

Article

Leveraging ChatGPT to Aid Construction Hazard Recognition and Support Safety Education and Training

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Abstract: Proper hazard recognition is fundamental to effective safety management in construction workplaces. Nevertheless, poor hazard recognition levels are a widespread and persistent problem in the construction industry. For example, recent investigations have demonstrated that a significant number of workplace hazards often remain unrecognized in construction workplaces. These unrecognized workplace hazards often remain unmanaged and can potentially translate into devastating and unexpected safety incidents. Therefore, interventions targeted at improving hazard recognition levels are foundational to enhancing safety management in construction workplaces. The main objective of the current investigation was to examine if ChatGPT, a language model recently launched by OpenAI, can aid hazard recognition when integrated into the curriculum of students pursuing a career in the construction industry. The investigation was carried out as an experimental effort with 42 students enrolled in the construction program at a major state university in the United States. First, prior to the introduction of ChatGPT as an intervention, the pre-intervention hazard recognition ability of the students was measured. Next, ChatGPT and its capabilities were introduced to the students in a classroom setting. Guidance was also offered on how the students could leverage ChatGPT to aid hazard recognition efforts. Finally, the post-intervention hazard recognition ability of the students was measured and compared against their earlier performance. The result suggests that ChatGPT can be leveraged to improve hazard recognition levels. Accordingly, integrating ChatGPT as part of safety education and training can yield benefits and prepare the next generation of construction professionals for industry success.

Keywords: ChatGPT; hazard recognition; hazard identification; education; educational intervention; safety education; safety management; occupational safety; safety training; generative AI



Citation: Uddin, S.M.J.; Albert, A.; Ovid, A.; Alsharef, A. Leveraging ChatGPT to Aid Construction Hazard Recognition and Support Safety Education and Training. *Sustainability* **2023**, *15*, 7121. <https://doi.org/10.3390/su15097121>

Academic Editor: Hao-Chiang Koong Lin

Received: 7 March 2023

Revised: 22 April 2023

Accepted: 23 April 2023

Published: 24 April 2023



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1. Introduction

The construction industry plays a pivotal role in supporting the needs of the broader society. For example, the construction industry focuses on building and maintaining the infrastructure that we use on a daily basis [1]. This includes everything ranging from roads, bridges, and the transportation infrastructure to our homes, commercial buildings, and industrial facilities [2]. The industry also offers a career to countless workers, supports economic growth, and is foundational to environmental preservation and energy production [3]. The industry is expected to play an even greater role in the coming decades as our infrastructure needs continue to expand and nations wrestle with renovating and rehabilitating the existing aging infrastructure [4].

Despite its critical role, the construction industry reports an unacceptable number of workplace safety incidents [5,6]. Many of these incidents result in injuries that include fractures, concussions, contusions, bruises, and others [7]. Some of these injuries also result in irreversible and severe outcomes such as fatalities, permanent disability, loss of body

parts, and others [7,8]. Apart from the physical and mental trauma, these injuries adversely impact the livelihood of workers and their families [9]. These injuries also translate into much unnecessary costs that are estimated to exceed billions of dollars annually in the United States [10,11]. The injuries also translate into project delays, cost overruns, and reputational damages that deter project success [12,13].

Because of these serious adverse outcomes, much research has focused on understanding causal factors that are linked with work-related safety incidents [14,15]. Among others, a large body of research has highlighted the role of proper hazard recognition in effective hazard management and injury prevention [16–18]. These efforts argue that if hazards are left unrecognized, they can translate into unexpected hazard exposure which can potentially lead to disastrous safety incidents [17–19]. On the other hand, effective hazard recognition allows for the implementation of proactive safety measures to eliminate hazard exposure and reduce injury likelihood [17].

Unfortunately, evidence suggests that poor hazard recognition levels are a widespread and persistent problem in construction workplaces [15,16]. In fact, evidence suggests that over 40% of safety hazards may remain unrecognized in typical construction workplaces [17,20–23]. Moreover, past research has demonstrated that all construction industry stakeholders—whether workers, engineers, managers, or superintendents—lack effective hazard recognition skills [16,24,25]. Poor hazard recognition levels are even more concerning among students newly entering the construction workforce [25,26].

In light of these concerning patterns, efforts targeted at enhancing hazard recognition skills are urgently needed for effective injury prevention and industry success. The current investigation focused on testing whether ChatGPT, a newly launched language model with versatile applications, can aid construction hazard recognition and support safety education for students pursuing a career in the construction industry.

This research fits the scope of sustainability in the context of infrastructure projects as worker safety is increasingly being acknowledged for its importance in achieving holistic sustainability goals [27]. Agencies such as the U.S. Green Building Council and the National Institute for Occupational Safety and Health have offered clarity on the necessity of integrating safety issues as part of sustainability considerations in infrastructure projects and beyond [28,29].

2. Background

2.1. Construction Hazard Recognition

Effective hazard recognition is fundamental to maintaining a safe and productive work environment in the construction industry [18,19,30]. This involves examining the workplace for hazardous conditions that can cause harm or injury and adopting appropriate hazard management initiatives [30,31].

Several tools have been developed to aid hazard recognition efforts. These include tools such as safety checklists and job hazard analyses (JHA) templates [32,33]. While they are useful, these tools suffer from important weaknesses that have been discussed in great detail in previous efforts [30,31,34–36]. For example, safety checklists may only encompass a finite number of safety hazards and may not fully capture the range of potential hazards in complex work environments [24,37]. On the other hand, job hazard analyses (JHA) that require workers to catalog hazards that are linked with specific tasks operate under the assumption that workers possess innate proficiency in hazard recognition, despite evidence suggesting otherwise [24,30].

Safety training efforts are also commonly adopted to improve safety performance and hazard recognition levels. Although beneficial, research has demonstrated that construction workplaces largely adopt poor safety training practices [38–40]. These training programs largely fail to sufficiently engage workers [38,41]. Consequently, traditional safety training efforts do not yield desirable levels of safety performance or hazard recognition levels [17].

Because of these issues, many safety hazards in construction workplaces remain unrecognized. For example, investigations from construction workplaces in the United States

reveal that over 40% of safety hazards may not be recognized in traditional workplaces [20,21,42]. Likewise, estimates from Australia suggest that up to 57% of safety hazards can possibly remain unrecognized [22]. Similar patterns of poor hazard recognition have been highlighted in construction workplaces across nations and geographical regions [16,18,22,23,43].

As already discussed, these unrecognized hazards can possibly translate into devastating safety incidents [18,30]. In fact, empirical evidence suggests that over 70% of work-related injuries in construction workplaces may be attributed to human factors such as poor hazard recognition ability [44]. Evidence also suggests that individuals are more likely to indulge in risky behavior when they do not recognize safety hazards that can cause harm [42,45].

Given the prevalence of poor hazard recognition levels and the potential consequences, research targeted at enhancing hazard recognition levels is urgently needed for the success of the construction industry. These efforts can dramatically reduce workplace safety incidents and protect the otherwise vulnerable construction workforce.

2.2. Construction Safety Education and Training

Construction professionals play a vital role in protecting the workforce and maintaining safe work operations in construction workplaces [46]. Among their many roles, these professionals are expected to develop effective safety management plans, foster a positive safety climate, and comply with federal, state, and local safety regulations [46–49]. They are also often tasked with optimizing work schedules to minimize safety risks, conducting regular site inspections and audits, and adopting field-level best practices to reduce safety risks while maintaining productivity goals [26,48,50]. In fact, as per OSHA's general duty clause, construction professionals are expected to serve as agents to their employers by offering safe workplaces for their other employees and field workers [19,51].

