Cover Page

Western Mining Safety and Health Training Resource Center: An Integrated Approach

University of Arizona

Final Report

Project Period
October 1, 2017 – September 30, 2020

Submitted by PIs
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Section 1

Highlights and Outcomes

Since 2010, the University of Arizona (UA) Western Mine Safety and Health Training Resource Center (TRC) has made significant strides to develop and deploy new, competency-based active learning resources and to enhance the capabilities of trainers across the mining industry in western states. Key outcomes of the UA Center include: 1) The number of mine workers (~12,000), mining supervisors (>150), and trainers (>600) trained from Oct. 2010 to Sep 2020; 2) Comprehensive needs assessment identifying critical deficiencies in mining training and safety culture, which have guided each phase of our Center and resulted in one dissertation (Brown, 2015); 3) The Health and Safety Technical Advisory Committee (TAC), a network of highly engaged western mine safety professionals representing >40 companies and agencies; 4) Development of new training materials that have been distributed nationally, including ~500 copies of our active learning guide, Mine Safety Training Handbook: Active Learning Resources for Trainers, >100 copies of our New Miner and Annual Refresher Training Program Guide, and >150 copies of our Very Good Day card game; 5) 52 modules of the Part 46 Toolbox Training for Construction Aggregate Miners translated to Spanish and freely downloadable from our website; 6) Creation of three sophisticated, computer-based "serious games," called Learn with Harry, with which >1,000 mine workers have been trained to date, with company-specific customization and extended support options available via a commercialization partner; 7) Two new courses providing critical health and safety expertise to aspiring mining professionals (Student Interactive Mining) and non-frontline employees (Mining 101); 8) The first competency model for mine safety trainers, which was validated and used to develop and pilot five courses for our Instructional Design Certificate Program (20 trainers graduated to date); 9) A new coaching program for trainers, encompassing our Higher Level Trainer (HLT) clinic and numerous focus-specific workshops in which >300 trainers have participated; 10) The Mining Institute for Supervisory Leadership (MISL), in which >100 supervisors have participated over four years; 11) Development of a multi-level, systems evaluation approach combining knowledge checks (e.g. using clickers and quizzes in class), competency assessment (e.g. using self-assessments and post-test serious games), and holistic evaluation (e.g. via andragogical surveys, audits, and follow-ups); 12) Development of an interactive Critical Controls Management workshop, in which 86 industry supervisors have participated to share over 100 controls covering material unwanted events such as heap leach failures, rock falls, slope failures, and tailings failures (curated database available through UA Lowell Institute for Mineral Resources); and 13) Numerous dissemination activities, which include 10 LinkedIn articles receiving over 18,000 views through fall 2020, 36 conference presentations and invited talks delivered nationally since 2017, and a dozen peer-reviewed articles (8 published and 4 in progress) contributed by UA Center researchers since 2015. Notably, all of these resources are readily available to the mining community and may be found either through the program website (https://miningsh.arizona.edu) or by contacting the UA Lowell Institute for Mineral Resources (https://minerals.arizona.edu).

To address the safety and health challenges in the western US, our Center used a competency-based framework integrated into three specific aims for the completed project period. Some key highlighted outcomes for each aim include:

1. *Offer active learning-based safety and health training to mine workers*. We have accommodated low literacy and educationally disadvantaged learners with the development of a suite of serious games. Our new offerings include a computer-based game (*Harry's Hazardous Day*) with multiple in-game scenarios and robust evaluation tools that enable rapid

analysis and a feedback loop for continuous improvement of in-game mechanics and scenarios. We have also developed and deployed a tabletop card game, *The Very Good Day Game*, with 32 safety hazards, 18 health hazards, and a new expansion deck for sand and gravel operations. The built-in Safety Index allows for rapid evaluation of trainee understanding. During the project period over 700 mine industry professionals have been trained using our computer-based serious games, and over 500 have been trained with our card game.

2. *Offer innovative train-the-trainer programs*. We have developed and offer the Instructional Design for the Safety and Technical Trainer Certificate Program, as well as the Mining 101 Tutorial Course. Each of these offerings is based on our Mine Trainer Competency Model, the first ever mining-specific competency model. In addition, we developed and piloted a tool for evaluating trainer competencies in spring of 2020. The tool allows an evaluator to assess a trainer based on 25 competencies linked to our model. It also allows trainers to provide their organization feedback regarding training support, materials, resources, etc. The tool has been received very positively by our pilot partner and we are continuing to refine it for expanded distribution to other partners.

3. *Establish collaborative partnerships for critical control management*. We developed and hosted 7 interactive Critical Controls Management workshops, in which 86 industry supervisors have participated, to share over 100 controls. Our online training course on critical controls provided 170 participants both passive and active virtual content that concluded each week with a synchronous question-and-answer session. The course was capped by a mini-symposium where participants presented case studies they had developed. The training was very well-received, with several companies expressing interest in incorporating it into their own on-demand training.

Western Mining Training Center web link

- The Western Mining Safety & Health Training Resource Center may be found online at https://miningsh.arizona.edu/.

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References

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Section B

Aim 1: Offer Active Learning-based Safety and Health Training to Mine Workers

Our research team, including the University of Arizona and CustosFratris, L3C, has established a strong collaborative with trainers to ensure our training products meet their needs and to increase the number of miners that we reach. We have scaled our training activities by interacting with more companies and developing partnerships, including: the Arizona State Mine Inspector, ASARCO's Ray Mine, Bisti Fuels' Navajo Mine, Coeur's Kensington and Rochester Mines, Hecla Mining's Lucky Friday Mine, the International Union of Operating Engineers, McCraren Compliance, Rio Tinto, Salt River Materials Group, San Xavier Mining Laboratory, South Dakota School of Mines and Technology (SD Mines), South32's Hermosa Mine, Vulcan Materials, and Westmoreland Coal's San Juan Mine. These partners represent a potential training reach of over 10,000 workers and over 100 safety and health trainers in 10 states. In addition to these, we actively worked to secure partnerships with Equinox Gold's Mesquite Mine, and Freeport-McMoRan Copper and Gold's Mine Training Institute. McCraren Compliance, Asarco, and Coeur Mining have been using our training products to enhance their miner training courses for some time. SD Mines has agreed to become a principal test site and will our resources to train mine site contractors as part of their MSHA State Grants Program. Highlights and major outputs of the Center's mine worker training program include synthetic learning environments, a new framework for integrative evaluation, and a tabletop card game for hazards recognition and mitigation.

Synthetic Learning Environments

Synthetic Learning Environments (SLEs), as defined by Dede et al. (1999) and Cannon-Bowers and Bowers (2015), lie at the confluence of gaming technology, subject matter, learner characteristics, and pedagogical (or andragogical) principles. A discussion on the merits of gamification and the design of SLEs for mine safety and health training may be found in Appendix A. In this project period, we have met several important milestones that increased the capabilities of our Dynamic Safety™ platform for training in hazards detection and mitigation. Through our next generation serious game, *Harry's Hazardous Day* (HHD), learners can operate two types of dump trucks, a loader, and a track drill in a realistic limestone quarry environment (see Figures 1 and 2). One scenario, "The Big Pour," places learners in a team-based, multiplayer scenario in which they must meet contracted production quotas under stressful time constraints (see Figure 1). Learners will perform workplace examinations and respond to hazardous situations involving equipment breakdowns and an unscheduled work stoppage. Numerous hazards have been chosen for "The Big Pour" based on the trends identified during testing with new and experienced miners (Eiter et al., 2017). Furthermore, HHD allows for mitigation of hazards through options that include reporting, guarding, correcting, and suspending work. Learners must select mitigation strategies based on risks to health and safety as well as time and resource constraints; the mitigation strategy will in turn impact the types of consequences realized in the game's decision tree.

Our first workplace exam (WPE), a fire extinguisher inspection, is fully developed and pilot-tested with a first-tier training group. Feedback was extremely positive, with learners and trainers speaking highly of the simulation fidelity, level of detail, and options for hazard mitigation. Areas for improvement related to scaffolding on the simulation state and operating procedures. We are incorporating pilot group lessons learned into WPEs currently in development, including a full-scale work area inspection of our virtual crusher facility (see Appendix B.1). Other WPEs, such as pre-shift equipment inspections, are also in active development.

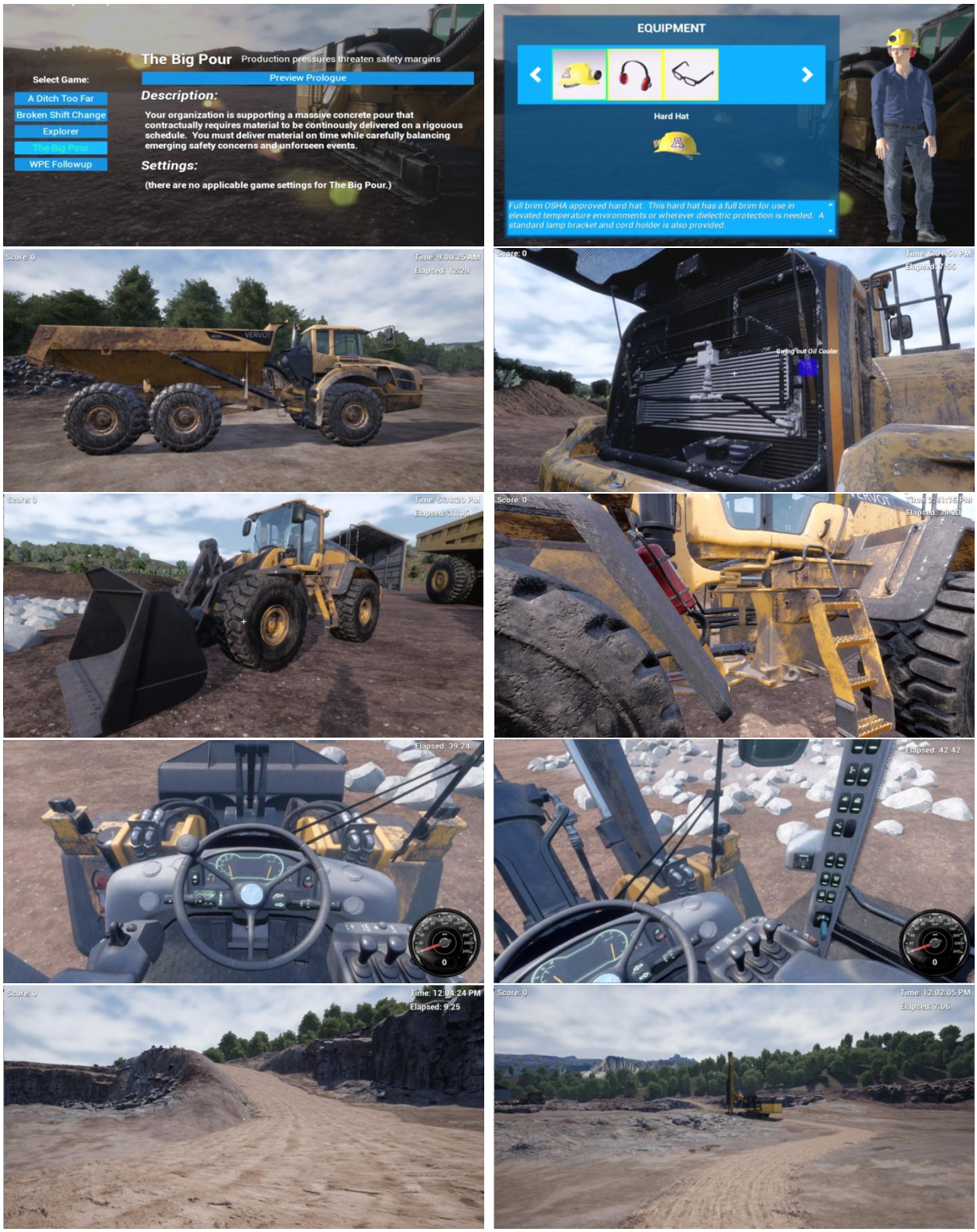


Figure 1. A new multiplayer synthetic learning environment for hazards recognition and mitigation. Our first story features haulage, loaders, and track drills working together in a dynamic production scenario.


