Trivial Pursuit for Safer Science Labs: Comparing Alternative Approach to Pre-Lab Safety Lectures

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Abstract

This study examines the impact of instructional formats on learning, retention of laboratory safety knowledge, and participant satisfaction. Using a multi-framework approach integrating safety psychology and educational theories, we compared traditional lectures to interactive trivia-based learning. Participants were randomly assigned to one of the two safety training formats. Effectiveness was assessed at baseline, immediately after treatment, and at a two-week follow-up to evaluate knowledge retention and behaviours. Participants also rated their satisfaction and perceived performance after the intervention.

Results showed both formats significantly improved safety knowledge from pre- to post-treatment, while only the lecture group experienced a significant decline at the two-week follow-up. Satisfaction surveys indicated that trivia-based participants reported significantly higher satisfaction and perceived better performance compared to the lecture group. These findings suggest that while both methods are effective, integrating interactive elements like trivia can enhance engagement, boost confidence, and improve satisfaction in safety training.

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Introduction

Safety, at its core, is about avoiding injury through the implementation of safeguards and preventative measures. Unfortunately, these measures are often reactive, introduced only after incidents have occurred, with the aim of preventing recurrence (Serou et al., 2021). This approach tends to focus on technical advancements to improve hardware safety, often overlooking the critical role of human behaviour and failing to adopt a proactive stance in reducing the overall rate of accidents (Fleming, 2017). Research in high-reliability organizations (HROs) —organizations that operate in complex, high-risk environments but consistently maintain high safety standards, such as nuclear power plants, aviation, and healthcare systems (Roberts, 1990)—further emphasizes that while reactive safety measures can effectively address specific incidents, they often miss the broader, systemic issues that could prevent incidents from occurring in the first place (Serou et al., 2021).

Evolution of Safety Practices

The concept of safety has undergone significant transformations over the centuries, evolving from basic, reactive approaches to sophisticated, proactive, and systematic methodologies (Hale & Hovden, 1998; Reason, 2000). Initially, safety was a response to accidents and disasters, and measures were only implemented after incidents occurred (Heinrich et al., 1980). This reactive approach, while necessary, often resulted in repeated failures due to a lack of understanding of underlying hazards and risks (Reason, 2000).

The Industrial Revolution marked a turning point in the history of safety practices (Hale & Hovden, 1998). As industries expanded, the frequency and severity of workplace accidents increased, leading to the development of systematic safety protocols (Hale & Hovden, 1998). These protocols were the precursors to modern safety practices, emphasizing the need for both preventive measures and a better understanding of human factors in safety (Heinrich et al., 1980).

The human aspect of safety—what motivates someone to act safely and how safety behaviour can be learned and improved—remains a critical area of exploration. Understanding these human factors is especially crucial in laboratory settings, where the complexity of experiments and the use of hazardous materials increase the risk of accidents. By examining the psychological and behavioural components of safety, we can develop more effective training methods that promote proactive safety practices among scientists. Laboratory safety is the foundation of any successful scientist’s career. More important than asking questions and seeking knowledge is doing so in a manner that maintains the health of those experimenting from start to finish. For most individuals, the path of serious scientific inquiry begins at the undergraduate level—a critical period when habits and opinions on laboratory safety are formed. This time is also pivotal for brain development, particularly in first-year undergraduate students (Trends in the Age Composition of College and University Students and Graduates, 2010). To perform experiments and learn safely, students must remain engaged with the safety material as much as possible (National Research Council, 2011).

Lectures as a Dominant Teaching Method

Lectures have been the cornerstone of university education for centuries, serving as the primary method for disseminating information to large groups of students. This approach has persisted largely due to its efficiency in terms of time and resources, making it a practical choice for universities, especially when dealing with large student populations (Bligh, 2000). Historically, lectures have been favored for their ability to deliver content in a straightforward manner, allowing instructors to cover substantial material within a limited time frame (Becker & Watts, 2001).

Bloom's Taxonomy, a well-known framework in education, supports the use of lectures for delivering foundational knowledge (Bloom, 1956). The taxonomy is divided into six levels: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (Bloom, 1956). Each level represents a step in the cognitive process, with foundational knowledge forming the base and more complex thinking skills building upon it.

At the lower levels of cognitive learning—Knowledge, Comprehension, and Application—lectures are particularly effective (Anderson & Krathwohl, 2001). Knowledge involves the recall of facts and basic concepts (Bloom, 1956), which can be efficiently conveyed through lectures as instructors deliver structured information in a clear and organized manner. Comprehension goes a step further, requiring students to understand and interpret the information they receive (1956), a process that lectures can support by providing explanations and examples that help clarify concepts. Application involves using knowledge in new situations, which lectures can address by presenting case studies or problem-solving examples that show how theoretical knowledge can be applied in practical contexts (Bloom, 1956; Anderson & Krathwohl, 2001).

As students progress to the higher levels of Bloom’s Taxonomy—Analysis, Synthesis, and Evaluation—traditional lectures may become less effective. Analysis requires breaking down information into its component parts to understand underlying relationships and patterns (Anderson & Krathwohl, 2001). Synthesis involves combining elements to form a coherent whole, often leading to the creation of new ideas or solutions (Anderson & Krathwohl, 2001). Evaluation requires making judgments based on criteria and standards (Anderson & Krathwohl, 2001). These higher-order thinking skills often demand active engagement, critical thinking, and creative problem-solving, which can be difficult to achieve through a lecture format alone (Krathwohl, 2002).

More recent educational models like connectivism and constructivism offer a response to the higher-order thinking skills lacking in lecture alone, advocating for more interactive learning environments that engage students actively in the learning process (Siemens, 2005; Fosnot & Perry, 1996). Constructivism posits that learners construct their own understanding through experiences and reflection, emphasizing that knowledge is best acquired through active participation rather than passive reception (Piaget, 1972; Vygotsky, 1978). In the context of lab safety training, for instance, constructivist approaches suggest that students learn most effectively when they are involved in hands-on activities, simulations, and collaborative problem-solving exercises that mimic real-life scenarios. This method not only helps students internalize safety protocols but also develops their critical thinking skills, preparing them to handle unexpected situations in the lab (Beetham & Sharpe, 2013).

Building upon the principles of constructivism, Situated Learning Theory further argues that learning is most effective when it occurs in contextually rich, authentic environments (Lave & Wenger, 1991). In lab settings, this theory supports immersing students in realistic scenarios where they must apply safety protocols as they would in actual lab work. This contextualized approach helps students develop practical, context-specific skills that are directly transferable to their future careers.

Problem-Based Learning (PBL), another constructivist-aligned approach, emphasizes learning through the process of solving real-world problems (Barrows & Tamblyn, 1980). In a lab safety context, PBL could involve students being presented with complex safety-related challenges that they must navigate using their existing knowledge and skills. This method fosters deep understanding and encourages the application of theoretical knowledge in practical, often unpredictable situations.

Although lectures are undoubtedly efficient, their effectiveness in ensuring deep learning and long-term retention of information has been questioned (Bruner, 1966). The constructivist critique, supported by theories like Situated Learning and Problem-Based Learning, has led to growing advocacy for student-centered learning approaches that prioritize engagement, critical thinking, and real-world application over rote memorization (Fosnot & Perry, 2005; Lave & Wenger, 1991; Barrows & Tamblyn, 1980).

Despite significant advancements in educational technology and the growing body of research advocating for more interactive, student-centered approaches, traditional lectures remain the predominant method of instruction in many higher education institutions. This is particularly evident in STEM (Science, Technology, Engineering, and Mathematics) fields, where recent studies have shown that most instructors continue to rely on lecture-based teaching despite the proven benefits of active learning strategies (Stains et al., 2018). The continued reliance on lectures can be attributed to several factors, including institutional resistance to change, the perceived efficiency of lectures, and the lack of widespread digital competence among some educators (Gess-Newsome et al., 2003).

The effectiveness of lectures has been increasingly called into question, as research indicates that they often result in passive learning. In such settings, students may not fully engage with or retain critical information, leading to less effective learning outcomes compared to more interactive methods (Prince, 2004). Active learning, which involves students in the learning process through activities and discussions, has been shown to significantly enhance student engagement and performance (Freeman et al., 2014). Despite these findings, the transition away from traditional lectures has been slow, reflecting the challenges of changing long-established educational practices (Stains et al., 2018).

The persistence of lectures, even in the face of overwhelming evidence supporting alternative methods, underscores the complexities of educational reform. While technological advancements have provided new tools for enhancing student learning, the deep-rooted nature of lectures in academic culture presents a significant barrier to the widespread adoption of student-centered learning approaches.

Challenges of Traditional Lecture-Based Safety Training

A study conducted on laboratory safety between 1966 and 1984 found that 81% of accidents occurred in teaching labs (Ménard & Trant, 2020). While the overall rate of accidents in labs is generally low, the current standard practice of stage-learning—where safety training begins with a standardized lecture followed by practice—has its flaws. Traditional lecture-based safety training, while efficient, often leads to passive learning, which fails to fully engage students. This is particularly concerning in modern lab environments, where the complexity of experiments and the need for heightened safety awareness demand more active engagement from students. Interactive and student-centered educational approaches, such as active learning strategies, address these gaps by promoting a deeper understanding and long-term retention of safety protocols (Freeman et al., 2014; Prince, 2004).

Case Study: The UCLA Incident and the Broader Scope of Laboratory Safety Issues

In 2008, Sheharbano Sangji suffered severe burns in an academic chemistry lab fire at UCLA and later succumbed to her injuries (Kemsley, 2018). At the time of the incident, she was not wearing proper personal protective equipment (PPE), highlighting a critical failure in lab safety practices. As Jyllian Kemsley notes in her article for *Chemical & Engineering News*, even ten years after Sangji's death, there remains significant pressure in academic labs to produce results rapidly, which can sometimes lead to safety being compromised (Kemsley, 2018).

This tragic incident is a prime example of a low-probability, high-consequence (LPHC) safety incident. Another such LPHC incident occurred in 2010 at Texas Tech University—where a graduate student was severely injured while handling explosive materials (Chemical Safety Board, 2011). These rare but devastating events highlight the need for proactive safety cultures in academic laboratories.

In addition to these LPHC incidents, higher-probability, lower-consequence safety incidents are alarmingly common in academic settings. For instance, studies have found that a significant percentage of students in chemistry and related fields report experiencing at least one safety incident, such as minor spills or unintended reactions, during their studies (National Research Council, 2011). While these incidents may not result in severe consequences individually, their frequency indicates systemic issues that can contribute to LPHC events if unaddressed.

According to data from the Bureau of Labor Statistics (BLS), there are cases of nonfatal occupational injuries and illnesses in the education and health services sector, which includes academic laboratories (BLS, 2019). While this data encompasses a broad category, it underscores that laboratory environments contribute significantly to workplace injuries within educational institutions.

Common factors contributing to both LPHC and higher-probability incidents include inadequate safety training, time pressure, and improper use of PPE. Surveys have indicated that a substantial number of students feel they do not receive sufficient safety training, emphasizing the need for improved safety education (American Chemical Society, 2012). The "publish or perish" culture in academia may inadvertently prioritize research output over safety practices, leading to negligence of safety protocols.

The common approach to LPHC incidents is reactive—responding after a high-consequence event occurs—rather than proactive. This reactive stance is far from ideal and should not be accepted by any institution. Although it is difficult to anticipate low-probability incidents, it is possible to help scientists remain vigilant to these dangers. For example, in air travel security screening, where the presence of a dangerous weapon or explosive is a low-probability event, simulated threats are used to maintain vigilance among security agents. These simulations require agents to identify and respond to potential hazards, and failure to detect them is recorded, emphasizing the importance of remaining alert (Wei et al., 2021).

By recognizing the prevalence of both low-probability, high-consequence incidents and higher-probability, lower-consequence incidents across various fields, and understanding the contributing factors, institutions can adopt proactive measures to foster a stronger culture of safety. Enhancing safety training, promoting consistent use of PPE, and addressing time pressures that lead to compromised safety are essential steps toward reducing the likelihood of accidents and improving overall safety in academic laboratories.

Addressing the Gaps: The Need for Interactive Learning in Lab Safety

As safety remains a perennial issue, it is essential to explore new methods of engaging students with lab safety materials. The traditional lecture format, while efficient in delivering information, often results in passive learning and fails to fully engage students (Bonwell & Eison, 1991; Prince, 2004). This is especially concerning in modern lab environments, where students need to be actively involved in understanding and retaining safety protocols (Lumpkin et al., 2015).

Recent advances in educational approaches, such as game-based learning, offer significant benefits in terms of student engagement, motivation, and retention of complex topics. Specifically, in health professions education, game-based learning has been shown to enhance both knowledge retention and skill acquisition, indicating its potential for improving safety training in university settings (Thesen et al., 2023). Beyond the health sector, gamification has been widely applied across diverse fields, including primary and secondary education, higher education, and corporate training environments (Kalogiannakis et al., 2021). In science education, for example, game-based methods are frequently used to teach biology, chemistry, and environmental science concepts, while fostering critical skills such as problem-solving, collaboration, and adaptive thinking (Kalogiannakis et al., 2021). Similarly, in professional training contexts, gamification enhances practical skills, such as decision-making and technical proficiency, by simulating real-world scenarios through interactive and narrative-driven approaches (Kalogiannakis et al., 2021). These findings underscore the versatility of game-based learning in developing both foundational knowledge and practical, application-oriented skills across a range of disciplines.

Integrating gamification into laboratory safety training has been explored in academic research, highlighting its potential to enhance engagement and comprehension among students. For instance, a study by Yang, Lian, and Zhao (2023) developed a gamified artificial intelligence educational robot to promote learning effectiveness and behaviour in laboratory safety courses for undergraduate students. The study found that this approach improved students' motivation and learning outcomes in laboratory safety education (Yang et al., 2023).

A systematic review by Haj-Bolouri et al. (2024) examined the incorporation of gamification into safety training. The review emphasized that gamified immersive safety training environments can emulate increased safety awareness by combining realistic risk perception elements with game elements, such as health bars and danger indicators, to visualize contrasts between safe and unsafe behaviours (Haj-Bolouri et al., 2024).