More recently, construction professionals are also being hired as consultants during the design phase to improve worker safety [52–54]. This approach, commonly known as Construction Hazard Prevention through Design (CHPtD), involves a collaborative effort between construction and design professionals to select safer design solutions with consideration for the safety of field workers [55–57]. On the basis of evidence linking poor design choices and safety incidents, many nations are requiring the consideration of safety during design through legislative reforms [58–62].

Given the importance of safety in construction project success, employers are seeking professionals with sufficient proficiency in recognizing and managing safety hazards in construction workplaces [63–65]. In fact, a survey of 45 industry stakeholders confirms that safety competency is the top skill sought among future construction professionals seeking to enter the workforce [66]. However, the current education curriculum is largely deficient in incorporating adequate safety content due to various reasons [67,68]. Barriers to the incorporation of safety content in the curriculum include limited resources, curriculum limitations, time constraints, and competing priorities [69–72]. Because of these barriers, much of the students graduating from construction programs remain unprepared for the safety challenges that the industry presents [26,71,73].

Although some universities and educational institutions are increasingly acknowledging the importance of safety in their curricula [74], there remain concerns about the widespread adoption of poor educational and training approaches. For example, a significant amount of research on safety education and training has emphasized the widespread utilization of lecture-based instructional methods [26,75,76]. These instructional methods have been discovered to be inadequate in promoting student engagement and have been labeled as “boring”, “passive”, “uninspiring”, and “monotonous” by many scholars [38,41,72,77,78]. Many experts and scholars have advocated for change and have called for replacing these passive instructional methods with more active and self-directed instructional approaches [42,75,79]. Others have proposed that the more prevalent pedagogical instructional methods that are more suitable for young children be replaced with

analogical approaches that are more suitable for adult learners—particularly those seeking a career in the construction industry [39,80–82].

Partly because of these issues, there is a shortage of construction professionals that are sufficiently competent in managing workplace safety [73,83]. This is evident in research that has shown that construction managers, engineers, and superintendents lack sufficient hazard recognition and management skills [24]. In fact, evidence demonstrates that these key industry stakeholders, similarly to field workers, fail to recognize a large proportion of safety hazards that can cause harm [16,25,30]. As a result, their ability to effectively oversee and maintain a safe work environment is compromised [21,30,42]. Therefore, educational and training programs must undergo revision and enhancement to adequately prepare future construction professionals (i.e., current students) to meet the safety challenges the industry presents.

2.3. Leveraging ChatGPT for Safety Education and Training

Since its launch by OpenAI in November 2022, ChatGPT has been capturing widespread attention and has become extremely popular [84]. It is a conversational language model capable of generating text that is coherent, grammatically sound, and fluent in response to a range of prompts and queries [85,86]. In just two months after its release, ChatGPT amassed over 100 million users, becoming the fastest-growing consumer application in history, surpassing the previous records set by well-known platforms such as Twitter, Facebook, and Instagram, among others [87].

The power and versatility of ChatGPT have been harnessed for numerous applications. For example, students utilize it to comprehend challenging course material [88,89], software developers employ it to troubleshoot computer code [90,91], and professionals rely on it to draft their emails [92]. In addition, ChatGPT has assisted researchers in conducting literature reviews [93,94], aided marketing experts in creating advertising campaigns [95,96], and facilitated script creation for musicians and filmmakers [97,98]. More recently, evidence has emerged suggesting that ChatGPT can perform successfully in various exams. For instance, it can outperform a significant number of students in the Wharton MBA exam [99], pass the University of Minnesota law exam [100], and succeed at the U.S. Medical Licensing Exam (USMLE) [101–103].

Generative Artificial Intelligence (AI) technologies such as ChatGPT are poised to have a significant impact on various industries such as healthcare, finance, and law. In healthcare, ChatGPT's ability to extract billable procedures from physician notes can streamline the process of filing insurance claims [104,105]. In finance, ChatGPT can provide personalized investment advice based on an individual's risk tolerance and market conditions [106]. Likewise, ChatGPT can serve as a personal virtual lawyer and assist in creating legal documents including contracts, wills, and disclosures [107].

Given its capabilities, ChatGPT has the potential to transform and revolutionize education. Despite this, it has faced considerable criticism among educators and related stakeholders. Among others, one of the primary concerns is that students may use ChatGPT to complete their essays and assignments instead of submitting their own work [108–110]. There are also worries related to cheating during exams, which has highlighted the need to revise traditional testing methods [111,112]. As a result of these concerns, a number of educational institutions have prohibited the use of ChatGPT on their campuses to maintain academic integrity and prevent plagiarism [113,114].

Despite these concerns, ChatGPT holds extraordinary potential as an educational tool. For example, it can serve as a private tutor that customizes learning experiences per the unique needs and learning styles of students [115,116]. ChatGPT can also offer answers to questions that students may have as they attempt to learn new and challenging concepts [117,118]. ChatGPT can also facilitate language learning and comprehension by offering text translation services in a learner's preferred language of choice [119].

In the context of construction education, ChatGPT can offer valuable and informative responses to questions such as “how does the construction industry serve the broader

society?”, “what is the role of a construction engineer or manager?”, and others that may be of interest to students. More specific to construction safety, ChatGPT can offer useful content on common hazards that construction workplaces pose, hazards that can be expected when a specific work operation is undertaken (e.g., welding, excavation, etc.), and hazards that can be introduced when particular pieces of equipment are used (e.g., crane forklift, etc.). ChatGPT can also potentially offer safety best practices that are appropriate for specific work situations.

Based on this evidence, the current study aims to investigate the possibility of integrating ChatGPT into the field of safety education and training. More specifically, this study seeks to examine if ChatGPT can be leveraged to aid construction hazard recognition in the context of construction operations.

Despite its strength, it is important to note that there are important weaknesses of ChatGPT that are acknowledged in the broader literature. For example, as acknowledged by OpenAI, ChatGPT occasionally generates incorrect information, biased content, and even harmful instruction [84]. Evidence also suggests that ChatGPT can present incorrect citations to sources that appear legitimate [120]. Users have also referred to the fact that ChatGPT generates non-identical responses to the same query or prompt given its characteristics as a generative AI platform [121]. Accordingly, different users may be presented with non-identical responses to similar prompts and the same user may receive non-consistent information when the same prompt is used multiple times.

Nonetheless, given that ChatGPT has been found to offer useful responses that are beneficial in a wide variety of applications as discussed above, the investigation examined the usefulness of ChatGPT in the context of workplace safety. The following sections present the approach taken to accomplish the objectives of the study.

3. Research Methods

The research objective was achieved through an experimental investigation involving 42 undergraduate students enrolled in the construction program at North Carolina State University’s Department of Civil, Construction, and Environmental Engineering. The participants were recruited by soliciting participation from all of the sophomores and juniors enrolled in the program. The effort resulted in the successful recruitment of over 90% of the sophomores or juniors enrolled in the construction program that were expected to enter the construction industry within the next three years. Approximately 81% of the students possessed less than one year of experience in the construction industry. Of the remaining participants, roughly 12% had less than three years of construction experience, while 7% possessed between three and eight years of relevant experience.

After the study participants were recruited, the study was conducted in a single 75 min session involving three stages as shown in Figure 1. The first stage focused on assessing the baseline hazard recognition ability demonstrated by the students which represented the pre-intervention stage. The second stage involved the introduction of ChatGPT as an educational intervention. Subsequently, the third stage focused on once again evaluating the hazard recognition ability demonstrated by the students which represented the post-intervention stage.

