Proposing and Validating a New Way of Construction Hazard Recognition Training in Academia: a Mixed-Method Approach

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ABSTRACT

We propose and experimentally validate a novel energy-based training module aiming at rapidly improving hazard recognition skills in Civil, Environmental, Architectural and Engineering (CEAE) students. The module is based on the established theory that every construction hazard is fundamentally related to the unwanted release of one or more energy sources. A class of 84 CEAE undergraduates was used as subjects during a 3-week long experiment. Adopting a rigorous A-B experimental design and validated protocol to measure hazard recognition, we found our module to increase students' hazard recognition skills by 67.8% on average ($p < 0.001$), with a lasting effect in time, while a standard OSHA-based lecture was not found to be significantly effective. Qualitative feedback gathered in the form of textual learning logs corroborated the quantitative findings. The study findings suggests that OSHA training may be complemented with components of the proposed method to improve hazard recognition levels.

INTRODUCTION

Motivation. Despite noticeable progress in safety performance over the past few decades, construction has still the dubious distinction of being one of the deadliest industries in the United States, and in many counties throughout the globe.

In America, fatalities and disabling injuries in construction have been estimated to be 3 times higher than the all-industry average (Pinto et al. 2011). Between 1992 and 2010, 21,301 construction workers lost their lives on the job, an average of about 1,120 annual fatalities (CPWR 2013), and in 2010, while only representing 7% of the overall U.S. workforce, construction workers were involved in 17.1% of the total 4,690 fatal work injuries, making construction the deadliest industry in the nation that year (CPWR 2013; BLS 2011). The direct costs of this poor safety performance have been estimated to approach \$15 billion annually (BLS 2011). Further, (Agarwal and Everett 1997) have estimated worker compensation premiums to account alone for 1.5% to 6.9% of total costs of new construction, a figure that appears to have remained stable over time (Waehrer et al. 2007). These statistics are particularly distressing because construction employment is expected to grow by 33% between 2010 and 2020, twice as much as the projected rate for the overall economy (CPWR 2013), indicating a potential for skyrocketing both the number and the cost of injuries.

[0]work was conducted during PhD at CU Boulder

Current problem. It is well known that construction site safety is impacted by the decisions and actions of those working upstream in design and management. However, research has shown that this segment of the industry is generally short of construction hazard knowledge, preventing an adequate approach of safety concerns to be adopted. Therefore, it is vital for the next generation of Civil, Environmental, Architectural and Engineering (CEAE) designers and managers to acquire the ability to accurately identify safety hazards associated with their decisions. At present, CEAE programs typically teach hazard recognition (HR) using OSHA fundamentals and formal lectures, which have not shown to particularly impact hazard recognition skill.

Contributions. We tested the translation of a new HR training method that yielded improvements in construction workers' HR skills, to CEAE students. The module is composed of a one-hour introduction to energy mnemonics based on the established theory that every construction hazard is fundamentally related to the unwanted release of one or more energy sources. Despite students' relative lack of contextual experience, we suspected the module was directly translatable to them.

Null hypotheses. A class of 84 CEAE undergraduates was used as subjects for our experiment. Over the course of three weeks at the rate of two classes per week, participants' HR skills were measured at the end of each class, and qualitative feedback was collected in the form of individual learning logs. The class was randomly split into two equal groups, and after a baseline was recorded, treatments were introduced at regular intervals in reversed orders for the two groups. The first group was first taught OSHA basics, and then exposed to the energy module. The second group was exposed to the module first, and then given the OSHA-based lecture. We tested the following null hypotheses:

- *the module did not significantly improve students' HR skills*,
- *the module was not more effective than a traditional OSHA-based lecture in improving students' HR skills*.

BACKGROUND AND POINT OF DEPARTURE

Injuries occur because too many hazards go unidentified. (Hinze 1997) showed that over 75% of construction injuries are caused by unsafe worker actions, which, according to (Carter and Smith 2006), is caused by workers' inability to adequately identify and respond to hazards.

While risk perception and risk-taking behavior are obviously impacted by many factors, such as emotional states (Tixier et al. 2014), (Haslam et al. 2005) revealed that at least 42% of accidents occur because construction personnel lack adequate safety knowledge. With such knowledge, workers would be aware of being exposed to some specific hazards, and would take appropriate measures to keep themselves safe. Actually, large-scale automated analysis of textual injury reports revealed that fundamental attributes of the work environment are highly predictive of construction injuries (Tixier et al. 2016a). Identifying these attributes and neutralizing them early enough would thus definitely help in reducing accident occurrence.

To improve hazard recognition and safety performance, several strategies have traditionally been adopted in the construction industry. For example, Job Hazard Analysis (JHA), checklists, and lessons learned are commonly used. Despite their usefulness, these methods suffer some limitations (Albert et al. 2014b). In response, researchers have proposed improvements and modifications. For example, (Rozenfeld et al. 2010) customized JHA to better suit the dynamic nature of construction. More recently, (Albert et al. 2014a; Albert et al. 2013; Tixier et al. 2013) developed HR strategies and training programs rooted in andragogy (i.e. designed for adult learners), serious games, and retrieval mnemonics. Implementing these methods in the field resulted in more than 25% improvements in HR skill among construction workers employed in diverse projects in the United States. The extent to which it is possible to obtain similar results in students who have limited field experience remained, until now, untested.