Non-digital, game-based learning activities, such as trivia games, have proven effective in enhancing classroom engagement and fostering peer interaction, particularly in helping students transition to higher education (Balakrishna, 2023). These methods have been successful in promoting academic integration and improving the retention of key safety information, suggesting that attempting the implementation of trivia card games in lab safety training could potentially lead to better engagement and understanding of safety protocols (Balakrishna, 2023; Thesen et al., 2023). Gamified teaching elements in education are associated with increased intrinsic motivation, which is crucial for promoting sustained learning and consistent adherence to safety practices (Thesen et al., 2023). By addressing students' basic psychological needs for autonomy, competence, and relatedness, trivia-based methods can foster a proactive approach to safety, ensuring that students internalize and consistently apply safety protocols (Thesen et al., 2023).

Previous Research on Lab Safety

Workplace safety neglect and ignorance is not simply an issue of the past. In a 2018 study, 88% of participants described safety as a high priority in their labs; however, only 40% of participants reported always wearing PPE while working laboratory (Ayi & Hon, 2018). Additionally, 27% of participants stated that they never conducted any form of risk assessment prior to conducting their work in the laboratory (Ayi & Hon, 2018). Another study from 2013, which specifically targeted undergraduate students in teaching labs, found that while 94% reported wearing safety glasses, only 35% stated they wore gloves (Sielof et al., 2013).

Whether the underlying reason for this lack of adherence to lab safety policies derives from ignorance, a perceived heavy-handedness

In a recent review, Ménard and Trant (2020) found that the validity of much of the existing research on safety training for undergraduates is questionable at best, especially when considering evidence-based policymaking on a broader scale or outside the specific context in which the data was collected. These studies rarely include control groups or randomization to the intervention, making it difficult to ensure that observed changes are due to the program alone and not to other factors. Studies often assess the combined impact of multiple initiatives simultaneously, which makes it challenging to isolate and identify the specific causative contribution of each intervention when any measurable change is observed (Ménard & Trant, 2020). Once more, what is even more troubling is the exclusive use of self-report data in many of these studies, including the work cited by Ayi & Hon (2018) and Sielof et al. (2013). There is a chance their results are inaccurate due to social desirability bias in participants' responses (King & Bruner, 2000). That is, the tendency of respondents to answer questions in a manner that will be viewed favorably by others (King & Bruner, 2000).

These concerns are evident in the survey conducted by Sieloff et al. (2013), which targeted 1,704 undergraduate chemistry students at a single university. The survey consisted of thirty questions addressing demographic information, acute injury status, symptoms of respiratory and mucous membrane irritation, and smoking behaviours. Three questions specifically assessed self-reported injuries in university labs, chemistry labs, and current-semester chemistry courses. For these questions, modified survey items previously validated by Shendell et al. (2010) were used, with response options including various injuries (e.g., chemical burns, cuts, gas inhalation) and the option to decline answering.

To evaluate laboratory behaviours, the authors developed a behavioural risk factor (BRF) scale comprising ten Likert items, ranging from one (never) to five (almost always), with higher scores indicating riskier behaviours. Positive behaviours were reverse-coded, and “not applicable” or “I do not want to answer” responses were scored as zero. Total scores ranged from 0 to 50 (Sieloff et al., 2013).

While correlations were found between BRF scores and factors such as gender and course enrollment, no correlation was identified between BRF scores and self-reported injuries. However, the study's findings are limited by methodological issues. Coding “not applicable” and “I do not want to answer” as zero likely underestimated risky behaviours, as these are non-answers and not valid data points. A more appropriate approach would involve excluding these responses when calculating mean scores. Additionally, the survey’s low response rate of 18.7% likely introduced bias, as students experiencing injuries may have been more likely to respond (Sieloff et al., 2013).

While there has been no direct repeated use of the BRF scale developed by Sieloff et al., it still serves as an important lesson in how important it is to consider the value of each option a participant is afforded the opportunity to respond with.

Research on Safety Behaviour and Human Factors

Research articles compiled by Ménard and Trant (2020) report that 15–30% of academic researchers have been involved in an accident or have sustained an injury. What is more troubling than these statistics is that despite a large percentage of respondents deeming the safety training they received to be unsatisfactory, most studies have shown that researchers still report feeling safe in their labs, perceive the risk level in their laboratories as low, and describe their institution as having a good safety culture. Ménard and Trant (2020) suggest that these findings may indicate that risky practices and a casual approach to safety have become normalized within academia, potentially leading to low standards in the field that are not always recognized or questioned by those within the system.

What becomes clear when reading through Ménard and Trant's 2020 review is that safety behaviour is a key factor. By constantly focusing on the easily quantifiable end result of the number of accidents, researchers have missed out on the nuance of the human factors that come together to answer the "why" of incidents and accidents (Reason, 2000). In his *Human Error: Models and Management*, James Reason (2000) explains that human error can be framed in two distinctive ways: the person approach and the system approach. The person approach, which is the predominant practice, blames incidents and accidents on an individual. Blame is focused on an individual's carelessness, lack of motivation, and inattention, among other factors. Reason describes the motto of this approach as "bad things happen to bad people."

In contrast, the system approach expects human error, and rather than blaming the perceived weaknesses of an individual, it seeks to determine the causal systematic factors that lead to the errors occurring (Reason, 2000). The system approach further defines why incidents or accidents (described as failures) occur. They can be placed into one of two categories: active failures and latent conditions. Active failures are slips and mistakes made by an individual, typically with short-lived consequences

(Reason, 2000). Latent conditions, described as “inevitable resident pathogens” within a system, can surface as error-provoking work conditions or lie dormant for years in the form of an undetected design flaw. It is often the combination of an active failure and latent conditions that leads to a more serious workplace incident. Importantly, while researchers may not be able to directly control active failures, latent conditions can be identified and addressed prior to the occurrence of an incident (Reason, 2000). This approach leads to proactive rather than reactive safety risk management.

Theoretical Framework: Safety Psychology

While engineering controls serve their purpose for increasing safety, they are but one of several controls that should be in place to protect lab workers (Occupational Safety and Health Administration, 2011). It is essential to take a step back and explore other non-mechanical ways to impact safety risk management. One promising path is through the work of past and present safety psychologists, who have developed various theoretical frameworks for understanding and improving safety behaviour.

There are two primary approaches to improving safety in the workplace: behaviour-based safety (BBS) and fostering a safety culture (DeJoy, 2005). Behaviour-based safety focuses on identifying, measuring, and changing unsafe behaviours through observation and feedback mechanisms. This approach is grounded in the principles of behavioural psychology, where reinforcement and punishment are used to shape and modify employee behaviours (Cooper, 2009). Research has demonstrated that BBS programs can lead to significant reductions in workplace accidents and injuries by promoting consistent and safe work practices (Krause et al., 1999; McAfee & Winn, 1989).

Fostering a safety culture involves creating an environment where safety is deeply embedded in the organizational values, beliefs, and practices (Guldenmund, 2010). Unlike BBS, which focuses on individual behaviours, safety culture emphasizes collective responsibility and the development of shared norms that prioritize safety (Guldenmund, 2000; Zohar, 1980). A strong safety culture is characterized by visible leadership commitment to safety, open communication, continuous learning, and an emphasis on safety at all levels of the organization (Reason, 1997; Geller, 2000). Studies have shown that organizations with robust safety cultures tend to have lower rates of accidents and higher levels of employee engagement in safety initiatives (Clarke, 2006; Mearns et al., 2003).

While BBS provides a structured approach to modifying specific behaviours, fostering a safety culture seeks to create an environment where safety becomes an inherent part of the organizational ethos. Both approaches are complementary and have been proven effective in enhancing workplace safety, with BBS offering more immediate, tangible results and safety culture fostering long-term, sustainable improvements in safety performance (DeJoy, 2005; Hale, 2000). Of these, fostering a safety culture aligns most closely with Self-Determination Theory (SDT), as it emphasizes creating an environment that supports intrinsic motivation, leading to internalized safety practices.

Self-Determination Theory

Self-determination theory (SDT), proposed by Deci and Ryan (1985), explains that individuals are driven by various types of motivation, which can be categorized based on how much they lead to self-directed or autonomous behaviour. SDT highlights that some motivations are internalized by the individual, while others require external factors to influence behaviour (Deci & Ryan, 1985; 2000; 2002; Gagné & Deci, 2005). According to SDT, motivation is complex, and it is essential to understand both its level and type when analyzing behaviour (Ryan & Deci, 2002). At its core, SDT identifies two primary types of motivation: intrinsic and extrinsic. Extrinsic motivation is driven by external rewards or outcomes contingent on behaviour, while intrinsic motivation stems from the inherent enjoyment or satisfaction derived from the activity itself.

In the context of lab safety, integrating SDT into training programs can foster intrinsic motivation among students, encouraging them to internalize safety practices rather than merely complying due to external pressures. Interactive learning methods, such as trivia games, have the potential to create a more engaging environment that may align with the basic psychological needs of autonomy, competence, and relatedness—key components of SDT (Ryan & Deci, 2000). This approach has also been supported in organizational contexts, where SDT has been shown to enhance motivation and performance through satisfying these psychological needs (Gagné & Deci, 2005). While these methods are consistent with SDT's principles, further empirical research is necessary to establish their specific effectiveness in the context of lab safety training.

Motivation and Learning in Safety Training

To address the issues identified in previous research, it is crucial to understand what drives student motivation. Motivation is the key to learning, with increased motivation leading to more efficient learning and synthesis of information (Murayama, 2018). There are two different types of goals that motivate an individual: mastery goals, which are driven by the desire to become self-sufficient in a particular task, and performance goals, which are motivated by the desire to perform well in comparison to others (Murayama, 2018).

To measure and compare how these forms of motivation impact learning, Murayama and Elliot (2011) conducted a behavioural study in which participants were given a problem-solving task followed by a surprise memory test related to the task. Participants were divided into one of two conditions: a mastery goal condition and a performance goal condition (Murayama & Elliot, 2011). Participants in the mastery goal condition were informed that their objective was to enhance their cognitive abilities through the task, whereas those in the performance goal condition were told that their goal was to showcase their abilities in comparison to other participants. The study found that those in the performance goal condition showed better memory performance in an immediate memory test. Despite this, when memory was assessed one week later, participants in the mastery goal condition showed better memory performance. These results indicate that performance goals help short-term learning, while mastery goals facilitate long-term learning (Murayama & Elliot, 2011).

Integrated Lab Safety Model

In real-world applications, numerous variables impact how an individual reacts within an environment. Therefore, it is useful to examine how proposed theories might interplay. Beus, McCord, and Zohar (2016) reviewed and synthesized studies conducted before 2016 and presented their findings in an integrated safety model (ISM). Their model takes a multilevel perspective and differentiates between distal (e.g., individual differences, contextual factors) and proximal antecedents (e.g., safety knowledge, skills, or motivation) of safety-related behaviours and subsequent accidents across individual and group levels of analysis. This model integrates theoretical propositions from five past seminal works (Burke & Signal, 2010; Christian et al., 2009; Neal & Griffin, 2004; Nahrgang et al., 2011; Zohar, 2011).

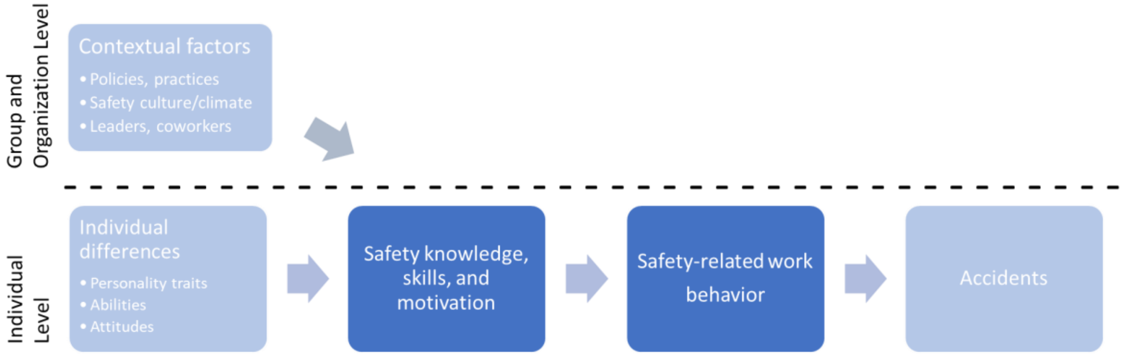

Figure 1. Proposed relationship between group and individual factors contributing to safety-related work behaviour and rate of accident and injury.

Burke & Signal (2010) proposed that individuals who experience a safety incident in the form of either an accident or illness are correspondingly influenced in their individual safety and motivation via reflection and dialogue. They, along with Christian et al. (2009), also propose that individual differences, including contextual factors and personal experiences, should impact safety knowledge, skills, and motivation, which in turn are expected to influence individuals' safety-related work behaviours. Additionally, Christian et al. (2009) found a strong positive association between safety knowledge and motivation with safety-related behaviour for individuals.

Neal and Griffin (2004) theorized that the core individual determinants of safety-related behaviour (such as job performance) are individuals’ safety-related knowledge, skills, and motivation. They proposed that these determinants are each a function of individual differences (such as personality or ability) and of safety climate and leadership.

Nahrgang et al.’s (2011) job demands-resources model demonstrates that safety-related job demands (e.g., work overload, job risks/hazards) and job resources (e.g., social support, autonomy) influence individuals’ safety-related behaviours by affecting the availability of their personal resources. According to organizational climate theory, proposed by Zohar (2011), behaviour-outcome expectancy mediates the influence of contextual factors on both individual safety-related behaviour and group-level patterns of safety-related behaviour. This behaviour-outcome expectancy can be defined as a subject’s motivational expectation regarding whether certain behaviours will be reinforced in their organizational setting (Zohar, 2011). Behaviour-outcome expectancy is an important context-based driver of both individual and group-level behaviour, as people are inherently motivated to identify cues in their environment that communicate the behaviours that will be most effective in achieving desired outcomes (Schneider, 1975). Theory concerning this causal sequence has focused primarily on safety climate as the chief source of safety-related behaviour-outcome expectancies (Zohar, 2011). Safety climate, as a perceptual reflection of the social context of safety, primarily encompasses more specific contextual factors that are generally conceptualized as indicators of climate (Zohar, 2011).

The presentation of this material in a single model (see figure 1) served as the basis for the creation of a more concise model focused on the individual level, highlighting the areas of this research intervention that looks at the possible ways in which safety knowledge, skills, and motivation impact safety-related work behaviour.

At the group and organizational level, contextual factors that impact safety behaviour include the university's safety rules and regulations, the personnel hired to teach and demonstrate safety materials and behaviours, and the existing safety culture at the university. While it is difficult to enact direct changes to university personnel, policies, and practices can be manipulated to ensure conformity, and over a relatively longer timeline, the safety culture climate can be improved.

