Gamification of Hazards Recognition in Mining with a Tabletop Card Game

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Abstract. We have developed a card game called *Very Good Day* to facilitate higher order thinking skills for hazard recognition and mitigation. Using a three-way matching game mechanic, learners are incentivized through competition and challenge to mitigate hazards by applying the hierarchy of critical controls. The game also emphasizes communication, as no mitigation strategy is valid without attaining group consensus. Stealth evaluation is provided via a composite "safety index" which is based on gameplay choices. Increasingly sophisticated controls require more thought to implement, translating to higher composite safety indices. Play testing was conducted over a 10-month period with 211 learners in the mining industry. Results indicated a high level of engagement, with 95% of users able to apply better controls than the minimums to mitigate hazards.

Keywords: Serious Games · Training · Mining · Usability · Hazard Recognition

1 Introduction

Occupational hazards are key topics for training in many high-risk industries. For example, "hazards recognition and avoidance" is a required topic for all safety courses in the U.S. mining industry, as outlined in the U.S. Code of Federal Regulations (CFR) Title 30 and enforced by the Mine Safety and Health Administration (MSHA), the regulatory body for mining. Although Bloom's Taxonomy [1] identifies a need for higher-order thinking as a key component of learning, hazards training is often pragmatic and aligned to simple identification skills – the lowest level of Bloom's Taxonomy. In this work, we propose a versatile card-based gaming activity to augment hazard recognition training with higher-order skills, including *application*, *synthesis*, and *evaluation*, which are vital to mitigate and ultimately prevent safety hazards in the workplace.

2 Related Work

Research suggests that experiential learning can enable knowledge retention rates as high as 90%, in contrast to passive methods such as lectures and videos, which have transfer rates under 30% [2]. Experiential methods such as *serious games* have been shown to engage and motivate learners to such a degree that they lose themselves in the activity [3]. Csikszetmihalyi [4] describes this as flow, a state in which "people become so involved in what they are doing that the activity becomes spontaneous, almost automatic; they stop being aware of themselves as separate from the actions they are performing." Research suggests that achieving flow may also have significant advantages for learning in both short term and long term [5].

In game design, achieving flow requires a careful balance of challenges with players' skills and abilities. Proper alignment can result in effective learning [6]. For example, a trading card game has been used to significantly increase the understanding of host-disease interactions among 8th grade (149%, $p<0.001$), 10th grade (126%, $p<0.001$) and medical students (110%, $p=0.049$) [7]. The learning performance of university students for select biology topics, such as respiration and circulation, also improved (137%) significantly when taught with a trick-taking card game, compared to conventional methods [8]. Finally, a combat card game was used to significantly ($p<0.01$) improve the understanding (130%) of adolescent students in immunobiology [9].

Serious games also afford opportunities to measure performance at higher levels of Bloom's Taxonomy [1], particularly when assessment is defined in terms of achievement in the game [10]. Chen & Michael [11] characterize three forms of assessment: completion, in-process, and teacher evaluation. Completion focuses on outcomes, while in-process focuses on the steps taken; teacher evaluation represents a combination of the two. In-game assessments are particularly interesting, as they allow a feedback loop that is well aligned to constructivist learning theory. A cycle of practice, re-teaching, and revision can be used to create embedded formative assessments which engage students and increase achievement [12]. These *stealth assessments* are "so seamlessly woven into the fabric of the learning environment that they are virtually invisible" [12].

3 *Very Good Day*: The Hazards Recognition Card Game

The *Very Good Day* (VGD) game was developed to augment higher-order thinking skills for hazard mitigation, in alignment with Bloom's Taxonomy [1]. The game has three learning objectives: 1) *evaluate* hazards; 2) *apply* the hierarchy of critical controls; and 3) *synthesize* risk. VGD was originally conceived as a board game, but feedback from industry partners suggested a need for increased versatility and a desire for more mobile training tools that could be used in site-specific activities, such as tailgates and safety briefings, in addition to MSHA training. Such activities occur on the worksite or in break rooms, which are less controlled and more technology prohibitive environments than the classroom. Our card game supports training in a range of situations by being low cost, durable, easy to clean, and easy to stow into a pocket or vest.