The experimental approach adopted in the current study offers several advantages. Its repeated-measures within-subject design, which compares the performance of the same participants before and after the intervention, controls for extraneous variables such as age, prior experience, and individual cognitive differences that were not of interest in the current investigation [122,123]. This form of “control by design” results in higher statistical power when compared to a between-subjects design with the same number of study participants [124]. Accordingly, such an approach offers the ability to make stronger causal claims concerning the intervention with a relatively smaller sample [125,126].

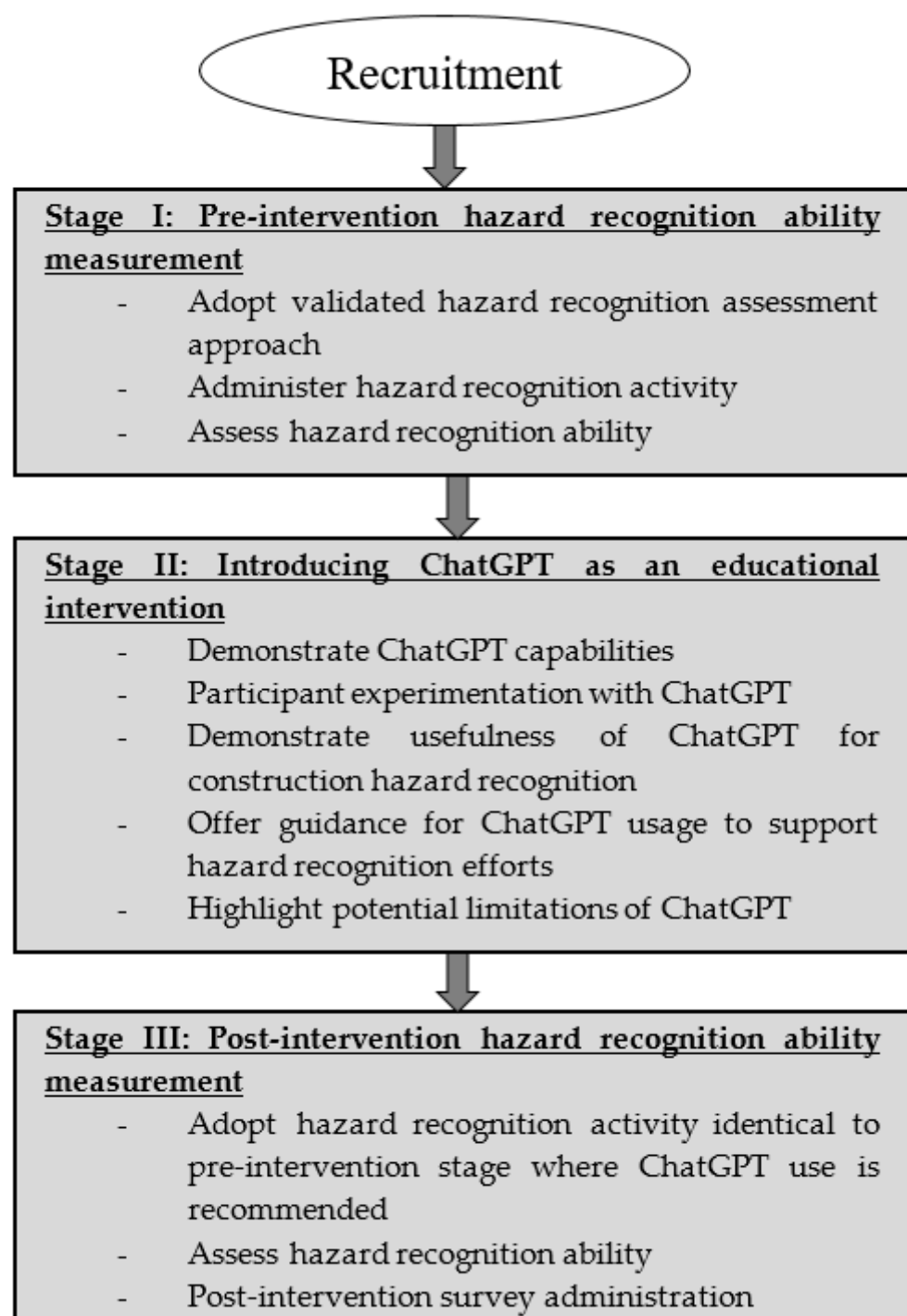


Figure 1. Research stages summary.

Apart from the main benefits, the experimental design also ensured that a specific group of participants (e.g., the control group) was not omitted from receiving the valuable and promising intervention, that has proven to be effective in many other areas [127,128]. By not designating an exclusive control group, all participants were allowed to receive and potentially benefit from the intervention. Furthermore, conducting all three stages of the experiment (i.e., pre-intervention, intervention implementation, and post-intervention stages) within a single 75 min session prevented external factors, such as concepts learned in other construction classes or student internships, from affecting the outcome of the study. This further enabled the drawing of strong causal conclusions. The next sections present

the three stages (i.e., pre-intervention, intervention implementation, and post-intervention stages) in detail.

3.1. Stage I: Pre-Intervention Hazard Recognition Ability Measurement

The hazard recognition ability demonstrated by the participating students was assessed using a hazard recognition activity at the pre-intervention stage. For this purpose, a previously validated approach for hazard recognition assessment was adopted [20]. More specifically, 16 case images that were selected from a pool of over 100 case images captured from real construction workplaces in the United States as part of a previous investigation were used. The case images depicted various construction operations including pipe laying, stud welding, excavation and trenching, steel welding, concrete pipe cutting, crane rigging and lifting, and others. The case images were reviewed by 17 safety professionals with a collective experience that exceeded 300 years as part of the previous investigation, and hazards represented in each of the case images were collaboratively pre-identified. The selection criteria for these safety professionals included a minimum of 10 years of occupational safety experience in the construction industry setting. Each of the case images included at least five safety hazards that posed risk for injuries. These case images along with the set of pre-identified hazards were leveraged to facilitate the hazard recognition activity planned for the current investigation. Figure 2 presents an example case image along with the corresponding pre-identified hazards for illustrative purposes.

