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Developing hazard recognition skill among the next-generation of construction professionals

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ABSTRACT

Globally, a large number of safety hazards remain unrecognised in construction workplaces. These unrecognised safety hazards are also likely to remain unmanaged and can potentially cascade into unexpected safety incidents. Therefore, the development of hazards recognition skill – particularly among the next-generation of construction professionals – is vital for injury prevention and safe work-operations. To foster the development of such skill, the current investigation examined the effect of administering a hazard recognition intervention to students seeking to enter the construction workforce. First, prior to introducing the intervention, the pre-intervention hazard recognition skill of the participating students was measured. Next, the intervention that included a number of programme elements was introduced. The programme elements included (1) visual cues to promote systematic hazard recognition, (2) personalised hazard recognition performance feedback, (3) visual demonstration of common hazard recognition search weaknesses, and (4) diagnosis of hazard search weaknesses using metacognitive prompts. Finally, the post-intervention skill demonstrated by the student participants was measured and compared against their pre-intervention performance. The results suggest that the intervention was effective in improving the hazard recognition skill demonstrated by the next-generation of construction professionals. The observed effect was particularly prominent among those that demonstrated relatively lower levels of skill in the pre-intervention phase. The research also unveiled particular impediments to hazards recognition that the participants experienced.

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Introduction

The construction industry continues to report an unacceptable number of safety incidents. For example, construction workplaces in the United States have consistently reported the highest number of fatalities since 2012 (Bureau of Labor Statistics 2017). Likewise, more than 200,000 non-fatal injuries are reported every year (Bureau of Labor Statistics 2017). These injuries not only cause substantial suffering among workers and their loved ones, but also results in annual costs that exceed $49 billion (Ahmed *et al.* 2006, Zou and Sunindijo 2015).

To reduce these adverse outcomes, decades of research has focussed on identifying industry problem areas and best practices to foster injury prevention (e.g. Hinze *et al.* 2013, Tutt *et al.* 2013, Lingard *et al.* 2015a, 2015b, Oswald *et al.* 2018, Smith 2019). Among others, the importance of effective hazard recognition is widely accepted across the research and professional community (Carter and Smith 2006, Sacks *et al.* 2013, Perlman *et al.* 2014, Albert *et al.* 2017). For example, if safety hazards are not recognised, they are also likely to remain unmanaged; which can translate into unexpected injuries and illnesses (Jeelani *et al.* 2016, Pandit *et al.* 2019).

Therefore, to reduce the likelihood of injuries and illnesses, construction professionals must possess the necessary skills to sufficiently recognise and manage safety hazards. Unfortunately, a large body of evidence suggests that construction professionals – including engineers, managers, and supervisors – that are currently employed in the industry do not possess the necessary hazard recognition skill for effective safety management (Toole 2005, Fleming 2009, Perlman *et al.* 2014, Han *et al.* 2018, Pandit *et al.* 2019). Therefore efforts to improve hazard recognition skill is fundamental to the success of the industry (Namian *et al.* 2016).

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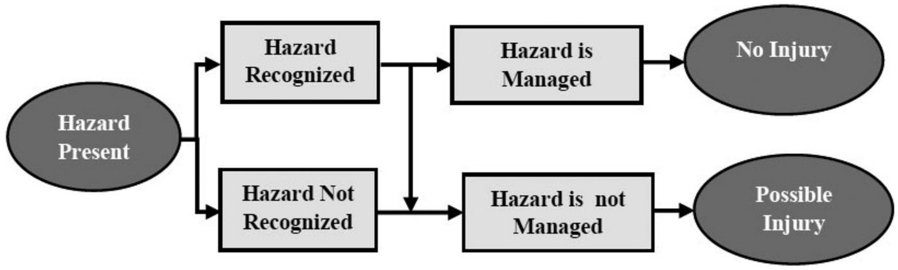

Figure 1. Role of hazard recognition in injury prevention.

To begin addressing this issue, the purpose of the presented study was to evaluate the efficacy of an intervention in improving the hazard recognition skill of students – seeking to enter the construction workforce. Because these students represent the next-generation of construction professionals, improving their hazard recognition skill prior to their entry into the industry can have profound benefits for safety management. In addition, the research intended to understand why certain safety hazards may remain unrecognised during hazard recognition operations.

Background

Hazard recognition in the construction industry

Most safety management efforts focus on managing hazards that are recognised as shown in Figure 1. Therefore, if safety hazards are not recognised, they are also likely to remain unmanaged (Jeelani *et al.* 2016, Pandit *et al.* 2019). These unrecognised and unmanaged safety hazards can potentially translate into unexpected safety outcomes including injuries and illnesses (Carter and Smith 2006, Sacks *et al.* 2013, Perlman *et al.* 2014, Albert *et al.* 2017).

Unfortunately, existing research suggests that a large number of safety hazards are not recognised in construction workplaces. For example, research from the United States estimates that over 40% of safety hazards may remain unrecognised in typical construction workplaces (Albert *et al.* 2013). Likewise, research from the United Kingdom and Australia suggests that up to 57% of safety hazards may remain unrecognised (Carter and Smith 2006, Bahn 2013). In fact, poor hazard recognition has been identified as a global challenge within the construction industry (Fleming 2009, Perlman *et al.* 2014, Jeelani *et al.* 2016).

Past research has also found causal evidence linking poor hazard recognition and injury occurrences. For example, investigations suggest that more than 70% of workplace injuries can be attributed to human factors – including poor hazard recognition and management skill (Haslam *et al.* 2005, Carter and Smith 2006, Choudhry and Fang 2008). Likewise, causal relationships have been established between poor hazard recognition and risk-taking behaviour in construction workplaces (Choudhry and Fang 2008, Han *et al.* 2018).

Therefore, research focussing on improving hazard recognition levels in the construction industry is necessary to improve safety performance levels. Such efforts can dramatically reduce construction injury rates and promote the safety and wellbeing of the construction workforce.

Role of the next-generation of construction professional

Construction professionals play a pivotal role in maintaining safety in construction workplaces. Among other roles, they are expected to lead safety management efforts, cultivate a positive safety climate, and make crucial safety decisions (Hon *et al.* 2011, Choi *et al.* 2016). Their duties also include scheduling and planning high-risk work tasks, identifying and managing resources for safe operations, and protecting field-workers from undesirable hazard exposure (Toole 2002, Arditi *et al.* 2009, Clevenger *et al.* 2017). In fact, construction professionals, based on the Occupational Safety and Health Administration's (OSHA) general duty clause (29 U.S.C. § 654, 5(a)1), are expected to ensure the safety and the well-being of the workforce – on behalf of their employers (Toole and Gambatese 2002).

In recent years, construction professionals are also being involved in the design stage – where they serve as consultants to the designers. More specifically, they review preliminary design specifications and recommend revisions to enhance safety, productivity, and constructability (Weinstein *et al.* 2005, Atkinson and Westall 2010, Lingard *et al.* 2014). This emerging best practice is known by different names including Prevention through Design (Ptd), Construction Hazard Prevention through Design (CHPtD), Design for Construction Safety (DCS), and Safety through Design

(StD) (Behm 2005, Toole and Gambatese 2008). This practice is becoming particularly popular with the introduction of more collaborative project delivery methods such as the Integrated Project Delivery (IPD) method – where contractors are engaged earlier in the project cycle to enhance safety and planning (Zhang *et al*. 2013).

