0	360.38	63863.0	-0.172	0.863
Other	69 (21)	0	358.50			
Projectiles						
PE/ED	53 (14)	0	359.44	64175.5	-0.014	0.989
Other	47 (14)	0	359.57			
Spills or Splashes						
PE/ED	53 (14)	0	356.44	63032.5	-0.684	0.494
Other	53 (16)	0	362.96			
Fumes						
PE/ED	30 (8)	0	360.27	63906.0	-0.229	0.819
Other	25 (7)	0	358.63			
Broken Glass						
PE/ED	24 (6)	0	359.61	64155.0	-0.037	0.970
Other	21 (6)	0	359.37			

Note. Involved = number of participants who reported this item was involved in an accident; PE/ED = Pre-engineering and engineering design courses; PE/ED n = 381; Other n = 337, * = $p < 0.05$

Discussion

Despite the implications for improving safety in P-12 engineering education courses, this study does have some limitations that need to be acknowledged. Although there was a high percentage of white and male participants among the subsamples, this mirrors demographic findings from other recent national [30] and state level [31] P-12 engineering education studies. Moreover, in an attempt to make the TEE-FAS more user friendly, participants were prompted to report accident occurrences as ordinal data instead of continuous data. This required the use of polychoric correlation analyses which were also used in other P-12 engineering education safety studies [5,24,26,28]. While these analyses helped to identify potential safety hazards/resulting safety risks and protective items that were significantly associated with accident occurrences, previous studies suggest such results be interpreted with caution [5,26,28]. It is important to note that these correlational analyses do not suggest causation; however, they merely highlight a relationship exists between the specified safety issues and the occurrence of accidents.

Furthermore, the findings in this study were derived from voluntarily self-reported data. It is unknown if participating educators had an increased interest in being involved with this study because of safety issues they experienced and felt strongly about sharing. Reported accident data were dependent upon participants' recollection of accidents over the past five years. Previous studies have discussed limitations with self-reported safety and accident data [32-34]. Threeton and Walter [32] described limitations regarding the accuracy of safety data self-reported by educators as they found "close calls" often went unreported if no injury or damage occurred in CTE programs. Moreover, studies from industry have discovered inaccuracies in accident data self-reported by employees. Andersen and Mikkelsen [33] found that self-reported, one-year retrospective accident surveys completed by employees in industry only reflected 37% of the actual accident occurrences. The literature on accident reporting in the workplace indicates underreporting occurs at both the organizational-level and the individual-level for various reasons (e.g., negative publicity for the organization, fear of retaliation from the employer, etc.) [34]. This could also apply to educational settings, suggesting the number of accidents reported by educators (employees) may be underreported. Although the TEE-FAS survey did not collect identifying information, participants may have been hesitant to report their experiences related to accident occurrences. Future research should investigate the accuracy of accident reporting within the context of P-12 engineering education.

Accident occurrences in pre-engineering and engineering design courses (RQ1)

The first research question revealed there was no significant difference between PE/ED courses and other P-12 engineering courses in regard to the number of minor accidents that occurred in those courses. While this is encouraging to see, readers must be cautioned that this finding does not indicate that there are fewer potential safety hazards and resulting risks in PE/ED courses. This finding simply suggests that PE/ED courses were not found to have a significantly higher rate of minor accident occurrences. To this effect, it is suggested that readers also examine the findings from the national sample published by Love et al. [5]. These findings may be applicable to the broad array of engineering education courses taught across P-12.