Design for safety is fruitless in part because designers lack HR skills. It is important that workers are able to identify and mitigate workplace hazards. But even more important is to proactively identify, consider, and remove as many hazards as possible from the jobsite *before* the construction phase even begins.

Indeed, many experts believe that injury prevention activities should be conducted early in the project lifecycle (Hinze 1997). However, a prerequisite for efficiently implementing this *design for safety* concept is that the people working upstream in design possess adequate construction safety knowledge, and more specifically, construction HR skills.

Another concern is whether it is possible to spot hazards while not being actually present on the jobsite. With proper training, this seems to be achievable, as even computer programs were shown to be able to detect hazards from limited information (short textual descriptions of the work environment) with high precision and recall (Tixier et al. 2016b).

Unfortunately, designers, managers, and safety professionals have been proven to lack HR knowledge just as much as workers do (Fleming 2009). For instance, a recent study (Almén et al. 2012) showed the existence of direct links between building design and hazards such as falls from height or exposure to excessive workload. Designers have even claimed that they do not know how to adequately address construction safety concerns in their drawings. More generally, designers' construction hazard knowledge was shown to be insufficient (Weinstein et al. 2005; Smallwood 2002; Gambatese and Hinze 1999).

Consequently, design professionals may unwillingly place construction workers at risk by failing to anticipate, identify, and mitigate potentially hazardous situations. The needs for the next generation of designers to acquire excellent knowledge of construction site hazards are thus pressing.

Future designers need to grow HR skills. Education needs to incorporate these concerns and make students attentive to the numerous ways by which their future decisions will have the power to influence those working onsite (Gambatese and Hinze 1999), so that a change can be made (Hinze and Wiegand 1992).

Current construction safety education is very limited. Good knowledge of construction safety is one of the key expectations from employers (Bhattacharjee et al. 2013), but research has shown that new graduates, while having a good mastery of engineering fundamentals, were often unprepared for the practical aspects of their jobs (Martin et al. 2005; Mills et al. 2003). In fact, current safety education in the Civil Engineering curriculum focuses almost exclusively on OSHA regulatory requirements (Mitropoulos et al. 2005) that are delivered through formal lectures, rather than on providing practical tools via context-based learning (Mills et al. 2003)

Active and experiential pedagogy methods are promising but not easy to implement. With the aim of effectively training students before they become active in the industry, scholars have been testing active learning methods requiring trainees to take part in meaningful activities and think about what they are doing, favoring engagement and knowledge retention (Smart and Csapo 2007; Lim et al. 2006; Felder et al. 1998)

Experiential learning theory sees learning as a process creating knowledge through the transformation of experience (Kolb 2014). Ergo, training should embrace all the facets of the *situational* *awareness* process, and involve perceiving, feeling, thinking, and behaving (Kolb and Kolb 2005). Most of the studies involving experiential pedagogies reviewed by (Gosen and Washbush 2004) reported significant learning gains and increase in skill.

In engineering education, (Prince 2004) found broad support for the elements of active learning. For instance, students remembered more content if brief activities were introduced to the lectures, and if collaborative and cooperative learning exercises were performed in the classroom. Knowledge retention was also found to be increased when students were taught methods involving *doing* rather than *seeing* or *imagining* (Kvam 2000).

Current OSHA-based construction safety education clearly does not make use of the potential of active or experiential learning. Research has thus been suggesting for a long time to associate traditional lectures with context-driven training using frequent site tours or through collaboration between institutions and construction companies (Tener 1996). However, for obvious safety, liability and productivity reasons, these approaches are highly dissuading for construction companies. These strategies thus cannot bring alone a definitive solution to the current issue faced by academia.

RESEARCH METHODS

As shown in Figure 1, the data collection process involved (1) randomly splitting students in the class into 2 equal groups, (2) recording a baseline, (3) exposing the 2 groups to both OSHA fundamentals and the HR module at regular intervals in reversed orders, and finally (4) recording a post-interventions phase.

At each step of the process, hazard recognition (HR) skill was objectively measured, and qualitative feedback was collected in the form of individuals learning logs. Once these data were gathered, an A-B testing approach was used to assess whether each treatment led to statistically significant improvements in HR skill. Here, the details of the data collection process are reviewed, focusing on the subject recruitment, experimental design, and the valid and reliable measurement of HR skill and collection of qualitative feedback.

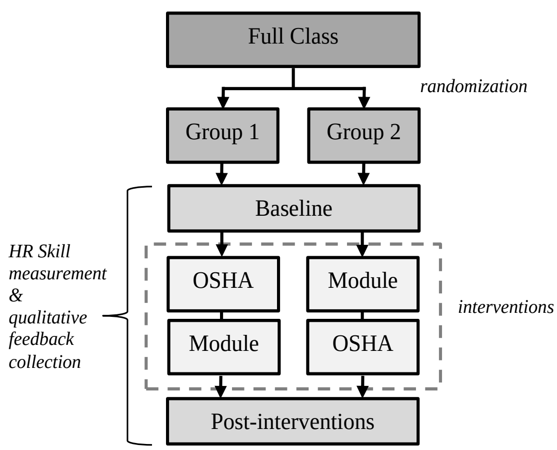

Fig. 1. Research approach

Subject recruitment

Participants to this study consisted of 84 University of Colorado at Boulder Civil, Environmental, Architectural and Engineering undergraduates. 15.5% were female, and the mean age was 22.3

years. Subjects participated in the study as part of their enrollment in a Construction Equipment and Methods course. A basic background information questionnaire revealed that 33% of students had been on a construction site before and 65.5% were planning to work in the construction industry. Among the latter, 36% intended to become design professionals, and 47% projected to work in the field.