Figure 2. Synthetic learning environments that provide training for workplace exams, centered around our virtual crushing facility.

A series of game mechanics have also been designed to support competency-based evaluation and improved health and exposure training. Using a Role-Playing Game (RPG) methodology, we are codifying a 5-tiered approach to occupational safety which aligns to our Mine Health and Safety Competency Model (see Figure 3 and Appendix B.2). Using the RPG analogy, a learner's Class designates his or her pre-existing knowledgebase in a particular job or profession (e.g. driver, mechanic, electrician, etc). Core Attributes provide a measure of intrinsic behavioral tendencies and talents for the individual, which can be derived from existing personality assays such as Predictive Index. Skills and Abilities define the components which are subsequently measured through the learner's performance on Standard Operating Procedures (SOPs) during game tasks; simulated SOPs will include hazards mitigation, vehicle inspection, loader operation, haul truck driving, and parking. The learner's choices and behaviors subsequently impact the Derived Attributes of his or her game avatar, providing gamified feedback, rewards, and penalties that enhance engagement.

We continue to use our earlier serious game, *Harry's Hard Choices* (HHC), to provide high quality, engaging training for new miner, annual refresher, and mine rescue training courses (see Figure 4). Although the game focuses on an emergency evacuation scenario, it incorporates a variety of critical Part 48 training topics, including hazard recognition and mine communication. Coeur's underground metal mine in Kensington, AK, has been using HHC, among other resources. Notably, Coeur uses HHC as a capstone in their 40-hour new miner training program, providing a key source of new evaluation data. McCraren Compliance is also looking at new usage paradigms for HHC, including break-time competitions that will enable more first-person interaction and subsequent opportunities for performance analysis. To date, we have trained more than 1,300 miners using HHC, including over 130 members of mine rescue teams.

Integrative Evaluation Framework

Vital data on human performance may be gathered from sources both within and outside the classroom. These *heterogeneous* data sources include personality profiles, paper-based survey instruments, mobile app and clicker-based data aggregation tools (e.g. word cloud programs), synthetic learning environments, job task analyses, and sensing devices on the Internet of Things (see Figure 5). Bringing these data together affords new opportunities to glean useful information on performance trends and workplace competency.

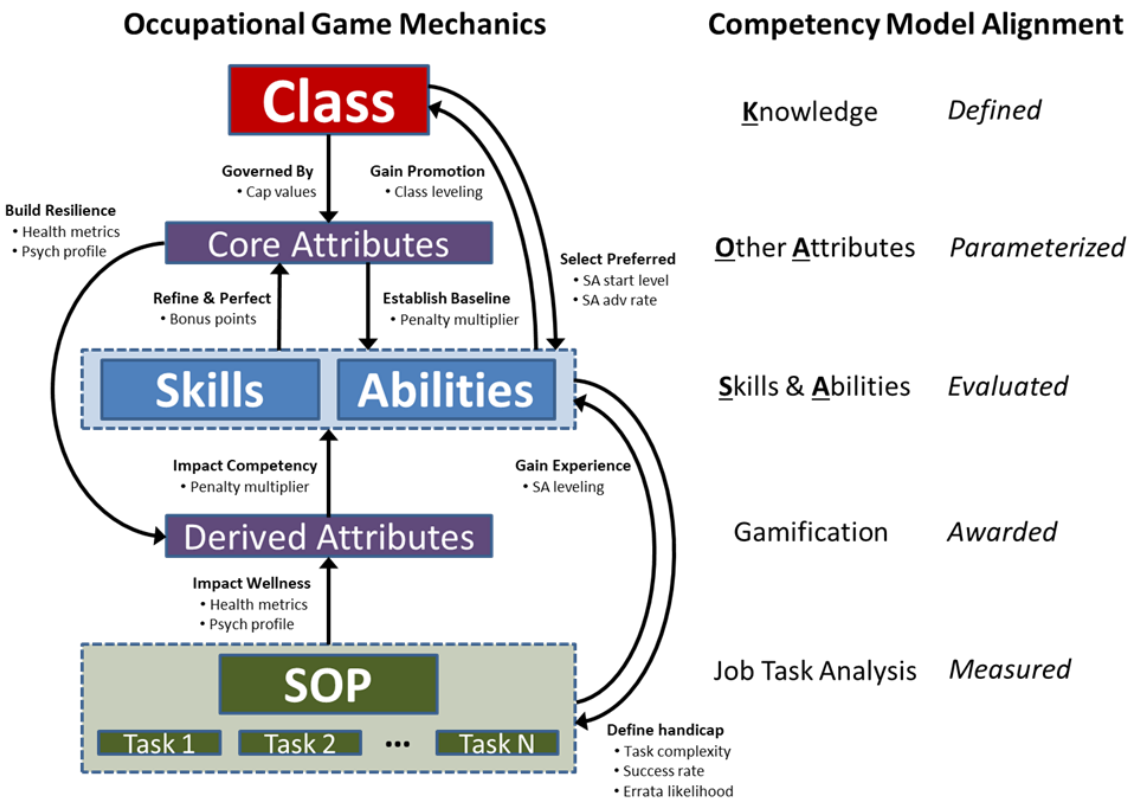


Figure 3. Game mechanics in *Harry's Hazardous Day* and their alignment to evaluation metrics.

Figure 4. Training with computer-based serious games. Left: Emergency response drills with a mine rescue team; Right: Scenario-based supervisory leadership training.

To support this goal, we are constructing a data collection framework using an enterprise level back-end from Amazon Web Services. This back end, which grew out of our need to store log data from serious games, offers parsing capabilities to extract key performance indicators, a PostgreSQL relational database for fast access, and advanced statistical analysis capabilities. We are extending this framework to aggregate data from other applications and training products in the mining community, including NIOSH training resources such as EXAMiner, as well as MSHA's publicly available accident, productivity, mine and personal health sample datasets.

In training with HHC, over 150,000 data points have been collected from hundreds of users to date. A focus of our analysis has been to identify differences in performance between new miners (novices) and mine rescue teams (experts). For example, we have considered usage frequencies over time for key safety equipment, such as gas meters (see Figure 6-a), and failure rates for identifying important types of hazards (see Figure 6-b). We have employed a variety of standard statistical methods, including time series analysis, hypothesis testing, and association rule mining, to analyze the discrete random variables of our simulations; however, these representations fail to capture the situational and environmental context, which are often key in determining safety competency (see Appendix A.1). We have developed a high-dimension feature vector which better encapsulates the context of decision-making in SLEs. The representation allows for more sophisticated sub-space analysis and correlation than was possible with simpler statistical techniques. Furthermore, these feature vectors can work over heterogeneous information spaces that include nominal, ordinal, and quantitative data and so may be extended to incorporate new data sources as we integrate them into our system.

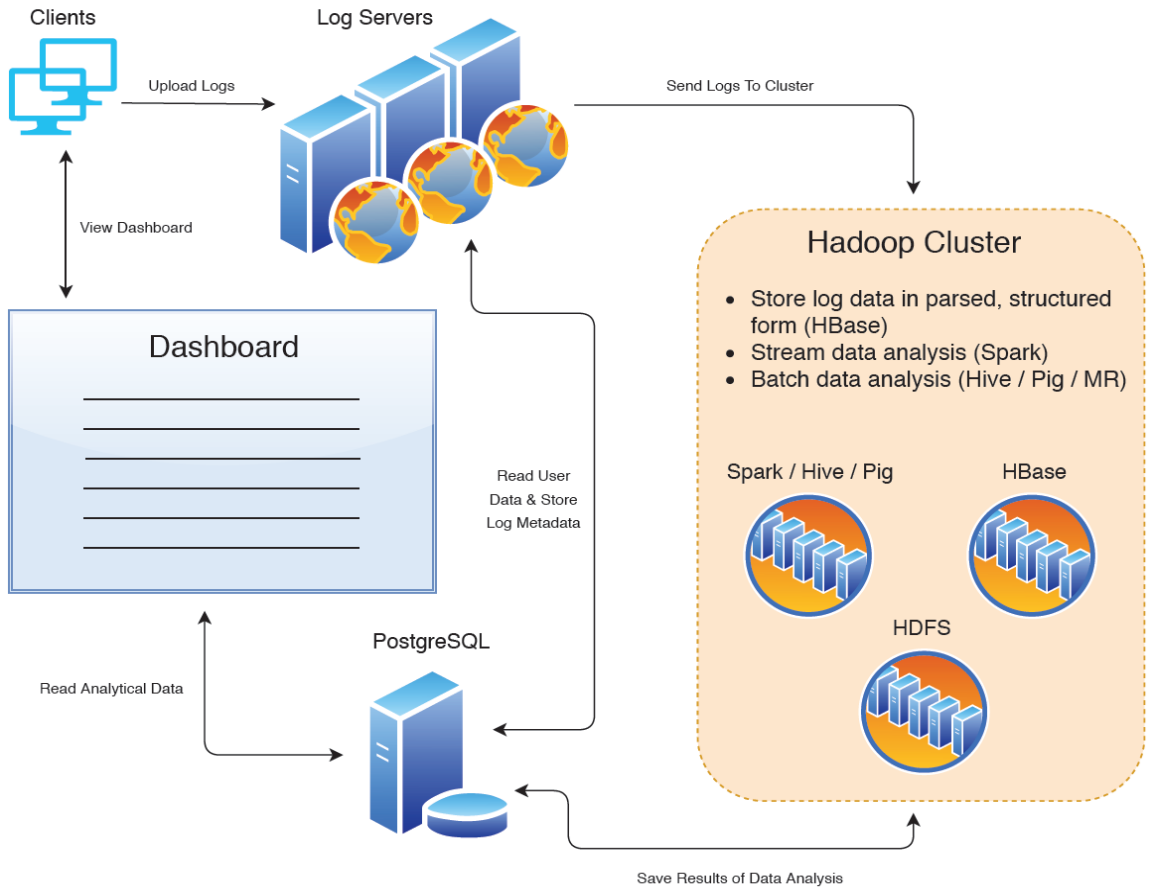
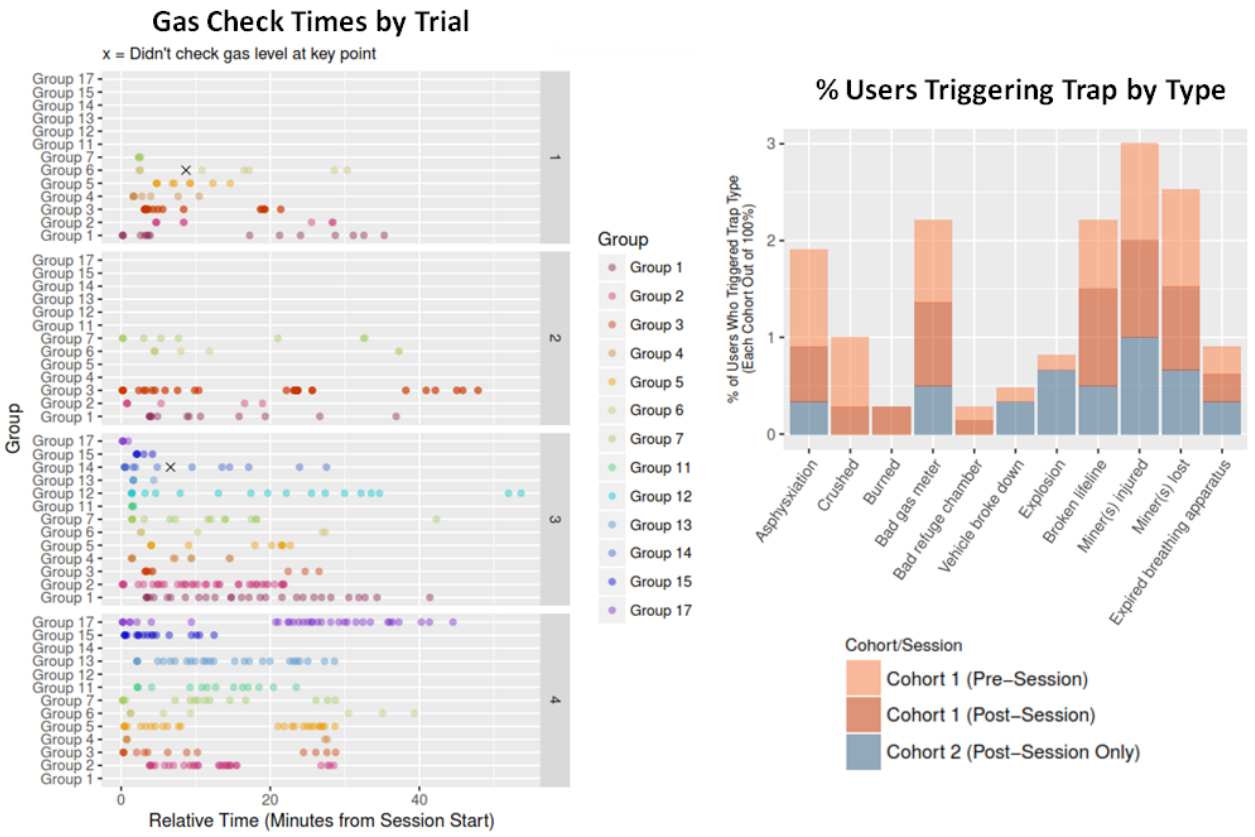