Given the important role of construction professionals in safety management, their ability to recognise safety hazards is fundamental. Not surprisingly, a recent study involving 45 employers and industry experts revealed that the primary competency employers seek in the next-generation of construction professionals is their ability to manage construction safety challenges (Clevenger *et al*. 2017). Unfortunately, current evidence suggests that traditional construction professionals – including construction engineers, managers, and superintendents – lack sufficient hazard recognition skill (Carter and Smith 2006, Fleming 2009, Perlman *et al*. 2014). Therefore, efforts to foster the development of such skill can yield substantial safety benefits.

While a growing number of universities are beginning to increase their coverage of safety topics such as hazard recognition in their construction curriculum, several scholars have expressed concerns with the use of less-effective instructional practices and delivery methods (Tixier *et al*. 2013, Pedro *et al*. 2016, Lee *et al*. 2020). For example, the broader literature has alluded to the pervasiveness of lecture-based instructional methods where learners largely play a passive role during learning experiences (e.g. Bernold 2005, Vorster 2011). A large body of literature has argued that the replacement of these passive instructional methods with more active, interactive, and engaging learning experiences can yield superior learning outcomes and skill development (e.g. Namian *et al*. 2016, Mojtahedi *et al*. 2020). Likewise, others have argued that andragogical principles where learners understand the benefits of developing the new targeted skill and adopting self-directing measures to foster skill development is superior for adult learners; compared to the more prevalent pedagogical approaches which are more suitable for young children (e.g. Wilkins 2011, Albert and Hallowell 2013, Smith 2017, Bhandari *et al*. 2019).

Therefore, apart from adopting efforts to enhance hazard recognition skill among the next-generation of construction professionals, carefully crafted educational experiences that are informed by the principles of learning and educational science is necessary to achieve desirable levels of performance.

Research objectives

The study had three primary objectives. The first objective involved examining the efficacy of an intervention in improving the hazard recognition skill demonstrated by the next-generation of construction professionals. More specifically, the objective was to test the hypothesis that the introduction of an intervention will yield measurable improvements in the hazard recognition skill demonstrated by students seeking to enter the construction workforce.

The second objective focussed on examining if the intervention yields any differential effects among student participants. More specifically, this objective focussed on examining if individuals that demonstrated relatively lower levels of hazard recognition in the pre-intervention stage benefitted more from the intervention. This assessment was made because individuals who perform relatively more poorly have a larger room for improvement; compared to individuals who already demonstrate high levels of performance.

The final objective was to gain an understanding of why these future construction professionals fail to recognise certain safety hazards (i.e. impediments to hazard recognition). The approach adopted to accomplish these objectives are discussed in more detail in the research methods section. Such an effort was undertaken to understand the impediments experienced by students in effectively recognising safety hazards and better understand the relative strengths of the introduced intervention. The next section introduces the intervention that was tested in the current study.

Intervention description

The intervention included a number of programme elements that were identified in studies which were customised for the purpose of the current investigation (Dunlosky and Metcalfe 2008, Perera *et al*. 2008, Tixier *et al*. 2013, Albert *et al*. 2013, Dzeng *et al*. 2016, Jeelani *et al*. 2016). The individual programme elements are discussed below:

Visual cues to promote systematic hazard recognition

Typical hazard recognition efforts often involve visually examining the construction work environment to identify potential hazards that can cause harm (Hadikusumo and Rowlinson 2002). During such efforts, construction personnel generally do not rely on a particular strategy or approach to aid their visual examination process. In most cases, they randomly

Figure 2. Energy sources used to serve as visual cues.

examine the work environment with the assumption that safety hazards – if present – will automatically capture their attention (Jeelani *et al.* 2016).

However, recent investigations have shown that such unguided visual examinations can result in superficial search operations that can yield poor hazard recognition levels (Nickles *et al.* 2003). For example, evidence suggests that workers often prematurely terminate their hazard recognition process after a few generic safety hazards such as trips, falls and struck-by potential are identified – even if additional safety hazards may still remain unrecognised (Fleming 2009, Jeelani *et al.* 2016). Likewise, individuals may also devote attention to only particular work areas – such as the area where the primary task is being undertaken – while ignoring other relevant work areas (Dzeng *et al.* 2016, Jeelani *et al.* 2016).

In comparison to such unguided approaches, systematic and guided search efforts have yielded better results in various domains including the military, mining, and construction (Nickles *et al.* 2003, Albert *et al.* 2013). As part of this programme element, the plan was to provide the student participants with a list of visual cues based on the Haddon's energy release theory – to guide the hazard recognition process as suggested by Albert *et al.* (2013). According to this theory, any undesirable or unwanted exposure to any energy source can potentially cause workplace injuries or illnesses (Haddon 1973). Therefore, the students were provided with a catalog of 10 energy sources, as shown in Figure 2, along with relevant examples to guide their hazard recognition process. For example, hazards that fall under the gravity category include falling objects or working at heights. Similarly, power lines and energised equipment will fall under the electrical category. More examples of safety hazards corresponding to each of the energy sources can be found in Albert *et al.* (2013).

This element to improve construction hazard recognition was incorporated based on previous evidence where the success of using the visual cues was demonstrated among both students (Tixier *et al.* 2013) and construction workers (Albert *et al.* 2013, Jeelani *et al.* 2016).

Hazard recognition performance feedback

The importance of personalised feedback in learning and skill development has been highlighted in a large body of literature (e.g. Lyster and Saito 2010). For example, when feedback is provided, individuals better understand what is expected of them and what desirable-performance looks like (Perera *et al.* 2008). When individuals do not meet the desired levels of performance, such feedback can provide an opportunity to adopt self-directed corrective and remedial action (Benn *et al.* 2009); as per andragogical principles. On the other hand, individuals who already demonstrate desirable levels of performance are often motivated to maintain their performance-levels due to the positive reinforcement (Locke *et al.* 1981, Mouratidis *et al.* 2008).

Unfortunately, in construction workplaces, feedback on hazard recognition performance is rarely offered (Namian *et al.* 2016). In most cases, feedback on poor hazard recognition performance is only obtained when an incident is experienced – when remedial actions cannot undo the undesirable event (i.e. lagging indicator) (Hinze *et al.* 2013, Namian *et al.* 2016). More importantly, because injuries are relatively infrequent when compared to the number of near-misses and safety violations in construction workplaces, learning from such feedback is generally insufficient (Cambraia *et al.* 2010, Yorio and Moore 2018).

To foster the development of hazard recognition skill in the current study, the decision was made to engage the next-generation of construction professionals in a hazard recognition activity where their performance is measured prior to the intervention. Subsequently, the plan was to provide feedback on the hazards that were successfully recognised and those that remained unrecognised as part of the intervention.

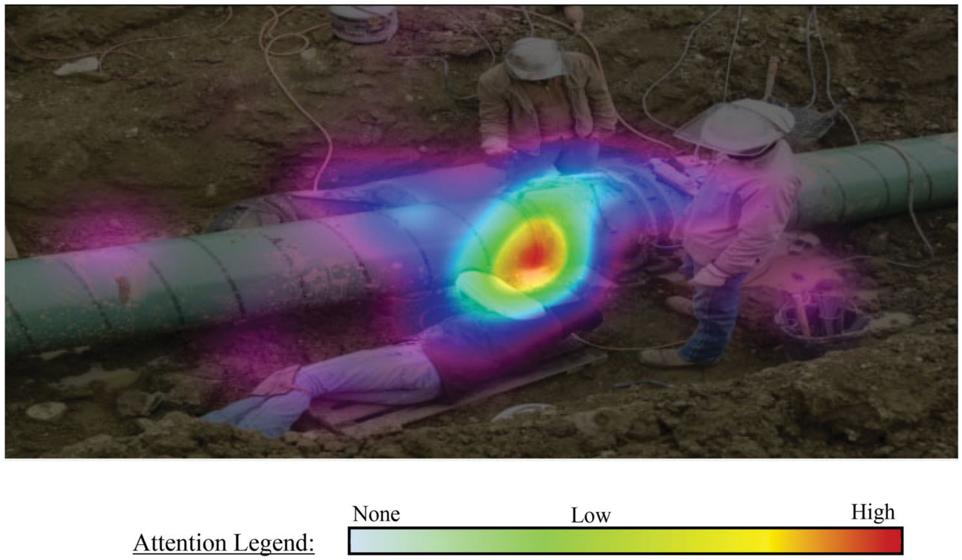

Figure 3. Demonstration of selective attention captured using eye-tracking technology.