Tools/items involved in accidents (RQ3)

Research question one also discovered that PE/ED courses in the U.S. had a significantly lower occurrence of major accidents when compared to other P-12 engineering courses. When thinking about the types of tools/equipment/items typically used in PE/ED courses compared to other P-12 engineering courses (e.g., manufacturing courses), one might hypothesize there would be a greater risk of accidents in the engineering courses outside of PE/ED because of the increased hazards associated with items like miter saws and other course related equipment. This poses some valuable considerations about the types of equipment used, frequency of use of that equipment, and the potential safety hazard and resulting level of risk of that equipment used in different P-12 engineering education courses. When examining RQ3 the number of accidents involving hot glue guns was significantly higher in PE/ED classes. In studies examining the national findings, hot glue guns were reported to be the most frequently involved item in a safety incident [3]. However, the number of accidents involving equipment or machinery was significantly higher in other P-12 engineering education courses than in PE/ED courses. This is similar to findings from a study examining the safety of mid-Atlantic P-12 engineering educators

[26]. One suggestion from Love's mid-Atlantic safety study [26] which may also apply here is educators teaching P-12 engineering courses may need additional training and support to emphasize safety related to equipment and machinery use. These findings may not be surprising given the nature and frequency of the activities conducted in PE/ED courses compared to the other engineering courses that may be more aligned with engineering technology fields. Further analyses are needed to more closely examine the characteristics related to the use of different equipment in PE/ED courses compared to other P-12 engineering education courses.

When looking at the other potentially hazardous items and resulting risks involved with accidents, there were no significant differences found. There could be a number of confounding variables that have an effect on these results, which requires further investigation. For example, it is not accurate to conclude from these findings that PE/ED courses may have fewer potential safety hazards/resulting risks or use much safer items. Hot glue guns can cause serious burns if not used correctly, just as hand and power tools can pose potentially different safety hazards and resulting risks if not used correctly. However, items like hot glue guns do have different safety operating procedures which may be easier to supervise in a class/lab full of students. What is unknown from this study is the influence that teacher safety training and safety practices might have had on helping to reduce potential risks in PE/ED courses compared to participants who taught other engineering courses. The demographics (Table 1) indicates that a greater percentage of PE/ED teachers held a bachelor's degree in a professional engineering field and were certified by their state to teach engineering education. Regardless of the potential safety hazards and resulting risks that are present, whether it be hot glue guns or table saws, research has demonstrated that teacher safety training and classroom/laboratory management practices (including safety demonstrations and direct supervision) are paramount to reducing the risk of accidents [5]. Readers must remember there will always be potential safety hazards and resulting risks associated with hands-on P-12 engineering teaching and learning, but data-informed actions can help to proactively decrease those risks [35].

Safety issues associated with accident occurrences (RQ2)

Research question two provided some very detailed and valuable insight about the specific safety issues that were found to be associated with accident occurrences in PE/ED courses. There were a number of significant safety items identified in this study which were also found to be significantly associated with accidents in previous studies [5,24,26,28]. The potential safety hazards and resulting risks associated with independent student table saw use, percentage of SWD, percentage of class time doing hands-on activities, and course enrollment size were all important and significant safety issues discussed in detail in previous national studies [3,5]. As described throughout the literature, the percentage of SWD and course enrollment have been longstanding concerns in hands-on engineering and science laboratory courses [3,5,6,26,28]. This study reiterates the critical importance of addressing high occupancy loads (as mandated by the *National Fire Protection Association* (NFPA) *101 Life Safety Code*) [3,5] in P-12 engineering courses and the assistance needed to help P-12 engineering educators legally meet the needs of all students' while maintaining a safer learning environment [3]. There were a few safety issues that were found to be significant in this study which were not significant in the national studies. Student access to storage areas was a significant potential safety hazard and resulting risk, and as described by Love and Roy [3] this can pose some serious legal ramifications. Additionally, copies of all SDSs retained by the department, a school district policy for PPE, and an educator's housekeeping practices were all found to be significantly associated with accident occurrences in PE/ED courses. Regarding SDSs, a copy should be kept on file for any hazardous materials or chemicals in the lab/room. A copy of all SDSs should be retained by the department, school nurse, district facilities/safety director, and local fire marshal [3]. There should be aligned PPE policies at the class, department, and district levels to maintain consistency in appropriate and required use of all PPE [3]. Lastly, housekeeping efforts are extremely important for numerous reasons. First, it is enforced by the *NFPA 101 Life Safety Code – Means Egress/Exits* to ensure all occupants can evacuate safely in the event of an accident. Second, it is a preventative safety measure enforced through OSHA's general industry housekeeping standard 1910.22, and can be used as documentation of an educator's safety habits in the event of a lawsuit [3]. While the polychoric correlation coefficients indicate which items had a stronger association with accident occurrences, it should be noted that all items in Table 4 present potential hazards which can be potentially reduced through appropriate engineering controls, better professional safety practices, and legal safety standards [3,5,26].