3.1 Game Mechanics

The goal of VGD is to mitigate hazards using appropriate critical control cards. The game is based on a three-way card-matching mechanic where the first player to use up his or her control cards wins the game. Specifically, the deck consists of three card types: area, hazard, and control (Fig. 1). Area cards display photos of various mine work areas, such as conveyors, highwalls, processing facilities, roadways, and maintenance shops. Each player is randomly dealt a specific area card and becomes the "supervisor" of that work area. Players are also dealt control cards, each indicating one of five random levels in the hierarchy of controls [13]. The levels include elimination, substitution, engineering, administrative, and personal protective equipment (PPE). For a typical game, a player starts with seven control cards, although fewer control cards may be assigned to reduce play time. On each turn, players select a random hazard card from the stack. This hazard must be mitigated, if possible, using one of the player's control cards. Hazards were selected for the game from three sources, each representing a tier of risk severity: 1) MSHA fatality reports (high), 2) top 10 MSHA reportable injuries (medium), and 3) 10 common yet frequently missed hazards [14] (low). Note that when a selected hazard card is not applicable to the player's work area, it must be given to the supervisor for an area in which that hazard is likely to occur.

Group discourse is also a critical element of the VGD game mechanics. First, no hazard card may be controlled without adequately describing how that hazard applies to the specific work area, and how the control card works to mitigate the risk to workers. The sufficiency of the explanation may be determined by either group consensus or designated moderator (e.g. the trainer). Second, each mitigation may be *challenged* by another player who believes he or she has a more effective control for the hazard. Again, the victor is determined by consensus or moderator. The loser of the challenge must retrieve a card and forfeit the turn. Furthermore, if no player offers a suitable control for a hazard in the current round, the game enters a penalty "stop work" state, in which the hypothetical mine shuts down and each player draws a card from the control stack in succession until a suitable mitigation is found. No hazard may be left uncontrolled after a round of play; the game mechanics continuously drill players on the immediacy of hazards recognition and mitigation in the workplace.

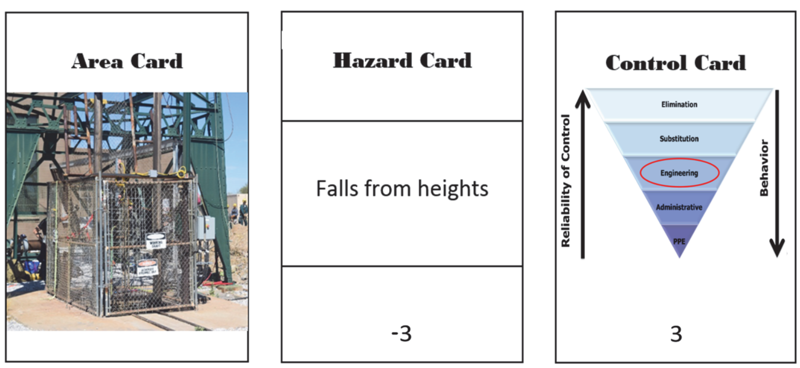

Fig. 1. Sample playing cards from the *Very Good Day* card game, including Area Card (*left*), Hazard Card (*center*), and Control Card (*right*). Note safety indices listed at bottom of cards.

3.2 Learning and Assessment

The VGD card deck consists of 16 unique areas, 32 unique hazards, and 32 5-level control cards. We provide replay value and support evaluation through the inherent combinatorial complexity of the card game. Consider that all 32 hazards must be evaluated against 16 work areas, yielding 512 area × hazard combinations. There are subsequently five levels of critical controls that may be used to mitigate each hazard. Each of the controls must be weighed against the area × hazard circumstances and accepted or rejected. In total the game offers 2,560 unique card combinations (i.e. area × hazard × control), at least one of which is presented to the learner on each round of play.

Stealth assessment is built into the game via a composite "safety index." All control cards are assigned positive point values based on their level in the hierarchy of controls, providing a course estimate of mitigation effectiveness. For example, elimination (+5) provides the most points while PPE (+1) provides the least. Similarly, hazard cards are assigned negative point values based on their severity level, ranging from fatality-event hazards (-3) to common yet frequently missed hazards (-1). A player's composite safety index for a match is taken as the sum of all hazard × control card pairings for the hazards he or she has successfully mitigated. Higher final scores indicate that more effective controls were consistently used to mitigate each of the three tiers of safety hazards.