Figure 5. Our cloud framework and evaluation framework provide for longitudinal data collection, integration, exploratory analysis, and an interactive dashboard with evaluative visualizations.



(a) (b)

Figure 6. Sample data analysis for training sessions in *Harry's Hard Choices*: (a) Plot of gas meter check times during simulation; (b) Recognition rates for key hazard types in an underground mine emergency.

A final challenge involves mapping the information space into outputs that are both insightful and easy to understand for trainers and other industry stakeholders. The learning curve of information visualization is a well-known and major obstacle to usability (Card, 2007; Agrawala, Li, & Berthouzoz, 2011). We are developing a new, domain-specific method to visualize evaluation in terms of identifiable *models of competency*, such as our Mine Health and Safety Competency Model and the NIOSH Coal Mine Self-Escape Competency Model (Haas, Peters, & Kosmoski, 2015). The core of our model-based approach involves: 1) Working with domain experts to define measurable knowledge, skills, ability, and other attributes (KSAOs) for each competency and 2) defining task flow models and constraints to characterize each SOP. Using computational techniques, the learner's patterns of activity can be optimally aligned to an SOP's task flow and then measured in terms of the KSAOs at each step. Complex collections of game variables and states can hence be transformed into understandable *metrics of competency*. The results are visualized in our evolving dashboard, using best practices in information visualization (Shneiderman, 1996). Specifically, information is structured into clear hierarchies providing performance summaries at the highest level, followed by drill-down to SOPs, and finally KSAOs on demand. Visual cues, such as associative arrows, enclosures, and color-coding, assist in navigation and sense-making (Card, 2007). As an example, Figure 7 illustrates the evaluation of an SOP for hazards recognition and mitigation; the breakout table identifies a learner's measured responses on KSAOs for a step of the SOP, namely her efficiency in finding various types of hazards. Color coding illustrates performance thresholds. A proof of concept was presented for trainer feedback at the Training Resources Applied to Mining (TRAM) workshop (Beaver, WV) and the Mine Safety and Health Conference (Reno, NV) during Q4 of 2019.

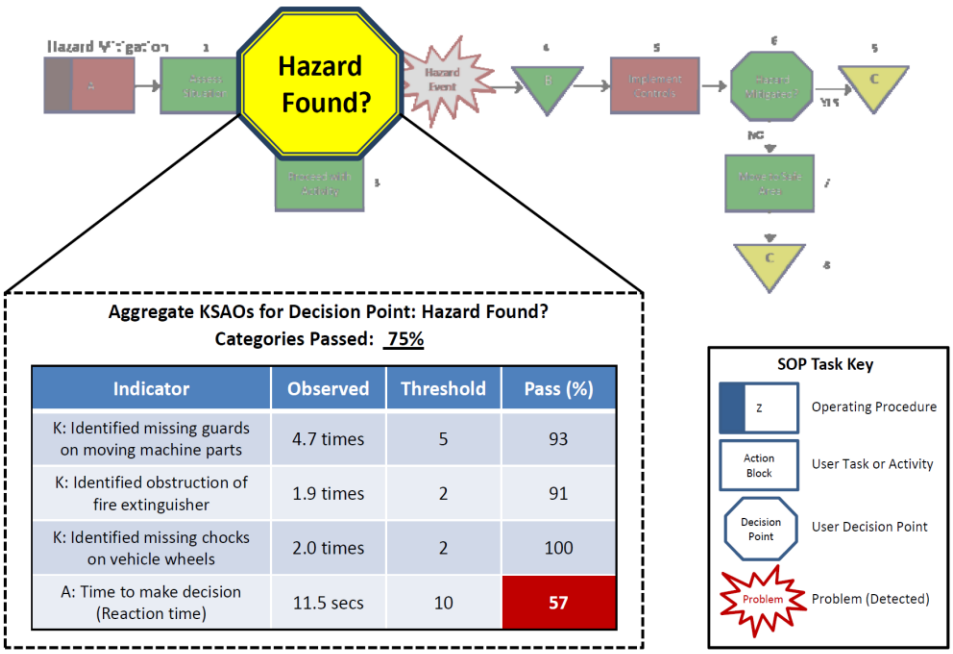


Figure 7. An interactive visual for competency in hazards recognition and mitigation. A task flow model illustrates the learner's overall achievement on an SOP, while a breakout box specifies performance on KSAOs relating to a particular sub-task, namely finding various types of hazards (time & accuracy).

Tabletop Card Game

As a complement to our computer-based serious games, we continue to refine and distribute a tabletop card game entitled *The Very Good Day Game* (Figure 8). The purpose of the game is to engage and incentivize miners through friendly competition, while increasing their awareness of workplace hazards and mitigation strategies. The game may be played in a variety of locations under different training conditions, including tailgate meetings, safety briefings, new miner training, and refresher training. Learners play the game in small groups with the goal of mitigating risks in a specified area by controlling hazard cards. Once each hazard has been controlled, the learner who has mitigated the most hazards wins the game. *The Very Good Day Game* is versatile in that it can be customized for each mining sector and for surface and underground operations. Competency assessment is also built into the game via an Evaluation Card, which provides a "Safety Index" assessing the learner's ability to recognize types of hazards and apply relevant critical controls (see Appendix C).

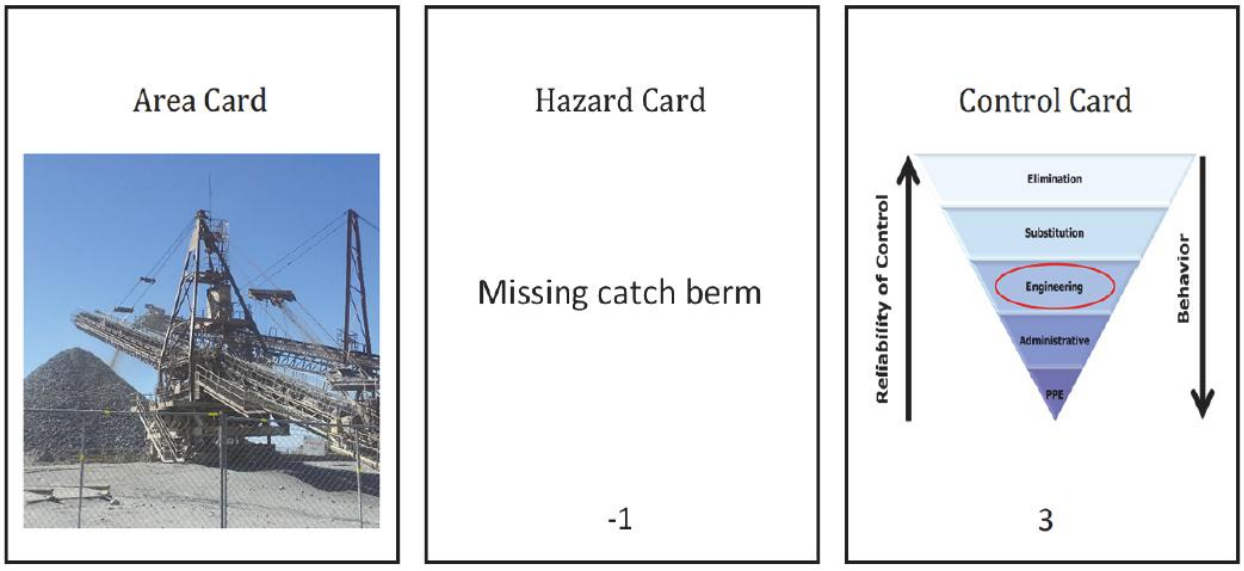


Figure 8. Sample playing cards from *The Very Good Day Game*, which is being piloted in our partners' training courses. Left: Area card; Center: Hazard card; Right: Control card.

Since October of 2017, over 1,250 participants have played *The Very Good Day Game* as part of their training. The game has been used in-house as well as through our network of training partners, including McCraren Compliance, SD Mines, Coeur (multiple sites) and Asarco, LLC. The feedback that we have received from users has been overwhelmingly positive, and we are working to fill multiple requests for distribution and utilization. An expansion pack with hazards specific to sand and gravel operations, as well as 18 health hazards, has been developed and will be included in future print editions (see Appendix C.3).

In our performance evaluation of learners, the median Safety Index (or score) attained was 6.5, indicating that all risks were mitigated during the gameplay and that the best control was generally considered for the associated hazard card (see Appendix C.1). The interquartile range was 5. There were three negative scores, which is an improvement over our pilot test studies – as negative scores indicate that not all risks were properly mitigated. The average time spent playing the game was 50 minutes. A five-number summary of all scores to date is provided in Table 1 below. In addition, trainee scores were normally distributed, with some left skewness (see Figure 10). The median scores achieved by players, as well as the count of players in our partner's trainings, have trended upward since November 2018 (see Figure 11). For an unknown reason, players tend to score better when there are more players present in the training (see Figure 12). To better understand the decisions of the participants are developing a scoring sheet to evaluate their decisions in pairing of control and hazard cards.

Table 1. Statistical summary for *A Very Good Day* card game scores to date.