At the level of an individual learner, the three key factors that influence safety knowledge, skills, and motivation are an individual's personality traits, their abilities, and their attitude. Students may arrive at a lab from across the globe, with varying levels of technical ability. While individual personality traits do impact safety behaviour, these traits cannot be altered in this context. However, increasing ability and fostering a positive attitude toward safety-related work behaviour can directly lead to increased safety knowledge, skills, and motivation. These three elements are the focus of this model, as they hold promise as an effective way to influence safety behaviour. The more knowledge an individual has on a given safety-related topic, and the more motivated they are to use their knowledge and skills to complete the associated safety-related task, the more their safety-related work behaviour will improve. This, in turn, leads to a decreased rate of safety-related incidents and accidents. It is worth noting that accident rate is not the focus of this model; instead, the focus is on controlling the variables that directly impact accident rates.

Approach to Training

Maximizing the absorption and retention of information is a central focus in behavioural psychology, particularly in contexts where safety is critical, such as laboratory environments. Several foundational psychological theories provide valuable insights into the factors that drive motivation, enhance safety knowledge, and develop essential skills. These theories offer frameworks for ensuring that learners comprehend and adhere to crucial safety protocols. By examining these theories, educational environments can be designed to foster effective learning and long-term retention, ultimately reducing the likelihood of safety incidents or accidents in the lab.

Proposed by B.F. Skinner (1969), reinforcement theory states that an individual's behaviour is a function of its consequences. It is based on the "law of effect," which posits that behaviours with positive consequences tend to be repeated, while behaviours with negative consequences tend not to be repeated. This theory is an ideal tool for analyzing the mechanisms that control individual behaviour, however it does not address the underlying causes of individual behaviour. Bandura's social-learning theory (1977) highlights the significance of observing, modeling, and imitating the behaviours, attitudes, and emotional reactions of others. Social learning theory considers both environmental and cognitive factors as they interact to influence human learning and behaviour. It aligns with the behaviourist learning theories of operant conditioning (B.F. Skinner) and classical (Pavlovian) conditioning but introduces two key concepts: mediating processes occur between stimuli and responses, and behaviour is learned from the environment through observational learning.

In 1985, Anderson published his stage-learning theory, which, like Kanfer and Ackerman (1989), defines learning in three distinct segments. The first segment is the acquisition of declarative knowledge, followed by knowledge compilation, and finally the proceduralization of knowledge (Anderson, 1985). In these theories, declarative knowledge is defined as the mastery of factual material, while procedural knowledge is defined as the mastery of the physical task of performing a given task (Burke et al., 2008). In the first segment, learners are consumers of information delivered by an expert on the topic at hand, which requires considerable attentional resources. During the second segment, learners integrate the cognitive and physical processes required to complete the task, with lesser attentional demand, allowing the knowledge to solidify in long-term memory. In the final segment, learners must demonstrate that they can perform the task with minimal attentional resources, indicating that procedural knowledge and skills have been acquired.

Learning can also be described as a social experience, both in the sense that individuals learn from one another and that social interaction mediates the learning process (Vygotsky, 1987). Kolb's (1984) theory of experiential learning further highlights the dynamic interplay between hands-on activities, reflection, and real-world application in creating meaningful educational experiences. This approach is particularly relevant in contexts where collaboration and practical engagement are key to success.

Case Study: The Rotterdam Eye Hospital

At the Rotterdam Eye Hospital, a trivia-card game was introduced in 2015 as part of an innovative approach to staff training and development (van der Heijde & Deichmann, 2018). This experiential learning tool allowed employees to engage in a fun, interactive format that encouraged collaboration and active participation. As highlighted in the *Harvard Business Review*, this method improved outcomes, including patient-safety audit scores and staff job satisfaction, which rose from 8.0 to 9.2 on a 10-point scale (van der Heijde & Deichmann, 2018).

This success aligns with reinforcement theory (Skinner, 1969), suggesting that the positive experience of participating in the trivia game reinforces desirable behaviours. Additionally, social-learning theory (Bandura, 1977) underscores how the opportunity for observation and interaction among peers enhances the learning process, demonstrating the power of engaging, hands-on methodologies in professional and educational settings.

The proposed experimental design offers an alternative approach to traditional lab safety training by incorporating principles from reinforcement theory, social-learning theory, stage-learning theory, and experiential learning theory. This novel approach to lab safety training aims to create a more engaging, interactive learning environment that fosters intrinsic motivation, enhances safety knowledge and skills, and ultimately reduces safety-related incidents in the lab.

Hypotheses

1) Group Trivia Game Effectiveness

    a) Participants in both the lecture and trivia-card groups will score significantly higher in the post-test phase than in the baseline phase.

    b) The trivia-card group will score significantly higher than the lecture group at the post-test phase.

2) Knowledge Retention
    a) Participants in both groups will score higher at the follow-up phase compared to the baseline phase.
    b) Participants in the trivia-card group will score significantly higher than the lecture group at the follow-up phase of testing.
3) Participant Satisfaction

    Participants in the trivia group will report significantly higher satisfaction levels compared to participants in the lecture group.

Method

Study Design

The study employed a between-subjects experimental design. Prior to recruitment, the study was cleared with the Research Ethics Board (REB) under file number 23-004. Participants signed up for two sessions, spaced two weeks apart. The first session required participants to come in person to a Saint Mary's University seminar room. Upon arrival, each participant was read and required to sign an informed consent form. Participants were randomly assigned to either the Lecture group (Group L) or the Trivia group (Group T) to ensure comparable groups. The second session was conducted online via Qualtrics survey software. Randomization was achieved by having participant registration anonymous, and having the sessions pre-selected as either group T or group L.

Participant anonymity within completed tests/surveys was achieved by having each participant generate a unique code on each handout, made up of the first two letters of their first name, the first two letters of their middle (or last name if no middle name), and two digits of the day of the month they were born. By writing this code on each handout, data tracking was possible while maintaining participant anonymity and confidentiality. A statistical power analysis was conducted. The conventional level of power in sample size calculations is 80% (Gelman & Carlin, 2014). This indicated a need for a sample of 88 participants (44 per group) in order to find a medium effect size with power of .80 and with a 95% confidence interval. (Cohen, 1992).

Procedure

In-person session

During the first session, participants completed a 21-question baseline test, consisting of true/false and multiple-choice questions. The test covered fundamental laboratory safety concepts. Following the baseline test, participants received one of two interventions. Those in the Lecture group were lectured on generic lab safety via twenty slide PowerPoint presentation read aloud by the Student

Principal Investigator. Participants in the Trivia group engaged in a trivia-card game with comparable safety information. While the Student Principal Investigator observed, they worked together, taking turns asking questions, flipping the card to see the answer, and having the next person repeat the process for all to hear. There were nineteen trivia cards in total. The number of questions read aloud by each participant was dependant on the number of participants present in the individual trivia game sessions. No trivia game treatments were conducted when there were less than two participants present. Immediately after their select intervention activity was complete, all participants completed a post-treatment test, which also consisted of 20 true or false and multiple-choice questions, different but comparable to the baseline test.

Online session

The second session occurred two weeks later from participants' respective first sessions, at which point they were emailed a link to Qualtrics, asked to complete a follow-up test with the same format as previous tests, 20 questions total. In addition to the follow-up test, participants were also asked to complete a satisfaction survey that asked specific questions about the treatment they received, measuring their satisfaction with the method. The satisfaction survey contained six or seven questions, dependant on responses to branched questions.

Materials

The three knowledge tests were developed to assess essential laboratory safety knowledge. The test items were designed in alignment with Saint Mary's University's Science Lab Safety Orientation Checklist (Saint Mary's University, 2013) and WHMIS 2015 standards (Government of Canada, 2015). These guidelines cover crucial areas such as PPE, chemical handling, and emergency procedures, ensuring that the test items reflect real-world safety practices, relevant to undergraduate students.

Knowledge test question format

Multiple-choice questions were selected for their versatility in assessing both lower-order factual recall and higher-order cognitive skills. Research indicates that well-designed multiple-choice questions can effectively evaluate not only factual knowledge but also application and critical thinking skills, making them well-suited for safety training (Franzen et al., 2018).

True/false questions were included for their simplicity and ease of administration, allowing quick assessment of participants' knowledge of basic lab safety rules. While there are concerns regarding guessing with this format, it remains a widely used tool in educational settings for initial assessments of factual understanding (Brassil & Couch, 2019).

The knowledge tests were developed by first creating a comprehensive set of questions that encompassed all the key safety learning outcomes common to undergraduate science labs. This pool of questions was then divided between the baseline test and the post-treatment and two-week follow-up tests to ensure that all content areas were adequately covered across all assessments. As a result of this division, the baseline test had an additional question, totaling 21 questions, while the subsequent tests each contained 20 questions. The extra question in the baseline test was included to enhance the capacity to identify potential baseline differences in participants' knowledge, which is important for determining whether groups are statistically comparable at the outset. Tests were evenly split between multiple-choice and true/false questions. This approach ensured that the assessments remained focused on the essential content without overly taxing participants cognitively, especially since they were asked to complete two of the tests on their first research day.

Satisfaction survey format

The satisfaction survey used in this study primarily aimed to assess participants' satisfaction with the instructional method they experienced, whether it was the lecture or trivia approach. The survey included specific questions designed to measure enjoyment, perceived performance improvement, and support for future use of the method received. Satisfaction was a key factor in determining participant preferences, as those who rated their experience as enjoyable are more likely to prefer that method in future training (Davis, 1989). This is an important component in understanding how well the method was received and whether it would be favorably recommended by participants.

The satisfaction survey employed multiple Likert scales to assess various dimensions of participants' experiences with the instructional methods they received, whether lecture or trivia. A 5-point satisfaction scale (1 = Not at all satisfied to 5 = Extremely satisfied) was used to measure participants' overall satisfaction with each method. This type of scale is widely used for capturing levels of satisfaction, allowing participants to express the intensity of their feelings and providing clear, ordinal data for analysis (Joshi et al., 2015; Boone & Boone, 2012). Additionally, a performance comparison scale (1 = Much worse to 5 = Much better) was used to gauge participants' perceptions of their post-test performance compared to their baseline test, enabling them to reflect on the effectiveness of the method in improving their learning.

The survey also included a support for future use scale (1 = Strongly oppose to 5 = Strongly favor), which measured participants' endorsement of the method for future lab safety training. This scale captured the strength of participants' preferences regarding the continued use of the instructional approach, providing insights into the long-term desirability of each method. Finally, an agreement scale (1 = Strongly disagree to 5 = Strongly agree) was used to measure participants' enjoyment of trivia games and their preferences for using the trivia format in lab safety training. This scale ensured that preferences related to personal enjoyment and utility were captured accurately.

By using these different Likert scales, the survey was able to assess specific constructs like satisfaction, perceived performance improvement, support for future use, and agreement with preferences. Each scale was tailored to its respective area, ensuring clarity and relevance for participants. The use of multiple Likert scales provided a comprehensive assessment of participant responses, allowing for more nuanced data collection (Joshi et al., 2015; Boone & Boone, 2012).

Assessment phases and data collection

Paper copies of the pre-treatment and post-treatment tests were completed by participants during the first research day, while the two-week follow-up test and satisfaction survey were administered electronically via Qualtrics on their second research day. The data collected from these tests were organized into three distinct phases: pre-treatment, post-treatment, and two-week follow-up, each corresponding to a specific point in time when participants were assessed.

The pre-treatment phase served as a baseline, capturing participants' knowledge before any intervention and providing a reference point for later comparisons. Following the interventions, the post-treatment phase measured the immediate impact of the lecture or trivia session on participants' knowledge. This phase directly informs hypothesis 1.a, which predicts higher performance for the trivia group compared to the lecture group. Finally, the two-week follow-up phase assessed knowledge retention over time, offering insights into the lasting effects of each intervention.

Finally, the two-week follow-up phase was designed to evaluate the retention of the information or skills gained during the intervention, thereby offering insights into the long-term effectiveness of each treatment. This was the focus of hypothesis 1.b as it examines retention over time. By breaking down the data into these phases, the analysis was able to track changes over time and assess the effectiveness of the different treatments more accurately.

Data Preparation

The data collected from each phase of knowledge tests were then normalized to account for the different number of questions in each test. To ensure comparability of scores across the different phases of the study, normalization of the data was necessary due to the varying number of questions in each phase. The pre-treatment phase included 21 questions, while the post-treatment and follow-up phases consisted of 20 questions each. This normalization allowed for a direct comparison of scores across the phases, ensuring that the number of questions did not skew the results. Without normalization, the raw scores from these phases would not be directly comparable, as the difference in the number of questions could skew the results. Normalizing the scores allows for the conversion of raw scores into a common scale, enabling meaningful comparisons across all phases of the study (Vogt & Johnson, 2011).

The method of normalization involved calculating the percentage score for each phase (Field, 2018). For the pre-treatment phase, normalization was achieved by dividing the raw score by 21, the total number of questions, and then multiplying by 100 to obtain a percentage score. Similarly, for both the post-treatment and follow-up phases, the raw scores were divided by 20, the total number of questions for these phases, and then multiplied by 100 to convert them into percentage scores. This approach ensured that all scores were on the same scale, facilitating accurate comparisons across the pre-treatment, post-treatment, and follow-up phases.

Test Selection

Before conducting parametric tests such as t-tests and ANCOVA, it was essential to assess the assumptions of normality and homogeneity of variances. These assumptions ensure the validity of the statistical tests and the accuracy of the conclusions drawn from the data.

Levene's Test for Homogeneity of Variances

Levene's Test was used to evaluate whether the variances of the dependent variables were equal across groups. This test is particularly important for ensuring that the assumption of homogeneity of variances is not violated, which is a key assumption for parametric tests like the t-test and ANCOVA.