Experimental design

The study took place during 6 consecutive classes over the course of 3 weeks, at the rate of 2 classes per week. Each class was 1 hour and 15 minutes in length. The last 5 minutes of each session were dedicated to measuring students' HR skills. Also, students had to submit learning logs to a website after each class was over and before the following class started.

The full class of 84 undergraduates was randomly split into two equal groups. After a baseline was recorded, the first group was taught OSHA fundamentals, then the energy-based HR method, whereas the second group was first given the energy method lecture and then taught OSHA basics. More precisely, as shown in Figure 2, baseline recording occurred on Days 1 and 2 with a full class, the first group was taught OSHA fundamentals on Day 3, both groups received energy mnemonics instruction on Day 4, the second group was given the OSHA-based lecture on Day 5, and Day 6 was a post-interventions day for both groups. The second group did not attend class on Day 3, while the first group was exempt of class on Day 5.

On Days 1, 2, and 6, regular construction equipment and methods topics were tackled during classes as no new treatment was introduced. Only HR measurement occurred on these days, at the end of each class, as was already explained.

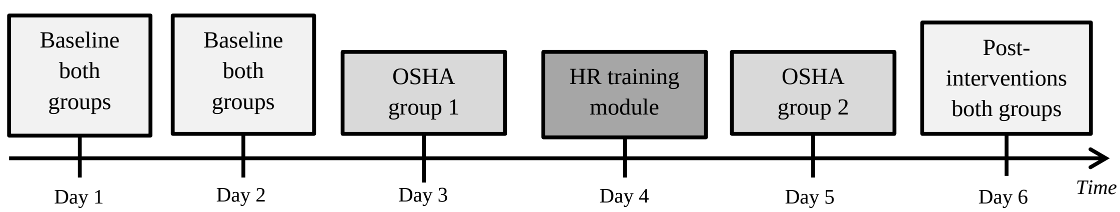

Fig. 2. Experiment timeline

Measuring HR skill

As was already explained, hazard recognition (HR) skill was measured on each day at the end of class. More specifically, each participant was randomly assigned a set of 3 photographs among 6 possible sets. The sets were named, in order to ensure that each participant was assigned a different set on every session.

The pictures were picked among a database of photographs selected by experts, and depicted real construction site situations. Each construction situation featured some level or risk (from benign to extremely hazardous) and involved various hazards, representing the whole palette of energy sources. Some situations were associated with a large number of hazards whereas others featured only a couple of dangers. The pictures were randomly split between the sets, so that overall, no set was associated with riskier situations than the others. Furthermore, since on each day, an equal number of participants was randomly assigned each of the 6 sets, the proportion of hazards identified on each day was not dependent upon the different sets.

The photographs were printed in large format (7.5 by 5 inches), high definition, and in black and white due to the high number of pictures required (more than 250). A picture example is provided in Figure 3. The hazards (resp. associated energy sources) present in this picture are (1) worker/object at height (gravity), (2) tripping hazards (gravity), (3) moving equipment (motion), (4) electrical cords (electricity), (5) sharp edges (motion), and (6) congested work space (motion).

Fig. 3. Photograph example. 6 different hazards can be identified here: (1) worker/object at height, (2) tripping hazards, (3) moving equipment, (4) electrical cords, (5) sharp edges, and (6) congested work space.

On a provided answer sheet divided into three sections (one per picture), students were asked to list as many hazards as they could identify in each of the 3 pictures of their assigned set. As will be explained in the analysis part, HR scores were computed based on the proportion of hazards identified in the pictures.

Collecting qualitative feedback

Qualitative feedback was also collected in the form of individual learning logs. Participants had to download a learning log template on the class webpage, as a one-page long MS Word document featuring two open-ended questions: (1) *"How did you feel about your performance?"*, and (2) *"What knowledge did you rely upon when identifying hazards?"*. Students had to upload their answers in MS Word or PDF format on the course webpage after each session was over and before the start of the following session. These deadlines ensured regular submissions and guaranteed the absence of memory biases. The qualitative feedback collected allowed the research team to support and better understand observable changes in HR scores over the course of the experiment.

OSHA class

On Day 3 for the first group, and on Day 5 for the second group, students were given a standard lecture about OSHA fundamentals. This lecture included the key elements of the OSHA 10-hour certification and a description of the common hazards faced in the construction industry as they relate to specific standards. The presentation was consistent with the the first hour of the standard 10-hour OSHA certification process. Specifically, the presentation included a discussion of workers' rights, employer responsibilities under the act, sample reports, and an overview of the OSHA "focus-four" hazards (i.e., falls, electrocution, struck-by, and caught-in).