Measure	Score
Minimum	-2
Q1	4
Median	6.5
Q3	9
Maximum	20

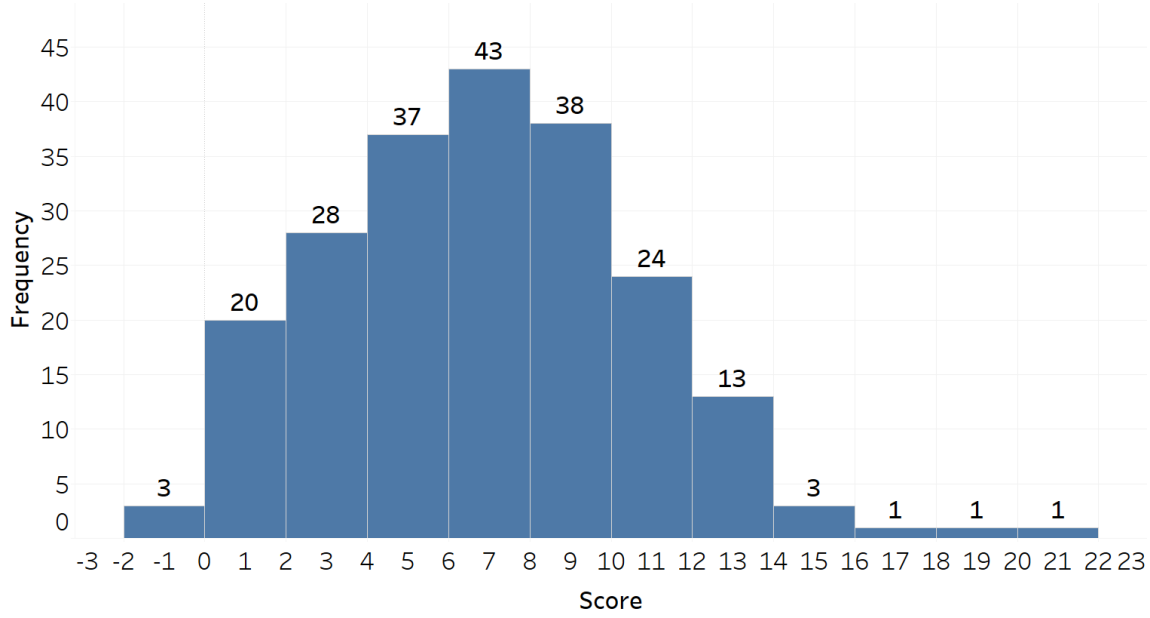


Figure 10. Frequency of scores for *A Very Good Day* card game. Note that data presented here represent results from a single partner, McCraren Compliance.

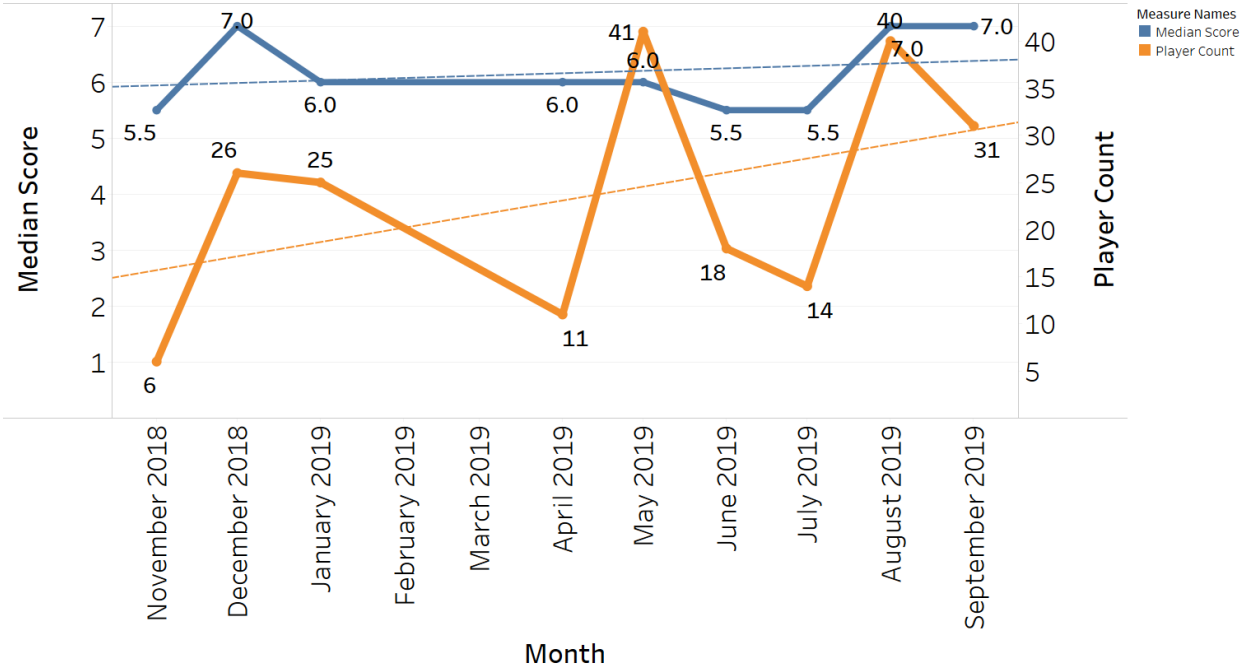


Figure 11. Median scores (blue) and player count (orange), by month, for *A Very Good Day* card game. Note that data presented here represent results from a single partner, McCraren Compliance.

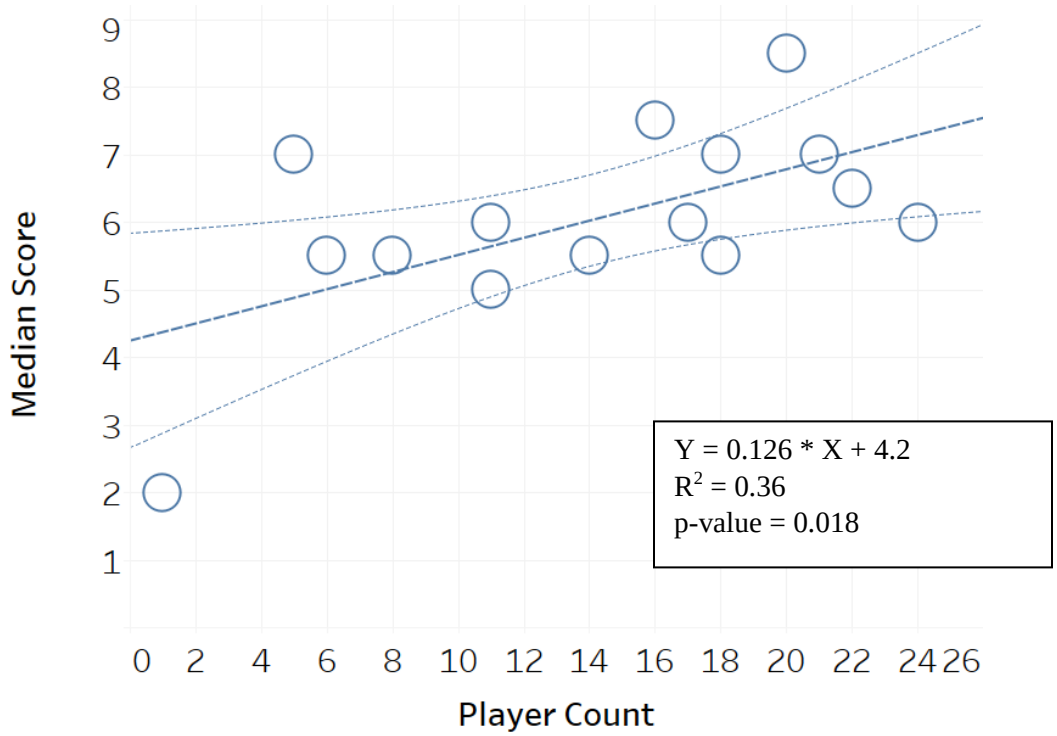


Figure 12. Median scores by the number of players present in the training session for *A Very Good Day* card game. Note that data presented here represent results from a single partner, McCraren Compliance.

Outcome Metrics

In order to evaluate the effectiveness of unique training resources implemented by three of our partners, (one underground and two surface metal mines), we analyzed two outcome metrics (injury and days lost rates) for each partner, their controller company mines, and other mines of the same type.

The first partner (Partner A) is a large surface metal mine. During the summer of 2018 UA personnel met with Partner A's mine safety and health trainers to conduct a training needs assessment, as well as describe and demonstrate the TRC's available safety training resources. The mine site opted to incorporate our MSHA New Miner and Annual Refresher Training Program Guide (TPG) and the Very Good Day (VGD) card game into the site's MSHA New Miner and Annual Refresher trainings. For each adopted resource, Partner A's mine safety and health trainers were enrolled in and completed a comprehensive train-the-trainer workshop.

The second partner (Partner B) is a mineral processing department at a medium surface metal mine. In late 2017 Partner B implemented a warm-up exercise program that was developed in-house and to be conducted before work and during a few breaks. The objective of the training program was to better prevent injuries by increasing workers' blood flow and mobility. The warm-up program consisted of a poster with visualizations of each exercise, an instructor observation checklist, and user guide. The program's 11 exercises included ankle rotations, arm circles, arm raises and crosses, back and side stretches, calf raises, hip circles, knee circles, neck tilts, shoulder shrugs, and squats. Posters were placed in line-out areas and break rooms. Front-line supervisors received train-the-trainer training and were periodically evaluated using the instructor observation checklist.

The third partner (Partner C) is a medium underground metal mine. In early 2019 Partner C opted to use and implemented our TPG and HHC for New Miner and Annual Refresher training. For each adopted resource, Partner C's mine safety and health trainers were enrolled in and completed a comprehensive train-the-trainer workshop.

Publicly available data were retrieved from MSHA's Open Government Initiative Portal (MSHA, 2020), including the Accident Injuries, Employment/Production, and Mines data sets. Datasets were cleaned, filtered, and joined using Tableau Prep Builder (2020.1; Tableau Software; Mountain View, CA), and figures were prepared using Tableau Desktop (2020.2, Tableau Software; Mountain View, CA). The quarterly rate of injuries and days lost per 100,000 hours worked were computed and compared between pre- (2012 to intervention) and post-intervention (intervention to 2020) for each partner, other sites operated by the same company, and all metal mines of the same type (excluding abandoned mines).

From Q4 2018 to Q1 2020 Partner A trained over 1,200 learners, an undetermined number of which were repeat learners, using our resources. For a summary of Partner A's outcomes please see Figures 7 and 8 below. From the pre- to post-intervention period, Partner A reported a decrease in average injuries per 100,000 hours worked from 1.4 to 1.1 (-23.6%), compared to Company A's 100% increase (1.5 to 3.0), and the decrease observed at surface metal mines of 5.3 to 2.4 (-54.7%; see Figure 13). Partner A observed a decrease of 72.5% (32.2 to 8.9) in average days lost per 100,000 hours worked from pre- to post-intervention period. Company A observed a decrease from 43.0 to 31.1 (-27.7%) for the same metric, while surface metal mines observed a decrease of 10% (47.5 to 42.7; see Figure 14).