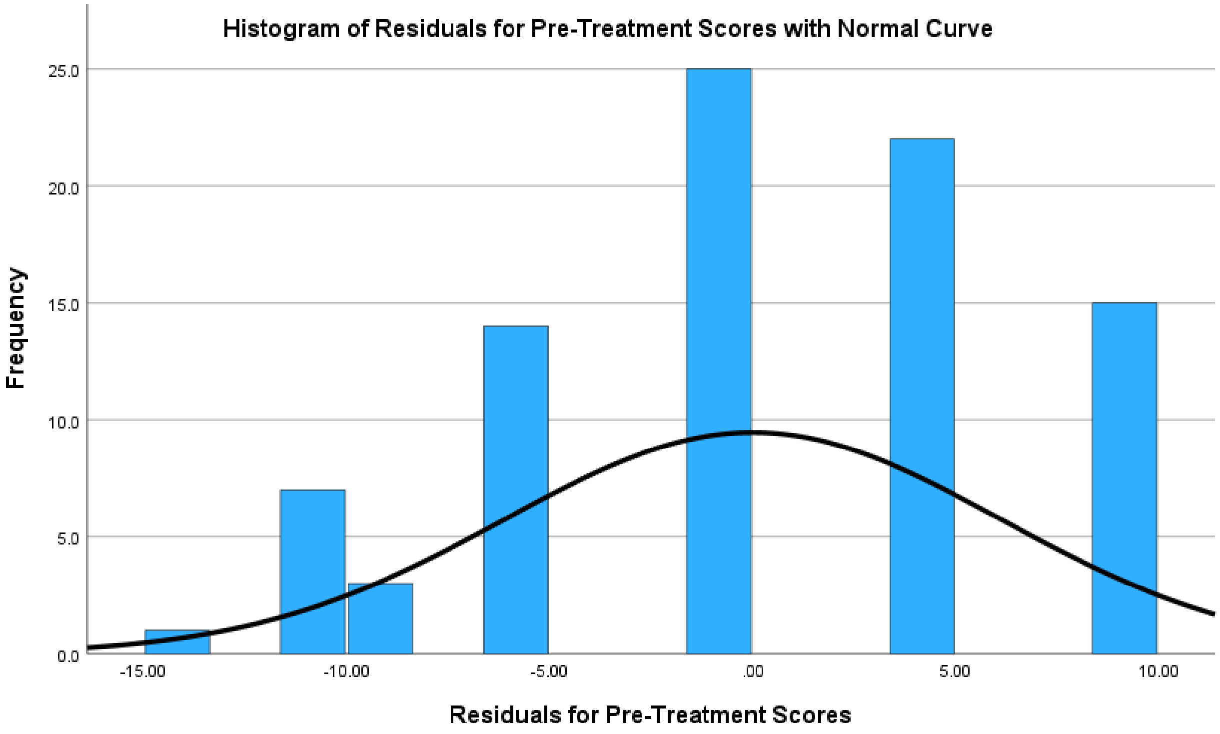

Figure 2. Histogram of residuals for Pre-Treatment scores with normal curve, based on participants' baseline knowledge prior to intervention.

For the Pre-Treatment scores, Levene's test yielded a non-significant result, F(1, 85) = 0.575, p = 0.451, indicating that the variances between the Lecture and Trivia groups were equal. Similarly, Levene's Test revealed that the assumption of homogeneity of variances was met for the Post-Treatment scores (F(1, 85) = 0.091, p = 0.764).

Levene's Test indicated a violation of the homogeneity of variances for the Follow-Up Normalized scores (F(1, 85) = 4.608, p = 0.035). The p-value was less than 0.05, meaning that the variance between the groups was significantly different. Despite this violation, parametric tests such as ANCOVA were still performed, as ANCOVA can be relatively robust to violations of this assumption, especially when group sizes are similar.

For the effect size in these analyses, two measures were utilized: Cohen's d and Partial Eta Squared. Cohen's d was employed as a measure of effect size for the paired and independent t-tests, quantifying the magnitude of difference between the two sets of scores. Cohen's d provides an intuitive understanding of the practical significance of the differences observed, complementing the statistical significance results from the t-tests (Cohen, 1988). A larger Cohen's d indicates a greater effect of the intervention on participants' scores (Cohen, 1988).

For the ANCOVA, Partial Eta Squared was used to assess the effect size, providing insight into the proportion of variance in post-test and follow-up scores that could be attributed to the treatment, after controlling for baseline scores. Partial Eta Squared helps quantify how much of the variation in the dependent variable is explained by the instructional method, indicating the practical significance of differences between the trivia and lecture groups (Richardson, 2011).

By incorporating these effect size measures, the analysis not only evaluated statistical significance but also provided meaningful insights into the magnitude and practical implications of the interventions, offering a robust interpretation of the results.

Data Handling and Storage

All data collected were anonymized and stored securely in a password-protected database. Only the Faculty Supervisor and the Student Principal Investigator had access to the data.

Ethical Considerations

The study was conducted in accordance with Saint Mary's University's Research Ethics Board guidelines. Informed consent was obtained from all participants, and confidentiality of responses was ensured throughout the study.

Results

Descriptive Statistics

The participant sample pool was comprised of undergraduate students who were enrolled in at least one course in the department of psychology, giving them access to SONA which in turn allowed them to register for this research. Participants were of all ages above 18, and no other demographic information, such as gender, were recorded or selected for. In total, 89 participants signed up and participated in at least the first phase of the study. 87 participants completed the entire study including the two-week follow up phase.

Previous Lab Safety Training Experience

To assess whether prior lab safety training might influence participants' performance in the study, participants were asked on the satisfaction survey about their previous experience with lab safety training. Understanding this variable was important to determine if prior knowledge could impact baseline scores or the effectiveness of the instructional methods used.

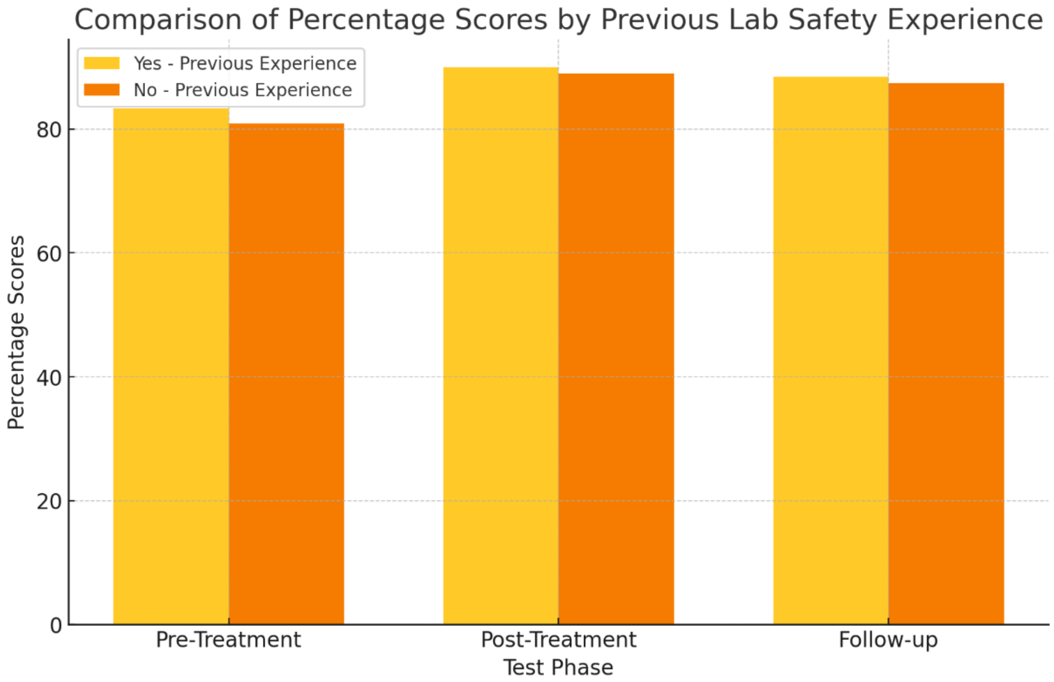

Figure 3. Comparison of knowledge test scores (%) across all three phases for participants that did and did not report having had previous lab safety experience. Sample sizes: Yes = 63, No = 24.

To the item "I have a previous experience receiving lab safety training (e.g., attended any first-year undergraduate science lab, WHMIS)" 73.26% of participants indicated that they had previous experience receiving lab safety training, while (26.74% reported having no prior lab safety training experience. To investigate whether prior experience impacted performance on the pre-treatment, post-treatment, and follow-up tests, independent t-tests were conducted to compare the mean scores between participants with and without prior lab safety experience for each testing phase.

For the pre-treatment phase, the t-test compared the baseline knowledge of the two groups. The results indicated no significant difference in pre-treatment scores between the groups (t = 0.31, p = 0.76). A second independent t-test was performed to compare post-treatment scores, which measured immediate knowledge retention after receiving either the lecture or trivia-card game intervention. Again, there was no significant difference in post-treatment scores between participants with and without prior lab safety experience (t = 0.24, p = 0.81). Finally, the follow-up phase was analyzed to assess long-term retention of lab safety information. The results of the follow-up test comparison showed no significant difference between the two groups (t = -0.15, p = 0.88).

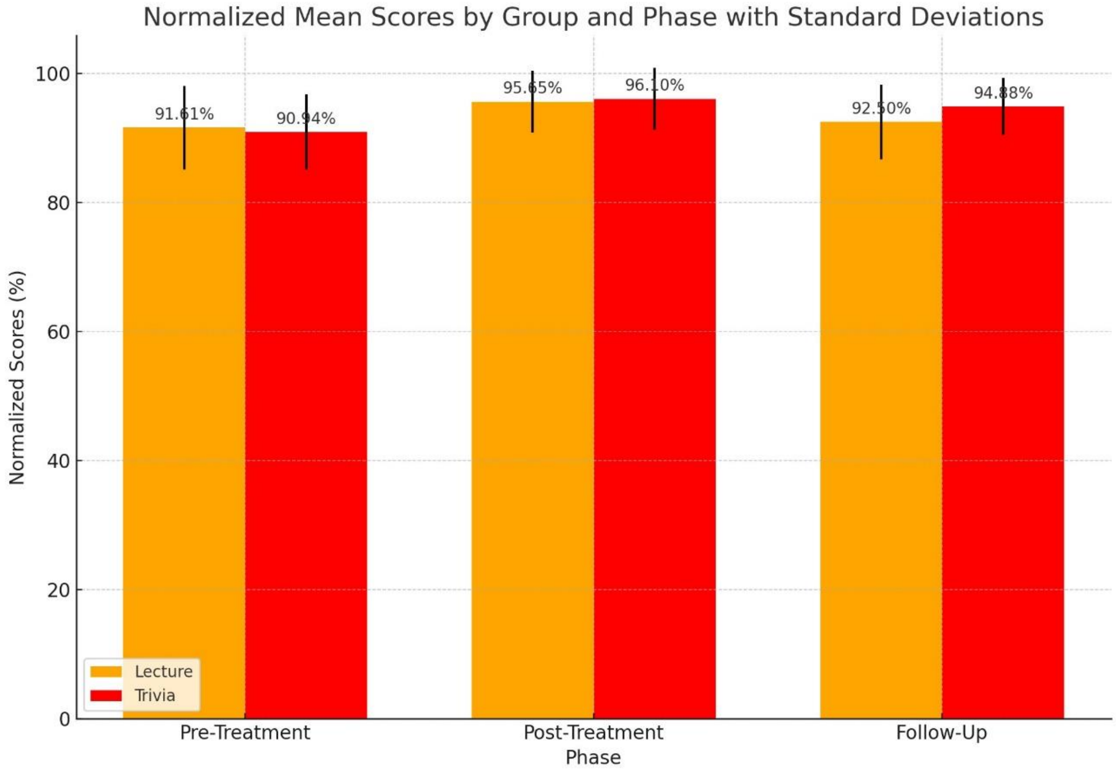

Figure 4. Normalized mean scores (%) of participants' knowledge tests by group and phase with standard deviations. Error bars represent standard deviations of the mean scores.

The independent samples t-test was chosen to compare the scores between the trivia and lecture groups across the three phases: pre-treatment, post-treatment, and follow-up. This test is used when the assumption of normality is met. The independent samples t-test compares the means of two independent groups to determine if there is a statistically significant difference between them. A t-statistic represents the degree of separation between the two groups' means, and a larger t-value suggests a more significant difference between the groups.

Due to significant results from normality tests[1], non-parametric tests were also employed to verify the findings (see Appendix B for detailed results). However, given the robustness of parametric tests to violations of normality assumptions in large samples, the use of the independent samples *t*-test was justified and is presented here for clarity and consistency. Previous research supports this approach, demonstrating that parametric tests like the *t*-test maintain their reliability and Type I error rates even when normality is violated in large samples (Rasch et al., 2011). This robustness is attributed to the Central Limit Theorem, which states that the sampling distribution of the mean approximates normality as sample size increases (Lumley et al., 2002).

Hypothesis 1.a: Participants in Both the Lecture and Trivia-Card Groups Will Score Significantly Higher in the Post-Test Phase Than in the Baseline Phase

To evaluate Hypothesis 1.a, which posited that both the lecture and trivia groups would show significant improvements from the baseline to the post-test phase, paired t-tests were conducted within each group. In the lecture group, the paired t-test revealed a statistically significant improvement in scores from the baseline to the post-test phase ($t(45) = 3.198$, $p = 0.003$) Cohen's d (0.471) indicated a medium effect. This reveals that participants who received the lecture demonstrated substantial gains in knowledge immediately following the intervention. Similarly, the trivia group showed a significant enhancement in scores between the baseline and post-test phases ($t(40) = 4.382$, $p < 0.001$). The effect size (Cohen's d) was 0.684, indicating a large effect. These findings support Hypothesis 1.a, confirming that both instructional methods led to significant improvements in participants' scores from the baseline to the post-test phase.

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[1] Shapiro-Wilk tests indicated deviations from normality in some groups, prompting the use of non-parametric tests as supplementary analyses.

Hypothesis 1.b: The Trivia Group Will Score Significantly Higher Than the Lecture Group in the Post-Test Phase

Hypothesis 1.b aimed to determine whether the trivia group would outperform the lecture group in the post-test phase. An independent samples t-test was conducted to compare the post-treatment scores between the two independent groups. The results indicated no significant difference in post-test scores between the trivia and lecture groups ($t(86) = -0.719$, $p = 0.476$). This suggests that both instructional methods were equally effective in enhancing immediate knowledge acquisition among participants. Therefore, Hypothesis 1.b was not supported, as the trivia group did not score significantly higher than the lecture group in the post-test phase.

Hypothesis 2.a: Participants in Both Groups Will Demonstrate Significantly Higher Scores at the Follow-Up Phase Compared to the Baseline Phase

To assess long-term retention as proposed in Hypothesis 2.a, paired t-tests were utilized to compare baseline scores with follow-up scores within each group. For the lecture group, the analysis showed no significant difference between the baseline and follow-up scores ($t(45) = -0.719$, $p = 0.476$). This indicates that the knowledge gained from the lecture was not retained over time, and participants reverted to their baseline performance levels. In contrast, the trivia group demonstrated a statistically significant improvement from the baseline to the follow-up phase ($t(40) = 4.761$, $p < 0.001$), with a large effect size (Cohen's $d = 0.744$). This finding suggests that the trivia-based intervention had a lasting impact on participants' knowledge retention. These results partially support Hypothesis 2.a: while the trivia group exhibited significant long-term retention, the lecture group did not show a similar effect.

