FINAL RPPR

COVER PAGE

Project Title: Western Mining Safety and Health Training Resource Center: Evidence-based Learning Laboratories	
Grant Number: 5U60 OH010014-13	**Project/Grant Period**: Sep 1, 2020 – Aug 31, 2023
Reporting Period: Sep 1, 2020 – Aug 31, 2023	**Date Submitted**:
Program Director/ Principal Investigator Leonard D. Brown, PhD	**Administrative Official Information** Marcel Villalobos Director, Postaward Services (520) 626-6000 sponsor@email.arizona.edu
Change of Contact PD/PI:	
Human Subjects: No	**Vertebrate Animals:** NA
hESC: NA	**Inventions/Patents:** 5

B. ACCOMPLISHMENTS

B.1. What are the major goals of the project?

Building on our past University of Arizona Miner Safety and Health Training Programs-Western United States (U60) grants, we expanded our collaborative training programs with industry partners to offer competency-based safety and health training for miners, trainers, supervisors, and safety and health personnel. These collaborative programs have been developed into Learning Laboratories (LLs) offering a menu of choices to the trainers, incorporating our current and future training resources as well as those provided by NIOSH and other academic and industry institutions. We continue to offer and evaluate the training under a single competency framework, providing a more coherent structure

for evaluation and impact. The framework also allows us to integrate research and evaluation findings so each training product can be revised to improve efficacy and shared across the LLs. Through these efforts we have greatly expanded the number of miners trained using new products and directly evaluated their effectiveness in improving safety and health.

1. *Establish collaborative, evidence-based Learning Laboratories*. We will expand our collaborative efforts with training consultants and company and labor-based training programs to develop LLs. Augmenting our current focus on new miner, refresher, and train-the-trainer training, we will include supervisors, one of our previous focus areas, as well as safety and health personnel. LL trainers will receive longitudinal support via a well-defined and scaffolded mentorship program, and leadership training will be provided for supervisors and safety and health personnel. New evaluation infrastructure will be developed to support the LLs, which includes a heterogeneous database capable of aggregating and analyzing data from a variety of sources and formats (including quantitative, qualitative, and multi-modal). It will incorporate data obtained from existing training resources and additional resources provided by our center, including the 3D synthetic learning environments (SLEs) *Harry's Hard Choices* and *Harry's Hazardous Day*, new hybrid tabletop games (see Aim 3), and additional training products from NIOSH, other academic programs, and industry. We will also introduce and evaluate a promising new industrial athlete warm-up program shared by one of our industry partners which in an initial pilot study has greatly reduced workplace injuries. These LLs will meet CFR Part 46 and 48 training requirements, enhancing but not duplicating existing training programs including those provided by MSHA and OSHA.
2. *Improve health training*. For the NIOSH National Occupational Research Agenda (NORA) cross-sector topic areas, traumatic injury prevention will continue to be a part of all levels of training (miner, trainer, supervisors and safety and health personnel) and experiential learning activities including gaming. Other cross-sector topics including musculoskeletal health, hearing loss prevention, respiratory health, heat-related illnesses, and fatigue will be addressed through addition of health modules in new miner, refresher, and train-the-trainer training materials to be employed in the LLs (Aim 1) and new training products (Aim 3).
3. *Develop new technologically driven training products.* Building upon our past successes with experiential learning and highly engaging serious games, we will extend our suite of existing training products sharable through a repository with new content focusing on NORA cross-sector topics (see Aim 2) and hazard mitigation. New modules will be developed that include an expansion pack for our Very Good Day card game and a new story-based scenario for the SLE *Harry's Hazardous Day*. Furthermore, we will create 'hybrid' games that serve as a bridge between traditional tabletop activities and full-scale SLEs. Using readily available mobile devices such as smartphones and tablets, the hybrid games will provide a shared physical workspace for collaboration (e.g. tabletop) that is augmented by personalized digital content delivered via the mobile devices. Digital content will feature challenges, rewards, and scaffolding specific to each learner. Two hybrid games will be developed, including a digitally enhanced card game called *Mining Strong* and a new strategy board game called *Coming Home Alive*.

Program outputs include:

1. Establishment of a network of collaborative LLs providing effective, high quality training
2. Improved, integrated health training materials
3. New training products
4. Robust evaluation methods, grounded in systems thinking and system theory, to determine the effectiveness of training products and resources
5. A quality improvement feedback mechanism to continually monitor training components under changing environments and make necessary corrective actions to maintain optimal efficiency

The end outcomes of the program will include a culture shift empowered by cohesive LL teams to reduce mining injuries, illnesses, and fatalities.