Visual demonstration of common hazard recognition search weaknesses

As already mentioned, most hazard recognition efforts involve the visual examination of the construction workplace to identify relevant safety hazards. Therefore, how an individual examines the workplace can affect performance levels and whether particular hazards are recognised (Dzeng *et al*. 2016, Jeelani *et al*. 2018).

The visual examination process that an individual adopts is often affected by a number of mental and subconscious factors that include previous experiences, training, and knowledge (Dzeng *et al*. 2016, Jeelani *et al*. 2018). However, such subconscious mental processes are largely inaccessible to the individuals themselves and to researchers for more careful investigation.

One recently used approach to gain some understanding of these mental and visual search processes has been the use of eye-tracking devices. These are devices that can capture the search processes adopted by individuals by tracking eye-movement data during any visual search operation (Holmqvist *et al*. 2011). The capabilities of this technology have been used in various applications including understanding how radiologists examine radiographs to identify tissue abnormalities and how security personnel scan passenger baggage at an airport terminal to identify contraband items (Manning *et al*. 2004, Cain *et al*. 2013). Several of these efforts have identified various search weaknesses that result in poor search performance.

In the current study, demonstrations of commonly identified visual search weaknesses in the context of construction hazard recognition were included as part of the intervention. These demonstrations were captured from a pilot effort using the EyeTech VT3 eye-tracker. An example demonstration is presented in Figure 3. As can be seen, the image presents a case of *selective attention* where an individual devoted much of their attention to the primary task being undertaken while participating in a hazard recognition activity. Consequently, safety hazards around the activity (e.g. Gravity – trip potential from electrical cables or uneven surfaces) that are relevant were not identified during the hazard recognition operation.

Another example is presented in Figure 4. Here, as can be seen, attention was devoted or distributed more widely across the work area in the image on the right compared to the one on the left. As a result, the individual that demonstrated the search pattern in the right image identified a larger number of safety hazards during the hazard recognition activity for the same work scenario. Other examples of selective attention and inattention that were discussed based on previous research included the higher likelihood of recognising hazards that are closer to workers or are of a similar nature (e.g. gravity-related hazards such as trip, slip, and falling potential as opposed to other types such as chemicals and radiation-related hazards) (Jeelani *et al*. 2016). It is important to note that eye-tracking devices were not used as part of the current effort; only demonstrations captured as part of previous pilot efforts were adopted to illustrate search weaknesses.

Other errors that were demonstrated included *detection errors* and *search errors*. A detection error occurs when an individual allocates attention on a

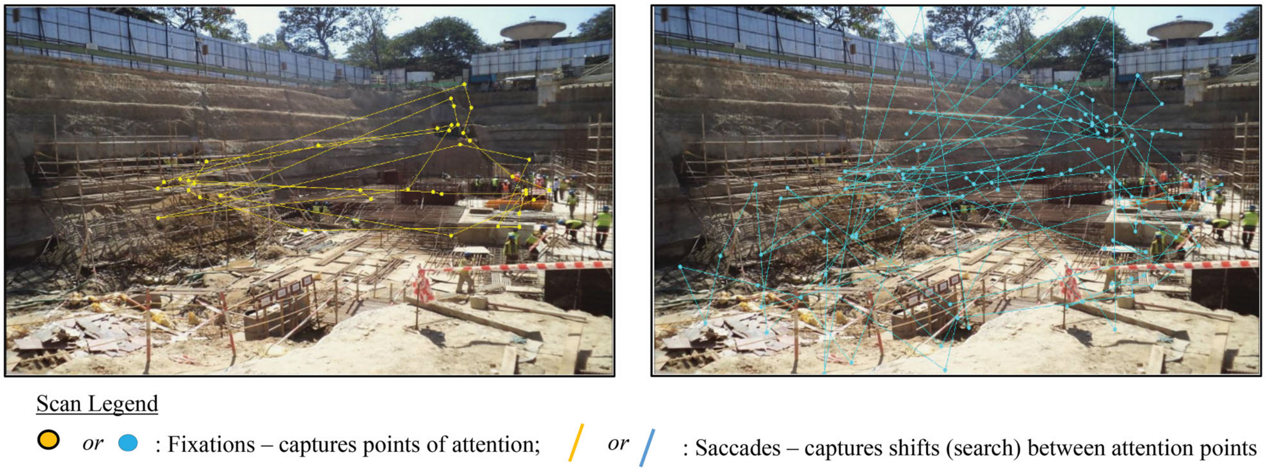

Figure 4. Demonstration of the distribution of attention captured using eye-tracking technology.

hazard or hazard stimuli, but fails to detect the hazard or hazard stimuli (i.e. does not report it as a hazard). An example can be seen in Figure 3 where the individual clearly devoted attention to the welding operation – but failed to report the fumes generated during the operation as a safety hazard. On the other hand, a search error occurs when an individual does not recognise a safety hazard simply because the individual did not allocate attention on a particular hazard or hazard stimuli (e.g. exposure to electricity from the electrical cables as shown in Figure 3).

The above-discussed search weaknesses were demonstrated using a number of images depicting various construction operations including grinding, pipe-laying, stud welding, excavation operations, and others. The objective of using these demonstrations was to communicate search patterns that can lead to poor performance and to encourage deliberate self-regulation among the participants to avoid the demonstrated search weaknesses. Such as approach can foster self-directed learning and action among participants as advocated by Garrison (1997) and others (e.g. Wilkins 2011, Bhandari *et al*. 2019); thereby yielding superior learning and performance outcomes.

Diagnosis of hazard search weaknesses using metacognitive prompts

Past research has unveiled a number of reasons why construction personnel fail to recognise safety hazards (Jeelani *et al*. 2016). For example, as already discussed earlier, they may prematurely terminate the hazard recognition process after a few generic, and well-known safety hazards such as trip potential and pinch-point likelihood are identified (Fleming 2009). Others may fail to recognise certain hazards types – such as those that may not result in an immediate injury, illness, or adverse outcome – such as exposure to welding fumes and carcinogens (Zohar and Erev 2006). In fact, a recent effort focussing on understanding why construction hazards remain unrecognised unveiled 13 underlying impediments or factors that can lead to unrecognised safety hazards (Jeelani *et al*. 2016).

As part of this intervention, it was decided that the 13 impediments or factors that were identified as part of the previous effort will be provided to the participants (see Figure 5) along with discussions and illustrations. Apart from understanding the underlying reasons that contribute to unrecognised hazards, the purpose of providing these factors was to trigger metacognition. Metacognition is a process where individuals reflect on their own performance to identify underlying reasons that contributed to their poor or good performance (Dunlosky and Metcalfe 2008). Accordingly, the plan was to provide the 13 impediments as shown in Figure 5 to the study participants, and task them with self-diagnosing why they failed to identify each of the unrecognised safety hazards. It is also important to note that a particular safety hazard may remain unrecognised because of one or more factors as shown in Figure 5. Therefore, the participants can choose multiple factors for each unrecognised safety hazard.