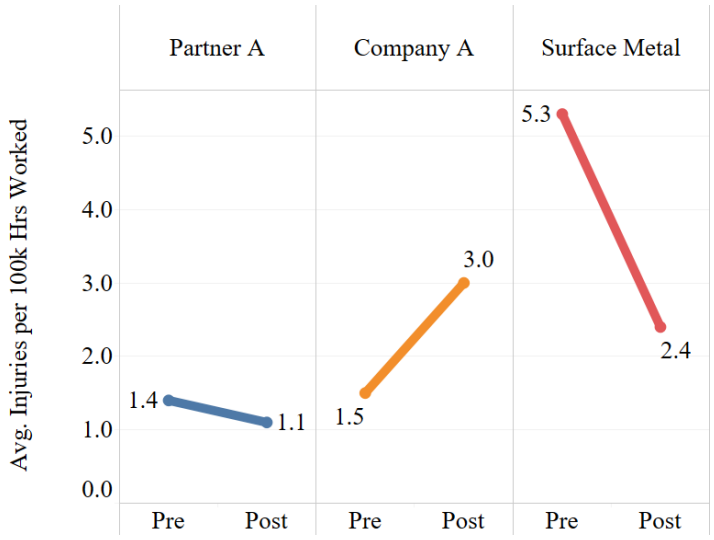


Figure 13. Average injuries per 100,000 hours worked for the Partner A vs three Company A-controlled mines and Surface Metal mines (n=65; excluding abandoned mines). 'Pre'-intervention period includes 2012 to Q3 2018. 'Post'-intervention period includes Q4 2018 to Q1 2020.

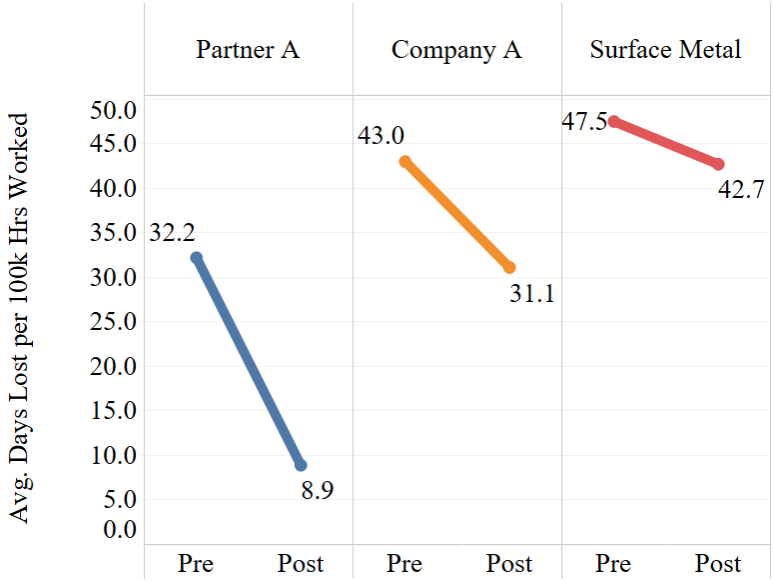


Figure 14. Average days lost per 100,000 hours worked for the Partner A mine vs three Company A-controlled mines and Surface Metal mines (n=65; excluding abandoned mines). 'Pre'-intervention period includes 2012 to Q3 2018. 'Post'-intervention period includes Q4 2018 to Q1 2020.

Preliminary outcomes reported by Partner B demonstrated year-over-year (2017 to 2018) decreases of 85.7% (seven to one), 100% (one to none) and 50% (four to two) in first aid, medical treatment and lost time injuries, respectively. From the pre- to post-intervention period, Partner B reported a decrease in average injuries per 100,000 hours worked from 1.1 to 0.4 (-63.6%), compared to Company B's 36.9% decrease (2.0 to 1.3) and that observed at surface metal mines: 5.5 to 2.6 (-52.7%) average injuries per 100,000 hours worked (see Figure 15). Partner B observed a decrease of 62.8% (21.8 to 8.1) in average days lost per 100,000 hours worked, while Company B observed a decrease from 43.0 to 31.1 (-66.9%), and surface metal mines observed a decrease of 3.6% (46.8 to 45.1; see Figure 16).

Partner C observed a decrease in average injuries per 100,000 hours worked from 1.7 to 1.0 (-41.2%) – identical to the average observed for the parent company's other two mines. During the same pre- to post-intervention period the average injuries per 100,000 hours worked increased 18.6% (4.8 to 5.7) at underground metal mines (see Figure 17). For the pre- to post-intervention period, Partner C experienced a decrease in average days lost per 100,000 hours worked, from 49.9 to 4.9 (-90.2%), compared to increases of 21.9% (30.1 to 36.7) and 0.7% at Company C and underground metal mines, respectively (see Figure 18).

While the analysis presented contains many limitations, including the lack of intra-site controls for confounding and randomization, we plan to address these moving forward by randomizing training and comparison groups within each mine site. We believe that the use of our training products likely explains a portion of the improvement in injury and days lost rates observed by our partners.

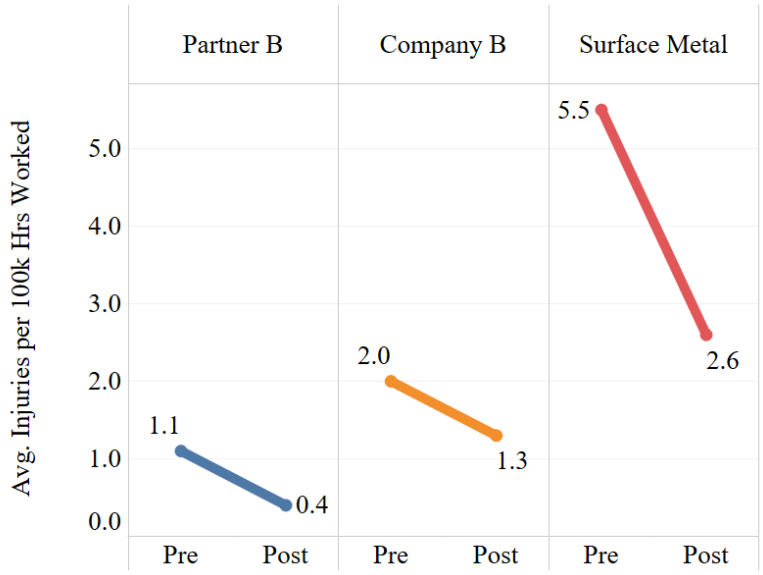


Figure 15. Average injuries per 100,000 hours worked for Partner B vs seven Company B-controlled mines and Surface Metal mines (n=65; excluding abandoned mines, subunit 'Mill Operation/Preparation Plant' only). 'Pre'-intervention period includes 2012 to 2017. 'Post'-intervention period includes 2018 to Q1 2020.

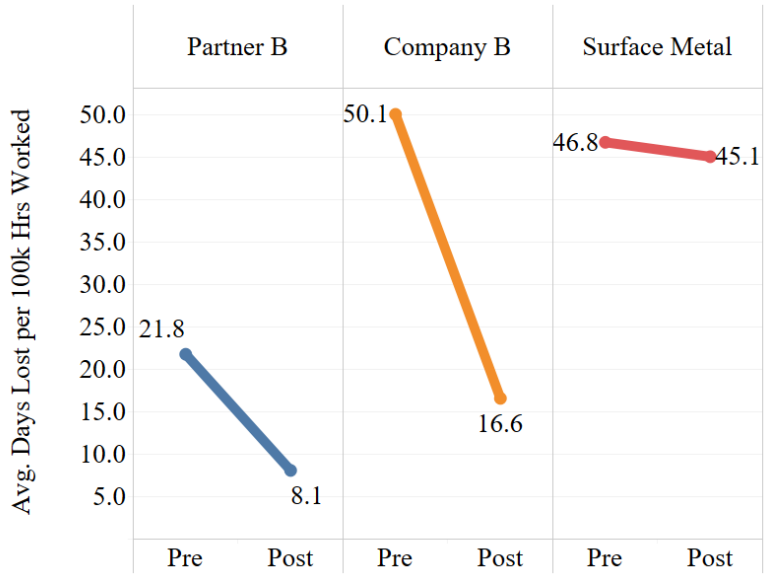


Figure 16. Average days lost per 100,000 hours worked for Partner B vs seven Company B-controlled mines and Surface Metal mines (n=65; excluding abandoned mines, subunit 'Mill Operation/Preparation Plant' only). 'Pre'-intervention period includes 2012 to 2017. 'Post'-intervention period includes 2018 to Q1 2020.

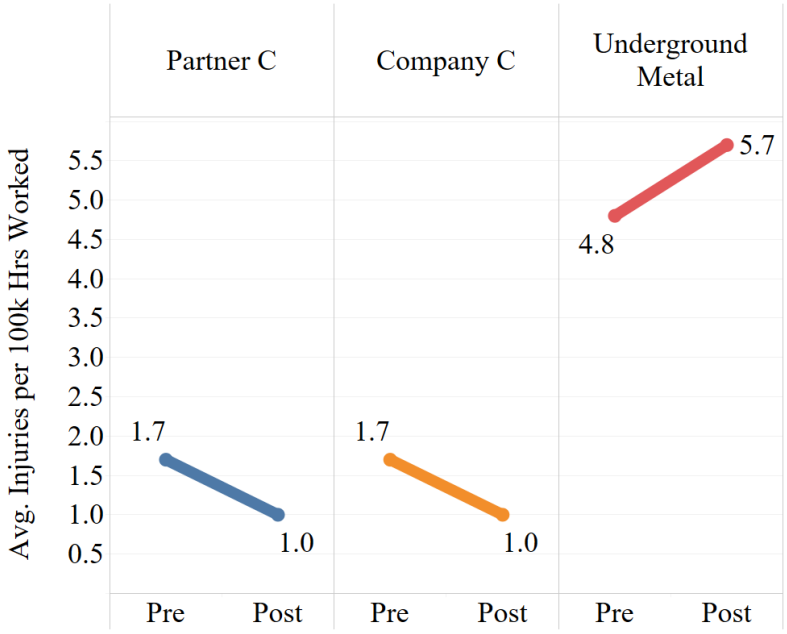


Figure 17. Average injuries per 100,000 hours worked for the Partner C vs two Company C-controlled mines and Underground Metal mines (n=17; excluding abandoned mines). 'Pre'-intervention period includes 2012 to Q4 2018. 'Post'-intervention period includes Q1 2019 to Q1 2020.

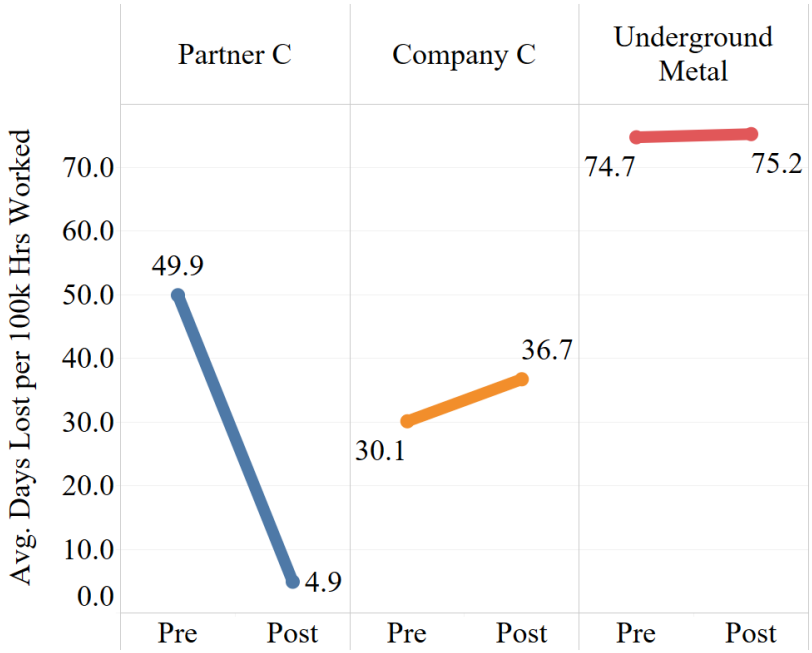


Figure 18. Average days lost per 100,000 hours worked for Partner C vs two Company C-controlled mines and Underground Metal mines (n=17; excluding abandoned mines). 'Pre'-intervention period includes 2012 to Q4 2018. 'Post'-intervention period includes Q1 2019 to Q1 2020.