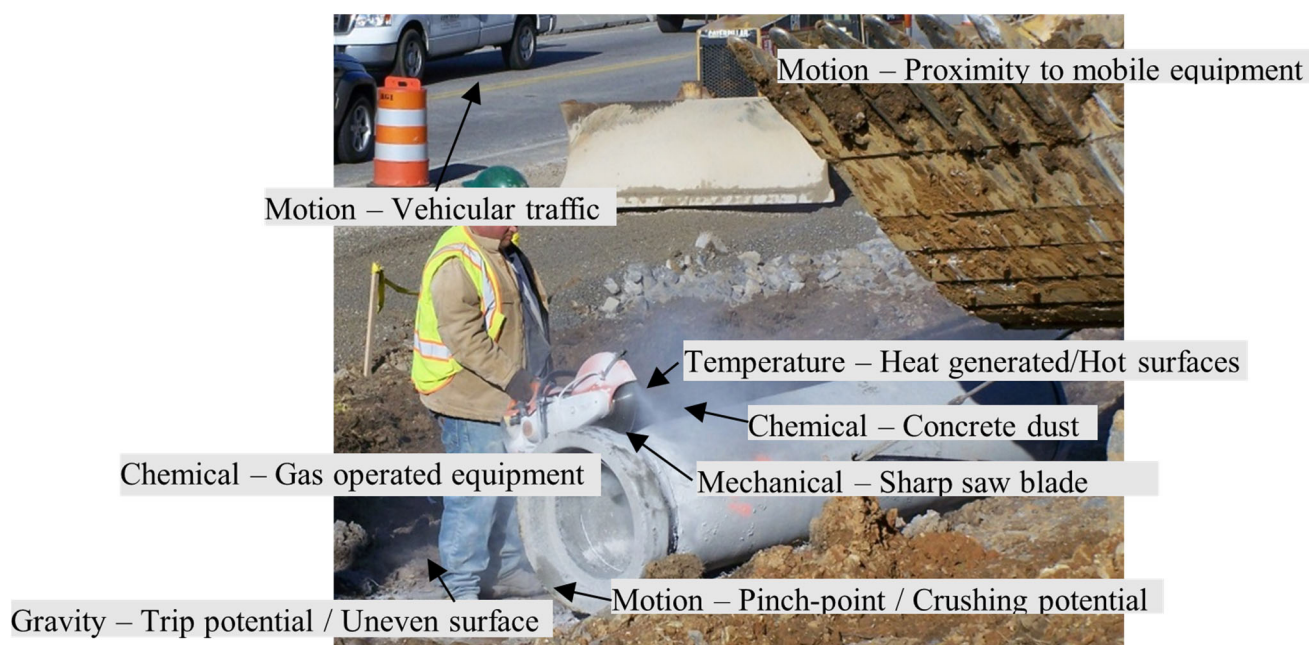


Figure 2. Example of case image with pre-identified safety hazards.

For this study, four distinct construction case images were randomly chosen from the larger set of 16 and shown to the participant to evaluate their pre-intervention hazard recognition ability. More specifically, the participants were requested to examine the case images and report all relevant hazards that can cause harm in writing. The students were offered 20 min for the hazard recognition activity and were asked to use arrows along with the textual description of the hazard as shown in Figure 2.

Based on the responses, a hazard recognition performance score was computed for each of the case images examined by each of the study participants using Equation (1).

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

As can be seen, the numerator represents the number of unique hazards that each study participant recognized in the context of a particular case image. On the other hand, the denominator represents the total number of unique hazards that are represented in a particular case image which consisted of the hazards collectively reported by the safety professionals in the previous investigation.

Next, the hazard recognition ability of each of the study participants was computed as the average hazard recognition performance demonstrated across the four examined case images.

3.2. Stage II: Introducing ChatGPT as an Educational Intervention

After the data from the pre-intervention phase was captured, the students were then introduced to ChatGPT as an intervention. As a first step, the capabilities of ChatGPT were demonstrated to the students. For this purpose, ChatGPT was opened and presented to the students via a projector screen. The students were then shown that ChatGPT can answer most questions that students may have. As an example, the question “What are the various sectors in the construction industry?” was input into ChatGPT. ChatGPT offered the response presented in Figure 3.

A

What are the various sectors in the construction industry?



The construction industry can be broadly divided into the following sectors:



1. Residential Construction: This sector involves building homes, apartments, and other residential structures.
2. Commercial Construction: This sector involves constructing non-residential structures like offices, retail stores, restaurants, and other commercial buildings.
3. Industrial Construction: This sector involves constructing facilities like factories, warehouses, power plants, and other industrial buildings.
4. Infrastructure Construction: This sector involves constructing public works projects like highways, bridges, tunnels, airports, and other essential infrastructure.
5. Heavy Construction: This sector involves constructing large-scale projects like dams, tunnels, and other massive structures.
6. Specialty Construction: This sector involves constructing unique and specialized structures like sports stadiums, museums, and other buildings with specific requirements.

Figure 3. ChatGPT response exhibit #1.

Next, the question “What is the role of a construction engineer or manager?” was typed into ChatGPT. A snippet of the response generated by ChatGPT is presented in Figure 4.

Having introduced the students to ChatGPT, the students were asked to open ChatGPT via the OpenAI API and the students were asked to create an account if they already did not have one. They were encouraged to experiment and interact with the ChatGPT interface and become familiar with its capabilities. A few example questions that the students could possibly use as prompts to learn more about ChatGPT were offered to the students. The example questions included: “What is ChatGPT? What are its capabilities?”, “What are key skills that construction engineering and managers must possess?”, and “Give some examples of construction engineering marvels”.

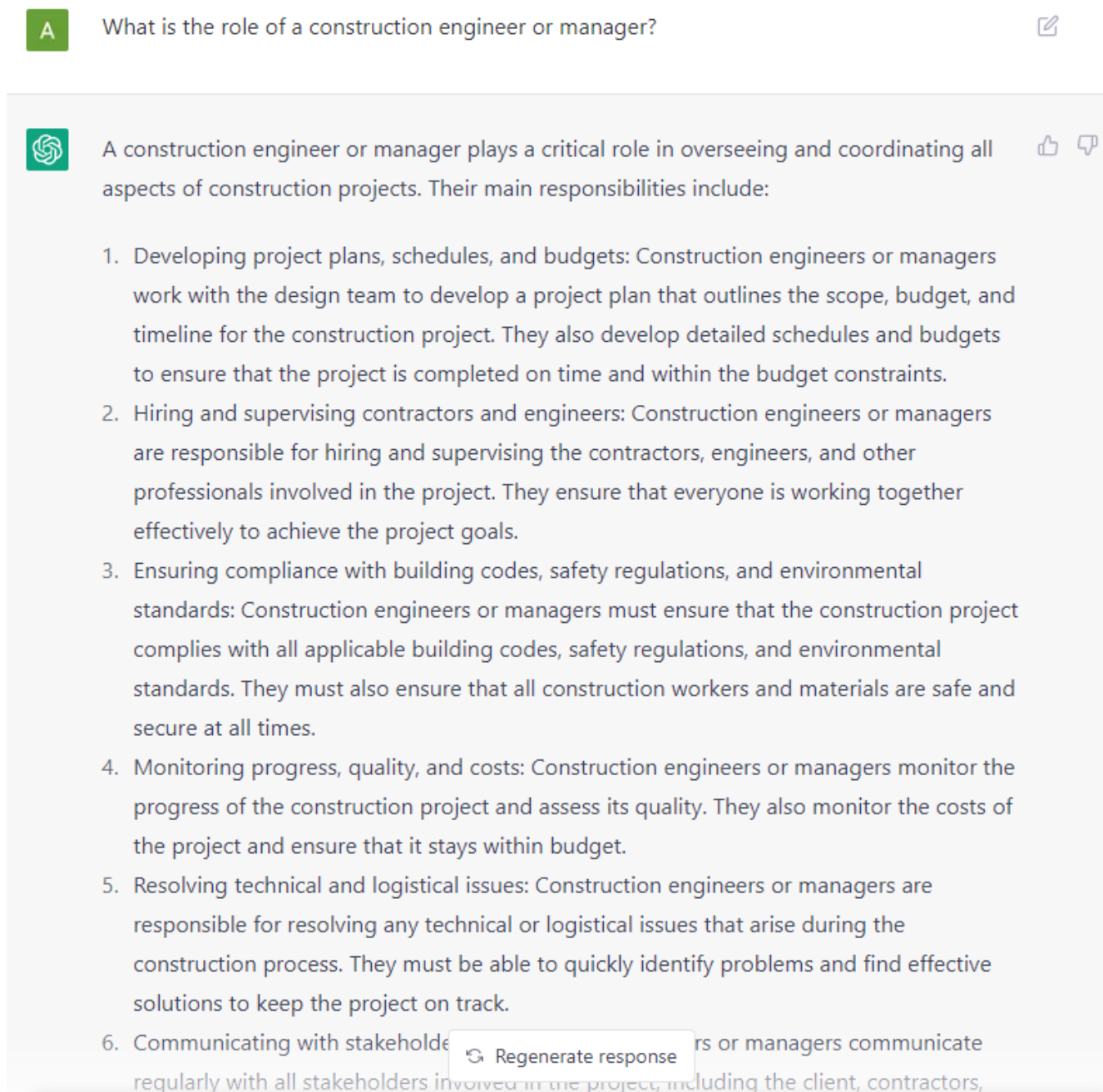


Figure 4. ChatGPT response exhibit #2.