Energy mnemonics class

On Day 4, all students were taught the energy mnemonics Hazard Recognition (HR) method. This method is based on Haddon's energy release theory of accident causation (Haddon Jr 1973), and holds that every hazard can be associated with one or several energy sources (Fleming 2009). As illustrated by the energy wheel (see Figure 4), energy sources can be classified into 10 categories: *gravity*, *motion*, *mechanical*, *electrical*, *pressure*, *temperature*, *chemical*, *biological*, *radiation*, and *sound*. An injury occurs whenever energy is released from one or more of these sources and transferred to the human body.

Fig. 4. The energy wheel

For instance, a suspended load is a source of gravity and motion, as it has the potential to fall and swing. If a worker is struck by this suspended load, motion energy will be transferred from the load to the worker and absorbed by their body, causing an injury. Other examples of energy sources on construction sites include radiation from welding, hot and cold objects and environments, compressed gas cylinders, hazardous substances, moving and noisy equipment and vehicles, objects and bodies at height... A complete list of definitions and examples can be found in (Albert et al. 2013).

The reasoning behind providing energy sources as cognitive cues is based on a whole body of literature showing direct association between the use of mnemonics and improved retention. For example, (Stalder 2005) showed that acronym use improved performance on introductory psychology exams. In (Thaut et al. 2014), a musical mnemonic was proved to enhance deep brain encoding during verbal learning in multiple sclerosis patients, and (Maxwell et al. 2014) demonstrated that one's ability to recall names given faces was maximized when using a face-name mnemonic strategy. In addition to improved retention, these mnemonics provide a planned protocol for HR activities. Specifically, the strategy provides mental cues for HR that dramatically reduces cognitive demand, but also improves the number of hazards identified and addressed.

During class, students were introduced to the energy theory. More specifically, the 10 energy sources were defined and discussed in detail, and concrete construction-related examples were provided. Students were also given a reference sheet featuring the energy wheel (see Figure 4), and brief definitions of the energy sources along with short examples.

ANALYSIS

Computing Hazard Recognition scores

As was already explained, each student had to analyze a set of 3 pictures at the end of each class over the course of the study (a different set every time). For each picture, as many hazards as possible were to be listed on a provided answer sheet. HR scores were computed for each picture, for each student, and for each day as the number of hazards correctly identified over the total number of hazards present in the picture, as shown by Equation 1:

$$HR = \frac{H_{identified}}{H_{total}} \tag{1}$$

where $H_{identified}$ represents the total number of hazards actually present in the picture and identified by the student, and H_{total} represents the total number of hazards actually present in the picture (i.e., HR is a measure of *recall*). For the photograph in Figure 3 (featuring a total of 6 hazards), if 4 is the number of hazards identified by a given student, the student's HR score would be equal to $4/6$, or 66.7%.

In preparation for this study, the hazards present in each picture (H_{total}), that is, the gold standard for each task, were gathered through a planned effort, where input was sought from various individuals including 14 highly experienced construction and safety professionals, 4 researchers from 2 universities, and more than 40 construction workers employed in 4 different projects in the United States.

For each student and for each day, a global HR score was calculated by taking the average of their 3 HR scores.

Content analysis of the learning logs

Students' learning logs for each session were manually analyzed in order to record the answers for the two open-ended questions that were asked: (1) *"How did you feel about your performance?"*, and (2) *"What knowledge did you rely upon when identifying hazards?"*. When reading the first batch of reports, the answers to each question naturally self-organized into several major themes (see Figures 7 and 8). We then simply recorded the evolution over time of the proportion of respondents falling into each of these categories.

RESULTS

Quantitative results

The evolution of the HR scores throughout the experiment is shown in Figure 5 and 6 respectively for the first and the second group.