Hypothesis 2.b: The Trivia Group Will Exhibit Significantly Higher Retention Scores at the Follow-Up Phase Than the Lecture Group

Hypothesis 2.b predicted that the trivia group would exhibit better retention at follow-up compared to the lecture group. An independent samples t-test was performed to compare the follow-up scores between the two groups. The results showed a significant difference in knowledge retention between the trivia and lecture groups at the follow-up phase (t(85) = -2.146, p = 0.035), with the trivia group scoring higher. Therefore, Hypothesis 2.b is supported, indicating that the trivia group exhibited significantly better knowledge retention at the follow-up stage compared to the lecture group.

ANCOVA Results

To further assess the differences between the lecture and trivia groups while controlling for baseline (pre-treatment) scores, an ANCOVA was conducted. The ANCOVA for the Post-Treatment scores, controlling for Pre-Treatment scores, revealed no significant difference between the groups (F(1, 84) = 0.152, p = 0.697), indicating that after adjusting for pre-existing knowledge, both groups performed similarly in the Post-Treatment phase. However, the ANCOVA for the Follow-Up phase showed a significant difference between the Lecture and Trivia groups after adjusting for Pre-Treatment scores (F(1, 84) = 5.310, p = 0.024). The effect size (Partial Eta Squared = 0.059) suggests that the trivia-based intervention had a small to medium impact on long-term knowledge retention. Additionally, Pre-Treatment scores were a significant covariate (F(1, 84) = 4.515, p = 0.037), indicating that participants' initial knowledge levels influenced their retention outcomes. These results reinforce previous findings that the Trivia group retained more knowledge over time compared to the Lecture group, even after accounting for initial differences in pre-treatment knowledge.

Hypothesis 3: Participants in the Trivia-Card Group Will Report Significantly Higher Satisfaction Levels Compared to Participants in the Lecture Group

An independent samples *t*-test was conducted to compare the satisfaction ratings between the two groups. The results revealed a statistically significant difference in satisfaction ratings between the trivia-card and lecture groups (*t*(85) = 4.76, *p* < .001). The mean satisfaction rating for the trivia-card format was 4.18 (SD = 0.62), while the lecture format had a mean satisfaction rating of 3.24 (SD = 0.95). Cohen's *d* was calculated to be 1.04, indicating a large effect size. These results suggest that participants in the trivia-card group were significantly more satisfied with their experience compared to those in the lecture group.

Further examination of the satisfaction levels revealed that the trivia-card format had higher percentages of participants who reported being "Very satisfied" (51.11%) and "Extremely satisfied" (33.33%). In contrast, the lecture format showed a more varied distribution of satisfaction, with notable percentages in "Moderately satisfied" (38.10%) and "Slightly satisfied" (23.81%).

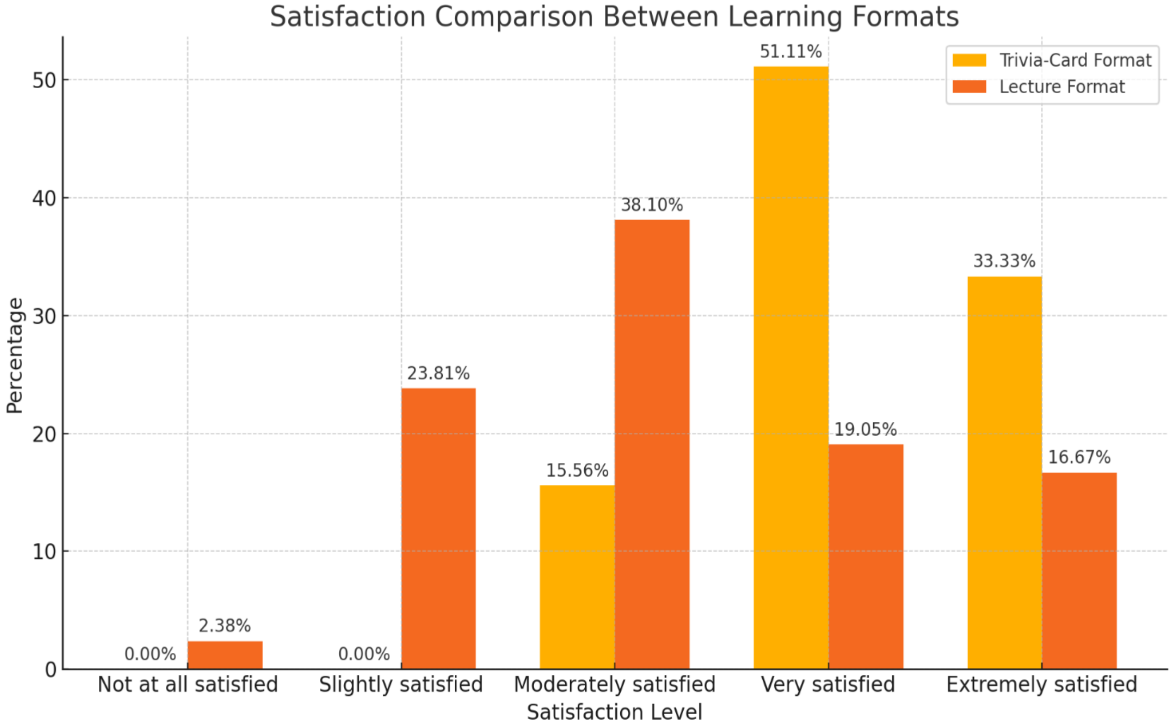

Figure 5. Comparison of reported participant satisfaction for both learning formats. Participants were only asked to rate their satisfaction for the learning format they received.

Participants were also asked to rate how well they felt they scored on the post-test (after receiving either the lecture or trivia-card treatment) compared to the baseline test. The trivia-card format had higher percentages of participants reporting "Somewhat better" (45%) and "Much better" (26%). In contrast, the lecture format showed higher percentages of participants reporting "About the same" (65%).

On a scale from 1 (much worse) to 5 (much better), the overall mean rating for perceived performance improvement (combining both trivia-card and lecture groups) was 3.59 (SD = 0.78). The mean rating for the trivia group was 3.97 (SD = 0.74), perceived performance improvement for the lecture group was 3.29 (SD = 0.67).

An independent samples t-test was conducted to compare perceived performance improvement between the trivia-card and lecture groups. The results indicated a statistically significant difference in perceived performance between the two formats, favouring the trivia-card group. (t(85) = 4.23, p < 0.001).

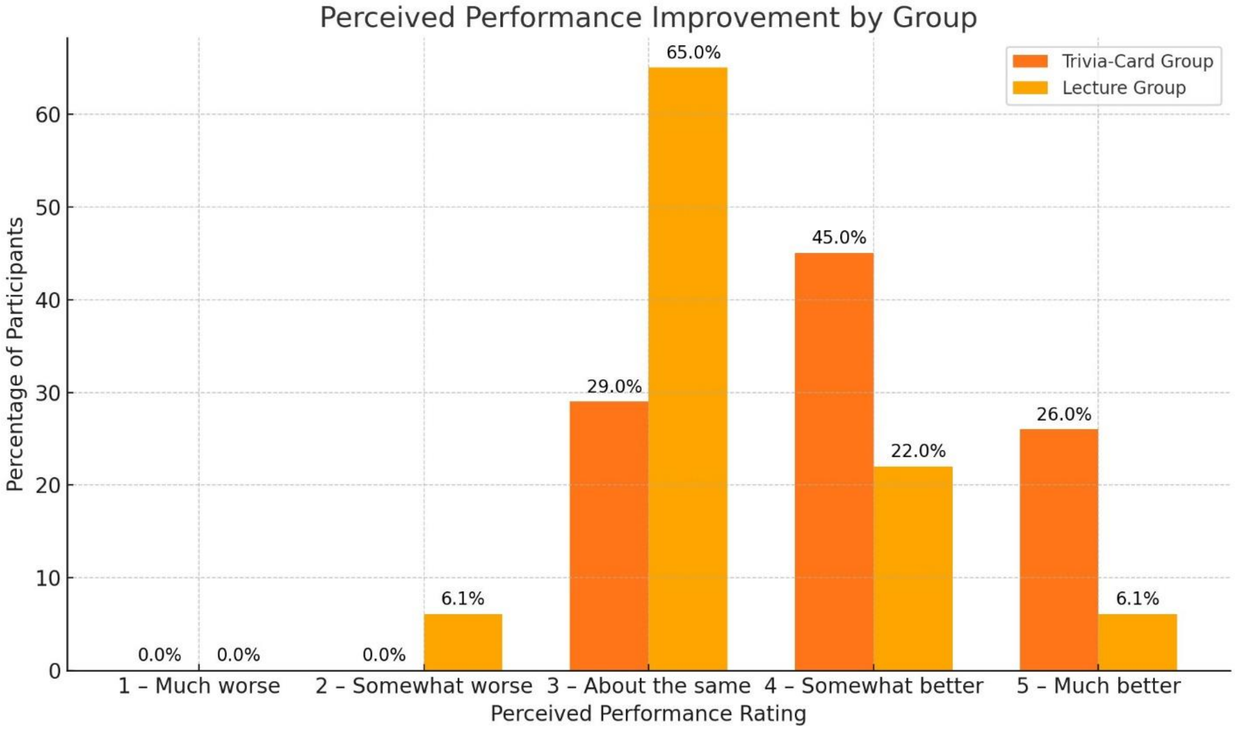

Figure 6. Perceived participant performance on post-test compared to baseline test.

Lecture Group Support

Participants who had been randomly assigned to the lecture treatment group were asked to rate their level of support if all future lab safety training were to be given in the traditional lecture format on a scale from 1 (strongly oppose) to 5 (strongly favor). The mean support rating for the traditional lecture format was 3.07 (SD = 0.77).

Trivia-Card Group Support

Participants who had been randomly assigned to the trivia-card treatment group were asked to rate their level of support if all future lab safety training were to be given in the trivia-card style format on a scale from 1 (strongly oppose) to 5 (strongly favor). The mean support rating for the trivia-card style format was 4.27 (SD = 0.57). Most participants selected "Somewhat favor" (60.00%) for the trivia-card style format. A third of participants indicated "Strongly favor" (33.33%), while a small percentage selected "Neutral" (6.67%). None of the participants selected "Strongly oppose" or "Somewhat oppose" for this question.

Personal Preferences and Experiences with Trivia-Card Games

All participants were asked to select the statement that they most closely relate to regarding their preferences and experiences with trivia-card games. There was a diverse range of experiences and preferences, however the vast majority of participants (70%) responded positively to preference and experience with trivia-card games ("I like playing trivia card games", "If I had the choice I would choose to complete safety training in which trivia card games were used", "I Often play trivia card games").

Based on these satisfaction survey findings, Hypothesis 3 is supported. Participants in the trivia-card group reported significantly higher levels of satisfaction (4.18) and perceived performance improvement (3.97) compared to those in the lecture group (3.24 and 3.29, respectively). The large effect size (Cohen's *d* = 1.04) indicates a substantial practical impact. Additionally, participants in the trivia-card group expressed strong support for the use of the trivia-card format in future lab safety training (4.27), and a majority of all participants showed positive attitudes toward trivia-card games.

Discussion

This study aimed to evaluate the effectiveness of two instructional methods—trivia-card games and traditional lectures—in enhancing knowledge acquisition and retention of laboratory safety information among undergraduate students. It was hypothesized that both the lecture and trivia groups would show significant improvements from the baseline to the post-test phase (Hypothesis 1.a). Additionally, it was predicted that the trivia group would score significantly higher than the lecture group in the post-test phase (Hypothesis 1.b). For long-term retention, it was hypothesized that participants in both groups would demonstrate significantly higher scores at the follow-up phase compared to baseline (Hypothesis 2.a), and that the trivia group would exhibit significantly higher retention scores at the follow-up phase than the lecture group (Hypothesis 2.b). Finally, it was anticipated that participants in the trivia group would report higher levels of satisfaction compared to those in the lecture group (Hypothesis 3).

Test Results

The analysis revealed that both the trivia-card game and lecture formats were effective in improving scores from pre-treatment to post-treatment, with significant improvements observed in both groups. Specifically, within-group comparisons using paired t-tests showed substantial improvements in scores for both the trivia and lecture groups. This suggests that both learning formats had a significant positive impact on participants' knowledge immediately following the intervention. These findings align with Bloom's Taxonomy, which supports the use of lectures for delivering foundational knowledge effectively (Bloom, 1956). The trivia format, on the other hand, may have promoted active recall, a key component of constructivist learning theories that emphasize knowledge construction through engagement (Fosnot & Perry, 2005).

Engagement Levels and Retention

The significant improvements in scores from pre-treatment to post-treatment suggest that participants were effectively engaged with the safety material during the interventions, aligning with research indicating that initial improvements in performance are often a sign of effective engagement with learning activities (Freeman et al., 2014). Both groups experienced a decline in scores from post-treatment to follow-up. The trivia group showed a smaller, non-significant decline, while the lecture group experienced a significant drop in scores. Despite these declines, the follow-up scores for both groups remained higher than their pre-treatment scores. Notably, the trivia group demonstrated sustained improvement from baseline to follow-up, indicating that knowledge gains were partially retained over time. In contrast, the lecture group did not show a significant difference between baseline and follow-up scores, suggesting that the knowledge gained from the lecture was not retained in the long term.

The trivia group’s smaller, non-significant decline in comparison to the lecture group's significant drop suggests that the interactive, gamified nature of trivia may help mitigate declines in knowledge retention over time. This aligns with findings from recent studies on interactive learning methods. For instance, De Micheli et al. (2022) demonstrated that a mixed reality (MR) platform for microfluidics training helped students retain knowledge over time through active, hands-on learning with virtual simulations. Similarly, the trivia-card format’s engaging, active approach likely promoted deeper cognitive processing and better retention by enabling participants to engage directly with the material, mirroring the interactive benefits observed in MR platforms.

The trivia format’s retention advantages are also supported by findings on VR-based safety training, where VR training outperformed traditional methods in both engagement and retention due to its immersive environment (Abdellatif & Sasse, 2021). This suggests that interactive environments, whether through VR or trivia games, allow learners to experience and actively respond to content, leading to enhanced engagement and retention.