Having exposed students to the capabilities of ChatGPT, the potential usefulness of ChatGPT as a tool to aid with construction hazard recognition was demonstrated to the students. For this purpose, the students were again directed at the projector screen and the following prompt was presented to ChatGPT “Share detailed examples of common construction hazards”. ChatGPT offered the following response (i.e., Figure 5) that the students were encouraged to examine closely:

A Share detailed examples of common construction hazards

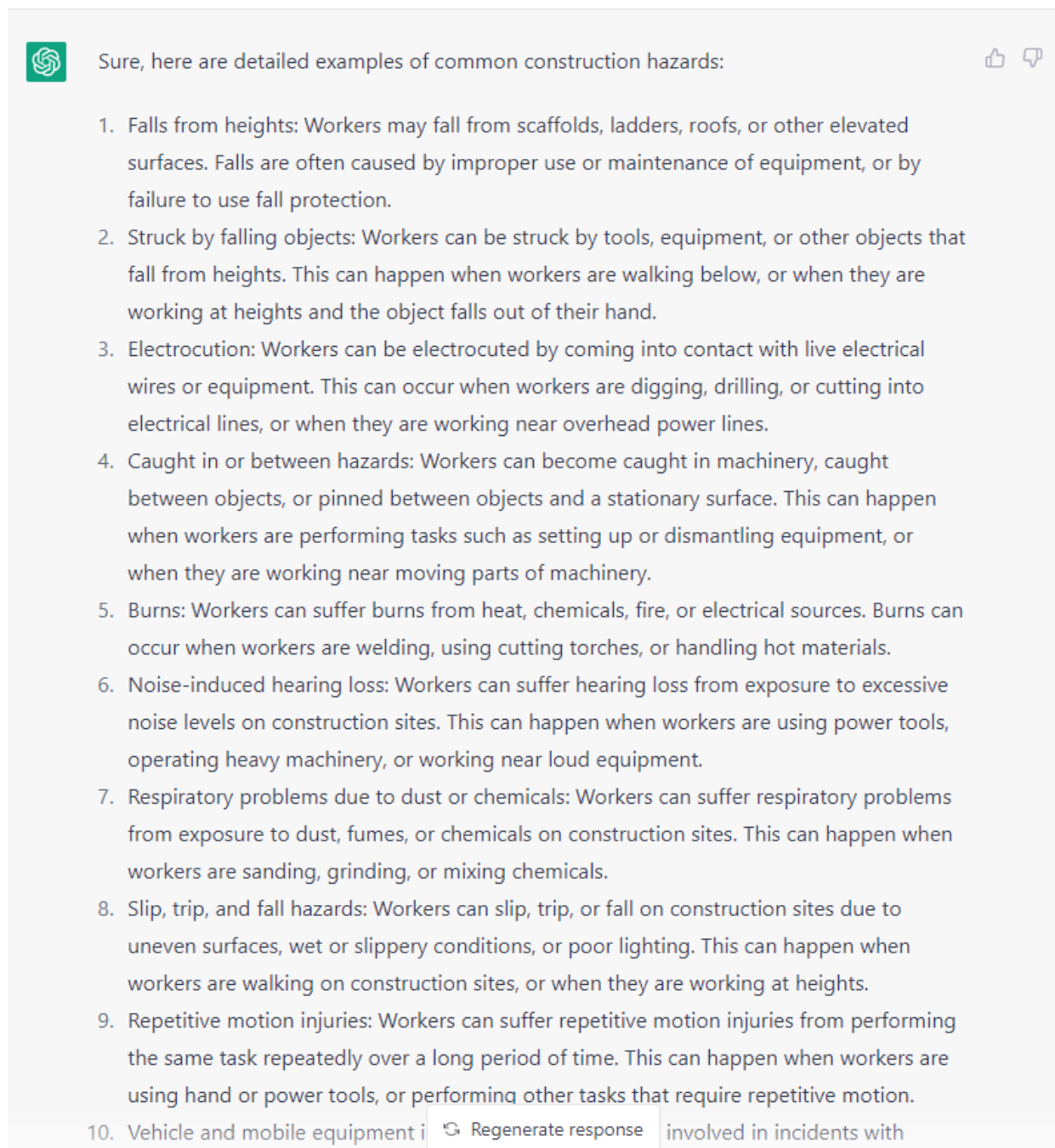


Figure 5. ChatGPT response exhibit #3.

The capabilities of ChatGPT to offer guidance in the context of specific work operations were also demonstrated to the students. More specifically, a case image not part of the 16 images used in the pre-intervention stage that depicted a welding operation was shown to the students and then the question “*What hazards can one expect as part of welding operations?*” was submitted to ChatGPT. ChatGPT presented the response shown in Figure 6 which was briefly discussed with the students.