As part of the intervention, the plan was to ask the participants to examine the performance feedback that was provided (as discussed in the Hazard Recognition Performance Feedback section), and identify impediments or factors that contributed to why particular hazards remained unrecognised by

Directions: In your opinion, why did you not recognize specific safety hazards during the hazard recognition activity?

	← Hazard 1 to Hazard n →			
	Hazard 1	Hazard 2	………	Hazard n
1. Operational unfamiliarity with construction tools and equipment: I was not familiar with the operations and the operational features of the equipment or tool to recognize the associated safety hazard.				
2. Hazard that is secondary or unassociated with the primary task: The hazard was not relevant to the primary task being carried out which I focused on. So, I missed this hazard.				
3. Hazards perceived to impose low levels of safety risk: The risk associated with the hazard was very low to be regarded as dangerous. So, I disregarded this as being a hazard.				
4. Premature termination of hazard recognition: After identifying several hazards, I thought I identified all of them, so stopped looking for more.				
5. Low prevalence or unexpected hazards: This hazard is quite rare for the work tasks being carried out and the workplace conditions. So, I missed this.				
6. Visually unperceivable / Obscure hazards: The hazard was not visually perceivable (e.g., hot surfaces, gasses) or was obscure within the workplace for me to recognize.				
7. Unexpected and unknown potential hazard set: I was not sure what hazards I could expect, or I needed to look for. So, I missed this hazard.				
8. Selective attention or Inattention: I did not pay attention to this type or category of hazard, or I just did not pay attention to this hazard.				
9. Multiple hazards associated with a single source or task: I thought I had already identified the hazard(s) associated with this source or task. But it turns out that the source or task was associated with other hazards as well.				
10. Task unfamiliarity: I wasn't aware of the potential hazards associated with the ongoing tasks or operations.				
11. Latent or stored energy hazards The construction hazard was latent or did not impose any immediate danger. However, it is true that a trigger or unexpected release of the stored energy can cause potential injury or illness.				
12. Hazard source detection failure: I wasn't able to identify the source of the hazard (e.g., material, tool, equipment, task, object, etc.). So I wasn't sure what the associated hazard was in this case.				
13. Hazards without immediate outcome onset: This hazard can cause injury or illness in the long term. But the outcome onset is not immediate. So I did not recognize this hazard.				

Figure 5. Diagnostic tool to identify impediments to hazard recognition.

completing the table shown in Figure 5 for each unrecognised safety hazard.

Subsequently, they were asked to self-reflect on strategies and remedial actions that they could adopt to overcome the identified weaknesses. For example, if a participant identified that the reason why they did not recognise a particular hazard was that they prematurely terminated the hazard recognition effort, they could decide to be more cautious and spend additional time to improve performance in subsequent efforts.

Research methods

The research objectives were accomplished by recruiting 45 graduate students who were expected to join the construction workforce within the next 18 months. The students were all enrolled in the Construction Engineering and Management (CEM) programme in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University. The participants represented over 85% of student-body admitted into the programme in the 2016–2017 and 2017–2018 academic year. Most of the participating students possessed less than one year of previous industry experience.

After the recruitment, the study was conducted in three sequential stages within a single three-hour session. The first stage focussed on assessing the pre-intervention hazard recognition skill that the participants demonstrated. This was followed by the introduction of the intervention in the second stage. Finally, the post-intervention skill demonstrated was assessed to estimate intervention effects.

Such an experimental approach where the same participants are tested in the pre-intervention and the

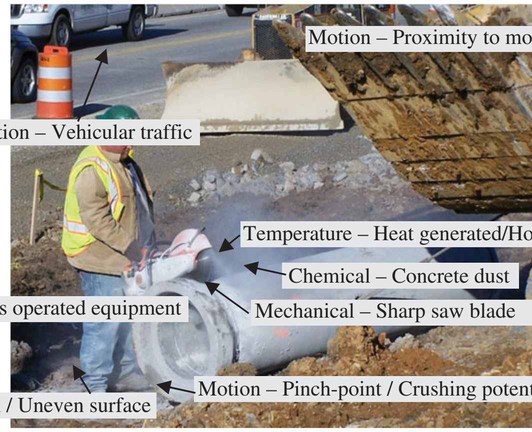

Figure 6. Example case image along with pre-identified safety hazards.

post-intervention stages (i.e. repeated measures) offer a number of advantages. For example, because inferences concerning the effectiveness of the intervention can be made by comparing the performance of the same participants in the pre-intervention and the post-intervention stages – the experimental approach effectively eliminates validity concerns related to external confounders (e.g. differences in prior experience, age, etc.) (Gravetter and Wallnau 2016). This is a common problem in other experimental approaches where the performance of a group of individuals that receive the intervention is compared against another group that does not receive the intervention. In addition, such an approach that eliminates the effect of extraneous variables offers the ability to make stronger causal claims with a relatively smaller sample size due to the increase in statistical power (Gravetter and Wallnau 2016).

Apart from the primary benefits, such an experimental design ensured that a particular group of participants are not deprived of a promising intervention that was designed to be a fundamental component of the Construction Engineering and Management (CEM) curriculum. Moreover, the completion of all the three stages of the experiment (i.e. pre-intervention measurement, intervention introduction, and post-intervention measurement) in a single three-hour session ensured that external factors such as concepts learned in other construction classes or student internships do not influence the demonstrated performance. The following sections describe the three individual stages in detail.

Stage I: measurement of the demonstrated pre-intervention hazard recognition skill

To measure the demonstrated pre-intervention skill, the participants were asked to participate in a hazard recognition activity. The activity was conducted using 16 construction case images selected from an initial pool of over 100 case images depicting diverse work operations. Examples of work operations included excavation, pipe-cutting, welding, crane rigging, and others. The case images were captured as part of a previous effort from real workplaces in the United States with the assistance of industry representatives (Albert *et al*. 2013). After the case images were gathered, 17 safety professionals representing the Construction Industry Institute (CII) member organisations examined each of the case images and pre-identified the safety hazards present using brainstorming sessions. An example case image with the pre-identified hazards is reproduced from Pandit et al. (2019) as presented in Figure 6 for illustration.

As part of the current study, a unique random set of four construction case images were selected from the initial set of 16 and presented to each study participants during the hazard recognition activity. The participants were tasked with examining the images and identifying all safety hazards in writing. Using the responses, the pre-intervention hazard recognition performance for each participant, corresponding to each case image, was computed using Equation 1.

$$\text{Hazard Recogntiion performance} = \frac{\text{No. of hazard recognized}}{\text{Total number of hazards present}} \quad (1)$$

As can be seen, the measure captured the relative proportion of hazards a particular participant recognised in a given case image relative to the total number of hazards that were present. The total number of hazards, for the purposes of this study, was defined as the total number of unique safety hazards that the safety professionals and the participants of the current study identified. Therefore, the measure of the hazard

Table 1. Effect of the intervention of hazard recognition skill.

Conditions	Mean	Standard Deviation	*t*-test statistic	*p*-value
Pre-intervention Hazard Recognition Skill	38.25%	6.84%	−17.004	<0.01
Post-intervention Hazard Recognition Skill	58.52%	6.76%		

recognition performance for each case image could potentially range from 0% to 100%.

Based on the performance of the participants in each of the four case images, the demonstrated hazard recognition skill was measured as the average performance across the images. Accordingly, a unique hazard recognition skill score was computed for each of the study participants.