In addition to VR and MR, studies using AI-enhanced learning further validate the impact of interactive formats. An AI-driven laboratory safety training platform, which employed real-time feedback and hazard recognition through machine learning, found that such immediate and adaptive responses improved knowledge retention and engagement (Luo et al., 2020). The trivia format's immediate feedback through questions and answers serves a similar purpose, reinforcing memory and understanding, and may have contributed to the sustained engagement and retention seen among participants in the trivia group.

The ANCOVA results further support these findings. For the post-treatment scores, after controlling for pre-treatment scores, there was no significant difference between the groups. This indicates that immediately after the intervention, both groups performed similarly when accounting for initial knowledge levels. However, for the follow-up scores, the ANCOVA revealed a significant difference between the lecture and trivia groups after adjusting for pre-treatment scores. The trivia-based intervention had a small to medium impact on long-term knowledge retention. Additionally, pre-treatment scores were a significant covariate for the follow-up phase, indicating that participants' initial knowledge levels influenced their retention outcomes. These results reinforce previous findings that the trivia group retained more knowledge over time compared to the lecture group, even after accounting for initial similarities in pre-treatment knowledge.

These results challenge the assumption that interactive formats like trivia inherently foster greater engagement compared to traditional lectures only in the short term. Instead, they suggest that the trivia format was more effective in sustaining participants' engagement with the material over time, leading to better long-term retention. This supports theories in educational psychology that emphasize the role of active engagement and interactive learning in promoting sustained knowledge retention (Guthrie & Wigfield, 2000).

Impact of Previous Lab Safety Training

An analysis was conducted to examine the effect of participants' previous lab safety training on their performance. According to the satisfaction survey, 73.26% of participants reported having prior lab safety training, while 26.74% reported having no prior lab safety training experience.

When examining the interaction between previous training and instructional methods post-hoc, a two-way ANOVA on the follow-up scores indicated that there was no significant interaction effect (F(1, 82) = 0.021, p = 0.885). Additionally, there were no significant main effects for previous training (F(1, 82) = 0.023, p = 0.880) or instructional method. These findings suggest that the effectiveness of the instructional methods was consistent regardless of prior lab safety training. Despite this suggestion of methodological efficacy across instructional methods, this does lead to the likely conclusion that the test contents were not sufficiently challenging for undergraduate students.

Theoretical Implications

The improvements observed in both groups align with the lower levels of Bloom’s Taxonomy—Knowledge, Comprehension, and Application—where lectures are traditionally effective (Bloom, 1956). The lecture format successfully conveyed foundational information, leading to immediate knowledge gains. However, the significant decline in the lecture group's follow-up scores highlights the limitations of traditional lectures in promoting higher-order cognitive skills and long-term retention.

The trivia format's sustained effectiveness may be attributed to its alignment with constructivist and connectivist learning theories, which emphasize knowledge construction through active engagement and interaction (Fosnot & Perry, 2005). This theoretical basis finds additional support in interactive learning research, such as the MR study by De Micheli et al. (2022) and the AI-enhanced laboratory safety platform (Luo et al., 2020), which both emphasize the role of immediate, adaptive feedback in promoting long-term retention. This is consistent with Anderson’s stage-learning theory, which posits that active participation and reinforcement aid in transitioning from declarative to procedural knowledge (Anderson, 1985).

Moreover, the trivia format embodies elements of Problem-Based Learning (PBL), which encourages learners to apply knowledge in problem-solving contexts, enhancing understanding and retention (Barrows & Tamblyn, 1980). By engaging in the trivia game, participants likely experienced enhanced motivation and interest, factors known to positively impact learning outcomes (Deci & Ryan, 2000). The positive effects observed in this study suggest that integrating interactive elements into learning activities—whether through trivia cards, VR, MR, or AI applications—can create meaningful and engaging learning experiences that support both immediate and long-term learning objectives.

Satisfaction Survey Results and Implications

Participants expressed higher satisfaction with the trivia-card format, as indicated by higher mean satisfaction scores ($M = 4.18$, $SD = 0.68$) compared to the lecture format ($M = 3.24$, $SD = 1.06$). A greater percentage of participants rated their experience with the trivia-card format as "Very satisfied" or "Extremely satisfied," suggesting that the interactive and engaging nature of this format contributed to a more positive learning experience. An independent samples t-test confirmed the significant difference in satisfaction ratings between the two groups ($t(85) = 4.76$, $p < 0.001$, Cohen's $d = 1.04$), indicating a large practical impact.

The higher satisfaction with the trivia-card format can be understood through theoretical frameworks discussed previously. The immediate positive feedback inherent in this format aligns with Skinner’s reinforcement theory, where positive reinforcement encourages the repetition of enjoyable behaviours (Skinner, 1969). Bandura’s social-learning theory also offers insight into how the trivia-card format enhanced participants' experiences through peer interaction and observational learning (Bandura, 1977). The collaborative environment fostered by the trivia game likely contributed to increased engagement and satisfaction.

Participants were also asked to rate their support for future labs being conducted in the learning format they received (see Table 3, Table 4). Comparing the responses to this question by group revealed a significant difference. Specifically, the trivia-card group reported a higher mean support rating of 4.27 (SD = 0.57), whereas the lecture group had a mean rating of 3.07 (SD = 0.77). An independent samples t-test revealed that this difference was statistically significant ($t(75) = -8.22$, $p < 0.001$), highlighting a clear preference for the trivia-card format among participants.

When examining participants' perceived performance improvement, there was a notable difference based on the instructional method. The majority of the lecture group (65%) felt their performance remained "About the same" after the lecture, with only 22% perceiving any improvement. In contrast, the trivia group showed a more positive distribution, with 71% of participants perceiving their performance as "Somewhat better" or "Much better," and none reporting worse performance. An independent samples t-test revealed a statistically significant difference in perceived performance between the two formats ($t(85) = 4.89$, $p < 0.001$).

These findings are supported by research indicating a strong link between student satisfaction and perceived academic performance. Keržič et al. (2021) found that students' satisfaction with the quality of their learning experience significantly impacted their perceptions of academic performance. The engaging nature of the trivia-card game may have contributed to participants' higher perceptions of improvement, as satisfying learning experiences often enhance confidence and perceived competence.

Participants who experienced the trivia-card format showed strong support for its use in future lab safety training, with a mean support rating of 4.27 (SD = 0.57). Most participants selected

"Somewhat favor" or "Strongly favor." In contrast, participants who experienced the lecture format had a more neutral stance, with a mean support rating of 3.07 (SD = 0.77). This suggests that while the lecture format is a familiar method, it may not be as engaging or preferred when compared to more interactive alternatives like the trivia-card game. These findings underscore the potential benefits of integrating interactive and engaging elements into educational formats to enhance satisfaction and learning outcomes. Importantly, the survey results stand out as the only aspect of the study where a statistically significant difference was observed between the two groups in terms of participant satisfaction.

Limitations

One significant limitation of this study was the high ceiling effect due to the participants' baseline knowledge, resulting in very high scores across all three phases. This made detecting differences between groups challenging. The uniqueness of the questions on each test and the lack of equivalency across different phases prevented the elimination of low-variance questions without risking an imbalance in assessments. Low-variance questions provide little valuable information because they do not effectively differentiate between participants’ knowledge levels (Nunnally & Bernstein, 1994). Ensuring question equivalency in future research could help detect smaller, more nuanced differences in learning outcomes.

One notable limitation is that the 5-point scales used in the survey were not validated against established metrics. While efforts were made to align survey items with the objectives of the study, the lack of validation introduces potential concerns about the reliability and validity of the measured constructs. Future research should consider employing or adapting validated scales to ensure more robust and interpretable results.

This study lacked any measure to assess participant motivation. Motivation plays a critical role in educational and experimental contexts, influencing both engagement and outcomes. However, this study did not include any attempt to measure participant motivation, which leaves a gap in understanding how this factor may have impacted the results. Future research should incorporate established measures, such as the Academic Motivation Scale (Vallerand et al., 1992), to better capture this variable.

Another limitation is the relatively short follow-up period of two weeks. While sufficient to assess short-term retention, it does not provide insights into the long-term effectiveness of the interventions. Extending the follow-up period in future studies would provide a better understanding of the sustained impact of these teaching methods.

The reliance on self-reported data for the satisfaction survey introduces the potential for response bias. Participants might have provided socially desirable answers rather than their true opinions, which could skew the results. The survey design did not include open-ended questions where participants could explain their preferences, limiting the depth of insights that could have been gained.

The experimental setup may have also impacted the results. The seminar room environment did not fully reflect real-world educational contexts, such as large lecture halls or actual laboratory settings. The small group sizes and direct interaction with the instructor may have positively influenced participants' satisfaction and engagement, particularly in the lecture group.

Additionally, the sample was limited to undergraduate students from a single institution, which may affect the generalizability of the findings. Future studies should include larger and more diverse samples to enhance the applicability of the results across different educational contexts and populations.

Future Directions

Future research should investigate the long-term effects of trivia-based learning on safety knowledge retention over extended periods, such as six months or a year, to determine its sustainability as a training method. Extending the follow-up period beyond the two-week scope of this study would provide a more comprehensive understanding of its effectiveness in reinforcing lasting knowledge.

Another avenue for research is to explore the generalizability of trivia-based learning by applying it across diverse educational contexts and participant samples where lectures are the current standard. This includes testing its effectiveness among students from various disciplines, such as engineering, healthcare, or the arts, and at different educational levels, from high school to postgraduate settings. Such studies would help establish the broader applicability of trivia-based methods and refine them to meet the needs of specific learner populations.

Future studies should also focus on identifying the specific elements of trivia-based learning that contribute most to its effectiveness in these student populations. For example, the collaborative nature of trivia games, their competitive aspects, and the role of immediate feedback in reinforcing knowledge could be studied independently. Understanding the relative impact of these components could guide the design of targeted educational interventions, maximizing their benefits while minimizing potential drawbacks.

Given the increasing prevalence of remote learning, investigating the effectiveness of trivia-based learning in online environments is another critical area for future research. Studies could examine how virtual interaction dynamics, such as reduced social cues or reliance on digital interfaces, influence engagement, satisfaction, and learning outcomes in trivia-based formats. These insights would be particularly valuable for designing effective remote safety training programs.

Finally, adopting mixed-methods approaches that combine quantitative assessments with qualitative methods, such as interviews or focus groups, could provide a richer understanding of learners' experiences with trivia-based training. Qualitative insights could uncover nuanced factors influencing satisfaction and engagement, while quantitative metrics would validate the effectiveness of these methods. Such a comprehensive approach would allow educators and researchers to optimize learning strategies and improve educational outcomes.

Implications for Educational Practices

The findings suggest that while both instructional methods are effective for immediate knowledge acquisition, the trivia-card game format offers superior long-term retention and higher participant satisfaction. This aligns with research highlighting the benefits of active learning strategies for enhancing retention and engagement compared to traditional lecture methods (Freeman et al., 2014; Prince, 2004). Incorporating interactive, game-based learning strategies into educational programs can therefore enhance learning outcomes and support knowledge retention over time.

Educators and training facilitators should consider blending traditional lectures with interactive activities to promote deeper engagement and better retention. For instance, studies have demonstrated that combining lectures with interactive methods, such as clicker questions or gamified activities, can improve both cognitive and affective learning outcomes (Kay et al., 2009; Wang, 2015). Lectures can deliver foundational knowledge, while trivia games or similar approaches can reinforce and apply that knowledge through active recall and feedback, supporting higher-order cognitive processes as outlined by Bloom's Taxonomy (1956). By catering to diverse learning needs and engaging a broader range of cognitive processes, this blended approach has the potential to improve educational outcomes across various contexts.

Concluding Remarks

Taken together, the findings have significant practical implications for educational practices in laboratory safety. While both teaching methods were effective in maintaining knowledge over time, the interactive nature of trivia appears to offer additional engagement benefits. Integrating interactive elements like trivia-based activities into safety training curricula can enhance student satisfaction, and boost confidence. Such methods not only make learning more enjoyable but also potentially increase the effectiveness of safety education, leading to better safety practices in laboratory settings.

Educators can leverage these findings to design more engaging and effective safety training programs. By incorporating gamified elements, educators can foster a more interactive learning environment that enhances student motivation and participation. This approach can be particularly beneficial in other educational contexts where engagement is crucial for learning complex or tedious material.

The results underline the importance of considering student satisfaction when designing educational interventions. Higher satisfaction with the learning method can lead to increased motivation and willingness to participate in future training, thereby sustaining long-term educational benefits. Acknowledging that prior experience did not significantly alter outcomes, educators can confidently apply interactive methods broadly to enhance learning for all students.

References

Abdellatif, R., & Sasse, M. A. (2021). Virtual reality in safety training: A systematic literature review and meta-analysis. *Safety Science*, *135*, 105119. https://doi.org/10.1016/j.ssci.2020.105119

American Chemical Society (ACS). (2012). *Creating Safety Cultures in Academic Institutions: A Report of the Safety Culture Task Force of the ACS Committee on Chemical Safety*. Washington, DC: American Chemical Society.

Anderson, J. R. (1985). *Cognitive skill acquisition*. In J. R. Anderson (Ed.), Cognitive skills and their acquisition (pp. 1–55). Hillsdale, NJ: Lawrence Erlbaum Associates.

Anderson, J. R. (1985). *Cognitive psychology and its implications* (2nd ed.). Freeman.

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. Longman.

Anderson, T. W., & Darling, D. A. (1954). A test of goodness-of-fit. *Journal of the American Statistical Association, 49*(268), 765-769. https://doi.org/10.2307/2281537

Ayi, H.-R., & Hon, C.-Y. (2018). Safety culture and safety compliance in academic laboratories: A Canadian perspective. *Journal of Chemical Health and Safety, 25*(6), 6–12. https://doi.org/10.1016/j.jchas.2017.09.001

Balakrishna, C. (2023). The impact of in-classroom non-digital game-based learning activities on students transitioning to higher education. *Education Sciences, 13*(4), 328. https://doi.org/10.3390/educsci13040328

Bandura, A. (1977). *Social learning theory*. Prentice Hall.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. Springer Publishing.

Becker, W. E., & Watts, M. (2001). Teaching economics at the start of the 21st century: Still chalk-and-talk. *American Economic Review, 91*(2), 446-451. https://doi.org/10.1257/aer.91.2.446

Beetham, H., & Sharpe, R. (2013). *Rethinking pedagogy for a digital age: Designing for 21st-century learning* (2nd ed.). Routledge.