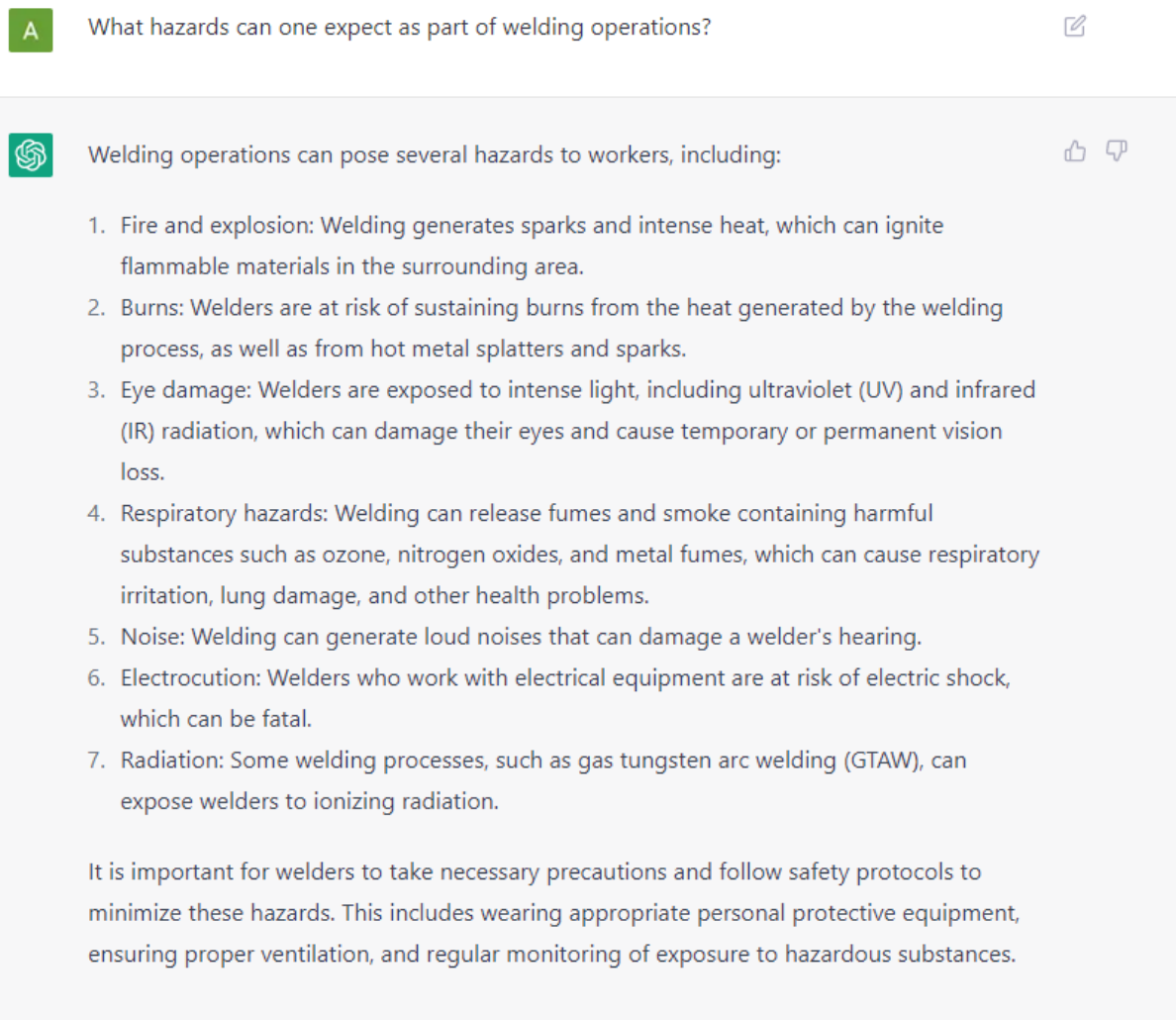


Figure 6. ChatGPT response exhibit #4.

Next, the students were offered some guidance on how they could possibly leverage ChatGPT to aid with hazard recognition via a handout for real-world practical situations. The guidance included the following statements:

As you engage in hazard recognition efforts, consider utilizing ChatGPT for assistance. For example, you may use the following example prompts or any others that you believe could be beneficial, as you work on cataloging relevant hazards:

- *Present common construction hazards in general (as demonstrated in the class earlier);*
- *Present hazards posed by a specific work operation (e.g., welding, excavation, etc.);*
- *Present hazards posed by specific pieces of equipment or tools (e.g., cranes, nail guns, etc.).*

Finally, before engaging students in the post-intervention tests, the possible limitations of ChatGPT were highlighted to the students. This included that ChatGPT may occasionally generate incomplete, inaccurate, or biased results as is the case with most AI tools.

3.3. Stage III: Post-Intervention Hazard Recognition Ability Measurement

After ChatGPT was introduced as an intervention, a post-intervention hazard recognition activity that was identical to the hazard recognition activity in the pre-intervention test was adopted. One difference in the post-intervention stage was that a new set of four randomly selected case images from the initial set of 16 was provided for the hazard recognition activity for each of the students. Care was taken to ensure that the individual participants did not examine any case images they had seen in the pre-intervention

stage. Another difference from the pre-intervention stage is that the students were then recommended to use ChatGPT as they participate in the hazard recognition activity per the guidance offered in Stage II.

Similarly to the pre-intervention data, the hazard recognition performance for each participant that corresponded to each case image was computed using Equation (1). Next, as was the case with the pre-intervention stage, the hazard recognition ability for each of the study participants was once again computed as the average hazard recognition performance across the four examined case images.

After the hazard recognition activity, the students were asked to provide the degree with which they agree with the following statement “*ChatGPT can aid construction hazard recognition and support safety education and training efforts*” using a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree). In addition, based on their experience with ChatGPT in the context of construction hazard recognition and safety education and training, the students were asked to provide the degree with which they agree with the following statements using the same five-point Likert scale. The statements were selected to assess the students’ experience of using ChatGPT and were informed by scales such as the System Usability Scale (SUS), the Technology Acceptance Model (TAM), the Technology Acceptance and Usage Questionnaire (TAUQ), the User Satisfaction Questionnaire (USQ), and the Post-Study System Usability Questionnaire (PSSUQ).

- ChatGPT is easy to access, use, and navigate;
- The information offered by ChatGPT is clear, relevant, trustworthy, and reliable;
- I am satisfied with my experience of using ChatGPT;
- I plan to use ChatGPT in the future for educational and training purposes;
- I would recommend that ChatGPT be adopted more widely.

Finally, the students were asked to offer any complementary comments on their experience of using ChatGPT in the context of construction hazard recognition and safety education. Response to this final question was optional.

4. Data Analysis and Study Results

Based on the methods discussed above, a unique hazard recognition ability score for each of the study participants was obtained for both the pre-intervention and post-intervention stages. A two-sample dependent or repeated-measures test was planned for adoption to assess whether ChatGPT led to any statistical change in the demonstrated hazard recognition ability.

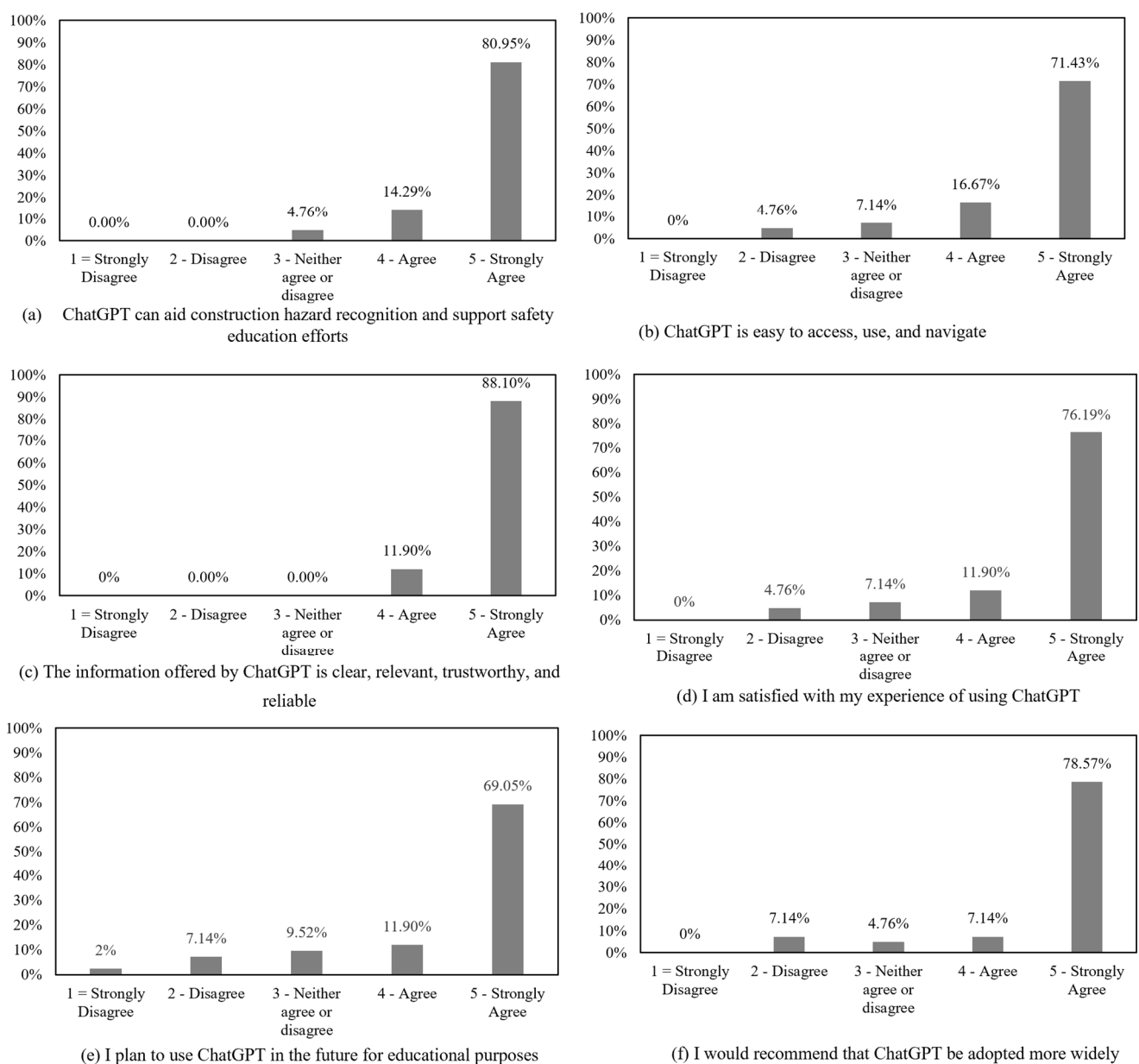
Before choosing the appropriate statistical test, the necessary statistical assumptions were tested. The test for normality using the skewness and kurtosis test suggested that the distribution of the data was not particularly skewed nor was it leptokurtic or platykurtic. Accordingly, the assumption of normality was accepted for the analyses.

