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Development of safe design thinking among engineering students

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) Prevention through Design (PtD) initiative recognizes engineering education as a primary source to infuse safe design knowledge with the purpose of affecting change in the United States. In line with NIOSH objectives, we: (1) develop and implement a PtD education intervention with engineering students, and (2) measure the change in knowledge and comprehension of occupational health and safety principles from an engineering design perspective from students' first-year to fourth-year. The intervention is an addition to engineering curricula and was applied to a cohort of undergraduate engineering students evaluated as a one group pretest posttest design. Over the time from first-year to fourth-year, the engineering students' thinking developed and changed regarding their design responsibility, what causes accidents, how they can reduce risk, and in applying the concepts in case studies. There was a shift in thinking from safe people to safe place and recognition that the hierarchy of controls can be utilized by engineers. The results supplement NIOSH goals and contribute to the body of knowledge in safe design education.

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1. Background

In the United States, the National Institute for Occupational Safety and Health (NIOSH) Prevention through Design (PtD) initiative recognizes that "one of the best ways to prevent and control occupational injuries, illnesses, and fatalities is to 'design out' or minimize hazards and risks early in the design process" (NIOSH, 2011). The approach to implement the initiative is framed within four functional areas: research, practice, education, and policy (Schulte et al., 2008). Within secondary and graduate education, the disciplines of engineering, architecture, and business most frequently are identified as prime opportunities for PtD education (Mann, 2008). Intervention development has already begun; NIOSH has developed four PtD lecture modules: reinforced concrete design, mechanical and electrical systems design, structural steel design, and architectural design and construction (Heidel, 2011).

Cowley and Murray (1992) contended that as fewer engineers are entering the occupational health and safety (OHS) profession and the misconception that engineering controls are difficult prevails, the full potential of the OHS discipline in improving the standard of workplace safety and health cannot be realized. OHS problem solving and improvement follows a hierarchy of controls. The American National Standards Institute (ANSI) states that the hierarchy "provides a systematic way to determine the most effective method to reduce risk associated with a hazard" (ANSI, 2012, p. 15). The hierarchy of controls in ANSI Z10 (2012) has six solution categories. In order of preferred problem solving efficacy, they are Elimination; Substitution of less hazardous materials, processes, operations, or equipment; Engineering Controls; Warnings; Administrative Controls; and PPE. For engineers and design professionals the hierarchy has been described as the acronym ERIC; in order that is eliminate, reduce, inform, and control (CITB, 2007). Eliminating and reducing hazards and risks means active design changes, whereas informing means passing information onto the contractor/operations/maintenance teams about the residual risk where a design change was not reasonably practicable in the designer's professional judgement. Control of the residual risk is in the hands of other on-site duty holders (CITB, 2007).

An often referenced diagram in the safe design literature is from Szymberski (1997); he proposed that the ability to influence site safety is inversely proportional to a project's schedule. We have modified his graph by replacing the "ability to influence safety" with "ability to utilize higher order controls". See Fig. 1. In other words, the ability to effectively utilize the hierarchy of controls is greater the earlier in the project you attempt to solve occupational safety and health issues. Once the hazard is on the site or fixed within the work system, many times the only feasible solution is to implement lower order controls, such as warning, procedures, training, and PPE. The hazards are already there; we cannot eliminate them or reduce them due to their purpose, cost of retrofit, or

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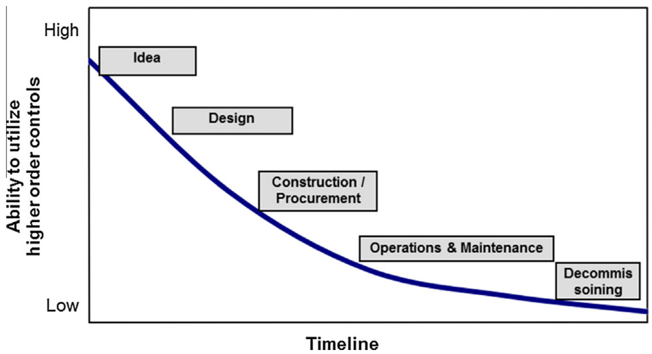

Fig. 1. Ability to utilize higher order controls (elimination, substitution, engineering) over time. Adapted from Szymberski (1997).

timing. Workers and safety professionals have little opportunity to utilize the higher order controls and be innovative. This is not to say workers and safety professionals are not innovative, and in fact quite the contrary, they are very creative and resilient to reduce risk within their sphere of influence. However, their sphere of influence is limited compared to other upstream entities, such as engineers and designers, who have a greater opportunity to eliminate and reduce hazards and risks.