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Aim 2: Offer Competency-based Train-the-trainer Programs

We developed a Mine Trainer Competency Model for those employees serving in learning and development roles. The model identifies the knowledge, skills, and abilities necessary to perform these roles successfully. The competency model is critical to all project Aims, as it serves to guide training content development and evaluation. The competency model has undergone a final round of validation with industry experts and is available through the TRC website portal.

When the project team compared the knowledge, skills and abilities outlined in the competency model to readily available courses and programs, significant gaps were identified. To address these gaps, we designed, developed, and implemented a series of high quality courses, including the Mining 101Tutorial Course, which targets safety professionals and front office management, and our Instructional Design Certificate Program, which focuses on improving the capabilities of industry trainers.

Mining 101 Tutorial Course
An online, noncredit, tutorial course was created to support the Mine Health and Safety Competency Model (Aim 1) for Tiers 4 and 5. The course was created based on feedback from trainers and safety managers that many professionals in safety departments have mining experience lack a broader understanding of the full mining cycle. In addition, they do not have time to pursue a university degree in mining or synthesize the little content available online that often lacks depth and breadth. The course has approximately 90 micro-learning modules and 200 hours of content. Modules have a branching structure to allow learners to pursue some content in more depth depending on their needs. The 10 macro-modules for Tier 4 are: Earth Processes, Exploration, Supply-Demand, Business of Mining, Mine Development, Mining Methods, Processing, Health and Safety, Environmental Stewardship, and Social License to Operate. The modules in Tier 5 are commodity-specific, covering Metals, Construction Materials, Coal, and Industrial Minerals.

A free basic version of the course, incorporating the key points in each module, will be available through University of Arizona's Continuing and Professional Education (CaPE) with no badging or certification. A fee-based version with the full content, badging, certification, and professional networking will also be available through CaPE. Most of the content for Tier 4 is complete and needs to be reviewed, recorded, and supplemented by elements of gamification and examination. The commodity-specific content for Tier 5 will be started when Tier 4 is complete.

Instructional Design for Safety and Technical Trainer Certificate Program
In the last project year, we began deployment of our Instructional Design Certificate Program. This program will provide mine trainers and training managers with the essential knowledge and skills to make highly effective training materials. It is an 18-month hybrid learning program which will provide participants with the following three courses:

- Instructional Design (focuses on using a systematic and reflective process to translate principles of learning and instruction into plans for instructional materials, activities, information resources, and evaluation);
- Instructional Development (focuses on learning to develop new instructional materials as well as assess and modify existing instructional materials); and
- Evaluation (focuses on learning to assess the effectiveness of learning solutions by gathering and organizing qualitative and quantitative data, comparing data to learning and performance metrics, and presenting data in a meaningful way to allow informed decisions).

Each course lasts 13 weeks. The first 12 weeks incorporate learning at a distance, including one hour per week of recorded lecture and practice AND one hour per week of live class via web conferencing. The final week will incorporate presentations of the capstone project at the University of Arizona campus or at a site convenient to the majority of the cohort. This approach is similar to that which Dr. Brad Ross successfully piloted for geotechnical experts (see Aim 3). It was received very favorably and blends asynchronous and interactive virtual training content.

For each course successfully completed, participants will earn four Continuing Education Units (CEUs) through the University of Arizona's CaPE Program. Credley Badging was also implemented to award students for completing each desired training competency. We have strengthened the program's health-related content to incorporate training content on heat stress and prevention of heat-related illnesses, respiratory health and prevention of pneumoconiosis, cardiovascular health and prevention of heart attacks, and overall fitness and methods for avoiding musculoskeletal injuries.

While working to fill the void in high quality training for the mine trainer, the team identified a need for similar courses addressing safety and technical trainers in other industries, such as rail, heavy construction, and the military. Like mining, trainers in these industries were frequently promoted to the training department based on their expertise in a technical trade or craft – such as best welder or best equipment operator. Similar to mine trainers, they often lacked the knowledge and skills to successfully make or deliver training. We have developed programs to increase the capabilities of trainers in a variety of high-risk industries. As discussed in our Instructional Plan, the programs all share the same foundational content which can be supplemented by specific practice exercises developed for each industry. This approach allows us to fill the critical gap in trainer professional development while using examples that are industry-specific and contextualized to the audience. Appendix D provides a sampling of Train-the-Trainer resources developed or enhanced during the project period), including exercise activities for scenario-based training (D.1), the Harry's Hard Choices Trainer Manual (D.2), Harry's Hard Choices Pre-Session Tutorial (D.3), Trainer Competency Assessment (D.4), and Pre-Post Competency Self-Assessment (D.5), among others. Many of these resources are now available on our website (see Figure 19).

Evaluation

Our evaluation program for Aim 2 centers on qualifying changes in trainers' curriculum over time as part of a stepwise development process. As such, the Instructional Design Certificate Program requires detailed follow-up and evaluation of training materials as part of each trainer's course grade; we begin by assessing materials and curriculum when a trainer enters the program, establishing a baseline, and then observe how those materials improve as the trainer progresses. To support this process, an evaluation checklist has been developed to address the instructional design competencies in our Mine Trainer Competency Model. Additionally, a complementary safety competency checklist is under development to assess those materials in terms of critical safety knowledge, skills, and abilities.

We piloted the Instructional Design Certificate Program in the Fall semester of 2017 with a cohort of 12 trainers and supervisors. The pilot cohort completed the program during the Spring semester of 2018. We are now analyzing the volume of data collected through our pilot program, and results will be reported during the upcoming project year.

In addition, we developed and piloted a tool for evaluating trainer competencies in spring of 2020. The tool, based on the Mine Trainer Competency Model, allows an evaluator to assess a trainer based on seven

aspects of their delivery and presentation skills, six competencies focused on their ability to engage students and facilitate groups, six competencies based on their ability to create and maintain a learner-centered environment, and six competencies that highlight their demonstration of a commitment to learning and self-improvement. The process involves in-class observation, a follow-up meeting between the evaluator and trainer, the development of specific trainer objectives, and future evaluation meetings. The tool and process also allow trainers to provide their organization feedback regarding training support, materials, resources, etc. The tool has been received very positively by our pilot partner and we are continuing to refine it for expanded distribution to other partners (see Appendix D.4).

Figure 19. Train-the-trainer and supervisor resources available at miningsh.arizona.edu.

Aim 3: Establish Collaborative Partnerships for Critical Control Management

The concept of a framework to share critical controls was introduced at the SME Annual Conference and Expo in February 2018. We then conducted a pilot Critical Controls Management (CCM) workshop on September 21, 2018 as part of a conference of geotechnical experts in Tucson, Arizona, hosted by the University of Arizona. Participants included over a dozen experts representing a variety of mining companies, geotechnical equipment manufacturing companies, consulting companies, university faculty, and students, with industry experience ranging from 7 to 38 years and a mean of 21.7 years. The workshop used the Bingham Canyon Landslide as a case study to facilitate the discussion, which included defining material unwanted events (MUEs), identifying and prioritizing MUEs, documenting and sharing critical controls, and refining the sharing process for future workshops.

Unsurprisingly, the highest priority MUEs were all geotechnical in nature and included slope failures, rock falls, and tailing failures. Once the MUE's were prioritized, the participants identified the critical controls that their companies used to keep workers safe for each of the top three MUEs. This proved to be an excellent discussion, with participants building on the experiences of others in the room. A total of 65 critical controls were shared during the meeting, including various types of monitoring (TDR, piezometers, LIDAR, RADAR, etc), engineering controls (design verification, pre-splitting of highwall faces, pre-dug trenching on final bench back breaks, etc), and enhanced training (rockfall analysis and risk assessment, detection of instabilities, safety culture stewardship, etc).

A smart phone-based polling app, called Mentimeter, was used by participants to share and vote on the most important MUEs and to create data visualizations, such as Word Clouds, illustrating the results. Feedback suggested that there was an increase in knowledge among participants in the Critical Control Process and MUEs after the workshop. Participants that did not report an increase in knowledge already possessed a relatively high level of competency in these topics. Among key lessons for future workshops, the group discussions were considered the most effective part of the workshop, while the didactic parts could be improved through some revisions to the slide decks and the inclusion of more situation and environmental context. We also found that a large majority of participants liked the technology used in the session to gather data, in particular the Mentimeter polling program.

During the month of October 2018, work continued to build upon the data collected during the first Critical Control Workshop. The critical controls that were collected during the workshop were documented and distributed to the 12 original workshop participants and an addition 72 geotechnical experts for review. As a result of the review, 16 new critical controls were submitted, making a total of 81 geotechnical critical controls.

On November 9th, the Global Mining Law Program at the University of Arizona held a summit entitled "Mining Safety: Sharing Solutions". The purpose of the summit was to discuss reasons why critical controls are not shared within the mining industry. Dr. Brad Ross collaborated in the planning of the summit and made a presentation on the importance of sharing critical controls and some of the work being done through the Western Mining Safety and Health Training Resources Center. Ultimately the reasons for not sharing critical safety controls came down to concerns regarding the perceived risk of liability, penalties from MSHA, and reputational damage.

The 2019 SME Conference was held in Denver Colorado from February 23 – 27. A pre-printed paper entitled "Sharing Critical Controls" by Ross, Williams, Burgess and Granillo was submitted in December

of 2018. Four different presentations were given during the SME Conference that included information on sharing critical controls. Dr. Ross made a presentation during the NORA Session that focused entirely on Aim 3.

Dr. Ross also made a presentation on Sharing Critical Controls to the Tucson Section of SME on March 13th in Tucson, Arizona. During the talk 54 members of the audience participated in a highly condensed version of a Sharing Critical Control Workshop, using the Mentimeter polling application.

Two additional Sharing Critical Controls Workshops were held during the Summer of 2019. The first workshop was held on May 13th on the University of Arizona Campus. This workshop included 8 participants in addition to the facilitator (Dr. Brad Ross). The participants were volunteers that had attended the Sharing Critical Controls presentation that was given to the Tucson SME Meeting on March 13, 2019. All of the participants for the May meeting worked as consultants or the mining service industry. A majority of the participants were working in the geotechnical area and were focused on heap leach failures. The group came up with 16 Critical Controls for heap leaches and 8 general safety controls. Mentimeter was used as a polling program to track participant feedback, before and after the feedback session. Demographics were gathered from the polling program as well as feedback on the effectiveness of the workshop. Mentimeter proved to be an excellent tool for gathering the data.

On July 15, 2019 a second workshop was held with employees of Nevada Gold Mining Company was held in Elko Nevada. This workshop included 12 geotechnical and hydrology professionals from a variety of Nevada Company Mining Company mines. Mentimeter was used as the polling program. Although there were few unique critical controls that had not already been recorded, the feedback showed that the participants believed the workshop was very relevant to their fields and most believed that the discussion and case study were very effective tools.