4 Play Testing

We conducted a series of play tests with industry stakeholders to address three objectives: 1) validate the game design of VGD; 2) verify learner engagement; and 3) establish much needed baselines for learners' knowledge of hazard mitigation procedures. Using a beta version of the card deck, VGD was pilot tested with 15 senior industry stakeholders, including supervisors and trainers, at the Mining & Exploration International (MEI) Conference in Las Vegas, NV (Aug. 2018). Subsequent improvements were made in the presentation of the VGD cards, such as enlarging fonts and reformatting pictures to address accessibility issues, but no further changes were identified in the game's technical design. Over a 10-month period beginning in Nov. 2018, an in-depth study was then conducted to examine learner engagement and performance by deploying VGD into the MSHA training curriculum of an industry partner.

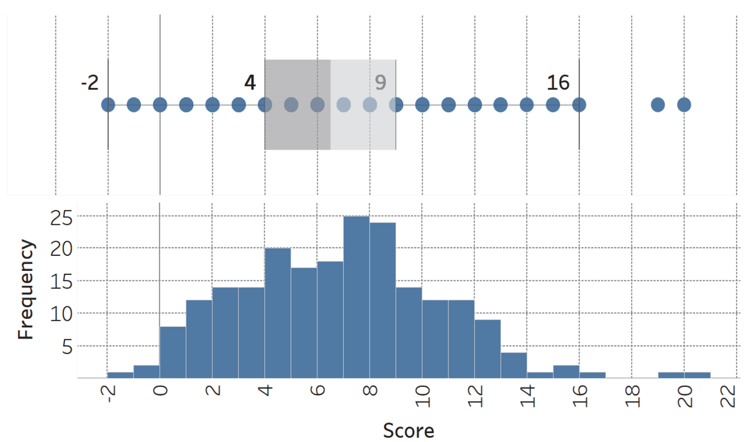

Fig. 2. Distribution of player scores (n = 211) using box plot (*top*) and histogram (*bottom*).

4.1 Methods

Testing was conducted at McCraren Compliance, a training partner in the Tucson, AZ area. VGD was used in MSHA courses that included 24- and 40-hour new miner as well as 8-hour annual refresher. These courses covered workers from all sectors of the mining industry. Three MSHA-certified trainers conducted the play tests with learners. Prior to teaching with the card game, each trainer received train-the-trainer instruction, including a 3-hour orientation and instructional design session. VGD was used with 14 cohorts (c = 14) totaling 211 mining workers over 10-months. The average cohort size was 15 (s.d. = 6.06), with a min of 5 and a max of 24. Learners came from a variety of backgrounds and levels of experience, and they occupied a range of mining industry professions, including miners, engineers, safety managers, and haul truck drivers.

Each game session lasted up to an hour. The session began with a 10-minute tutorial to outline the competitive objectives of VGD (Sec. 3.1) and demonstrate a sample of gameplay. Trainees were then divided into groups of 2-4 players per table and provided with a deck of VGD cards. Note that safety indices were tallied at the end of the session; the meanings of the scores on each card were not revealed until that time. As the game was used in the context of normal training activities and performance metrics, no informed consent was necessary for our play testing. Trainees could opt out of playing the game (although none did), but participation in the enveloping discussion was mandatory as per CFR training requirements.

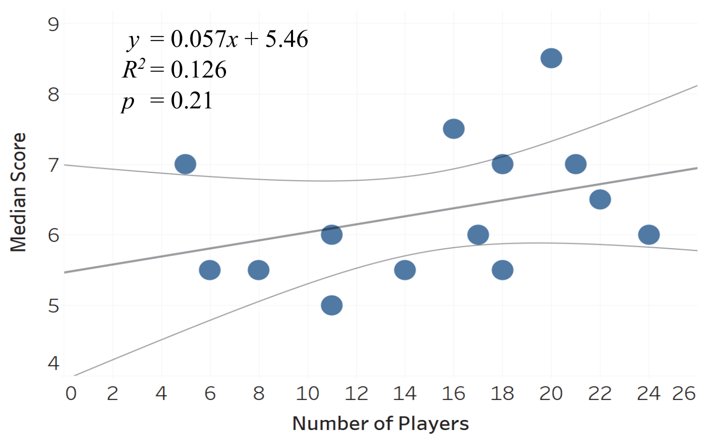

Fig. 3. Cohort median scores by number of players (c = 14). Included is the trend line equation as estimated using Ordinary Least Squares method. Confidence bands shown at the 95% level.