B.2. What did you accomplish under these goals?

See Attachment 1.

B.3. Competitive Revisions/Administrative Supplements

None.

B.4. What opportunities for training and professional development did the project provide?

All activities in this project are related to training and professional development. Principally, training was provided to mine workers, trainers, and safety and health professionals participating in the Learning Laboratories program through the activities described in Section B.2. Over 16,000 mine industry professionals received training through this program.

Opportunities for professional development were also provided to graduate and undergraduate students at the University of Arizona through academic and directed research (individual study) courses, which included ISTA 416 / INFO 516 (Human-Computer Interaction), ISTA 425 / INFO 525 (Algorithms for Games), INFO 492 / INFO 692 (Directed Research), and MNE 426 / 526 (Safety and health in Mining). Professional development activities in these courses centered on occupational health, needs assessments, training technology, empirical evaluation, and data analytics.

Through these interdisciplinary courses, 12 students (7 graduate and 5 undergraduate) from the fields of Computer Science, Industrial Engineering, Information Science, Mining Engineering and Public Health received mentorship and professional development. In addition, four students participated as authors/presenters at conferences and workshops which included the SME Annual Conference (MINExchange), Mine Safety & Health Conference (MSAH), and the Symposium of the America Rock Mechanics Association (ARMA). Individual Development Plans (IDPs) were used to verify that students achieved degree objectives and/or thesis requirements in their respective fields of study.

B.5. How did you disseminate the results to communities of interest?

Our training resources are available on the Western Mining Safety and health Training Resource Center website at https://miningsh.arizona.edu. This includes over 1,000 pages of resources that are publicly available.

In addition, we delivered 37 presentations at professional conferences and symposia (SME Annual Conference, Training Resources Applied to Mining, Mine Safety and Health Conference, Human Factors in Simulation & Modeling (HFSIM), regional MSHA Fall Freeze and Spring Thaw events, etc.) and published seven scholarly articles with six more submitted or in preparation.

B.6 - What do you plan to do during the next reporting period to accomplish the goals?

In the next phase of the Western Mining Safety and Health Training Resource Center, we will expand our Learning Laboratories (LLs) program to serve as a testbed for new safety and health (S&H) training methodologies and research. The expanded LLs program will increase the capabilities of training practitioners and provide new avenues for experimentation among partnering researchers, yielding long-term and mutually beneficial collaborations that improve S&H outcomes for the mining industry. We will achieve these objectives through three specific aims:

Aim 1. Provide new pathways for training and research through collaborative learning laboratories. Our LLs program offers a powerful mechanism for collaboration between researchers, safety professionals, and industry trainers. The program will be extended to meet all six core elements of NIOSH's Research to Practice (R2P) initiative: 1) Partnerships. Partnerships will be expanded to address trainers serving contractors, small operators, and other underserved groups. 2) Intramural Science. We will work with investigators at NIOSH to identify industry needs, facilitate their research programs, and deploy NIOSH products for extended testing and/or longitudinal evaluation of outcomes. 3) Extramural Science. We will work with investigators in academia, including other U60 recipients, to cross-deploy our programs'

existing resources and co-develop new training materials for distribution through the LLs. 4) Technology Transfer. Historically, we have developed an average of two new training technologies per year. These technologies will be deployed and/or licensed to operators and other partners for non-exclusive use and continued enhancement, which may then be cycled back into the LL program and into the greater mining community. 5) Communication. The LL program will conduct quarterly supervisory meetings to engage with industry partners, offer specialized workshops to individual partners upon request, and provide new platforms for sharing materials and best practices. We will develop a cloud-based metaverse to provide access to training resources and increase partner interaction through a Discord social media forum. 6) Evaluation. Our program mentors will establish baselines and coordinate evaluation across the LLs, using a secure, cloud-based platform and heterogeneous database to aggregate and analyze results.

Aim 2. Improve health training. For the NIOSH National Occupational Research Agenda (NORA) cross-sector topic areas, traumatic injury prevention will continue to be a part of training at all levels (miner, trainer, supervisors, and S&H personnel). Training will be facilitated using a range of experiential learning activities and serious games (Aim 3). Through the addition of new health modules in new miner, annual refresher, and train-the-trainer materials, other cross-sector topics will be addressed, including chronic disease, musculoskeletal health, hearing loss prevention, respiratory health, and heat strain. We will incorporate materials on well-being using the Total Worker Health framework, including topics such as mental health, substance abuse, and fatigue. New training materials will be developed to explore critical thinking and the interplay between safety and health, compelling workers to anticipate and explore the health outcomes of their decisions on the worksite.