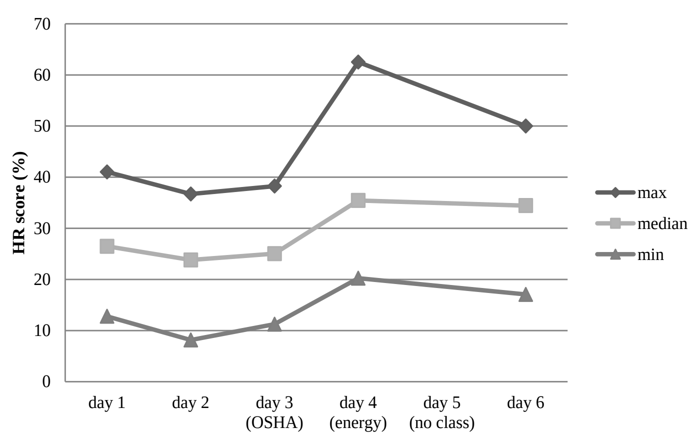

Fig. 5. HR score evolution for group 1

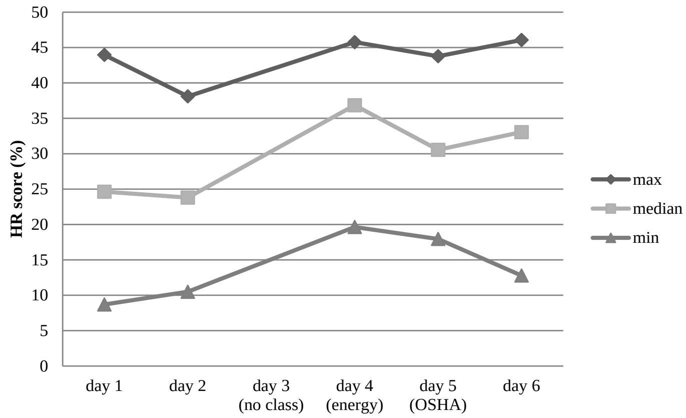

Fig. 6. HR score evolution for group 2

Visually, it is easy to identify jumps in HR scores for both groups when the energy mnemonics method is introduced on Day 4. On the other hand, the OSHA-based lecture is only associated with a very small increase on Day 3 for the first group, and a decrease on Day 5 for the second group. Adopting an A-B design approach, we used the Wilcoxon signed-rank test*, the non-parametric equivalent of the repeated measurement t-test, to assess whether the differences in HR scores induced by the treatments were statistically significant. The tests were performed using the "stats" package in R (R Core Team 2013). An advantage of the Wilcoxon signed-rank test lies in its robustness to outliers because it transforms the data to ranks.

OSHA-based lecture. The A-B design is composed of a baseline ("A" phase), also called pre-treatment phase, and of an intervention ("B" phase), or treatment phase. If there is a statistically significant change in the variable being measured, the treatment is said to have had an effect. When studying the effect of the OSHA-based lecture on HR scores for the first group, the mean values of the HR scores on Days 1 and 2 for all students in group 1 were compared to their scores on Day 3. A sample of the data used is provided in Table 1.

Group 2 received the OSHA fundamentals lecture on Day 5. The "A" phase HR scores for this group were thus the scores on Day 4, and the "B" phase scores were the means of the HR scores for Days 5 and 6. A sample of the data used is provided in Table 2.

student	A	B
1	23.18%	24.51%
2	26.12%	22.78%
3	30.36%	26.11%
4	26.93%	23.88%
5	23.18%	24.51%

TABLE 1. data sample for the A-B test corresponding to the OSHA treatment, for group 1.

The null hypothesis tested by the Wilcoxon signed rank test is that the distribution of the scores of the "A" phase and the distribution of the scores of the "B" phase are the same. For both groups, no statistical evidence to reject the null hypothesis was found. Indeed, the *p*-values were very high:

*https://stat.ethz.ch/R-manual/R-devel/library/stats/html/wilcox.test.html

student	A	B
1	31.79%	40.55%
2	24.36%	25.92%
3	44.96%	32.16%
4	43.16%	35.27%
5	40.37%	35.37%

TABLE 2. data sample for the A-B test corresponding to the OSHA treatment, for group 2.

0.72 for group 1 and 0.98 for group 2, making impossible to conclude that a statistically significant change in HR scores followed the OSHA-based instruction.

Energy mnemonics. Since the OSHA interventions on Days 3 and 5 could not be proven to have significantly impacted participants' HR scores, we made the decision to use the OSHA days as additional "pre-energy" (A phase) and "post-energy" (B phase) days, to enhance the reliability and power of the statistical analysis by taking into account more data points. Therefore, the "A" phase values for group 1 were computed by taking the average of the HR scores on Days 1, 2 and 3, and the mean of Days 4 and 6 were used to get the values for the "B" phase. Table 3 shows a sample of the data.

student	A	B
1	12.40%	28.84%
2	17.40%	26.14%
3	15.84%	24.53%
4	16.48%	26.94%
5	28.58%	38.30%

TABLE 3. data sample for the A-B test corresponding to the energy treatment, for group 1.

For group 2, the "A" phase values were the means of the HR scores on Day 1 and 2, and the averages of the scores on Days 4, 5, and 6 were taken for the "B" phase values. A sample of the data used is provided in Table 4

student	A	B
1	25.21%	35.04%
2	24.75%	25.26%
3	25.16%	33.49%
4	28.40%	38.83%
5	26.72%	40.37%

TABLE 4. data sample for the A-B test corresponding to the energy treatment, for group 2.

Wilcoxon signed rank test's null hypothesis was very strongly rejected both for group 1 and group 2 ($p < 0.001$), indicating that in both cases, the change in HR scores associated with the energy-based instruction was significant and was not due to chance. Averaging the 3 pre-energy scores and comparing them to the post-energy scores showed an increase from 24.84% to 36.06%, that is on average, a 67.8% relative increase in HR scores.

Moreover, because we used an aggregation of the scores before and after the intervention, and not just the scores right before and right after, we can conclude that the energy method had some diffusing effects in time. Indeed, session number 6 took place six calendar days after session number 4 (when the energy method was introduced) and the scores were still very high. This lasting temporal effect shows well on the time series diagrams (see Figures 7 and 8).

An interesting phenomenon for group 2 is that the scores decreased on Day 5 (OSHA), and then increased again to get closer to what the scores were on the energy instruction day. This can be due to the fact that on Day 5, students were more focused on learning OSHA fundamentals than on trying to use the energy method they were taught in the previous class. On Day 6, when able to focus again on the energy method, their scores increased and got closer to the scores on Day 4. This phenomenon will be further discussed in the next section, in light of the qualitative feedback offered by students' learning logs.