Stage II introduction of the intervention and identifying impediments to hazard recognition

After the pre-intervention assessment of the hazard recognition skill, the intervention was introduced to the study participants. First, the students were introduced to the *visual cues to promote systematic hazard recognition*. This involved exposure to the ten energy sources as discussed earlier along with a PowerPoint presentation of illustrative case images depicting hazards corresponding to each of the energy sources.

Next, the *hazard recognition performance feedback* was provided using the same case images the particular participants examined as part of the pre-intervention stage. More specifically, the same case images along with the pre-identified safety hazards as illustrated in Figure 6 were provided to each of the participants individually in a separate sheet. The participants were encouraged to compare their performance against the pre-identified safety hazards as part of the feedback process.

Following this, the *visual demonstration of the common hazard recognition search weakness* was introduced and discussed as mentioned earlier. Finally, the *metacognitive prompts*, as presented in Figure 6, were shared with the participants and they were encouraged to diagnose their demonstrated weaknesses and self-reflect on strategies that they can adopt to overcome the weaknesses. The responses from the self-diagnosis process were also gathered to identify the most commonly reported impediments to hazard recognition that corresponded with each unrecognised hazard – to accomplish the third objective of the study.

Stage III measurement of post-intervention hazard recognition skill

At the conclusion of the intervention, a new hazard recognition activity following the same procedure adopted for the pre-intervention stage was conducted. This involved randomly selecting a new set of four construction case images and repeating the same procedure for the post-intervention assessment. Care was taken to ensure that the study participants were examining case images that were different from those examined in the pre-intervention stage for which feedback was already provided. Based on their performance in each of the case images, the demonstrated hazard recognition skill was again computed as was done in the pre-intervention stage. The process yielded a new set of hazard recognition skill scores for each of the 45 participants for comparison against the pre-intervention skill – to accomplish the first objective of the study.

In addition, as performed in Stage II, the participants were once again provided feedback on their hazard recognition performance, and they were asked to indicate again why particular hazards may have remained unrecognised using the table in Figure 5. Comparing this data against the data captured in Stage II would provide information on the impediments that remained after experiencing the intervention.

Data analysis, results and discussions

Objective I: effectiveness of the intervention in improving hazard recognition skill

As discussed, the repeated-measures approach provided a demonstrated hazard recognition skill score for each of the 45 study participants in the pre-intervention and the post-intervention phase. The descriptive statistics of the scores are presented in Table 1.

As can be seen, overall the study participants, on average, recognised less than 39% of the safety hazards in the pre-intervention phase. However, after experiencing the intervention, they were able to identify over 58% of the safety hazards on average. Therefore the average observed improvement in the hazard recognition skill exceeded 20% across the study participants.

To test whether the observed difference is statistically significant, first, the normality of the data was tested using the Skewness and Kurtosis test. The results suggested that the assumption of normality can be assumed for the data. Next, the two-sample

Table 2. Differential effect of the intervention on the study participants.

Predictors	Coefficient	Std. Error	*t*-value	*p*-value	LLCI	ULCI	r^2
Constant (β_0)	46.836	5.573	8.404	<0.01	35.596	58.076	0.353
ΔHR (β_1)	−0.694	0.143	−4.841	<0.01	−0.984	−0.405	

Note: LLCI & ULCI = Lower and upper limit of 95% confidence intervals, respectively.

dependent *t*-test was conducted with an alpha level of 0.05. The results of the test are also included in Table 1. As can be seen, the *p*-value associated with the *t*-test statistic is less than the selected alpha level of 0.05. Therefore, the results suggest that the difference in performance is statistically significant. Therefore, there is sufficient evidence to conclude that the introduction of the intervention caused a significant improvement in the hazard recognition skill among the next-generation of construction professionals.

Objective II: examining differential effects of the intervention

Additional analysis was conducted to evaluate whether there were differential effects among the study participants. In other words, there was interested in evaluating whether certain participants demonstrated higher levels of improvement than others. Because participants whose performance was relatively lower in the pre-intervention phase had a much larger room for improvement, the analysis focussed on evaluating whether these individuals demonstrated higher levels of improvement. In other words, there was interest in testing if there were higher gains in skill among those that were relatively poorer in recognising safety hazards in the pre-intervention phase. For example, the analysis focussed on evaluating whether an individual who identified only 30% of the safety hazards in the pre-intervention phase is likely to show higher levels of improvement than another individual who may have identified 50% of the safety hazards in the pre-intervention phase.

To test whether such a differential effect existed, the regression model presented as Equation 2 was estimated. As can be seen, the regression coefficient β_1 is the coefficient that is of the most interest in the analysis as it captures the differential effect across the study participants. More specifically, if the participants who demonstrated lower levels of skill in the pre-intervention phase demonstrated higher levels of improvement than the others, then the value of β_1 will be negative and statistically significant. In other words, as the demonstrated pre-intervention hazard recognition skill increases across the participants, the relative improvement will decrease:

$$\Delta HR = \beta_0 + \beta_1 HR_{\text{pre}} + \varepsilon \quad (2)$$

Where, ΔHR is the demonstrated improvement in the hazard recognition skill, HR_{pre} is the hazard recognition skill demonstrated in the pre-intervention phase (i.e. measures across four construction case images), β_0 is the intercept of the regression model, β_1 represents the slope between the relationship between the demonstrated pre-intervention hazard recognition skill (HR_{pre}) and the demonstrated improvement (ΔHR), and ε is the error term in the mathematical regression model.

The results of the estimation of the regression model are presented in Table 2. As can be seen, the coefficient (β_1) associated with the improvement in the demonstrated hazard recognition skill is negative. This suggests that as the demonstrated pre-intervention hazard recognition skill increased across the study participants, the observed improvement in the demonstrated hazard recognition skill decreased. For example, according to the results in Table 2, a participant who demonstrates a pre-intervention hazard recognition skill of 30% is expected to demonstrate an improvement of 26% [i.e. 46.836−0.694 (30%)]. However, another participant who demonstrates a pre-intervention skill of 50% is expected to only demonstrate an improvement of approximately 12% [i.e. 46.836−0.694 (50%)]. Therefore, in summary, although the introduction of the intervention improved the demonstrated hazard recognition skill across the study participants, the effect was particularly stronger among those that demonstrated poorer performance in the pre-intervention phase.

Objective III: experienced impediments to recognizing safety hazards

Table 3 summarises the results of the metacognition activity where the participants identified why they might not have identified particular safety hazards. As can be seen, prior to the introduction of the intervention, *selective attention or inattention* was reported 385 times by the study participants as being a reason for not having identified specific safety hazards. This represented the most commonly reported reason that accounted for 18.07% of the total 2131 responses

Table 3. Impediments to hazard recognition.