Aim 3. Develop, extend, and integrate a continuum of training resources. We will extend our suite of existing training resources with new content focusing on NORA cross-sector topics (see Aim 2) as well as hazards recognition, mitigation, and prevention on the worksite. Successful training products developed by our program, NIOSH researchers, and LL training practitioners will be upgraded in novel ways to incorporate new content, capabilities, and interoperability. For example, we have successfully converted the NIOSH training scenario *Harry's Hard Choices* into a computer-based synthetic learning environment (SLE). We will develop resources addressing all levels of trainer capability, from easily integrated tabletop games to sophisticated SLEs. Emphasis will be placed on improving the accessibility of training and evaluation technologies, particularly for trainers serving smaller operators and at worksites lacking sophisticated computing hardware. We will provide secure, app-based games that function on low-cost mobile hardware and upgrade our SLE *Harry's Hazardous Day* with cloud-based online streaming capabilities.

*Please complete the additional information requested after section I.

C. PRODUCTS

C.1. Publications, conference papers, and presentations

Yes.

Publications

- Akubulut, N.B., Anani, A., Brown, L.D. & Wellman, E.C. "Innovative Approaches for Monitoring Underground Excavations," *Rock Mechanics and Rock Engineering*, Special Issue, Springer, 2024. (To appear)

- Brown, L.D., Pham, N. & Burgess, J.L. "Toward a Systems Framework Coupling Safety Culture, Risk Perception, and Hazards Recognition for the Mining Industry," *Human Factors and Simulation*, Wright, J. & Barber, D. (Eds.), AHFE International v.30, 2022.

- Lutz, E.A. "Considerations for the Adoption of Real-time Particulate Monitoring." *International Counsel of Mining and Metals* (*ICMM*), Peer-reviewed by ICMM S&H Committee. Jan 2022.

- Wilson, L.P, Brown, L.D., Reed, R.J. & Burgess, J.L., "Gamification of Hazard Recognition in Mining with a Tabletop Card Game," *Advances in Simulation & Digital Human Modeling*, Cassenti, D., Scataglini, S., Rajulu, S., & Wright, J. (Eds.), Intelligent Systems & Computing series, Springer LNCS, v.1296, 2021.

- Staack, D., Griffin, S., Lee, V., Lutz, E.A., & Burgess, J.L. "Evaluation of CBRN Respirator Protection in Simulated Fire Overhaul Settings." *Annuals of Work Exposures & Health,* v.65(7): 843-853, Aug 5, 2021.

Conference Papers

- Akbulut, N.B., Anani, A., Brown, L.D. and Wellman, E.C.=. "Innovative Approach for Monitoring Underground Excavations at San Xavier Underground Mine Laboratory," *Proc. 57th Symp. America Rock Mechanics Association* (ARMA), Atlanta, GA, June 25-28, 2023.

- Brown, L.D., Peltier, M.G. & Burgess, J.L. "Synthetic Learning Environments: Combining Simulation with Serious Games to Improve Training in Mine Safety and Health," *Proc. World Mining Congress*, Brisbane, AU, 2023.

Conference Presentations

- Brown, Leonard D., Yanyan Dong, Hong Cui, & Jefferey Burgess. "Injury Prediction and Root Cause Analysis Using Large Language Models." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- Meyer, Benjamin, Leonard D. Brown, John Keefner, James C. McNabb, Julia Potter, Robert Prescott, Brad Ross, & Chad Williams. "Automated Rockfall Detection Using Thermal Imaging: Recent Developments in Tracking, Prediction, and Alarming." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- Reed, Rustin, Leonard D. Brown, Glenna Smith, & Jefferey Burgess. "Lessons Learned: Gamification of Total Worker and Occupational Health Training." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- Reed, Rustin, Eric Lutz, Leonard D. Brown, & Jefferey Burgess. "Safety and Productivity Share the Same Sire: Competent Leadership." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- Potter, Julia, Benjamin Meyer, Leonard D. Brown, John Keefner, James C. McNabb, Robert Prescott, Brad Ross, & Chad Williams. "Geotechnical Applications of Thermal Imaging: Observations and Recommendations." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- Rezeau, Hervé, Ngan Pham, Justin Felker, & Leonard D. Brown. "Virtual Ore Microscope: An Interactive Cloud Application to Learn Optical Properties of Ore Minerals." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- McNabb, James, C., Julia Potter, Gillian Noonan, Leonard D. Brown, & Benjamin Meyer. "Modeling Surface Hydrology for Hazard Mitigation in Open Pit Mines Using High-Resolution Drone Photogrammetry." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Phoenix, AZ, Feb. 25-28, 2024. (To Appear)