4.2 Results

The average game lasted 49 minutes. Player performance evaluations, as suggested by safety index (Sec. 3.2), revealed a median final score of +6.5 with a min score of -2 and a max score of +20. There were three scores less than zero (1% of total), 8 scores of zero (4%), and 201 positive scores (95%). A histogram of scores is shown in Fig. 2. The interquartile range was 5 with mild right skew (skewness = 0.38, kurtosis = 0.30).

Tests of normality with the Kolmogorov-Smirnov Test indicated that the distribution of scores did not differ significantly from normal, $D(211) = 0.069$, $p = 0.26$. The relationship between cohort median score and number of players was also investigated (Fig. 3). Linear regression (OLS method) suggested a positive correlation between median score (i.e. safety index) and number of players, with a trend line at $y = 0.057x + 5.46$; however, low R-Squared value ($R^2 = 0.126$) indicated high deviation from the linear model, and the null hypothesis was not conclusively rejected ($p = 0.21$).

Qualitative feedback was also gathered from both trainers and learners. Table 1 presents a representative sample of comments. Positive feedback typically coalesced around high levels of engagement, game flexibility, and group dynamics, which elicited relevant discussion. Negative feedback centered on the limitations of the card-based medium – such as small graphics, limited number of hazards, and lack of photo evidence for hazard types – and the methodology of the safety index mechanism.

Table 1. Representative sample of feedback from trainers and learners during play testing.

Positive	Negative
"Participants get really engaged."	*"Pictures are small."*
"The game is easy to play, and I can use it in place of lecture for annual refresher."	*"More than one control might be needed ... but in the game you can only apply 1"*
"I love being able to make training fun and competitive."	*"Improve scoring: A fatal hazard might be best controlled [yet appears] still uncontrolled according to scoring"*
"Conversations around the game are great."	

5 Discussion

Player performance evaluations revealed a median final score of +6.5, demonstrating player ability to effectively match controls to hazards. There was a non-significant increase of VGD scores with the size of the cohort, which suggests that larger groups may be able to facilitate more discussion, provide more competing views, alter the level of challenge, and increase peer pressures among players. Further analysis (not shown) suggested that scores also increased slightly over the 10-month study, which may indicate that trainers became more proficient at using the new instructional technique in their classes. More study is required to explore these relationships.

The methodology of the safety index was questioned by some users. Our design assumes that, in real life situations, engineering, administrative, and PPE controls are often the most widely used forms of hazards mitigation. In terms of scoring, these controls provided +1, +2, or +3 points to acceptably mitigate a respective tier of hazards. For example, PPE (+1) is sufficient for minor hazards (tier 1), but it is undesirable as the primary control for a fatality-level hazard (tier 3). Substitution and elimination controls may be even more desirable (and thus afford the highest point values), yet they are also more difficult to implement and explain. With these "rules of thumb," our intent was to incentivize players toward higher order thinking skills as they considered more sophisticated controls as the primary means for dealing with all tiers of safety hazards.

6 Conclusions

Very Good Day is a matching card game designed to improve critical thinking around hazards and the hierarchy of controls. Through our network of mining industry partners, over 1,000 learners have experienced VGD in their MSHA training classes since Oct. 2018. The feedback received in play testing has been very positive, suggesting a high level of learner engagement. Tabletop games such as VGD show great potential to elicit useful discussions and support stealth assessment. In future editions of the game, including an upcoming expansion focusing on health metrics and sand and gravel operations, we will extend our safety index methodology to better couple the quality of the critical control with the specific circumstances of each hazard type.

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