Factors	Pre-intervention		Post-intervention		Change / Difference	
	Frequency / No. of hazards	Percentage	Frequency / No. of hazards	Percentage	Change in Frequency	Percentage Change
Operational unfamiliarity with construction tools and equipment	121	5.68%	101	13.13%	20	16.53%
Hazard that are secondary or unassociated with the primary task	129	6.05%	38	4.94%	91	70.54%
Hazards perceived to impose low levels of safety risk	222	10.42%	137	17.82%	85	38.29%
Premature termination of hazard recognition	360	16.89%	47	6.11%	313	86.94%
Low prevalence or unexpected hazards	63	2.96%	40	5.20%	23	36.51%
Unknown potential hazard set	251	11.78%	55	7.15%	196	78.09%
Visually unperceivable / Obscure hazards	136	6.38%	71	9.23%	65	47.79%
Selective attention or Inattention	385	18.07%	87	11.31%	298	77.40%
Task unfamiliarity	114	5.35%	79	10.27%	35	30.70%
Hazard source detection failure	57	2.67%	33	4.29%	24	42.11%
Multiple hazards associated with single source or task	80	3.75%	25	3.25%	55	68.75%
Hazards without immediate outcome onset	135	6.34%	39	5.07%	96	71.11%
Latent or stored energy hazards	78	3.66%	17	2.21%	61	78.21%
Total	2131	100%	769	100%	–	–

(i.e. 385/2131) presented under the pre-intervention column. As discussed in Jeelani *et al.* (2016), *selective attention or inattention* occurs when individuals allocate attention to only certain hazards that may be close to workers or are adjacent to the primary task being undertaken. In other cases, individuals may also selectively allocate attention only to certain hazard types or categories such as *gravity hazards* that include debris on the floor (i.e. trip potential), leading edges (i.e. fall potential), and falling material. This was closely followed by the *premature termination of hazard recognition,* which was responsible for close to 17% of the unrecognised safety hazards. As discussed earlier, this is a phenomenon where individuals terminate the hazard recognition process after a few generic and mundane safety hazards are identified – even if additional safety hazards may still remain unrecognised.

After the intervention was introduced, the most commonly identified impediment was *hazards perceived to impose low levels of safety risk* (i.e. 137/769 = 17.82%). This is a phenomenon when individuals do not report a particular safety hazard when they perceive that the risk imposed by the safety hazard is minimal. This was closely followed by *operational unfamiliarity with construction tools and equipment* (13.13%) – which occurs when individuals do not identify hazards because of their unfamiliarity with the operation or operational features of certain tools or pieces of equipment. For example, when an individual is not aware of whether a particular equipment (e.g. chainsaw, hand saw, etc.) is operated using gas, electricity, or battery, they may fail to accurately identify the associated safety hazards.

Table 3 also presents the change or difference in performance after the intervention was introduced. The change in frequency represents the difference in the frequency with which each of the factors were reported as being an impediment to hazard recognition between the pre-intervention and post-intervention stages. For example, the change in frequency corresponding to *operational unfamiliarity with construction tools and equipment* is 20 which is computed as the difference between the reported frequency in the pre-intervention (i.e. 121) and the post-intervention (i.e. 101) stages as shown in Table 3. This represents a percentage change of 16.53% compared to the pre-intervention frequency of 121 (i.e. 20/121 expressed as a percentage).

The change in performance results suggests that the highest impact of the intervention was on the *premature termination of hazard recognition*. More specifically, the frequency with which the participants reported *premature termination of hazard recognition* as an impediment to hazard recognition reduced by over 86% (i.e. 313/360 expressed as a percentage). This was followed by the intervention's effect on *latent or stored energy hazards* where the frequency reduced by 78% (i.e. 61/78 expressed as a percentage). This includes hazards such as pressurised piping – that do not appear to impose any imminent danger – but can result in catastrophic incidents if the latent or stored energy is unexpectedly released (e.g. rupture of pressurised piping). Another common example of a latent or stored energy hazard is the cave-in potential of an excavation that can occur with little or no observable warning.

The intervention had the least effect on hazards that were not identified due to the *operational unfamiliarity with construction tools and equipment* (i.e. 16.53%) and *task unfamiliarity* (i.e. 30.70%). This may be because the intervention was not particularly designed to target the unfamiliarity of the participants with particular construction tasks, pieces of equipment, or tools. Supplementing the current intervention elements with a description of common tasks, pieces of equipment, and tools may address this shortcoming of the current intervention.

Study contributions and practical implications

The current study makes a number of important contributions to literature and practice. First, the research successfully demonstrated that the presented intervention can be adopted to improve hazard recognition skill among the next-generation of construction professionals. Accordingly, educators and trainers can adopt such interventions to better prepare individuals to tackle the safety challenges experienced in the construction industry. Such efforts will not only address the skill requirements of the industry (Toole 2002, Clevenger *et al*. 2017), but can also lead to superior hazard recognition levels and a dramatic reduction in the number of injuries. The presented empirically-tested intervention also represents one of the few interventions that target skill development among the next-generation of construction professionals in the broader literature.

Second, while the intervention caused an improvement in the hazard recognition skill among the study participants, the intervention was particularly effective for those that demonstrated inferior levels of hazard recognition in the pre-intervention phase. Therefore, while the intervention is broadly relevant to all future construction professionals, it can be particularly useful to those that have little experience with construction hazard recognition.

Third, the research unveiled common impediments to hazard recognition experienced by the next-generation of construction professionals. Among others, *selective attention or inattention* was the most common. Fortunately, the intervention dramatically reduced the number of safety hazards that remained unrecognised due to each impediment in the post-intervention phase as shown in Table 3. Therefore, the intervention successfully targeted each of the impediments to hazard recognition that the participants demonstrated.

Fourth, the research also quantified the relative effect of the intervention on the various impediments to hazard recognition. More specifically, the intervention had the highest impact on reducing hazards that remained unrecognised because of the *premature termination of the hazard recognition*. The intervention also had a large effect on *latent and stored energy hazards*. However, the intervention had the least effect on *operational unfamiliarity with construction tools and equipment* and *task unfamiliarity*. This important finding suggests that the presented intervention can potentially be further improved by introducing additional elements that assist with gaining more familiarity with construction tasks, tools, and pieces of equipment. This is a potential area for future research given that more than 40% of the safety hazards still remained unrecognised, on average, in the current study – after the intervention was introduced (see Table 1). However, it should also be noted that the participants recognised up to 72% of safety hazards in the current study (i.e. maximum performance demonstrated by one of the study participants).

Finally, like findings from several previous efforts, the study participants in the current effort failed to recognise a significant proportion of safety hazards. More specifically, similar to many previous efforts involving both students and workers, the current study demonstrated that participants fail to recognise between 40 and 70% of safety hazards (i.e. pre-intervention performance) during hazard recognition efforts (e. g., Albert *et al*. 2013, Bahn 2013, Bhandari *et al*. 2020, Perlman *et al*. 2014, Jeelani *et al*. 2016). Such consistent findings demonstrate the prevalence of poor hazard recognition levels in the industry and the need for empirically tested interventions – such as the one presented in the current study – to enhance safety performance.

Strengths, limitations, and potential future efforts

Apart from the contributions, the primary strength of the research was the repeated measures experimental design that was adopted. More specifically, the repeated measures experimental design offered superior experimental control and statistical power. In fact, the results of the study demonstrated an effect size of 2.54 calculated using Equation 3 – which corresponds with a statistical power that is equivalent to 1 for making inferences. Therefore, the sample size in the current study was sufficient to avoid a Type II error (i.e. false negative) assuming an established Type I error rate criteria of 0.05. Moreover, the adopted experimental design ensured that a particular group of participants were not deprived of receiving the beneficial intervention:

$$d = \frac{|\Delta HR|}{\sqrt{s_1^2 + s_1^2 - (2rs_1s_2)}} \quad (3)$$

Where, d represents the effect size, ΔHR is the demonstrated improvement in the hazard recognition skill, s_1 is the standard deviation of the hazard recognition performance in the pre-intervention phase, s_2 is the standard deviation of the hazard recognition performance in the post-intervention phase, and r is the correlation between the hazard recognition performance values in the pre-intervention and the post-intervention stages

Despite the strengths of the study, there are few limitations that may be addressed in future research. First, in the current study, the hazard recognition skill was measured using construction case images rather than in real construction workplaces. This was done because it was unrealistic to transport the student participants to real construction workplaces where they could be potentially exposed to safety hazards. In addition, the use of the construction case images provided a standardised approach to measure hazard recognition skill and to offer feedback based on the pre-identified list of safety hazards. It is also important to note that previous efforts suggest that there is a strong correlation between performance measurements captured using construction case images and in real workplaces (Albert *et al*. 2013). Nonetheless, future efforts could be undertaken in real construction workplaces after sufficient safety precautionary measures are adopted, and a suitable experimental plan is developed.