- Brown, Leonard D., Rustin Reed, Glenna Smith, & Ngan Pham. "Improving Evaluation Strategies for Miner Safety and health Training Programs," Training Resources Applied to Mining Annual Workshop (TRAM), MSHA, Beaver, WV, Oct. 10-12, 2023. (Presented twice)

- Brown, Leonard D., Glenna Smith, & Ngan Pham. "Synthetic Learning Environments: Making Training More Accessible and More Effective," Training Resources Applied to Mining Annual Workshop (TRAM), MSHA, Beaver, WV, Oct. 10-12, 2023. (Presented twice)

- Brown, Leonard D., & Rustin J. Reed. "*Harry's Hazardous Day*: A Cloud-Based Streaming Game for Training and Human Performance Assessment." Mine Safety and Health Conference, Reno, NV, Oct. 23-25, 2023.

- Reed, Rustin J., & Leonard D. Brown. "Transform Your Mine's Safety Culture through Leadership." Mine Safety and Health Conference, Reno, NV, Oct. 23-25, 2023.

- Brown, Leonard D., Eric A. Lutz, & Rustin Reed. "Collaborations that Improve Training." MSHA Spring Thaw, Sponsored by Arizona Mining Assoc. & Arizona Rock Products Assoc., Phoenix, AZ, May 5, 2023.

- Brown, Leonard D., Aadhithya Dinesh, Hong Cui, & Jefferey L. Burgess. "Toward Smarter Safety Management Systems: Using Machine Learning to Predict Injuries and Identify Leading Indicators in Mine Operators' Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Denver, CO, Feb. 27 - Mar 1, 2023.

- Brown, Leonard D., Ngan Pham, Kelli McCormick, & Purushotham Tukkaraja. "Working SMARTer: Improving Site Situational Awareness, Records Keeping, and Compliance Reporting Using a Lightweight, Collaborative App." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Denver, CO, Feb. 27 - Mar 1, 2023.

- Peltier, Michael G., Leonard D. Brown, & Jefferey L. Burgess. "*Harry's Hazardous Day*: A Cloud-Based Streaming Platform for Training and Human Performance Assessment." Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Denver, CO, Feb. 27 - Mar 1, 2023.

- Potter, Julia, Edward Wellman, Robert Prescott, Leonard D. Brown, & Bradley J. Ross. "Automated Detection of Rockfalls from Thermal Imaging Data" Society for Mining, Metallurgy, & Exploration Annual Conference (SME), Denver, CO, Feb. 27 - Mar 1, 2023.

- Kelli McCormick & Ngan Pham. "SMART: MSHA Compliance Strategies: A Smart App to Improve Tracking, Reporting, and Analytics," MSHA Spring Thaw at the Safety + Health Conference, Sponsored by the North Dakota Safety Council, Bismarck, ND, Feb. 21, 2022.

- Kelli McCormick & Ngan Pham. "SMART: MSHA Compliance Strategies: A Smart App to Improve Tracking, Reporting, and Analytics," MSHA Fall Freeze, Sponsored by the WY MSHA State Grant Program, Gillette, WY, Nov. 3, 2022.

- Brown, Leonard D., Glenna Smith, and Tuan A. Bui. "Accessible Tech: Online and Mobile Apps for Training," Training Resources Applied to Mining Annual Workshop (TRAM), MSHA, Beaver, WV, Oct. 11-13, 2022. (Presented twice)

- Lee, Danny C.K., Glenna Smith, and Leonard D. Brown. "MSHA Sports: Using Football and Baseball to Evoke Discussion and Synthesis," Training Resources Applied to Mining Annual Workshop (TRAM), MSHA, Beaver, WV, Oct. 11-13, 2022. (Presented twice)

- Pham, Ngan, Leonard D. Brown, Tuan A. Bui and Purushotham Tukkaraja. "SMARTer Compliance = Better Training: Enhancing Workflows for Training, Tracking, and Reporting," Training Resources Applied to Mining Annual Workshop (TRAM), MSHA, Beaver, WV, Oct. 11-13, 2022. (Presented twice)

- Reiher, Michelle, Rustin Reed, and Leonard D. Brown. "Showing Your Hand: Card-based and Tabletop Games for Training," Training Resources Applied to Mining Annual Workshop (TRAM), MSHA, Beaver, WV, Oct. 11-13, 2022. (Presented twice)

- Brown, Leonard D. & Rustin Reed. "MSHA Compliance Strategies: A No-Cost Assistive Technology to Improve Tracking, Reporting, and Analytics, Particularly for Smaller Operators," Mine Safety and Health Conference, Scottsdale, AZ, Oct. 24-26, 2022.