Given that normality was accepted, the parametric paired *t*-test was adopted instead of the non-parametric Wilcoxon signed-rank test [129]. The results are presented in Table 1. As can be seen in Table 1, prior to the introduction of ChatGPT as an intervention, the students recognized less than 35% of the hazards. However, after having experienced the intervention, the students were able to recognize more than 60% of the hazards. This represents an improvement of over 25%. The associated *t*-test statistic and the relevant *p*-value suggest that this difference is statistically significant and cannot be attributed to random variability or chance. Therefore, the evidence suggests that ChatGPT can indeed aid construction hazard recognition and support safety education and training efforts. Because a repeated-measures within-subject design was adopted, this suggests that regardless of any variability in demographic information, such as age and experience among the study participants, ChatGPT offered significant benefits by aiding the participants with hazard recognition.

Table 1. Effect of ChatGPT on hazard recognition ability.

Conditions	Mean	Standard Deviation	<i>t</i> -Test Statistic	<i>p</i> -Value
Pre-intervention Hazard Recognition Ability	34.87%	5.68%	−18.248	<0.01
Post-intervention Hazard Recognition Ability	60.26%	8.60%		

Figure 7 shows the degree to which the students agreed with the statements presented to them. As can be seen in Figure 7, over 95% of the students either agreed or strongly agreed that ChatGPT can aid construction hazard recognition and support safety education and training efforts. Similarly, most students agreed or strongly agreed that ChatGPT is easy to access, use, and navigate.

**Figure 7.** Statement responses.

All study participants either agreed or strongly agreed that the information offered by ChatGPT is clear, relevant, trustworthy, and reliable in the context of their experience in the current investigation. Most students also were satisfied with their experience of using ChatGPT and planned to use ChatGPT in the future for educational and training purposes. Finally, over 88% of the study participants recommended that ChatGPT be adopted more widely.

Examining the comments that the students shared at the study's conclusion, 18 statements were received. Many of the statements were positive with many suggesting that the adoption of ChatGPT will be useful in practice, was fun to adopt in the classroom, and will be valuable for applications beyond hazard recognition and safety education. Example statements offered by the students include the following:

"I could not think of many hazards before using ChatGPT. ChatGPT helped me think about hazards that I would have otherwise overlooked."

"ChatGPT offered examples of construction hazards to watch out for. That guidance was super helpful."

"This should absolutely be used in the industry. Will help improve safety."

"I can see how this will help in the industry for safety planning. I will be using it. Thank you for the class activity."

"Thank you, Prof. [Name] for introducing us to this tool. This will help beyond this class and at work. This was a fun and unique class. We need more of these classes."

"I found ChatGPT to be enjoyable to use in class. It is a tool that has proved to be extremely useful and helped with hazard reporting"

"Extremely useful service. The future is exciting. These tools are so helpful"

"ChatGPT is awesome. Way cooler than Google."

Some of the comments were not positive. These comments largely expressed that ChatGPT did not function as desired as part of the activity. One comment expressed frustration with the need to create an account to access ChatGPT. Examples of these comments included:

"The software was at capacity and did not allow access initially"

"I was simply not able to get ChatGPT to work until it worked after more than 10 min"

"Why is it necessary to create an account to access this application. Should be accessible without one."

"AI is sketchy and dangerous"

One comment suggested a potential improvement that can be made to ChatGPT in the future. The comment suggested that it would be helpful if ChatGPT could automatically detect hazards if relevant case images depicting specific work operations were uploaded. The comment is reproduced below:

"I wish ChatGPT was more capable. It would be nice if I could upload the photographs to ChatGPT and it automatically detects and reports hazards and safety measures that I need."

Finally, one comment suggested that the student was unable to effectively leverage the potential of ChatGPT because the work operations depicted in the case images were either unclear or not evident to the student. The comment shared by the student is as follows:

"I couldn't figure out what work was going on. I could not get the help of ChatGPT for this reason. More information about the work will be needed."

From the above comment, it appears that the student was unable to leverage ChatGPT in the context of the specific task as was illustrated to the students as captured in Figure 6.

5. Study Contributions and Implications

The reported investigation makes a number of important contributions that have practical implications. First, the study demonstrates that ChatGPT can be leveraged in the classroom for educational and training purposes and such efforts can result in tangible benefits. While much of the previous discussions among academics have highlighted concerns such as plagiarism and cheating among students in the context of ChatGPT [110–112], the current study demonstrates that educators can successfully adopt ChatGPT in a classroom setting to fulfill important curriculum goals.

Second, the study findings suggest that the educational experience of using ChatGPT can be largely positive for students and can serve as an engaging form of knowledge dissemination. Such engaging and participatory educational experiences are particularly important given evidence that traditional instructional methods that are largely based on classroom lectures often fail to engage or kindle interest among students in the subject matter [41,42,75]. Educators and trainers now have the opportunity to utilize ChatGPT as a unique and appealing instructional method that can enhance the learning experience for students.

Third, the current investigation demonstrates that ChatGPT can be leveraged to specifically enhance the hazard recognition ability of students that seek to establish a career in the construction industry. Based on the reported findings, construction educators and trainers may offer ChatGPT as an intervention to their students and employees to prepare them for industry success. In the same manner, students and employees can adopt ChatGPT on their own as they prepare themselves for a successful career, given that third-party instructors are not necessary to leverage the capabilities of ChatGPT. Given that poor hazard recognition levels are widespread and are linked with a significant number of work-related injuries [18,30,44], such interventions can not only translate to superior hazard recognition levels, but can also possibly result in fewer workplace injuries and higher-quality workspaces. It is important to note that while the investigation focused on students enrolled in a construction program, ChatGPT may also be useful for other populations including new construction professionals and related stakeholders that are less proficient with specific field operations or related safety hazards. ChatGPT may also likely be useful for experienced professionals and workers given the evidence that these populations fail to recognize a large proportion of safety hazards [20,21,42].

Fourth, the study indicates that ChatGPT can serve as a cost-effective educational and training tool for students and possibly for working professionals in the context of occupational safety. This is particularly useful given that evidence suggests that employers often do not adopt effective training practices given concerns related to the associated costs [39]. Such concerns are particularly heightened in the construction industry because of the temporal nature of projects that leads to a transitional workforce that generally changes employers after a project is completed [130]. Existing research also suggests that employers are often concerned that their workforce which is offered effective and expensive training may simply be attracted and hired by their competitors that do not invest in offering their own training and educational experiences [131,132]. ChatGPT offers the ability to overcome these industry barriers against adopting effective training and educational experiences.