Conclusions

While this study focuses on safety pertaining to P-12 engineering education, specifically within PE/ED course contexts, it does provide implications for improving safety in post-secondary engineering education programs and the workforce. Knowing what specific safety risk and protective issues have a significant association with accident occurrences can help raise awareness about potential safety hazards that pose statistically higher resulting risks of accidents in PE/ED courses. This could consequently allow schools and universities to pay close attention to these issues when providing P-12 engineering education teaching and learning opportunities, potentially reducing the chance of accidents. Post-secondary engineering education programs and industry partners should consider utilizing these findings to develop safety training for incoming students or young workers and proactively address issues that the data has found to be areas of safety concern. This research has direct implications for P-12 engineering educators, administrators, school districts, school district safety officers, chemical hygiene officers, and engineering teacher preparation programs to help make P-12 engineering teaching and learning experiences safer. As instructors from various backgrounds and with various experiences are tasked with delivering engineering instruction, P-12 school systems would be wise to closely examine safety related to those issues and items that emerged as significant in this study. P-12 school systems, state departments of education, post-secondary education institutions, and industry partners should work collaboratively to prepare educators with the safety resources and training they need to provide a safer P-12 engineering teaching and learning experience for all students. In turn, this is an investment into the safety of post-secondary engineering education programs and the workforce as these students leave P-12 to pursue career and higher education opportunities.

Recommendations

While this paper reflects some similarities between the current study and previous P-12 engineering education safety studies, there might be some slight differences that are unique to the certain engineering courses which were not explicitly examined in this paper (e.g., manufacturing courses). There may also be some confounding variables which had an influence on the safety of educators teaching PE/ED courses compared to others (e.g., type of safety training received during one's undergraduate professional engineering coursework, teacher preparation program coursework). Additionally, differences in safety between the grade level educators taught (e.g., middle school versus high school) should be investigated as students are at different developmental stages and may face varying potential safety hazards and resulting risks. Further analyses examining these variables and how they affect accident occurrences in other P-12 engineering courses is warranted to better inform engineering education programs across the U.S. This study addressed part of a gap identified by Love et al. [5], calling for further research examining the types of safety issues and items that are significantly associated with accidents in specific engineering education courses (e.g., PE/ED courses). Additional research is still needed to examine how safety may differ from course to course and educator to educator. Post-secondary engineering educators conducting outreach work, engineering teacher preparation programs, state departments of education, occupational health and safety specialists, P-12 school systems, and P-12 engineering educators should consider the findings presented in this study to inform professional development efforts, safety training needs for instructors and students, and the support warranted for safer engineering instruction.

References

[1] T. S. Love, B. C. Duffy, M. L. Loesing, K. R. Roy, and S. S. West, "Safety in STEM education standards and frameworks: A comparative content analysis," *Technology and Engineering Teacher,* vol. 80, no. 3, pp. 34-38, 2020.