- Reed, Rustin & Leonard D. Brown. "Training-the-Trainer: A Collaborative Forum for Trainers and HSE Personnel to Share Best Practices and Improve Their Training Materials and Curricula," Mine Safety and Health Conference, Scottsdale, AZ, Oct. 24-26, 2022.

- Brown, L., Pham, N., McCormick, K., Burgess, J. "Small Mine Activities Reporting Tool: A Lightweight App to Improve Compliance Reporting and Track Outcomes." Society for Mining, Metallurgy & Exploration (SME) Annual Conference and Expo, Salt Lake City, UT, Mar 2, 2022.

- Reed, R., Brown, L., Burgess, J. "Evaluation of Mine Safety and Health Training Programs Using a Pretest-Posttest-Control Design." Society for Mining, Metallurgy & Exploration (SME) Annual Conference and Expo, Salt Lake City, UT, Mar 1, 2022.

- Brown, L. "Mobile Applications for Interactive Training and Performance Assessment." Training Resources Applied to Mining (TRAM) Virtual Summit, MSHA, Beaver, WV, Nov 3, 2021. (Presented twice)

- Reed, R. "Level Up by Measuring Safety and Health Training Outcomes." Mine Safety and Health Conference (MSHC), Las Vegas, NV, Oct 27, 2021.

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

C.2. Website(s) or other Internet site(s) – include URL(s)

The Western Mining Safety & Health Training Resource Center (TRC) may be found at https://miningsh.arizona.edu/. Digital versions of all program training resources may be found online through the TRC website.

C.3. Technologies or techniques

Software: *Harry's Hazardous Day* is a computer-based serious games to practice workplace examinations and safe operating procedures. Topics include fire equipment, crushers, conveyors, and vehicle inspections. The system is currently being tested with partners for Train-the-Trainer and New Miner training courses.

Software: A new mobile training app called *Coming Home Alive*. The game addresses annual refresher training topics, including traffic control, communication systems, ground controls, highwalls, and hazard recognition. This work is a collaboration with the Colorado School of Mines and South Dakota School of Mines.

Software: *Small Mine Activities Reporting Tool* (SMART) is a mobile app for iOS and Android that helps small operators with timely filing of hours worked, record-keeping for training, maintenance, and incidents, and proper notification of commencement and closure. The app also visualizes key metrics to provide a snapshot of site safety and health trajectory.

Educational Aid: *Mining Strong* is a cooperative card game with both online and tabletop versions. The game addresses knowledge gaps in total worker health and industrial hygiene. Both versions have been deployed for feedback with training partners.

Educational Aid: *MSHA Football* is a competitive card game which is used for knowledge synthesis in annual refresher training. Developed in cooperation with the Massachusetts MSHA State Grant program, the game is customizable and includes a scoreboard app for Windows.

Database: The *Dynamic Safety Cloud Data Services* are a set of cloud-based tools used to aggregate and visualize safety and health data analytics. Data stored in the system include company safety and health reports, industry accidents and injuries, metrics collected from computer-based serious games.

C.4. Inventions, patent applications, and/or licenses

Bui, Tuan Anh, Ngan Pham, & Leonard D. Brown. "*MSHA Football*: A Hybrid Sports App to Gamify MSHA Annual Refresher Training," University of Arizona (Disclosure Pending), 2023.

Brown, Leonard D., Tuan Anh Bui, Ngan Pham, & Justin Felker. "*Coming Home Alive*: A Mobile Gaming App for Safety and health Training," University of Arizona (Disclosure Pending), 2023.

Peltier, Michael G. & Leonard D. Brown. "*Harry's Hazardous Day*: A Cloud-based Streaming Platform for Workplace Examination and Hazards Training," University of Arizona (Disclosure Pending), 2023.

Pham, Ngan, Justin Felker, Leonard D. Brown, & Hervé Rezeau. "*Virtual Ore Microscopy*: An Interactive Cloud Application to Learn Optical Properties of Ore Minerals," University of Arizona (UA23-511), 2023.

Brown, Leonard, Ngan Pham, & Kelli McCormick. "*Small Mine Activities Reporting Tool* (SMART): A Mobile App to Improve Compliance Reporting and Track Outcomes," University of Arizona (UA22-013), 2022.