We have conducted seven Critical Controls Management workshops, summits or presentations. These events helped to define material unwanted events (MUEs), identify and prioritize MUEs, document and share critical controls, and refine the sharing process for future workshops. They also served to implement and trial different polling and data collection methods, including a smartphone-based app called Mentimeter. Feedback had generally indicated that some forms of training are perceived as more effective than others (see Figures 20 and 21). This scaffolding process continued to refine the workshop process and add critical controls to our repository for a total of 81 geotechnical critical controls.

On February 24, 2020 Dr. Brad Ross presented our findings at the SME 2020 Annual Meeting in Phoenix, Arizona. He shared information regarding the approach used to define and develop Critical Controls Management strategies and shared some of the lessons learned.

In addition, Dr. Ross successfully piloted an online training course that was originally planned as an in-person event for geotechnical experts. The course used a hybrid model of both passive and interactive virtual content. A group of 9 industry experts pre-recorded their training workshops, which were subject to a vetting process for quality assurance. A few hours of these workshops were then distributed to the 170 participants each week. At the end of each week a synchronous question-and-answer session was held. Finally, at the end of the training course a mini symposium was held where participants each presented a case study they had developed. The training was so well received that multiple companies have expressed interest in incorporating it into their own on-demand training. This successful pilot establishes a pattern from which we will develop online training modalities that can adapt to the challenges of COVID-19.

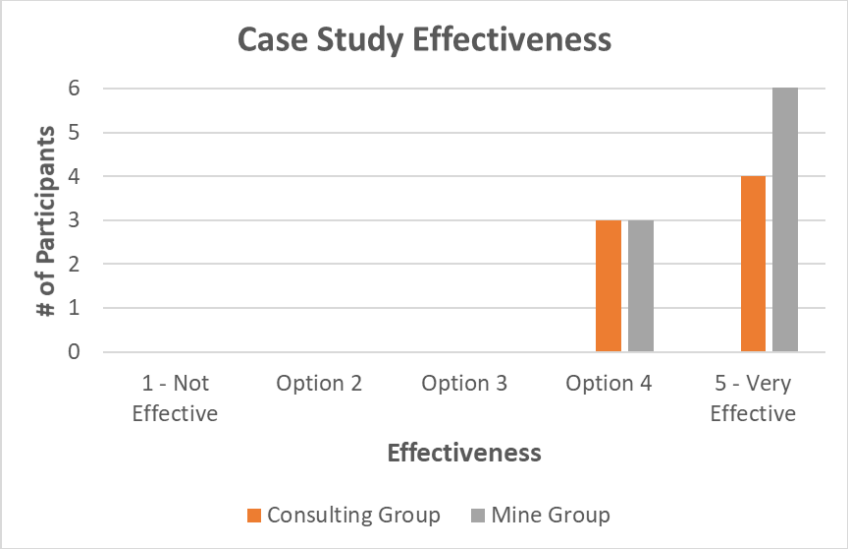

Figure 20. Perceived effectiveness of the Critical Control Case Study, by group.

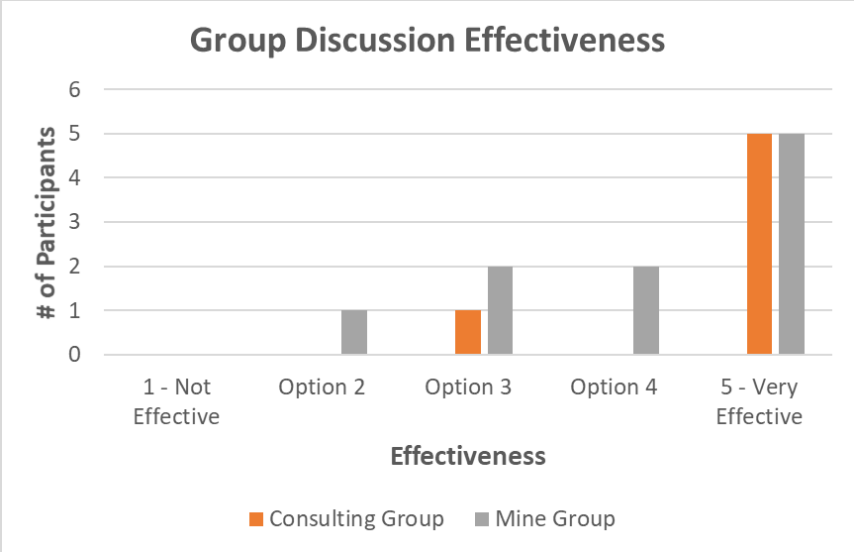

Figure 21. Perceived effectiveness of the Critical Control Group Discussion, by group.

Finally, we have published a technical paper sharing the critical controls collected and developed (see Appendix E.1) and continue developing and building our online repository through which critical control information are distributed (see Appendix E.2). The repository allows the Center to monitor visits to and downloads from our website. We also request that users voluntarily provide their contact information for follow-up regarding planned and actual implementation of controls information.

Section D

Table 2. Key Personnel

Key Personnel (PI/CoPI)	Role/Effort in WMTC	Contact Information
Jefferey L. Burgess, M.D., M.S., M.P.H. Assoc. Dean for Research	Director and Principal Investigator (0.60 mo)	Mel and Enid Zuckerman College of Public Health The University of Arizona 1295 N. Martin Avenue Room A317C Tucson, AZ 85724 520-626-4918 jburgess@email.arizona.edu
Leonard D. Brown, Ph.D. Assistant Research Professor	Co-Principal Investigator, Serious Games (Initially 12.0 mo)	Mel and Enid Zuckerman College of Public Health The University of Arizona 1295 N. Martin Avenue Tucson, AZ 85724 808-780-4910 ldbrown@email.arizona.edu
Brad Ross, Ph.D., P.E. Professor of Practice, Mining Engineering Director, Geotechnical Center for Excellence	Co-Principal Investigator, Critical Controls (Initially 1.2 mo)	Lowell Inst. for Mineral Resources The University of Arizona 1235 E. James E. Rogers Way Room 209 Tucson, AZ 85721 520-827-9649 bjr@email.arizona.edu
Brenda Granillo, M.S., MEP Director, Mountain West Preparedness and Emergency Response Learning Center	Co-Principal Investigator, Program Evaluation (2.4 mo)	Mel and Enid Zuckerman College of Public Health The University of Arizona 1295 N. Martin Avenue Room A219H Tucson, AZ 85724 520-626-0617 bgranill@email.arizona.edu

Table 3. Other Personnel

Other Personnel	**Role/Effort in WMTC**	**Contact Information**
Laurie Wilson, M.A. Senior Research Specialist	Training Coordinator and Instructional Designer (Initially 9.0 mo)	Lowell Inst. for Mineral Resources The University of Arizona 1235 E. James E. Rogers Way Room 209 Tucson, AZ 85721 520-626-9428 lauriewilson@email.arizona.edu
Rustin Reed, Ph.D., CIH, CSP Assistant Research Professor	Project Coordinator (Initially 6.0 mo)	Mel and Enid Zuckerman College of Public Health The University of Arizona 1295 N. Martin Avenue Tucson, AZ 85724 520-333-7585 rustin2@email.arizona.edu
Michael G. Peltier Senior Systems Analyst/ Applications Developer	Software Engineer, Serious Games (12.0 mo)	Lowell Inst. for Mineral Resources The University of Arizona 1235 E. James E. Rogers Way Room 209 Tucson, AZ 85721 520-621-2988 michaelpeltier@email.arizona.edu

Section II

Program highlights and impact

During the project period, 2,914 individuals received training using our materials and/or serious games (see Table 4). Since Oct 1, 2017 we have published five scholarly articles (4 additional manuscripts in progress), delivered 35 conference presentations, exhibited at 12 national conferences, and connected with partners at 61 industry meetings. To date, the Center has published 8 peer-reviewed articles, 1 dissertation, 2 inventions, and 121 invited presentations, and it conducted 61 meetings with industry partners.

Since October 1, 2017, the Center has produced the following outputs:

- 2,733 mine industry professionals trained, including 2,344 mine workers, 277 trainers, mine safety professionals and supervisors, 67 mine rescue team members, and 45 mine engineers (students).
- 820 mine industry professionals trained using computer-based serious games (e.g. *Harry's Hard Choices*), including 712 mine workers, 41 trainers and supervisors, and 67 mine rescue team members.
- 61 industry meetings with over 20 organizations, including ASARCO (Ray), Coeur Mining (multiple sites), Freeport-McMoRan, Hecla, McCraren Compliance, Rio Tinto, NIOSH Mining (Spokane), Univ. Texas at Austin, SD Mines, and many others.
- 12 conference exhibits on serious games and active-learning.
- 35 conference presentations, including 13 at the SME Annual Conference and Expo, 9 at MSHA's Training Resources Applied to Mining Conference (TRAM), 11 at the Mine Safety and Health Conference, and 2 at the International Conference on Human Factors and Simulation (HFSIM).
- 16 work products completed or in progress, including 1 tabletop activity (e.g. card game with expansion card deck for hazards recognition and worker health), 2 software tools (e.g. serious game environments for hazards detection and cloud data collection framework), an online Instructional Design Program, a new website portal connecting users to all of our training courses and resources, and a growing repository of MUEs and Critical Controls. These resources are available through our online gateway at https://miningsh.arizona.edu.

In addition to new miner and annual refresher training, we continue to offer specialized task training, mine rescue training, and instructional design courses and training tools, with an increasing emphasis on reaching underserved sectors of the mining industry and expanding our partnerships with stakeholders in those sectors.

Table 4. Summary of training for Oct 1, 2017 to Sept 30, 2020

Course Title	Courses	Participants	Mining Sector
MSHA Annual Refresher	35	1554	Metal/Sand and Gravel
MSHA New Miner Training (24- & 40-hr)	38	724	Metal/Sand and Gravel; Surface and Underground
Critical Controls Workshop	5	74	Various
Train the Trainer	13	167	Trainers
Mine Rescue	5	67	Military
Fall Protection Module	3	66	Various
Student Interactive Mining program	3	45	Students
Other Supervisory	3	36	Various
Totals	**105**	**2733**	

Section C

Publications

1. Wilson, L., Brown, L.D., Reed R.J., and Burgess, J.L, "Gamification of Hazard Recognition in Mining with a Tabletop Card Game," *3rd International Conference on Human Factors and Simulation* (HFSIM), Springer Nature, San Diego, CA, July 16-20, 2020.

2. Brown, L.D. & Poulton, M. "Improving Safety Training through Gamification: An Analysis of Gaming Attributes and Design Prototypes," *Advances in Human Factors in Simulation and Modeling*, D. Cassenti (Ed.), Intelligent Systems & Computing series, v. 780, Springer Nature, p. 392-403, 2019.

3. Williams, C., Ross, B., Zebker, M., Gaida, M., Morkeh, J., Robotham, M. "Assessment of Historic InSAR Monitoring Data Prior to the Manefay Slide at the Bingham Canyon Mine Using the Latest Analytical Techniques," *US Rock Mechanics/Geomechanics Symposium*, v.53, American Rock Mechanics Association, 2019.

4. Griffin S.C., Bui D.P., Gowrisankaran G., Lutz E.A., He C., Hu C., Burgess J.L. Risk management interventions to reduce injuries and maximize economic benefits in U.S. mining. *Journal of Occupational and Environmental Medicine*. 2018; 60(3): 226-233. PMID: 29227357.