Qualitative results

On each day at the end of class, students were asked to answer two open-ended questions: (1) *"How did you feel about your performance?"*, and (2) *"What knowledge did you rely upon when identifying hazards?"*. The temporal evolution of the answers to these questions are summarized in terms of major themes along with the median HR scores for both groups in Figures 7 and 8.

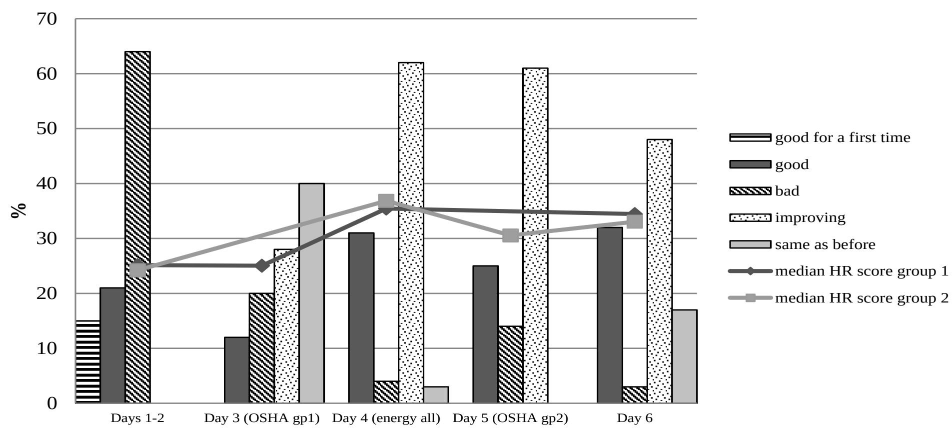

Fig. 7. Evolution of feeling about performance over time.

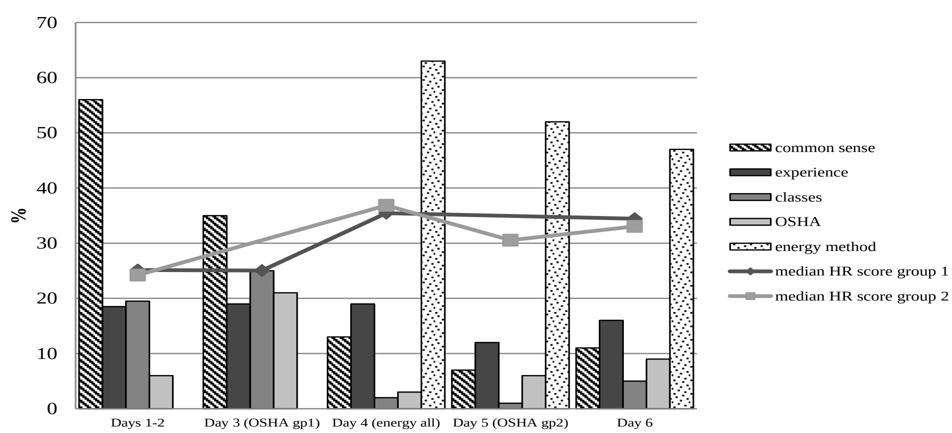

Fig. 8. Evolution of type of knowledge used over time.

Day 1 & Day 2 (baseline days). It emerges from the learning logs of the first 2 sessions that students were sorely lacking construction HR knowledge at the beginning of the experiment. They seemed to be lost, without a clear hazard spotting methodology. As a result, a vast majority of participants (55%) relied on common sense to identify hazards: *"I could only point out some things from my own experiences or basic human instinct. Like looking left and right before crossing the street. . . "*, *"I know that sparks cause fires. I relied on basic safety precautions, such as wearing proper safety gear"*.

Feedback about knowledge gained from academic curriculum was contrasted, with some students (20%) reporting that they had used knowledge gained in the classroom: *"I used what I have learned in my classes"*, *"This common knowledge has been engrained over the years of construction classes based on good construction practices"*, and some others claiming that such knowledge was almost inexistent: *"My knowledge was limited in terms of education based experience. I had little knowledge of the hazards from purely studying engineering at University"*, *"I've never had any real safety training"*, *"Chemistry class has taught us a few things about dangers but other than that, previous instruction was not very useful"*. Finally, some students stated to have relied on knowledge gained during previous work experience (20%): *"I also relied a bit on past knowledge from summer internship with a structural firm, but it wasn't very helpful"*, or OSHA-based instruction (5%): *"When identifying hazards, I relied upon knowledge I learned during an OSHA certification class"*.

Using common sense was not very effective, as shown by the low HR scores on these first two days (24.93% on average), and the learning logs proved that most students (64%) were indeed aware of their incapability to accurately identify hazards: *"I really have no idea how to recognize hazards on a construction project at this point!"*, *"Very poorly, I feel like I didn't find very many hazards. I feel like I wasn't looking for the right things. People would have died!"*. However, interestingly, some students (20%) stated that they felt their performance was good: *"I felt very comfortable"* (HR score=23.25%), *"Many of the hazards were very evident just from quickly looking at the photos"* (HR score=28.8%), but the low HR scores of these students indicate either a misperception of the expectations, or overconfidence. Finally, a few students (15%) were satisfied with their performance but with the reserve that this was a totally new activity for them. They were conscious that they still had lot of room for improvement: *"I feel like I was able to point out a good portion of the obvious hazards in each picture. However I know there are many other unidentified hazards I have yet to recognize"*.