C.5. Other products and resource sharing

Training Products

Coming Home Alive (Multi-topic app-based game, In progress)
Dynamic Safety Cloud Data Services (Secure cloud tracking and assessment framework)
Harry's Hazardous Day: Workplace Examinations Training (Computer-based serious game)
Leading Indicators of Safety (Data product for injury analysis and risk management)
MSHA Football (Card-based hybrid game and annual refresher synthesis activity)
Mining Strong (Card game for industrial hygiene and wellness)
SMART: Small Mine Activities Reporting Tool (Tracking and reporting compliance app)
Very Good Day, Version 2.0 (Hazards and hierarchy of controls card game, double deck)

D. PARTICIPANTS

D.1. What individuals have worked on the project? Please include calendar, academic, and summer months.

Commons ID	S/K	Name	Degrees(s)	Role	Cal	Aca	Sum	Foreign	Country	SS
leonardbrown	Y	Leonard Brown	PhD	PI	6.0			N		

burgess	Y	Jefferey Burgess	MD	PI/Co-I		0.6	0.0	N		
rustinj	Y	Rustin Reed	PhD	Co-I	3.0			N		
ealutz	Y	Eric Lutz	PhD	Co-I	3.6			N		
niluferakbulut	N	Nilufer Akbulut	MS	Graduate Student (Research Assistant)	2.0			N		
tuanabui	N	Tuan Bui	MS	Graduate Student (Research Assistant)	6.0			N		
adinesh	N	Aadhithya Dinesh	MS	Graduate Student (Research Assistant)	4.5			N		
yanyandong	N	Yanyan Dong	BS	Graduate Student (Research Assistant)	4.5			N		
	N	Justin Felker		Consultant	5.0			N		
jiayuehe	N	Jiayue He	MS	Graduate Student (Research Assistant)	2.0			N		
nkomandur	N	Nikhil Komandur	BA	Undergraduate Student	2.0			N		
	N	Anthony Lopes	BA	Consultant	2.9			N		
mostafalutfi	N	Mostafa Lutfi	PhD	Graduate Student (Research Assistant)	1.0			N		
	N	Michael Peltier		Technician	12.0			N		
nganpham	N	Ngan Pham	BA	Undergraduate Student	9.0			N		
cperez4	N	Cesar Perez	BS	Undergraduate Student	2.0			N		
	N	Glenna Smith		Other - Trainer	6.6			N		
jackshobinger	N	Jack Schobinger	BS	Undergraduate Student	1.0			N		

D.2 Personnel updates

a. Level of Effort: No.
b. New Senior/Key Personnel: No.
c. Changes in Other Support: No.
d. New Other Significant Contributors: No.

E. IMPACT

E.1 - What is the impact on the development of human resources, if applicable?

NA

E.2 - What is the Public Health Relevance and Impact? The investigator should address how the findings of the project relate beyond the immediate study to improved practices, prevention or intervention techniques, legislation, policy, or use of technology in public health.

The Western Mining Safety and Health Training Resource Center (Center) offers active learning-based safety and health training to mine workers, incorporating a suite of "serious games" and active learning exercises to encourage critical thinking and foster competency. Through serious games, low literacy and education-disadvantaged learners may be empowered to participate and engage in training in new and meaningful ways. To facilitate this approach, we have deployed and disseminated a collection of active learning resources, including handbooks, state-of-the-art computer-based serious games, mobile app-based games, training clinics, supervisory leadership workshops, and data products for safety and health risk management. These resources will have a lasting impact by increasing the number of miners who are better able to translate safety knowledge into competent practices in the workplace. Furthermore, these resources augment coverage of critical public health topics. For example, new simulations of environmental exposure conditions, including dust, noise, and heat stress, have been developed as part of our serious games initiatives, enhancing worker awareness and improving training around these topics. We believe this enhanced training will lead to reductions in exposures and instances of related disease among mine workers, yielding a positive impact on the mining industry and its communities.

Through the Learning Laboratories program, high quality training resources and lessons learned may be widely shared among mine operators and across sectors, increasing the reach and effectiveness of training. In particular, the Learning Laboratories program enhances collaboration among industry practitioners and academicians, reduces silos, and decreases the training quality gaps that exist between large and small operators, yielding better safety and health training for underserved groups. Collectively, these programs and resources will increase the number of highly effective trainers in the Western US and lead to systemic improvements in the mining industry's safety culture and performance, resulting in fewer mining injuries, illnesses, and fatalities.

F. CHANGES

F.1 – Changes in approach and reasons for change, including changes that have a significant impact on expenditures

None.

F.2 - Actual or anticipated challenges or delays and actions or plans to resolve them

None.

F.3 - Significant changes to human subjects, vertebrate animals, biohazards, and/or select agents

None.

G. Special Reporting Requirements

G.1 Special Notice of Award Terms and Funding Opportunities Announcement Reporting Requirements

None.

G.2 Responsible Conduct of Research

NA.