Bligh, D. A. (2000). *What's the use of lectures?* Intellect Books.

Bloom, B. S. (1956). *Taxonomy of educational objectives: The classification of educational goals* (Vol. 1). Longman.

Bonwell, C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom* (ASHE-ERIC Higher Education Report No. 1). The George Washington University, School of Education and Human Development.

Boone, H. N., & Boone, D. A. (2012). Analyzing Likert data. *Journal of Extension, 50*(2), 1-5.

Brassil, C. E., & Couch, B. A. (2019). Multiple-true-false questions reveal more thoroughly the complexity of student thinking than multiple-choice questions: A Bayesian item response model comparison. *International Journal of STEM Education, 6*(16). https://doi.org/10.1186/s40594-019-0169-0

Bruner, J. S. (1966). *Toward a theory of instruction*. Harvard University Press.

Bureau of Labor Statistics (BLS). (2019). *Employer-Reported Workplace Injuries and Illnesses – 2019*. U.S. Department of Labor.

Burke, M. J., Holman, D., & Birdi, K. (2008). A walk on the safe side: The implications of learning theory for developing effective safety and health training. *International Review of Industrial and Organizational Psychology 2006,* 1–44. https://doi.org/10.1002/9780470696378.ch1

Burke, M. J., & Signal, S. M. (2010). Workplace safety: A multilevel, interdisciplinary perspective. In H. Liao, J. J. Martocchio, & A. Joshi (Eds.), *Research in personnel and human resource management* (Vol. 29, pp. 1-47). Emerald Group Publishing Limited.

Chemical Safety Board (CSB). (2011). *Texas Tech University Laboratory Explosion*. Report No. 2010-05-I-TX.

Chugani, H. T. (1998). A critical period of brain development: Studies of cerebral glucose utilization with PET. *Preventive Medicine, 27*(2), 184–188. https://doi.org/10.1006/pmed.1998.0274

Christianson, S.-Å. (1992). Emotional stress and eyewitness memory: A critical review. *Psychological Bulletin, 112*(2), 284–309. https://doi.org/10.1037/0033-2909.112.2.284

Christian, M. S., Bradley, J. C., Wallace, J. C., & Burke, M. J. (2009). Workplace safety: A meta-analysis of the roles of person and situation factors. *Journal of Applied Psychology, 94*(5), 1103-1127. https://doi.org/10.1037/a0016172

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Cohen, J. (1992). Quantitative methods in psychology: A power primer. *Psychological Bulletin, 112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

Conover, W. J. (1999). *Practical nonparametric statistics* (3rd ed.). John Wiley & Sons.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. Plenum.

Deci, E. L., & Ryan, R. M. (2000). The 'what' and 'why' of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227-268. https://doi.org/10.1207/S15327965PLI1104_01

Deci, E. L., & Ryan, R. M. (2002). *Handbook of self-determination research*. University of Rochester Press.

De Micheli, A. J., Valentin, T., Grillo, F., Kapur, M., & Schuerle, S. (2022). Mixed reality for an enhanced laboratory course on microfluidics. *Journal of Chemical Education*, *99*(3), 1272–1279. https://doi.org/10.1021/acs.jchemed.1c00979

Fleming, M. (2017). Safety attitudes and motivations. Work Safe for Life. Retrieved from https://www.worksafeforlife.ca/Portals/WorkSafeForLifeRedesign/Documents/Research%20Papers/Fleming_Safety_Attitudes_Motivations.pdf?ver=2017-08-18-141310-677

Fosnot, C. T., & Perry, R. S. (1996). **Constructivism: A psychological theory of learning**. In C. T. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (pp. 8–33). New York, NY: Teachers College Press.

Franzen, D., Cuddy, M. M., & Ilgen, J. S. (2018). Trusting your test results: Building and revising multiple-choice examinations. *Journal of Graduate Medical Education, 10*(3), 337–338. https://doi.org/10.4300/JGME-D-18-00265.1

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410-8415. https://doi.org/10.1073/pnas.1319030111

Gagné, M., & Deci, E. L. (2005). Self-determination theory and work motivation. *Journal of Organizational Behavior, 26*(4), 331-362. https://doi.org/10.1002/job.322

Gelman, A., & Carlin, J. (2014). Beyond power calculations: Assessing type S (sign) and type M (magnitude) errors. *Perspectives on Psychological Science, 9*(6), 641-651. https://doi.org/10.1177/1745691614551642

Gess-Newsome, J., Southerland, S. A., Johnston, A., & Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching. *American Educational Research Journal, 40*(3), 731-767. https://doi.org/10.3102/00028312040003731

Gibbs, G., & Jenkins, A. (1992). *Teaching large classes in higher education: How to maintain quality with reduced resources*. Kogan Page.

Government of Canada. (2015). *Workplace Hazardous Materials Information System (WHMIS 2015)*. Retrieved from https://www.canada.ca/en/health-canada/services/environmental-workplace-health/occupational-health-safety/workplace-hazardous-materials-information-system.html

Guldenmund, F. W. (2010). (Mis)understanding safety culture and its relationship to safety management. *Risk Analysis, 30*(10), 1466-1480. https://doi.org/10.1111/j.1539-6924.2010.01452.x

Guthrie, J. T., & Wigfield, A. (2000). Engagement and motivation in reading. In M. L. Kamil, P. B. Mosenthal, P. D. Pearson, & R. Barr (Eds.), *Handbook of reading research* (Vol. 3, pp. 403-422). Lawrence Erlbaum Associates.

Hale, A. R., & Hovden, J. (1998). Management and culture: The third age of safety. *Safety Science, 29*(3), 193-205. https://doi.org/10.1016/S0925-7535(98)00060-4

Heinrich, H. W., Petersen, D., & Roos, N. (1980). *Industrial accident prevention: A safety management approach* (5th ed.). McGraw-Hill.

Hollander, M., & Wolfe, D. A. (1999). *Nonparametric statistical methods* (2nd ed.). John Wiley & Sons.

Joshi, A., Kale, S., Chandel, S., & Pal, D. K. (2015). Likert scale: Explored and explained. *British Journal of Applied Science & Technology, 7*(4), 396-403.

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in science education: A systematic review of the literature. *Education Sciences, 11*(1), 22. https://doi.org/10.3390/educsci11010022

Kanfer, R., & Ackerman, P. L. (1989). Motivation and cognitive abilities: An integrative/aptitude-treatment interaction approach to skill acquisition. *Journal of Applied Psychology, 74*(4), 657–690. https://doi.org/10.1037/0021-9010.74.4.657

Kay, R. H., & LeSage, A. (2009). Examining the benefits and challenges of using audience response systems: A review of the literature. *Computers & Education*, 53(3), 819–827.

Kemsley, J. (2018, December 28). 10 years after Sheri Sangji's death, are academic labs any safer? *Chemical & Engineering News*. Retrieved from https://cen.acs.org/safety/lab-safety/10-years-Sheri-Sangjis-death/97/i1

Keržič, D., Alex, J. K., Alvarado, R. P. B., Bezerra, D. da S., Cheraghi, M., Dobrowolska, B., Fagbamigbe, A. F., Faris, M. E., França, T., González-Fernández, B., Gonzalez-Robledo, L. M., Inasius, F., Kar, S. K., Lazányi, K., Lazăr, F., Machin-Mastromatteo, J. D., Marôco, J., Marques, B. P., Mejía-Rodríguez, O., … Aristovnik, A. (n.d.). Academic student satisfaction and perceived performance in the e-learning environment during the COVID-19 pandemic: Evidence across ten countries. *PLOS ONE*. https://doi.org/10.1371/journal.pone.0258807

King, M. F., & Bruner, G. C. (2000). Social desirability bias: A neglected aspect of validity testing. *Psychology & Marketing, 17*(2), 79–103. https://doi.org/10.1002/(SICI)1520-6793(200002)17:2<79::AID-MAR2>3.0.CO;2-0

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lumley, T., Diehr, P., Emerson, S., & Chen, L. (2002). The importance of the normality assumption in large public health data sets. *Annual Review of Public Health*, 23, 151–169.

Lumpkin, A., Achen, R. M., & Dodd, R. K. (2015). Student perceptions of active learning. *College Student Journal*, 49(1), 121–133.

Luo, H., Zhang, Y., Zheng, S., & Xu, G. (2020). Enhanced laboratory safety education through interactive applications of machine learning-boosted image processing technologies. *IEEE Transactions on Industrial Informatics*, *16*(12), 7838–7846. https://doi.org/10.1109/TII.2020.2975853

Mann, H. B., & Whitney, D. R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *The Annals of Mathematical Statistics, 18*(1), 50-60. https://doi.org/10.1214/aoms/1177730491

Massey, F. J. Jr. (1951). The Kolmogorov-Smirnov test for goodness of fit. *Journal of the American Statistical Association, 46*(253), 68-78. https://doi.org/10.2307/2280095

Ménard, A. D., & Trant, J. F. (2020). A review and critique of academic lab safety research. *Nature Chemistry, 12*(1), 17–25. https://doi.org/10.1038/s41557-019-0375-x

McAfee, R. B., & Winn, A. R. (1989). The use of incentives/feedback to enhance workplace safety: A critique of the literature. *Journal of Safety Research, 20*(1), 7-19. https://doi.org/10.1016/0022-4375(89)90003-8

Murayama, K., & Elliot, A. J. (2011). Achievement motivation and memory. *Personality and Social Psychology Bulletin, 37*(10), 1339–1348. https://doi.org/10.1177/0146167211410575

Murayama, K. (2018, June). The science of motivation. *American Psychological Association*. Retrieved from https://www.apa.org/science/about/psa/2018/06/motivation

Nahrgang, J. D., Morgeson, F. P., & Hofmann, D. A. (2011). Safety at work: A meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes. *Journal of Applied Psychology, 96*(1), 71–94. https://doi.org/10.1037/a0021484

National Research Council. (2011). *Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards (Updated Edition)*. Washington, DC: The National Academies Press.

Neal, A., & Griffin, M. A. (2004). Safety climate and safety at work. In J. Barling & M. R. Frone (Eds.), *The psychology of workplace safety* (pp. 15-34). American Psychological Association. https://doi.org/10.1037/10662-002

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric Theory* (3rd ed.). McGraw-Hill.

Occupational Safety and Health Administration (OSHA). (2011). *Laboratory safety guidance* (OSHA 3404-11R). U.S. Department of Labor. Retrieved November 20, 2024, from https://www.osha.gov/sites/default/files/publications/OSHA3404laboratory-safety-guidance.pdf

Piaget, J. (1972). *The psychology of the child*. Basic Books.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x

Rasch, D., Kubinger, K. D., & Moder, K. (2011). The two-sample *t*-test: Pre-testing its assumptions does not pay off. *Statistical Papers*, 52(1), 219–231.

Razali, N. M., & Wah, Y. B. (2011). Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors, and Anderson-Darling tests. *Journal of Statistical Modeling and Analytics, 2*(1), 21-33.

Reason, J. (2000). Human error: Models and management. *BMJ, 320*(7237), 768-770. https://doi.org/10.1136/bmj.320.7237.768

Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review, 6*(2), 135-147.

Riiskjær, E., Ammentorp, J., & Kofoed, P.-E. (2012). The value of open-ended questions in surveys on patient experience: Number of comments and perceived usefulness from a hospital perspective. *International Journal for Quality in Health Care, 24*(5), 509-516. https://doi.org/10.1093/intqhc/mzs039

Roberts, K. H. (1990). Some characteristics of one type of high reliability organization. *Organization Science*, 1(2), 160-176.

Ryan, R. M., & Deci, E. L. (2002). An overview of self-determination theory: An organismic-dialectical perspective. In E. L. Deci & R. M. Ryan (Eds.), *Handbook of self-determination research* (pp. 3-33). University of Rochester Press.

Saint Mary's University. (2013). *Science Lab Safety Orientation Checklist*. Retrieved from https://www.smu.ca/webfiles/ScienceLabSafetyOrientationChecklist.pdf

Schneider, B. (1975). Organizational climate: An essay. *Personnel Psychology, 28*(4), 447-479. https://doi.org/10.1111/j.1744-6570.1975.tb01386.x

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika, 52*(3-4), 591-611. https://doi.org/10.2307/2333709

Shendell, D. G., Jhaveri, M., Nowakowski, A. C. H., Wozniak, M. E., Campbell, J. K., Marshall, E. G., & Kelly, S. W. (2010). Incident surveillance in New Jersey career and technical education programs, 1999 to 2008: Attributes, severity, and reported use of personal protective equipment. *AAOHN Journal, 58*(9), 367–380. https://doi.org/10.3928/08910162-20100826-01

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning, 2*(1), 3-10.

Sielof, A. C., Shendell, D. G., Marshall, E. G., & Ohman-Strickland, P. (2013). An examination of injuries and respiratory irritation symptoms among a sample of undergraduate chemistry students from a public Northeastern university. *Journal of Chemical Health and Safety, 20*(3), 17–26. https://doi.org/10.1016/j.jchas.2012.11.002

Skinner, B. F. (1969). *Contingencies of reinforcement: A theoretical analysis*. Appleton-Century-Crofts.

Sugano, S. G. C., & Mamolo, L. A. (2021). The effects of teaching methodologies on students' attitude and motivation: A meta-analysis. *International Journal of Instruction, 14*(3), 827-846. https://doi.org/10.29333/iji.2021.14349a

Thesen, T., Bahner, I., Belovich, A. N., et al. (2023). Not just fun and games: Game-based learning in health professions education. *Medical Science Educator, 33,* 1301–1306. https://doi.org/10.1007/s40670-023-01859-z

Vallerand, R. J., Pelletier, L. G., Blais, M. R., Brière, N. M., Senécal, C., & Vallières, É. F. (1992). The Academic Motivation Scale: A measure of intrinsic, extrinsic, and amotivation in education. *Educational and Psychological Measurement, 52*(4), 1003-1017.

van Berkel, N., Goncalves, J., Hosio, S., & Kostakos, V. (2019). The promise of open survey questions: The validation of text-based job satisfaction measures. *PLOS ONE, 14*(2), e0212223. https://doi.org/10.1371/journal.pone.0212223

van der Heijde, R., & Deichmann, D. (2018, October 31). How one hospital improved patient safety in 10 minutes a day. *Harvard Business Review*. Retrieved from https://hbr.org/2018/10/how-one-hospital-improved-patient-safety-in-10-minutes-a-day

Vogt, W. P., & Johnson, R. B. (2011). *Dictionary of statistics & methodology: A nontechnical guide for the social sciences* (4th ed.). SAGE Publications.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Vygotsky, L. S. (1987). *Thinking and speech*. In R.W. Rieber & A.S. Carton (Eds.), *The collected works of L.S. Vygotsky* (Vol. 1, pp. 39–285). Plenum Press. (Original work published 1934)

Wang, A. I. (2015). The wear out effect of a game-based student response system. *Computers & Education*, 82, 217–227.