Fifth, the current study highlights the importance of integrating safety education and training into the curriculum of future construction engineers and managers. More specifically, the current investigation demonstrated that the participating students that are expected to be future construction engineers and managers recognized less than 35% of relevant hazards in the context of work operations. Given the link between poor hazard recognition levels, poor safety management, and increased likelihood of injuries, the current study demonstrates the importance of integrating learning experiences that will enable future professionals to offer a safer and more productive workplace for the construction workforce.

Finally, even after the adoption of ChatGPT, the current study demonstrates that students failed to recognize roughly 40% of the safety hazards. To address this issue, complementary educational and training approaches may need to be offered. For example, previous results have shown that a proper understanding of the tasks that are being performed is fundamental to informing hazard recognition efforts [30]. In fact, one of the students mentioned that they were not familiar with the task depicted in the case image to successfully leverage the capabilities of ChatGPT to aid with hazard recognition. Likewise, it is unlikely that individuals can effectively recognize hazards or leverage the capabilities of ChatGPT when they are unfamiliar with the tools or pieces of equipment used for specific construction operations. For example, if an individual recognizes that nail guns are being used for a specific work operation (e.g., roof work), they may prompt ChatGPT to offer insights on the safety risks posed by nail guns. On the contrary, if an individual is unable to recognize the tool or piece of equipment being used, they may fail to use effective prompts to arrive at a useful response from ChatGPT. Providing complementary education and training for future professionals targeted at identifying common work operations, equipment, and tools can enhance their ability to effectively utilize ChatGPT and further enhance hazard recognition performance.

6. Study Strengths, Limitations, and Proposed Future Research

Apart from the discussed contributions and implications, the study also possesses several noteworthy strengths that are worth mentioning. One of the primary strengths is its utilization of a repeated-measures within-subject experimental design, which provided enhanced experimental control and increased statistical power. This offered the ability to make strong inferences and conclusions with fewer study participants, compared to what would have been required if a between-subjects experimental approach had been utilized.

Furthermore, by conducting the pre-intervention, intervention, and post-intervention stages within a single 75 min session, it was possible to minimize the impact of any external factors—such as material learned in other classes or internship opportunities—from influencing the study results. In fact, this offered the ability to overcome the ethical dilemma of assigning a group of students to a control group that may have been deprived of a valuable and beneficial intervention.

While there are strengths, there are also limitations of the study that can possibly be addressed in future investigations. The most significant limitation is that case images that are representative of work environments were used in the current investigation. While the approach offered a standardized and tested approach to assess hazard recognition ability, future research could possibly be performed in real workplaces. However, such an approach will pose challenges with gaining access to worksites, transporting all the study participants, and having a uniform and reliable approach to measure hazard recognition ability. Moreover, there are liability concerns that are associated with having study participants in high-risk work environments where there is the potential for injuries. Despite this limitation, previous research has suggested that hazard recognition performance measured using case images is indicative or highly correlated with hazard recognition performance captured in real workplaces [20]. More specifically, an individual that is able to recognize a relatively larger proportion of hazards in case images can generally recognize a relatively larger proportion of hazards in the real world [20].

Finally, the study participants were recruited from one university in the United States. Therefore, the generalization of the findings beyond the university may not be possible based on the reported study. Future efforts may possibly target a larger number of students from various universities and possibly across nations. Introducing such an intervention would also yield generalizable results apart from better preparing students to manage safety hazards in the work context. Future efforts may also target other populations including new and experienced professionals, field workers, and other industry-relevant stakeholders.

Additional research is also needed to better understand the capabilities and deficiencies of ChatGPT and other emerging generative AI models for safety applications. Particular

attention should be targeted towards deficiencies given the criticality of workplace safety and its implications. These investigations are necessary given previous evidence that ChatGPT can offer incorrect information, biased content, harmful instruction, and inconsistent content [84,120,121]. Moreover, users of these generative AI platforms must be informed of these deficiencies apart from its strengths to responsibly leverage them for practical applications. It is noted that in the current investigation, all of the study participants either agreed or strongly agreed that the information offered by ChatGPT is clear, relevant, trustworthy, and reliable. However, this has not been the experience of all users of ChatGPT as reported by various sources [120,121]. Given the limited scope of the reported investigations, future efforts may examine ChatGPT's abilities and deficiencies in other safety related contexts apart from hazard recognition.

Finally, while the current investigation demonstrates that ChatGPT can aid with hazard recognition, the mechanism by which this is achieved may warrant additional investigation. For example, the observed improvement in hazard recognition could possibly be attributed to ChatGPT's ability to generate items similar to a checklist that serves as cues to support hazard recognition. More specifically, ChatGPT can generate a list of hazards that one needs to look out for in the context of any work operation (e.g., welding, excavation, and others), equipment use (e.g., crane, forklift, and others), or field setting (e.g., a brown field project). Alternatively, ChatGPT may empower users with knowledge that is new to them, which can aid with hazard recognition. For example, ChatGPT may alert a freshly graduated student entering the workforce with new knowledge regarding the harmful effects of welding fumes (e.g., welding fumes can contain ozone, nitrogen oxides, and metal fumes that can cause lung damage—see Figure 5). This newfound information can potentially empower individuals to recognize relevant safety hazards. It is also possible that the observed improvement may be attributed to a combination of these two mechanisms which may be investigated in the future.

7. Conclusions

Effective hazard recognition is fundamental to effective safety management [18,30]. However, previous research has demonstrated that a significant number of safety hazards are generally not recognized in construction workplaces [16,21,38]. If not managed, these unrecognized safety hazards can potentially translate into unfortunate safety incidents [18,30]. Therefore, efforts to enhance hazard recognition ability, especially among students who will be future construction professionals and industry leaders, is critical.

To achieve this goal, the current study focused on evaluating if ChatGPT can serve as an effective educational intervention to aid hazard recognition in the construction industry context. The study objectives were accomplished using an experimental approach involving students that are expected to join the construction workforce in the future. The experimental approach included a pre-intervention stage where the baseline hazard recognition ability of the study participants was assessed. This was followed by the introduction of ChatGPT and its capabilities, particularly in the context of construction hazard recognition, to the study participants. Finally, assessments of the participants' hazard recognition abilities were conducted following the intervention.

The results demonstrated that ChatGPT can indeed be beneficial in facilitating construction hazard recognition. In fact, the adoption of ChatGPT as an intervention in the current study yielded hazard recognition gains that exceeded 25%. The findings suggest that ChatGPT can serve as a useful educational and training tool that can support hazard recognition efforts. Accordingly, educators and trainers can leverage the capabilities of ChatGPT to enhance hazard recognition levels and prepare the next generation of construction workforce to meet safety, sustainability, and other industry goals.

Author Contributions: Conceptualization, S.M.J.U., A.A. (Alex Albert), A.O. and A.A. (Abdullah Alsharef); methodology, S.M.J.U., A.A. (Alex Albert), A.O. and A.A. (Abdullah Alsharef); formal analysis, S.M.J.U., A.A. (Alex Albert) A.O.; writing—original draft preparation, S.M.J.U. and A.A. (Alex Albert); writing—review and editing, A.O. and A.A. (Abdullah Alsharef); visualization,

S.M.J.U., A.A. (Alex Albert); supervision, A.A. (Alex Albert), and A.A. (Abdullah Alsharef). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of North Carolina State University (protocol code 25715; date of approval: 20 February 2022).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are available upon request.

Acknowledgments: We are grateful to the study participants that made themselves available to participate in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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