[2] *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. Reston, VA: International Technology and Engineering Educators Association (ITEEA), 2020. [E-book]. www.iteea.org/STEL.aspx

[3] T. S. Love and K. R. Roy, *Safer engineering and CTE instruction: A national STEM education imperative. What the data tells us.* Reston, VA: International Technology and Engineering Educators Association (ITEEA), 2022. [E-book]. https://www.iteea.org/SafetyReport.aspx

[4] T. S. Love, K. R. Roy, M. Gill, and M. Harrell, "Examining the influence that safety training format has on educators' perceptions of safer practices in makerspaces and integrated STEM labs," *Journal of Safety Research,* vol. 82, pp. 112-123, 2022. https://doi.org/10.1016/j.jsr.2022.05.003

[5] T. S. Love, K. R. Roy, and P. Sirinides, "A national safety study examining factors associated with STEM education and CTE accidents in the United States," *Safety Science*, vol. 160, no. 106058, pp. 1-13, 2023. https://doi.org/10.1016/j.ssci.2022.106058

[6] T. S. Love and K. R. Roy, "Critical safety considerations to support CTE," *Techniques,* vol. 98, no. 1, pp. 32-35, 2023.

[7] National Institute for Occupational Safety and Health (NIOSH), “Young worker safety and health,” https://www.cdc.gov/niosh/topics/youth/default.html [Accessed Feb. 2, 2023].

[8] T. S. Love, “Temporary concern or enduring practice? Examining the progress of safety in STEM education,” *Technology and Engineering Teacher*, vol. 78, no. 6, pp. 15-17, 2019.

[9] NGSS Lead States, *Next generation science standards: for states, by states*. National Academies Press, Washington, DC, 2013. https://doi.org/10.17226/18290

[10] T. S. Love, and A. Deck, “The ocean platform engineering design challenge: Flooded with STEM content and practices,” *Science Scope*, vol. 39, no. 3, pp. 33-40, 2015. https://doi.org/10.2505/4/ss15_039_03_33

[11] National Science Teaching Association, “Safety and the next generation science standards,” NSTA, Arlington, VA, 2020 [Online]. Available: https://static.nsta.org/pdfs/Safety%20and%20the%20Next%20Generation%20Science%20Standards_29Oct2020_FINAL.pdf

[12] T. S. Love, “The T&E in STEM: A collaborative effort,” *The Science Teacher*, vol. 86, no. 3, pp. 8-10, 2018. https://doi.org/10.2505/4/tst18_086_03_8

[13] M. E. Grubbs, T. S. Love, D. L. Long, and D. Kittrel, “Science educators teaching engineering design: An examination across science professional development sites,” *Journal of Education and Training Studies*, vol. 4, no. 11, pp. 163-178, 2016. https://doi.org/10.11114/jets.v4i11.1832

[14] P. A. Reed, K. Dooley, T. S. Love, and S. R. Bartholomew, “Overview of standards for technological and engineering literacy,” *Paper presented at the Annual Conference and Exposition of the American Society for Engineering Education, Minneapolis, MN*, 2022. https://peer.asee.org/41253

[15] T. S. Love, J. Cysyk, A. Attaluri, R. D. Tunks, K. Harter, and R. Sipos, “Examining science and technology/engineering educators’ views of teaching biomedical concepts through physical computing,” *Journal of Science Education and Technology*, vol. 32, pp. 96-110, 2023. https://doi.org/10.1007/s10956-022-09996-7

[16] T. S. Love, and A. J. Hughes, “Engineering pedagogical content knowledge: Examining correlations with formal and informal preparation experiences,” *International Journal of STEM Education*, vol. 9, no. 29, pp. 1-20, 2022. https://doi.org/10.1186/s40594-022-00345-z

[17] T. S. Love, “Perceptions of teaching safer engineering practices: Comparing the influence of professional development delivered by technology and engineering, and science educators,” *Science Educator*, vol. 26, no. 1, pp. 21-31, 2017.

[18] L. S. Litowitz, “A curricular analysis of undergraduate technology & engineering teacher preparation programs in the United States,” *Journal of Technology Education*, vol. 25, no. 2, pp. 73-84, 2014. https://doi.org/10.21061/jte.v25i2.a.5

[19] T. S. Love, “Examining the influence that professional development has on educators’ perceptions of integrated STEM safety in makerspaces,” *Journal of Science Education and Technology,* vol. 31, no. 3, pp. 289-302, 2022. https://doi.org/10.1007/s10956-022-09955-2

[20] P. A. Reed and M. K. Ferguson, “Safety training for career and content switchers,” *Technology and Engineering Teacher,* vol. 80, no. 7, pp. 16-19, 2021.