Wei, Y., Zhu, Z., Yu, H., & Zhang, W. (2021). A real-time threat image projection (TIP) model base on deep learning for X-ray baggage inspection. *Physics Letters A, 400,* 1–4. https://doi.org/10.1016/j.physleta.2021.127306

Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin, 1*(6), 80-83. https://doi.org/10.2307/3001968

Zohar, D. (2011). Safety climate: Conceptual and measurement issues. In J. C. Quick & L. E. Tetrick (Eds.), *Handbook of occupational health psychology* (2nd ed., pp. 141-164). American Psychological Association. https://doi.org/10.1037/10474-007

Appendix A: Tests for each phase with percentage correct by group

Pre-Test Phase

Shorts are permitted to be worn in science labs.

A. True

B. False

Answer: B. False

Lecture: 41.86%

Trivia: 57.78%

When diluting acid, always pour acid into water.

A. True

B. False

Answer: A. True

Lecture: 51.16%

Trivia: 64.44%

You can try new experiments even if they are not in the directions as long as you are curious about science.

A. True

B. False

Answer: B. False

Lecture: 95.35%

Trivia: 95.56%

Hand protection is only required to be worn on the hand that will be handling hazardous materials.

A. True

B. False

Answer: B. False

Lecture: 100%

Trivia: 100%

If you break glassware, it should be carefully disposed of in the general waste bins located in each lab.

A. True

B. False

Answer: B. False

Lecture: 97.67%

Trivia: 100%

Food and drink are not permitted in science labs.

A. True

B. False

Answer: A. True

Lecture: 100%

Trivia: 100%

It is ok to slide a scalpel across the lab bench to your friend who is waiting to use it.

A. True

B. False

Answer: B. False

Lecture: 100%

Trivia: 100%

In an experiment, use the exact amount of each chemical as specified in your lab instructions.

A. True

B. False

Answer: A. True

Lecture: 97.67%

Trivia: 100%

A stopper should be placed in any chemical bottle when it is not in use.

A. True

B. False

Answer: A. True

Lecture: 100%

Trivia: 100%

Specimen jars should not be opened unless instructed.

A. True

B. False

Answer: A. True

Lecture: 100%

Trivia: 100%

When an acid comes in contact with your skin, you should immediately wash it with what?

A. Soap

B. Oil

C. Weak base

D. Water

Answer: D. Water

Lecture: 97.67%

Trivia: 93.33%

Which of the following is the best footwear to use in the lab?

A. Sandals

B. Open-toed shoes

C. Closed-toed shoes

D. Slippers

Answer: C. Closed-toed shoes

Lecture: 79.07%

Trivia: 91.11%

Why should we not add water to a solution containing concentrated acids?

A. It would dilute the acid

B. It would cause the acid to cool down

C. Acid would splatter

D. Acid would go bad

Answer: C. Acid would splatter

Lecture: 79.07%

Trivia: 91.11%

What is the main purpose of wearing goggles and other eye protection devices?

A. To prevent glassware, heat, or chemicals from coming in contact with your eyes

B. To protect against fumes

C. To look stylish

D. To help you see better

Answer: A. To prevent glassware, heat, or chemicals from coming in contact with your eyes

Lecture: 100%

Trivia: 100%

What should you do when a chemical comes in contact with your eyes?

A. Wash your eyes thoroughly with water from the eyewash station

B. Wait for your instructor to assist

C. Do nothing if it doesn’t hurt

D. Wipe your eyes with a towel

Answer: A. Wash your eyes thoroughly with water from the eyewash station

Lecture: 97.67%

Trivia: 100%

If you do not understand a direction or part of a lab procedure, you should…

A. Ask the instructor before proceeding

B. Ask a friend

C. Skip that part of the experiment

D. Guess what to do

Answer: A. Ask the instructor before proceeding

Lecture: 95.35%

Trivia: 100%

Trivial Pursuit for Safer Science Labs

After completing an experiment, all chemical wastes should be…

A. Disposed of according to your instructor’s directions

B. Poured down the sink

C. Thrown in the garbage

D. Left on the table for the next class

Answer: A. Disposed of according to your instructor’s directions

Lecture: 97.67%

Trivia: 100%

If a lab experiment is not completed, you should…

A. Hurry to finish before the class ends

B. Do it at home

C. Discuss the issue with your instructor

D. Skip it entirely

Answer: C. Discuss the issue with your instructor

Lecture: 97.67%

Trivia: 100%

You are heating a substance in a test tube - always point the open end of the tube…

A. Away from all people

B. Towards yourself

C. Towards your lab partner

D. Towards the ceiling

Answer: A. Away from all people

Trivial Pursuit for Safer Science Labs

Lecture: 97.67%

Trivia: 100%

You are heating a piece of glass and now want to pick it up. You should…

A. Use your hands

B. Use tongs

C. Wait until it cools

D. Call your instructor

Answer: B. Use tongs

Lecture: 97.67%

Trivia: 100%

When gathering glassware and equipment for an experiment, you should…

A. Use the first items you see

B. Check all glassware for chips and cracks

C. Ignore small cracks

D. Only grab what looks clean

Answer: B. Check all glassware for chips and cracks

Lecture: 93.02%

Trivia: 100%

Post-Test Phase

Personal eyeglasses provide as much protection as…

A. a face shield.

B. safety glasses.

C. splashproof chemical goggles.

D. none of the above.

Answer: D. none of the above

Lecture: 93.02%

Trivia: 91.11%

Long hair in the laboratory must be…

A. cut short.

B. held away from the experiment with one hand.

C. always neatly groomed.

D. tied back or kept entirely out of the way with a hair band, hairpins, or other confining device.

Answer: D. tied back or kept entirely out of the way with a hair band, hairpins, or other confining device

Lecture: 95.35%

Trivia: 97.78%

In a laboratory the following should not be worn…

A. Loose clothing.

B. Dangling jewelry.

C. Sandals.

D. All of the above.

Answer: D. All of the above

Lecture: 100%

Trivia: 100%

Trivial Pursuit for Safer Science Labs

Which of the following footwear is best in the laboratory?

A. Sandals.

B. Open-toed shoes.

C. Closed-toed shoes.

D. Shoes appropriate for the weather.

Answer: C. Closed-toed shoes

Lecture: 97.67%

Trivia: 97.78%

Horseplay or practical jokes in the laboratory are…

A. always against the rules.

B. okay.

C. not dangerous.

D. okay if you are working alone.

Answer: A. always against the rules

Lecture: 97.67%

Trivia: 100%

If a piece of equipment is not working properly, stop, turn it off, and tell…

A. the custodian.

B. your lab partner.

C. your best friend in the class.

D. the lab instructor.

Answer: D. the lab instructor

Trivial Pursuit for Safer Science Labs

Lecture: 95.35%

Trivia: 93.33%

If an acid is splashed on your skin, wash at once with…

A. Soap.

B. Oil.

C. Weak base.

D. Plenty of water.

Answer: D. Plenty of water

Lecture: 100%

Trivia: 100%

When working with chemicals, biological specimens, and other lab substances, always…

A. Wear appropriate latex or nitrile gloves.

B. Wash your hands thoroughly with soap and water.

C. Wipe your hands on a towel.

D. Wipe your hands on your clothes.

Answer: A. Wear appropriate latex or nitrile gloves

Lecture: 97.67%

Trivia: 100%

When gathering glassware to conduct your lab experiment, you notice one of the beakers has a small crack. You should…

A. Discard it in the appropriately marked glass disposal and notify your instructor.

B. Throw it in the garbage can.

C. Use it anyway.

D. If the crack is near the top, only fill the beaker below the crack.

Answer: A. Discard it in the appropriately marked glass disposal and notify your instructor

Lecture: 93.02%

Trivia: 95.56%

When using an open flame, you should always…

A. Check how hot it is by holding your bare hand over top of it.

B. Wear a t-shirt.

C. Ensure your lab coat sleeves are not too long, rolling them up if necessary.

D. Keep a glass of water nearby just in case.

Answer: C. Ensure your lab coat sleeves are not too long, rolling them up if necessary

Lecture: 97.67%

Trivia: 100%

True/False Questions

Hot glass looks the same as cold glass.

Answer: True

Lecture: 100%

Trivia: 100%

All chemicals in the lab should be treated as if they are dangerous.

Answer: True

Lecture: 95.35%

Trivia: 97.78%

Chipped or cracked glassware is okay to use.

Answer: False

Lecture: 100%

Trivia: 100%

Never leave an open flame unattended.

Answer: True

Lecture: 100%

Trivia: 100%

It’s okay to start your lab work before the instructor arrives if you read your lab manual.

Answer: False

Lecture: 97.67%

Trivia: 95.56%

Never remove chemicals or other equipment from the lab unless your instructor explicitly says to do so.

Answer: True

Lecture: 95.35%

Trivia: 97.78%

Lab coats must be worn in lab when handling chemicals and can be removed when not.

Answer: False

Lecture: 97.67%

Trivia: 100%

Safety glasses or goggles do not need to be worn if you wear prescription eyeglasses.

Answer: False

Trivial Pursuit for Safer Science Labs

Lecture: 93.02%

Trivia: 95.56%

Long clothing and socks must be worn in lab to protect from hazardous spills and burns.

Answer: True

Lecture: 100%

Trivia: 100%

Gloves are not required to be worn when working under a fume hood.

Answer: False

Lecture: 93.02%

Trivia: 95.56%

2-Week Follow-Up Phase

When an acid comes in contact with your skin, you should immediately wash it with what?

A. Soap

B. Oil

C. Weak base

D. Water

Answer: D. Water

Lecture: 97.67%

Trivia: 93.33%

Why should we not add water to a solution containing concentrated acids?

A. It would dilute the acid

B. It would cause the acid to cool down

C. Acid would splatter

D. Acid would go bad

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A. To prevent glassware, heat, or chemicals from coming in contact with your eyes

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D. To help you see better

Answer: A. To prevent glassware, heat, or chemicals from coming in contact with your eyes

Lecture: 100%

Trivia: 100%

What should you do when a chemical comes in contact with your eyes?

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B. Wait for your instructor to assist

C. Do nothing if it doesn’t hurt

D. Wipe your eyes with a towel

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Trivia: 100%

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D. Guess what to do

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Trivia: 100%

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Lecture: 100%

Trivia: 100%

If a lab experiment is not completed, you should…

A. Hurry to finish before the class ends

B. Do it at home

C. Discuss the issue with your instructor

D. Skip it entirely

Answer: C. Discuss the issue with your instructor

Trivial Pursuit for Safer Science Labs

Lecture: 100%

Trivia: 100%

You are heating a substance in a test tube - always point the open end of the tube…

A. Away from all people

B. Towards yourself

C. Towards your lab partner

D. Towards the ceiling

Answer: A. Away from all people

Lecture: 100%

Trivia: 97.78%

You are heating a piece of glass and now want to pick it up. You should…

A. Use your hands

B. Use tongs

C. Wait until it cools

D. Call your instructor

Answer: B. Use tongs

Lecture: 100%

Trivia: 100%

When gathering glassware and equipment for an experiment, you should…

A. Use the first items you see

B. Check all glassware for chips and cracks

C. Ignore small cracks

D. Only grab what looks clean

Answer: B. Check all glassware for chips and cracks

Lecture: 93.02%

Trivia: 100%

True/False Questions

Shorts are permitted to be worn in science labs.

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Lecture: 41.86%

Trivia: 57.78%

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Trivia: 93.33%

Trivial Pursuit for Safer Science Labs

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Trivia: 100%

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It is ok to slide a scalpel across the lab bench to your friend who is waiting to use it.

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Lecture: 100%

Trivia: 100%

In an experiment, use the exact amount of each chemical as specified in your lab instructions.

Answer: True

Lecture: 97.67%

Trivia: 100%

A stopper should be placed in any chemical bottle when it is not in use.

Answer: True

Lecture: 97.67%

Trivia: 100%

Specimen jars should not be opened unless instructed.

Answer: True

Trivial Pursuit for Safer Science Labs

Lecture: 100%

Trivia: 100%

Appendix B: Non-parametric test results

The Mann-Whitney U Test was utilized to compare the trivia and lecture groups across three phases—pre-treatment, post-treatment, and follow-up—as a non-parametric alternative to the independent samples t-test when normality assumptions may not hold (Mann & Whitney, 1947). This U-statistic measures the frequency with which observations from one group precede those from another in ranked data, identifying distribution differences between groups (Mann & Whitney, 1947).

Hypothesis 1.a: Baseline to Post-Test Improvement

A Wilcoxon Signed-Rank test evaluated improvements within each group from baseline to post-test. The lecture group exhibited a significant gain ($W = 622.0$, $p = 0.013$, medium effect size = 0.425), and the trivia group showed a significant improvement as well ($W = 655.0$, $p < 0.001$, moderate effect size = 0.239), confirming that both teaching methods resulted in immediate score increases post-intervention.

Hypothesis 1.b: Comparison of Trivia and Lecture Groups at Post-Test

For Hypothesis 1.b, a Mann-Whitney U test compared post-test scores between groups and found no significant difference ($U = 1003.0$, $p = 0.583$), indicating that both methods were equally effective in promoting immediate knowledge acquisition.

Hypothesis 2.a: Long-Term Retention from Baseline to Follow-Up

To assess long-term retention, Wilcoxon tests compared baseline to follow-up scores within each group. The lecture group showed no significant difference ($W = 504.0$, $p = 0.708$), suggesting no sustained knowledge retention. However, the trivia group exhibited a significant improvement from baseline to follow-up ($W = 663.0$, $p < 0.001$, moderate effect size = 0.230), indicating effective long-term retention.

Hypothesis 2.b: Comparison of Trivia and Lecture Groups at Follow-Up

A Mann-Whitney U test for Hypothesis 2.b revealed a significant difference in follow-up scores favoring the trivia group (U = 1164.0, p = 0.050, Cliff's Delta = 0.234), supporting the trivia intervention's superiority for long-term retention over the lecture approach.