Day 3 (OSHA for group 1). The proportion of students using common sense to identify hazards decreased from 55% on the first two days to 35%, and students relying on OSHA-based knowledge increased from 5% to 21%, indicating that a portion of students tried to use what they had just learned during the OSHA-based lecture. However, HR scores did not increase on Day 3 (24.67% on average, compared to 24.93% on Days 1 and 2), reflecting the ineffectiveness of the OSHA lecture. This was corroborated by the qualitative feedback. Actually, most students did not find what they had learned to be very helpful: *"I basically used the same techniques as I did before and tried to apply my knowledge from the OSHA lecture. I'm not entirely sure if it significantly improved my performance, however"*, *"The standard OSHA class only covered details about OSHA, not actual rules for safety"*. As a result, students were still relying mostly on common sense (35%), previous work experience (19%) and classes (25%) to identify hazards: *"I haven't really learned anything new since the last two times that we reviewed the photos so I was mostly just using common sense and what little experience I have in the field or classroom"*.

Most students (40%) reported that their performance was unchanged since the last two sessions: *"For the most part, I think I performed about the same as I did the last two sessions, so not that well"*, or that they simply did a bad job (20%): *"Even though we discussed OSHA procedures and regulations today in class, I still do not feel like I have a good understanding of hazards at a work site"*, *"I still didn't feel very efficient in seeing the full picture of the hazards. I feel like I only identified the obvious ones"*.

However, some students (28%) did report an improvement in their performance, but without necessarily linking it to the OSHA instruction: *"A slight improvement from the last iteration. I still need a lot of training/practice"*. *"I felt more confident this time around while identifying hazards because I have been exposed to more photos lately I believe"*. Finally, a few students (11%) stated that their performance was good: *"I felt good because I was able to quickly identify a couple hazards right off the bat for each of the three pictures"*, but again, this false positive impression can be attributed to a misalignment with respect to the objectives, the goal being obviously to identify a majority of the hazard presents, not just *"a couple"* of them.

Day 4 (energy, whole class). Day 4 was marked by a significant jump in HR scores from about 24% on Days 1, 2 and 3 to 36%, which represents a 67.8% relative increase. This major improvement can be largely attributed to the introduction of the energy mnemonics method, according to students. Indeed, 63% of the class reported to have used the just learned energy method to identify hazards: *"I really felt like today's introduction to the energy method helped me think about approaching hazard recognition in a completely new light"*, *"Thinking about the different energies as a checklist was very useful"*, *"I had a different mindset. Being aware of the various types of energy makes it much easier to identify the hazards that could potentially harm you"*, *"The idea of looking for specific things helped a lot"*. As a result, the number of students relying on common sense decreased from 35% to 12% and almost no student was using OSHA-gained knowledge anymore (2%). Intelligently, some students were using the energy method to complement their pre-existing hazard identification knowledge: *"I first used the common sense approach from before by identifying the hazards that jumped out at me first. After that, I used the hazard sheet that was handed out in class to identify more. Even though I got more answers from common sense, the energy sources helped me find a few more that I missed"*, *"It was much easier to use my earlier experience when I could look for the hazards inside the separate energy groups"*.

Consistent with the quantitative increase in HR skill, 61% of participants reported an improvement in their performance, and 31% stated that their performance was good: *"I think I managed to identify a majority of the hazards. I do not think that very many got away from me"*. At the same time, the number of participants dissatisfied with their performance decreased significantly from 20% on Day 3 to reach a very low level of 3%. Since spotting hazards was less of an issue, problems evoked in the learning logs shifted from basic HR concerns to more specific issues like quantifying the severity of the hazards or time management: *"I did pretty well at identifying the hazards and what they were but I have some more work to do especially on identifying the severity of the hazards"*, *"I felt confident in my performance. In fact I felt that I did not have enough time to fill out everything that I saw"*.

Day 5 (OSHA, group 2). Day 5 saw a decrease in HR scores from 36% on Day 4 to 31.4%, which as was previously evoked can be explained by the fact that students were more focused on the OSHA material they had just been taught than on the energy method while performing the HR task at the end of class. However, only 5% of participants reported to have relied on OSHA fundamentals, whereas 51% claimed to have used the energy mnemonics instruction. Consistent with Day 3's qualitative results, feedback about the OSHA lecture was very negative: *"I don't think the OSHA gave any insight in how to identify hazards, it really just taught about the structure of the OSHA department and why it was created"*, *"We talked more about policy and procedure in the OSHA lecture than we did about actual hazard recognition, so that wasn't all that useful"*. Even though they had just been given this lecture, only 6% of students reported to have used OSHA knowledge when spotting hazards.

Following the noticeable decrease in HR scores, the number of students stating they had done well went down from 31% on Day 4 to 25%. However, it is to be noted that the number of students reporting an improvement stayed almost the same as on Day 4 (60.5% instead of 61% on Day 4). This appeared clearly in the learning logs: *"I feel that my performance is getting better. I am able to identify hazards that I would not normally recognize"*, *"I felt better than I have in previous attempts, as evidenced by the fact that I ran out of time identifying hazards"*. Some students confessed an improvement but were aware that they still had considerable room for improvement: *"Definitely improving but nowhere near acceptable"*, *"I think I am improving after learning the energy method but I'm still not proficient in hazard identification"*. Finally, the number of participants stated that they had performed badly increased from only 3% on Day 4 to 14%: *"I didn't feel very well about my performance. I didn't discover a whole lot of hazards for any of the pictures"*.