Gambatese and Hinze (1999) recommend that one of the means by which engineers can become more responsive to the safety needs of workers is through education. Engineers must be made aware of the various means by which their design decisions impact the jobsite safety conditions for construction workers. The way a design professional thinks about safety will influence their decisions and philosophies about designing for safety. Culvenor (1996) describes this as a safe place or a safe people philosophy. A safe place philosophy focuses on the source of hazards and can be more easily implemented in the design and upstream phases. On the other hand, if the engineer believes in the safe people philosophy, then why bother evaluating it to eliminate or reduce when controls should be implemented at the site.

Safety and engineering are often tied together in higher education. For example, in Europe, engineering schools were found to be the most common place where OHS graduate courses and degrees were offered (Arezes and Swuste, 2011). This is not the case in the US. Although safety is considered as an important area of engineering instruction, particularly for practicing engineers, it is often not addressed adequately in a curriculum (Heidel, 2011; Noakes et al., 2011). There was a clear consensus in the education group of the 2007 NIOSH PtD workshop that PtD will be best introduced in educational curricula through modules, rather than in complete courses (Mann, 2008). The main reason given is that the US engineering curriculum is already full with courses and there is no additional room for another required course. Authors in the United Kingdom (HSE, 2009), and Australia (Culvenor and Else, 1997) found this to be the case as well. Davidson et al. (2010) observed that few engineering schools have made major updates to their courses and curricula over the past few decades.

Other engineering education authors have described efforts in system or process safety (Noakes et al., 2011; Louvar, 2009; Dahoe and Molkov, 2008). Our study is a look at occupational or personal worker safety. Reason (1997) distinguished between these types of safety; however, he notes the similarities in the preventive approach to both. The discipline of chemical engineering focuses on safety and inherent design. In chemical engineering, Brennan (2006) highlighted the need for operations knowledge to apply safe and inherent design for normal operations and how operators respond to unforeseen events. Noakes et al. (2011) described developing an animated software teaching module to teach a process safety technique to chemical engineering students. Saleh and Pendley (2012) highlight the importance of safety literacy and the contributions that engineering students can make in the long-term towards accident prevention. They describe a model for the structure and content of an introductory course on "system" accident causation noting the differences between system and occupational accidents (Saleh and Pendley, 2012). While previous archival literature describes the educational interventions or the recommended methods, there is no clear assessment. Educational interventions and their effectiveness in changing engineering student knowledge and perceptions with regards to OHS are lacking in the peer-reviewed archival literature. The focus on occupational health and safety and its evaluation are our points of departure for the research; they are also our contributions to the body of knowledge.

Specifically, NIOSH has a PtD Education Strategic Goal that, "Designers, engineers, machinery and equipment manufacturers, health and safety (H&S) professionals, business leaders, and workers understand PtD methods and apply this knowledge and skills to the design and re-design of new and existing facilities, processes, equipment, tools, and organization of work." (NIOSH, 2011, p. 24). Within that strategic goal NIOSH (2011, p. 25) also has a specific activity/output goal to "enlist the support of Deans of Engineering Schools to include basic PtD principles and occupational safety and health principles in required engineering courses".

2. Methodology

2.1. Research objective

The objectives of the research were to: (1) develop and implement a PtD education intervention with engineering students, and (2) measure the change in knowledge and comprehension of occupational health and safety principles from an engineering design perspective from students' first-year to fourth-year.

2.2. Instrument

We utilized a survey that asked the students about their perceived design responsibility, what causes accidents, what can be done to prevent or minimize accidents, and asked them to rank proposed solutions in four case studies. The survey utilized questions with a 5-point Likert scale (Strongly Disagree to Strongly Agree) and ranked answers; it has been utilized in previous research (Behm and Culvenor, 2011). The tables in the Results section reveal the questions. The University Institutional Review Board approved the survey for participants 18 years and older (#10-0047). Alternative hypotheses, along with the measurement and statistical analysis in parenthesis, are listed below. Data are treated as paired data for statistical analyses.

Ha1. There is a change in the perceived design responsibility among engineering students from their first-year to fourth-year (5-point Likert scale, Strongly Disagree [1] to Strongly Agree [5]; *t*-test).

Ha2. There is a change in the perception of what causes accidents at work among engineering students from their first-year to fourth-year (5-point Likert scale, Strongly Disagree [1] to Strongly Agree [5]; t-test).

Ha3. There is a change in the perception that accidents are preventable among engineering students from their first-year to fourth-year (1-Less than half; 2-Hardly any; 3-Half; 4-More than half; 5-Nearly all; t-test).

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