[21] T. S. Love, and Z. J. Love, “The teacher recruitment crisis: Examining influential recruitment factors from a United States technology and engineering teacher preparation program,” *International Journal of Technology and Design Education*, vol. 33, no. 1, pp. 105-121, 2023. https://doi.org/10.1007/s10798-022-09727-4

[22] T. S. Love, and T. Maiseroulle, “Are technology and engineering educator programs really declining? Reexamining the status and characteristics of programs in the United States,” *Journal of Technology Education,* vol. 33, no. 1, pp. 4-20, 2021. https://doi.org/10.21061/jte.v33i1.a.1

[23] International Technology and Engineering Educators Association, “Safer Engineering and CTE Instruction: A National STEM Education Imperative. State Reports,” [Online]. Available: https://www.iteea.org/SafetyReport.aspx. [Accessed Feb. 3, 2022].

[24] T. S. Love, K. R. Roy, and P. Sirinides, “What factors have the greatest impact on safety in Pennsylvania’s T&E courses?,” *Technology and Engineering Education Association of Pennsylvania Journal,* vol. 69, no. 1, pp. 5-22, 2021.

[25] T. S. Love, and K. R. Roy, “Key findings from Wisconsin’s responses to the 2020 national T&E education safety survey,” *Interface: Journal of the Wisconsin Technology Education Association,* vol. 61, no. 1, pp. 22-23, 2021.

[26] T. S. Love, “Accident occurrences and safety issues reported by mid-Atlantic P-12 engineering education programs,” *Paper presented at the Annual Conference and Exposition of the American Society for Engineering Education: Middle Atlantic Section, Harrisburg, PA*, 2022.

[27] D. J. Sheskin, *Handbook of parametric and nonparametric statistical procedures*, 5th ed. New York, NY: Chapman and Hall, 2011.

[28] T. S. Love, P. Sirinides, and K. R. Roy, “Examining factors associated with accidents in CTE and STEM education labs: A national safety study,” *Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA.* 2022. https://doi.org/10.3102/1888047

[29] E. E. Rigdon and C. E. Feguson, Jr., “The performance of the polychoric correlation coefficient and selected fitting functions in confirmatory factor analysis with ordinal data,” *Journal of Marketing Research*, vol. 28, no. 4, pp. 491-497, 1991.

[30] T. O. Williams and J. V. Ernst, “Technology and engineering education teacher characteristics: Analysis of a decade of institute of education sciences nationally representative data,” *Journal of STEM Education: Innovations and Research*, vol. 23, no. 4, pp. 16-21, 2022. https://jstem.org/jstem/index.php/JSTEM/article/view/2576

[31] T. S. Love, “Examining the demographics and preparation experiences of foundations of technology teachers,” *The Journal of Technology Studies*, vol. 41, no. 1, pp. 58-71, 2015. https://doi.org/10.21061/jots.v41i1.a.7

[32] M. D. Threeton and R. A. Walter, *Managing technical programs and facilities*. Oceanside, NY: Whittier Publications, Inc., 2013.

[33] L. P. Andersen and K. L. Mikkelsen, “Recall of occupational injuries: A comparison of questionnaire and diary data,” *Safety Science*, vol. 46, no. 2, pp. 255-260, 2008. https://doi.org/10.1016/j.ssci.2007.06.014

[34] T. M. Probst and M. Graso, "Pressure to produce=pressure to reduce accident reporting?" *Accident Analysis and Prevention*, vol. 59, pp. 580-587, 2013. https://doi.org/10.1016/j.aap.2013.07.020

[35] T. S. Love, “Addressing safety and liability in STEM education: A review of important legal issues and case law,” *The Journal of Technology Studies*, vol. 39, no. 2, pp. 28-41, 2013. https://doi.org/10.21061/jots.v39i1.a.3