Second, the study participants were all recruited from the student body enrolled in the construction engineering and management programme in one institute. Although the participants were sufficient to make meaningful statistical inferences, future efforts could focus on a larger cohort of students from across the nation and beyond. Not only will such efforts yield more generalisable results, but will also foster the development of hazard recognition skill more widely across the next-generation of construction professionals.

Finally, as already discussed, while the intervention significantly improved the hazard recognition skill of the study participants, the research revealed that the intervention did not sufficiently address the lack of familiarity with tasks, tools, and pieces of equipment. Future research could explore the addition of other intervention elements to further improve the effectiveness of the discussed intervention.

Conclusion

Past research has established that a large number of safety hazards remain unrecognised in construction workplaces (Carter and Smith 2006, Albert *et al*. 2013, Bahn 2013, Perlman *et al*. 2014). These unrecognised safety hazards are also likely to remain unmanaged and can potentially cascade into unexpected safety incidents (Jeelani *et al*. 2016). Therefore, effective hazard recognition skill is fundamental to effective safety management and injury prevention.

To improve performance, the current research focussed on testing an intervention targeted at improving the hazard recognition skill among the next-generation of construction professionals (i.e. students seeking to enter the construction workforce). The intervention included a number of programme elements such as: visual cues to promote systematic hazard recognition, personalised hazard recognition performance feedback, visual demonstration of common hazard recognition search weaknesses, and diagnosis of hazard search weaknesses using metacognitive prompts.

After measuring the pre-intervention hazard recognition skill of the study participants, the intervention was introduced. The post-intervention assessment suggested that the intervention successfully improved the hazard recognition skill demonstrated by the study participants. In addition, the intervention was effective in addressing a number of common impediments to effective hazard recognition.

The results of the study can be used to equip the next-generation of construction professionals with the necessary skill to effectively recognise safety hazards. Such efforts can dramatically improve safety performance and reduce injury likelihood in the construction industry. The results of the study will be of interest to construction educators, professional trainers, and safety researchers.

The study contributes to tackling the issue of poor hazard recognition that has been widely acknowledged in previous research (e.g. Carter and Smith 2006, Albert *et al*. 2013, Bahn 2013, Perlman *et al*. 2014). The article also builds upon previous research that has focussed on identifying factors that influence hazard recognition levels (e.g. Namian *et al*. 2016, Bhandari *et al*. 2020, Pandit et al., 2020) and interventions that target poor hazard recognition skill among workers, professionals, and students seeking to enter the construction workforce (e.g. Tixier *et al*. 2013, Hallowell and Hansen 2016, Jeelani *et al*. 2016).

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References

Ahmed, S. M., Azhar, S., and Forbes, L. H., 2006. Costs of injuries/illnesses and fatalities in construction and their impact on the construction economy. In: Int*ernational* Conf*erence* on Global Unity for Safety and Health in Construction, Tsinghua University Press, Beijing.

Albert, A., *et al*., 2017. Empirical measurement and improvement of hazard recognition skill. *Safety science*, 93, 1–8.

Albert, A., Hallowell, M.R., and Kleiner, B.M., 2013. Enhancing construction hazard recognition and communication with energy-based cognitive mnemonics and safety meeting maturity model: multiple baseline study. *Journal of construction engineering and management*, 140 (2), 04013042.

Albert, A. and Hallowell, M.R., 2013. Revamping occupational safety and health training: integrating andragogical principles for the adult learner. *Construction economics and building*, 13 (3), 128–140.

Arditi, D. and Ongkasuwan, D, Committee on Management Practices in Construction (MPIC) of the ASCE Construction Institute. 2009. Duties and responsibilities of construction managers: perceptions of parties involved in construction. *Journal of construction engineering and management*, 135 (12), 1370–1374.

Atkinson, A.R., and Westall, R., 2010. The relationship between integrated design and construction and safety on construction projects. *Construction management and economics*, 28 (9), 1007–1017.

Bahn, S., 2013. Workplace hazard identification and management: the case of an underground mining operation. *Safety science.*, 57, 129–137.

Behm, M., 2005. Linking construction fatalities to the design for construction safety concept. *Safety science.*, 43 (8), 589–611.

Benn, J., *et al*., 2009. Feedback from incident reporting: information and action to improve patient safety. *Quality & safety in health care*, 18 (1), 11–21.

Bernold, L.E., 2005. Paradigm shift in construction education is vital for the future of our profession. *Journal of construction engineering and management*, 131 (5), 533–539.

Bhandari, S., Hallowell, M.R., and Correll, J., 2019. Making construction safety training interesting: a field-based quasi-experiment to test the relationship between emotional arousal and situational interest among adult learners. *Safety science.*, 117, 58–70.

Bhandari, S., *et al*., 2020. Using augmented virtuality to examine how emotions influence construction-hazard identification, risk assessment, and safety decisions. *Journal of construction engineering and management*, 146 (2), 04019102.

Bureau of Labor Statistics (BLS). 2017. Injuries, illnesses, and fatalities. Available from https://www.bls.gov/iif/ [Accessed January 2018).

Cain, M.S., Adamo, S.H., and Mitroff, S.R., 2013. A taxonomy of errors in multiple-target visual search. *Visual cognition*, 21 (7), 899–921.

Cambraia, F.B., Saurin, T.A., and Formoso, C.T., 2010. Identification, analysis and dissemination of information on near misses: a case study in the construction industry. *Safety science.*, 48 (1), 91–99.

Carter, G. and Smith, S., 2006. Safety hazard identification on construction projects. *Journal of construction engineering and management*, 132 (2), 197–205.

Choi, B., Ahn, S., and Lee, S., 2016. Role of social norms and social identifications in safety behavior of construction workers. I: theoretical model of safety behavior under social influence. *Journal of construction engineering and management*, 143 (5), 04016124.

Choudhry, R.M. and Fang, D., 2008. Why operatives engage in unsafe work behavior: investigating factors on construction sites. *Safety science.*, 46 (4), 566–584.

Clevenger, C.M., *et al*., 2017. Initial assessment of a newly launched interdisciplinary construction engineering management graduate program. *Journal of professional issues in engineering education and practice*, 143 (3), 04017001.

Dunlosky, J., and Metcalfe, J., 2008. *Metacognition*. Thousand Oaks, California: Sage Publications.

Dzeng, R., Lin, C., and Fang, Y., 2016. Using eye-tracker to compare search patterns between experienced and novice workers for site hazard identification. *Safety science*, 82, 56–67.

Fleming, M.A., 2009. Hazard recognition techniques. *By design, ASSE*, 9 (3), 15–18.

Garrison, D.R., 1997. Self-directed learning: toward a comprehensive model. *Adult education quarterly*, 48 (1), 18–33.

Gravetter, F. J. and Wallnau, L. B., 2016. *Statistics for the behavioral sciences*. Boston, MA: Cengage Learning.

Haddon, W., 1973. Energy damage and the ten countermeasure strategies. *Human factors*, 15 (4), 355–366.

Hadikusumo, B. and Rowlinson, S., 2002. Integration of virtually real construction model and design-for-safety-process database. *Automation in construction.*, 11 (5), 501–509.

Hallowell, M.R. and Hansen, D., 2016. Measuring and improving designer hazard recognition skill: critical competency to enable prevention through design. *Safety science*, 82, 254–263.