5. Lutz E.A., Reed R.J., Lee V.S.T., Burgess J.L. Comparison of personal diesel and biodiesel exhaust exposures in an underground mine. *Journal of Occupational and Environmental Hygiene*. 2017; 14(7): D102-D109. PMID: 28166462.

6. Lutz E.A., Reed R.J., Lee V.S.T., Burgess J.L. Occupational exposures to emissions from combustion of diesel and alternative fuels in underground mining – a simulated pilot study. *Journal of Occupational and Environmental Hygiene*. 2015; 12(3): D18-25. PMID: 25412337.

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8. Brown, L.D. *Design, Evaluation, and Extension of Serious Games for Training in Mine Safety.* Ph.D. Dissertation, Dept. of Computer Science, University of Arizona, Tucson, AZ, 637 pgs, Dec. 2015.

Publications in Progress

9. Brown, L.D., Poulton, M., Burgess, J.L., and Burleson, W. "Derivation and Analysis of an Enhanced Workflow for Safety Training using Synthetic Learning Environments," *Intl. Journal of Artificial Intelligence in Education* (Manuscript in progress).

10. Reed, R.J., Brown, L.D., Wilson, L., Burgess, J.L., "Safety and Health Outcomes of Mine Training Interventions," *Mines, Metallurgy, and Exploration* (Manuscript in progress).

11. Brown, L.D., Peltier, M.G., Poulton, M., and Burgess, J.L. "Synthetic Learning Environments for High Consequence Training in Mine Health and Safety," *Safety Science* (Manuscript in progress).

12. Brown, L.D., Reed, R., Poulton, M., and Burgess, J.L. “Design Guidelines for Safety Training: A Contextual Inquiry Approach,” *Journal Safety Research* (Manuscript in progress).

Conference papers and Presentations

1. Reed, R. “Level Up Your Safety and Health Training with Gamification and Evaluation.” Arizona Health and Safety Summit, ASSP and AIHA, Phoenix, AZ, Mar 19, 2021. (Accepted)

2. Brown, L. Reed, R., Smith, G., Wilson, L. “Learning Laboratories: An Outcomes-Focused Mentorship and Evaluation Program for the Health and Safety Trainer.” *Training Resources Applied to Mining* (*TRAM*), MSHA, Beaver, WV, Oct 14, 2020.

3. Wilson, L., Brown, L.D., Reed R.J., and Burgess, J.L, "Gamification of Hazard Recognition in Mining with a Tabletop Card Game," 3rd International Conference on Human Factors and Simulation (HFSIM), San Diego, CA, July 16-20, 2020.

4. Brown, L. “The Continuous Improvement Lifecycle: A Human Performance-based Safety Management System to Create Experts.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 24, 2020.

5. Brown, L. “Evaluating Mine Emergency Competency: Lessons Learned from Harry's Hard Choices.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 24, 2020.

6. Reed, R. “Taking Safety Training to the Next Level with Serious Games and a Data-Driven Approach.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 24, 2020.

7. Ross, B. “Sharing Critical Controls.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 26, 2020.

8. Wilson, L. and Brown, L. “Making Safety Personal: Resources for Training Curriculum Design & Assessment.” *Mine Safety and Health Conference*, Reno, NV, Oct 23, 2019.

9. Brown, L. and Reed, R. “Evaluating Competency and Risk through Synthetic Learning Environments.” *Mine Safety and Health Conference*, Reno, NV, Oct 22, 2019.

10. Brown, L. “The Continuous Improvement Lifecycle: A Human Performance-based Safety Management System to Create Experts,” *Training Resources Applied to Mining* (*TRAM*), MSHA, Beaver, WV, Oct 17, 2019.

11. Brown, L. “The Continuous Improvement Lifecycle: A Human Performance-based Safety Management System to Create Experts.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 24, 2020.

12. Brown, L. “Evaluating Mine Emergency Competency: Lessons Learned from Harry's Hard Choices.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 24, 2020.

13. Reed, R. “Taking Safety Training to the Next Level with Serious Games and a Data-Driven Approach.” *SME Annual Conference and Expo*, Phoenix, AZ, Feb 24, 2020.

14. Wilson, L. and Brown, L. “Making Safety Personal: Resources for Training Curriculum Design & Assessment.” *Mine Safety and Health Conference*, Reno, NV, Oct 23, 2019.

15. Brown, L. and Reed, R. “Evaluating Competency and Risk through Synthetic Learning Environments.” *Mine Safety and Health Conference*, NV, Oct 22, 2019.

16. Brown, L. “The Continuous Improvement Lifecycle: A Human Performance-based Safety Management System to Create Experts,” *Training Resources Applied to Mining* (*TRAM*), MSHA, Beaver, WV, Oct 17, 2019.

17. Noiva, K. and Brown, L. “Developing an Effective Safety Training Toolbox: Guidelines and Lessons Learned,” *New Mexico Mine Safety and Health Conference*, Albuquerque, NM, May 10, 2019.

18. Ross, B. “Sharing Critical Controls.” *SME Annual Conference & Expo*, Denver, CO, Feb 27, 2019.

19. Brown, L., Granillo, B. and Poulton, M. “Usage Paradigms for Synthetic Learning Environments: Strategies and Lessons Learned.” *SME Annual Conference & Expo*, Denver, CO, Feb 26, 2019.

20. Ross, B. “Mining Safety: Sharing Solutions.” *SME Annual Conference & Expo*, Denver, CO, Feb 26, 2019.

21. Wilson, L., Brown, L. and DiBona, R. “Measuring the Effects of Active Learning on Health and Safety Training.” *SME Annual Conference & Expo*, Denver, CO, Feb 25, 2019.

22. Wilson, L. and DiBona, R. “Training Materials for Active Learning.” *Mine Safety and Health Conference*, Reno, NV, Oct 23, 2018.

23. Brown, L. and M. Poulton. “Guidelines for Developing an Effective Safety Training Toolbox.” *Training Materials Applied to Mining (TRAM)*,” MSHA, Beaver, WV, Oct 9, 2018.

24. Brown, L. and Poulton, M. “Participatory Design and Efficacy Testing of Serious Games.” *Training Materials Applied to Mining (TRAM)*,” MSHA, Beaver, WV, Oct 9, 2018.

25. Wilson, L. and McCraren, S. “Capturing Institutional Knowledge: Resources for Curriculum Design & Assessment.” *Training Materials Applied to Mining (TRAM)*.” MSHA, Beaver, WV, Oct 9, 2018.

26. Wilson, L., M. Poulton, M. Momayez, E. Lutz, M. Lutz. “Upping your safety game: New approaches to training and tracking worker health and safety.” *Mining & Exploration International*. Las Vegas, NV, Sept 6, 2018.

27. Brown, L. and M. Poulton. "Improving Safety Through Gamification: An Analysis of Gaming Attributes and Design Prototypes." *Applied Human Factors & Ergonomics (AHFE): Human Factors & Simulation (HFSIM)*. Orlando, FL, July 25, 2018.

28. Brown, L. and B. Granillo. "A Framework to Evaluate Safety Competencies Through Serious Games." *SME Annual Conference & Expo*, Minneapolis, MN, Feb 28, 2018.

29. Brown, L., M. Peltier, M. Poulton. "Learn with Harry: Toward a Comprehensive Training Solution Using Serious Games." *SME Annual Conference & Expo*, Minneapolis, MN, Feb 28, 2018.

30. Brown, L. and M. Poulton. "Usability Design Guidelines for Training in Mine Safety and Health." *SME Annual Conference & Expo*, Minneapolis, MN, Feb 27, 2018.

31. Ross, B. "Sharing Safety Critical Control Measures: Bingham Canyon Case Study." *SME Annual Conference & Expo*, Minneapolis, MN, Feb 27, 2018.

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35. Granillo, B. and L. Brown. "Usage Paradigms for Serious Games: Strategies and Lessons Learned." *Training Materials Applied to Mining (TRAM)*." MSHA, Beaver, WV, Oct 11, 2017.

Website(s) or other Internet site(s) – include URL(s)

1. Western Mining Safety & Health Training Resource Center may be found online at https://miningsh.arizona.edu/.

Inventions, patent applications, and/or licenses

1. Harry's Hard Choices serious game is now licensed through TechLaunch Arizona (Invention Disclosure UA14-160) for commercial distribution with a startup company, Desert Saber, LLC (Mar.2017).

2. Learn with Harry software suite is now licensed through TechLaunch Arizona (Invention Disclosure UA17-245) for commercial distribution with a startup company, Desert Saber, LLC (Oct. 2017).

Section E

E.1 Impact on the development of human resources

This work offers active learning-based safety and health training to mine workers. Our training uses a suite of serious games and active learning exercises to encourage critical thinking about safety and the development of safety-related competencies. Our approach empowers low literacy and education-disadvantaged learners to participate and engage in safety training in new and meaningful ways. These efforts result in an increased number of miners who are better able to translate their training knowledge to competent practices in the workplace.

Our train-the-trainer programs use a competency model, and helps managers and executives learn about critical controls. The networking mechanism we are building through online resources allows lessons learned to be shared across companies and industry sectors. We believe that we can, through these programs, generate individual and cultural improvements in the mining industry's safety culture and performance. A result of this work is increased numbers of highly effective trainers in the Western US that meet a recognized level of competency.

E.2 Impact on physical, institutional or information resources

This work provides competency-based training methods and critical control management curricula to small- and medium-sized mines. We continue to establish collaborative partnerships with associations in California, Arizona, Texas, Nevada and Colorado. New information resources produced include health metrics in new miner, refresher, and train-the-trainer curricula, as well as a training short course (Mining 101 Tutorial Course), a growing repository of MUEs and Critical Controls, and 1 software program. This work provides industry with better access to high quality training for small- and medium-sized companies and for education of disadvantaged miners.

The Center has worked with industry partners to create the first competency model for mine safety trainers in the U.S. We have designed and implemented active learning strategies for mine safety training and have trained trainers across all commodity sectors throughout the Western U.S. on methods to improve safety training. Our active learning tools include a handbook of techniques, state-of-the-art serious gaming software, tabletop card game, a training clinic, a supervisor leadership workshop, and a forum for sharing critical controls for potentially fatal health risks. New modeling of health metrics and environmental exposure conditions, including dust, noise, and heat stress, are being developed as part of our serious games initiative to enhance worker awareness and improve training on those public health topics. Furthermore, we have developed a new approach to evaluation during our training courses using rapid response technology. Collectively these outcomes should result in fewer mining injuries, illnesses, and fatalities.

E.3 Impact on technology transfer

The serious game, *Harry's Hard Choices*, continues to be deployed. Although the game focuses on mine emergency preparedness, it incorporates a variety of training topics, including hazard recognition and mitigation. Through our training courses and those of our collaborators, we continue to reach more miners, trainers, and supervisors with the game. We also continue to extend the capabilities of our Dynamic Safety™ platform, with a focus on hazards detection, critical controls, and performance on standard operating procedures. For example, our serious game, *Harry's Hazardous Day*, provides a dynamic training

environment for sand, gravel, and stone mining. The game features a prototypical crusher facility, conveyors, and operating haulage (including two types of dump trucks), as well as a functional limestone quarry with high walls, berms, and access roads. The game can now be used for flagging and mitigating hazards in a dynamic, team-based training activity. We have begun testing new workplace examination scenarios with our partners. A new data collection and visual analytics framework is also being developed in tandem. Both *Harry's Hard Choices* and *Harry's Hazardous Day* are licensed through TechLaunch Arizona (Invention Disclosure UA14-160 and UA17-245, respectively) for commercial distribution through a startup company, Desert Saber, LLC.