Day 6 (post all treatments, whole class). Note that in order to avoid expectation biases (i.e., "this is the last one, we have to do well"), students were not aware that the sixth session was the last on in the series.

Interestingly, even though Day 6 took place almost a week after Day 4, use of the energy method remained at a high level. Indeed, almost half of the class (48%) declared using the energy mnemonics to identify hazards on that day.

Only 9% of students stated to have used OSHA-related knowledge, proving again the limitations of this form of instruction: *"I definitely am almost entirely relying upon the energy method to identify hazards. The OSHA training I received during my internship and during class I don't believe is as thorough and defined as the energy method"*, *"For this session, I think I actually relied on the energy method more than common sense and previous experiences. I did not use any information from the OSHA lecture"*, *"OSHA didn't improve our ability to identify hazards because we didn't actually learn about hazards during that lecture, only what OSHA is and does and the process of a site visit"*.

31% of students felt good about their performance, the highest level since Day 4: *"I doubt that I missed anything significant. From what I saw, I'm pretty sure I accounted for all imminent dangers as well as any latent ones"*, *"I felt great with the activity yesterday. I felt as though I almost recognized every hazard associated with the photos"*, and 49% of the class still reported an improvement in HR skill: *"With every class, I seem more capable of identifying the hazards"*, *"I feel I have improved from last time"*. Consistent with the fact that no new HR related instruction had been delivered on Day 6, and that the OSHA basics lecture on Day 5 (group 2) did not add value, 18% of students reported that their performance was the same as before: *"I feel just okay about my performance. After the OSHA lecture there hasn't been any additional information to help identify hazards"*, *"I feel I have improved since the beginning but have remained at the same level since learning the energy method"*. Only 2% of the students claimed to have performed badly.

LIMITATIONS

There were several limitations associated with this study that may compromise the replicability and validity of the results.

First, the training that was delivered cannot be perfectly standardized. This is true for both OSHA material and the energy module. Although this limitation is pervasive in the study, we did ensure that the same instructor delivered both materials and that the OSHA section followed standard OSHA guidelines.

Second, although OSHA 10-hour training focuses on hazard recognition rather than compliance, there is much content in the full 10-hour course that is not focused on hazard recognition. For this reason, one should not expect that the method would be as strong as a module solely dedicated to hazard recognition skill improvement.

Third, the study was conducted with only one class at one university, which may limit the generalizability of the results. Nevertheless, the sample size is high and there were multiple modes of both quantitative and qualitative data collection, which enabled us to explain why specific results were obtained.

Fourth, one can argue that 5 minutes is not much to identify all the hazards in a picture. It may be true, but all students were treated equally. Plus, in real life, one clearly has much less time to become aware of their environment in order to keep themselves safe. The hazard recognition process has to be quasi-instantaneous, and the updates continuous. Also, the extent to which all the hazards present in a picture had been listed by experts (i.e., the quality of the gold standard) can be questioned. But again, all participants were treated equally, and what we were tracking during our experiment was primarily the *change* in scores over time, so the absolute values themselves were not critical.

Finally, even if the photographs were of high quality, they were in black and white, which arguably can make hazard recognition slightly more difficult than with polychrome images. The same can probably be said of using static, silent pictures instead of video excerpts featuring a soundtrack. But although videos are indeed more representative of the dynamic nature of construction sites and are also more immersive, with them it becomes difficult to come up with a clear gold standard. Also, our experiment would have obviously been much more difficult to organize had we used videos.

CONCLUSIONS, CONTRIBUTIONS, AND RECOMMENDATIONS

This study offers important insights into how students acquire hazard recognition skills, which is a new line of inquiry in construction education research. In particular, the study focuses on the efficacy of a new training method, energy mnemonics, that is thought to improve the ability of an individual to recall hazards and provides a cognitive pathway to more complete scanning of an environment. The study revealed stark improvements in skill after the mnemonic was introduced in a one-hour class session. Students describe that the task of hazard recognition became easier, indicating a decrease in cognitive demand.

The study also provides a comparison between the new mnemonic and standard OSHA training. Although there is not a fair comparison, one can consider the observed difference in performance as a comparison to a control. This is necessary because one may expect an improvement in hazard recognition skill after any induction to construction safety if they were otherwise uneducated in the domain.

The results of the study indicate that the mnemonic may be an effective and efficient means for construction educators and trainers to improve students' hazard recognition skills, which can have profound impacts on their ability to forecast and respond to danger on site. This is a critical skill for new engineers and construction managers who are often given the responsibility of site safety, even if only indirectly. Because OSHA training does not appear to improve the hazard recognition skill of individuals, trainers and educators may consider complemeting their training programs with components of the proposed intervention.

The authors suggest further research into hazard recognition in construction education. This is the first specific study to address this competency, although it is critical for future engineers and managers to employ techniques like prevention through design, job hazard analyses, and safety audits. Traditional education may target an understanding of these strategies; however, the energy mnemonics may promote quality performance of such methods.

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