Han, Y., *et al.*, 2018. Employees' safety perceptions of site hazard and accident scenes. *Journal of construction engineering and management*, 145 (1), 04018117.

Haslam, R.A., *et al.*, 2005. Contributing factors in construction accidents. *Applied ergonomics*, 36 (4), 401–415.

Hinze, J., Hallowell, M., and Baud, K., 2013. Construction-safety best practices and relationships to safety performance. *Journal of construction engineering and management*, 139 (10), 04013006.

Hinze, J., Thurman, S., and Wehle, A., 2013. Leading indicators of construction safety performance. *Safety science.*, 51 (1), 23–28.

Holmqvist, K., *et al.*, 2011. *Eye tracking: a comprehensive guide to methods and Measures*. Oxford, NY: OUP.

Hon, C.K., Chan, A.P., and Yam, M.C., 2011. Empirical study to investigate the difficulties of implementing safety practices in the repair and maintenance sector in hong kong. *Journal of construction engineering and management*, 138 (7), 877–884.

Jeelani, I., Albert, A., and Gambatese, J.A., 2016. Why do construction hazards remain unrecognized at the work interface? *Journal of construction engineering and management*, 143 (5), 04016128.

Jeelani, I., *et al.*, 2016. Development and testing of a personalized hazard-recognition training intervention. *Journal of construction engineering and management*, 143 (5), 04016120.

Jeelani, I., Albert, A., and Han, K., 2018. Are visual search patterns predictive of hazard recognition performance? Empirical investigation using eye-tracking technology? *Journal of construction engineering and management*, 145 (1), 04018115.

Lee, Y.Y.R., Samad, H., and Miang Goh, Y., 2020. Perceived importance of authentic learning factors in designing construction safety simulation game-based assignment: random forest approach. *Journal of construction engineering and management*, 146 (3), 04020002.

Lingard, H., *et al.*, 2014. Exploring the link between early constructor involvement in project decision-making and the efficacy of health and safety risk control. *Construction management and economics*, 32 (9), 918–931.

Lingard, H., *et al.*, 2015a. Looking and learning: using participatory video to improve health and safety in the construction industry. *Construction management and economics*, 33 (9), 740–751.

Lingard, H., *et al.*, 2015b. Are we on the same page? exploring construction professionals' mental models of occupational health and safety. *Construction management and economics*, 33 (1), 73–84.

Lyster, R., and Saito, K., 2010. Oral feedback in classroom SLA: a meta-analysis. *Studies in second language acquisition*, 32 (2), 265–302.

Locke, E.A., *et al.*, 1981. Goal setting and task performance: 1969–1980. *Psychological bulletin*, 90 (1), 125.

Manning, D.J., Ethell, S., and Donovan, T., 2004. Detection or decision errors? Missed lung cancer from the posteroanterior chest radiograph. *The British journal of radiology*, 77 (915), 231–235.

Mojtahedi, M., *et al.*, 2020. Flipped classroom model for enhancing student learning in construction education. *Journal of civil engineering education*, 146 (2), 05019001.

Mouratidis, A., *et al.*, 2008. The motivating role of positive feedback in sport and physical education: evidence for a motivational model. *Journal of sport & exercise psychology*, 30 (2), 240–268.

Namian, M., *et al.*, 2016. Role of safety training: impact on hazard recognition and safety risk perception. *Journal of construction engineering and management*, 142 (12), 04016073.

Namian, M., *et al.*, 2016. Improving hazard-recognition performance and safety training outcomes: integrating strategies for training transfer. *Journal of construction engineering and management*, 142 (10), 04016048.

Nickles, G.M., Melloy, B.J., and Gramopadhye, A.K., 2003. A comparison of three levels of training designed to promote systematic search behavior in visual inspection. *International journal of industrial ergonomics*, 32 (5), 331–339.

Oswald, D., *et al.*, 2018. Exploring safety management challenges for multi-national construction workforces: a uk case study. *Construction management and economics*, 36 (5), 291–301.

Pandit, B., *et al.*, 2019. Impact of safety climate on hazard recognition and safety risk perception. *Safety science*, 113, 44–53.

Pandit, B., Albert, A., and Patil, Y., 2020. Developing Construction Hazard Recognition Skill: Leveraging Safety Climate and Social Network Safety Communication Patterns. *Constr. Manage. Econ*, 38 (7), 640 10.1080/01446193.2020.1722316

Pedro, A., Le, Q.T., and Park, C.S., 2016. Framework for integrating safety into construction methods education through interactive virtual reality. *Journal of professional issues in engineering education and practice*, 142 (2), 04015011.

Perera, J., *et al.*, 2008. Formative feedback to students: the mismatch between faculty perceptions and student expectations. *Medical teacher*, 30 (4), 395–399.

Perlman, A., Sacks, R., and Barak, R., 2014. Hazard recognition and risk perception in construction. *Safety science.*, 64, 22–31.

Smith, S.D., 2019. Safety first? Production pressures and the implications on safety and health. *Construction management and economics*, 37 (4), 238–242.

Smith, S.P., 2017. Adult learners: effective training methods. *Professional safety*, 62 (12), 22–25.

Tixier, A., Albert, A., and Hallowell, M. R., 2013. Teaching construction hazard recognition through high fidelity augmented reality. *In:* Proceedings of 120th ASEE Annual Conference and Exposition*, American Society of Engineering Education*, Washington DC, 1–23.

Toole, T.M. and Gambatese, J., 2008. The trajectories of prevention through design in construction. *Journal of safety research*, 39 (2), 225–230.

Toole, T.M., 2005. Increasing engineers' role in construction safety: opportunities and barriers. *Journal of professional issues in engineering education and practice*, 131 (3), 199–207.

Toole, T.M., 2002. Construction site safety roles. *Journal of construction engineering and management*, 128 (3), 203–210.

Toole, T.M. and Gambatese, J.A., 2002. Primer on federal occupational safety and health administration standards. *Practice periodical on structural design and construction*, 7 (2), 56–60.

Sacks, R., Perlman, A., and Barak, R., 2013. Construction safety training using immersive virtual reality. *Construction management and economics*, 31 (9), 1005–1017.

Tutt, D., *et al.*, 2013. In the air'and below the horizon: migrant workers in UK construction and the practice-based nature of learning and communicating OHS. *Construction management and economics*, 31 (6), 515–527.

Vorster, M.C., 2011. Teaching and learning: the critical balance in effective education. *Journal of construction engineering and management*, 137 (10), 916–922.

Weinstein, M., Gambatese, J., and Hecker, S., 2005. Can design improve construction safety?: Assessing the impact of a collaborative safety-in-design process. *Journal of construction engineering and management*, 131 (10), 1125–1134.

Wilkins, J.R., 2011. Construction worker's perceptions of health and safety training programmes. *Construction management and economics*, 29 (10), 1017–1026.

Yorio, P.L. and Moore, S.M., 2018. Examining factors that influence the existence of Heinrich's safety triangle using site-specific H&S data from more than 25,000 establishments. *Risk analysis*, 38 (4), 839–852.

Zhang, S., *et al.*, 2013. Building Information Modeling (BIM) and safety: automatic safety checking of construction models and schedules. *Automation in construction.*, 29, 183–195.

Zohar, D. and Erev, I., 2006. On the difficulty of promoting workers' safety behaviour: overcoming the underweighting of routine risks. *International journal of risk assessment and management*, 7 (2), 122–136.

Zou, P. X. and Sunindijo, R. Y., 2015. *Strategic Safety Management in Construction and Engineering*, John Wiley & Sons, NY.