G.3 Mentor's Research Report or Sponsor Comments

NA.

G.4 Human Subjects

G.4.a Does the project involve human subjects?

No.

G.4.b Inclusion Enrollment Data

Nothing to report.

G.4.c ClinicalTrials.gov

Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?

No.

G.5 Human Subject Education Requirement

Are there personnel on this project who are newly involved in the design or conduct of human subject's research?

No.

G.6 Human Embryonic Stem Cells (HESCS)

Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?

No.

G.7 Vertebrate Animals

Does this project involve vertebrate animals?

No.

G.8 Project/Performance Sites

University of Arizona (Main Campus), Tucson, AZ.

G.9 Foreign Component

None.

G.10 Estimated Unobligated Balance

G.10.a Is it anticipated that an estimated unobligated balance (including prior year carryover) will be greater than 25% of the current year's total approved budget?

Yes. $331,379 is available for Carryover.

G.11 Program Income

Is program income anticipated during the next budget period?

No.

G.12 F&A Costs

Is there a change in performance sites that will affect F&A costs?

No.

I. OUTCOMES

I. Provide a concise summary of the outcomes or findings of the award, written for the general public in clear and comprehensible language, without including any proprietary, confidential information or trade secrets.

Note: project outcome information will be made public in NIH RePORTER

The Western Mining Safety and Health Training Resource Center (Center) at the University of Arizona works to improve miner safety and health by developing, evaluating, and sharing training resources, and by facilitating educational partnerships among industry, academia, and government. A key activity of the Center is to promote active learning during training, which is much more effective than passive methods like lectures, slides, or videos. In collaboration with numerous industry partners, the Center has developed a collection of active learning handbooks, computer-based "serious games", mobile apps, training clinics, and data products that address the diversity of trainer needs, capabilities, and classroom requirements. New health training has also been developed to enhance worker awareness and competency on critical public health topics, such as environmental exposure conditions, including dust, noise, and heat stress, as well as worker wellness. Furthermore, during the last phase of our program, the Center's reach greatly expanded and now incorporates over 20 partnering mine operators in 15 Western US states; training and training resources were provided to over 16,000 miners during this phase, through courses that included professional development, supervisory training, and exercise programs, in addition to the MSHA-mandated safety and health training (i.e., 723 total courses). These activities have resulted in positive changes to workplace safety culture, worker competency, and safety and health outcomes in the mining industry.

Changes in training and safety culture. Mine operators now recognize the value of active learning and the added capabilities of our technology-based training resources, making them more willing to invest resources in these initiatives as a step toward sustainable improvements in their workers' safety and health. For example, two mine operators recently transitioned from lecture-based to hands-on training methods after surveying our resources and training

programs. After observing the capabilities of computer-based serious games, seven operators recently deployed serious games in their new miner training. The use of our computer-based games increased 4x, to over 3,000 miners, during the last phase of our Center.

Improvement in worker competency. Workers have demonstrated improvements in knowledge and safety competency using our active learning resources, as measured with post-test assessments. For example, in studies with seven groups of miners (148 miners in total), there were substantial improvements in their ability to recognize hazards – as high as 50% for some hazard types – when using computer-based serious games.

Improvement in S&H outcomes. Case studies of our training interventions have indicated reductions in both the frequency and severity of workplace injuries. For example, a partnering worksite reported decreases in average injuries and days lost at 23.6% and 72.5%, respectively. This outcome compares favorably to the 100% increase and 27.7% decrease in the same measures, respectively, at the operator's other worksites, which were not using our training programs. Average reductions in days lost exceeded 60% across all operators using our programs – a favorable outcome versus the sector trend, which showed only a marginal reduction of 3.6% over the period.

Collectively, the Center's efforts have resulted in an increased number of miners who are better able to translate their training knowledge to competent practices in the workplace and increased the sharing of highly effective active learning materials across mine operators and sectors, leading to reductions in accidents, injuries, and fatalities.

* Additional information is required: (Attach to Section B.2)

- **Abstract (*for the full study*; 500 words or less)**
- **Significant or Key Findings (*identify by specific aim or in parentheses after related findings/statements for each specific aim*)**
- **Translation of Findings**
- **Research Outcomes/Impact (*some contents may also be reported in E. Impact and I*. Outcomes.)**

ATTACHMENT 1

Abstract (500 words)

For 20 years (2002 – 2022), the trends in both mining injury and lost time rates have remained nearly flat (MSHA 2022). Notably, lack of training was a root cause or contributing factor in 40% of the 32 fatalities from 2021 for which a final report was available (MSHA, 2021). In addition, NIOSH surveillance data (McWilliams et al, 2012) showed that most trainers were using lecture-based training materials, which are less effective for adult learners (Armbruster et al., 2017). Delivering quality and competency-based safety and health (S&H) training continues to be a major challenge in the mining industry. Building on our past University of Arizona Miner Safety and Health Training Programs-Western United States (U60) grants, the program seeks to improve S&H training for miners, trainers, supervisors, and S&H personnel, leading to increased worker safety competency, improvements in safety culture, and reductions in injury and illness rates across the mining industry in the Western States. Goals will be implemented through the following three specific aims:

Aim 1: Establish collaborative, evidence-based Learning Laboratories. We will expand our collaborative training programs with industry partners to develop Learning Laboratories (LLs) which offer training resources, mentorship, and professional development to trainers and S&H personnel. Notably professional development will include new programs in supervisory leadership and new frameworks for program evaluation and S&H risk management. Through LLs, a platform will be established to identify S&H needs, establish new collaborations, and share resources that improve S&H for the broader mining community. At least 20 mining organizations are expected to participate in this program, leading to a significant expansion in minters trained (>16,000) and broader adoption of high impact active learning resources developed by this program and collaborators.

Aim 2: Improve health training. For the NIOSH National Occupational Research Agenda (NORA) cross-sector topic areas, traumatic injury prevention will continue to be a part of all levels of training, with new emphasis on hearing loss prevention, musculoskeletal health, and respiratory health. Principal health training outputs will include a new tabletop card game called *Mining Strong*, which will address both industrial hygiene and Total Worker Health, and a new health profile system for *Harry's Hazardous Day*.

Aim 3. Develop new technologically driven training products. We will extend our existing suite of active learning-based training products to address a range of trainer capabilities and classroom technical requirements. Notably, accessibility will be increased through tabletop games, mobile app-based games, and web-based online approaches. Advancements will include: 1) extending *Harry's Hazardous Day* with new modules addressing NORA cross-sector topics (Aim 2) and new workplace examinations; 2) designing an app-based game called *Coming Home Alive*; 3) developing a hybrid tabletop + app game called *MSHA Football*; 4) implementing SMART, a multiuser mobile app to improve tracking and reporting for small and mid-sized operators; and 5) deploying machine learning algorithms for *Dynamic Safety*, our cloud-based tracking and data analytics platform. These technologies serve as a foundation to improve training, augment evaluation, and enhance reporting practices across the mining industry.

Significant or Key Findings

Aim 1: Establish collaborative, evidence-based Learning Laboratories (LLs). We developed the LLs program to provide needs-specific training, resources, and mentorship to workers, trainers, supervisors, and S&H professionals across all sectors of the mining industry. The scope of this program was scaled to include more than 20 mining organizations and operators representing over 20,000 mine workers in the Western US. Through the LLs network, training and resources were provided to 16,080 mining industry personnel during the project period, through courses that included professional development, supervisory training, and exercise programs, in addition to the MSHA-mandated S&H training (i.e., 723 total courses). The LLs were further developed into a platform to foster collaboration and conduct extramural research.

Quarterly Learning Laboratory Meetings. Starting in July 2021, we hosted quarterly webinar meetings (10 meetings in total) attended by over 30 LL representatives from more than 20 mining organizations. The purpose of the meetings was to establish S&H needs, identify goals, and share resources and best practices. Each meeting featured two speakers covering topics relevant to training (e.g. addressing opioid use, brain-centric design, VR simulations, evaluation strategies, etc.).

Extramural Research and Collaboration. Extramural research activities were expanded through participation of investigators at NIOSH (Pittsburgh and Spokane Mining Research Divisions), five universities and colleges, and several state agencies (MSHA State Grants Program awardees). The expanded LLs program increases the capabilities of training practitioners and provides new avenues for experimentation among partnering researchers, yielding long-term and mutually beneficial collaborations that improve S&H outcomes for the mining industry.

Aim 2: Improve health training. Significant health training outputs included the following: 1) *Mining Strong*, a tabletop card game. Developed in collaboration with the Colorado School of Mines EMCIS program, *Mining Strong* includes two versions, Industrial Hygiene and Total Worker Health, which teach workers strategies for controlling health hazards and improving wellness, respectively. We have further incorporated feedback from MSHA trainers at the TRAM Conference and our LL partners to improve and simplify the gameplay. 2) Health profiles and exposure models for the computer-based synthetic learning environment (SLE) *Harry's Hazardous Day*. Persistent chronic health effects are modeled for each player's avatar, including hearing disorders, musculoskeletal disorders, and respiratory health. Players may reference a health profile diagram with color-coded status monitors for organs and joints. Green indicates there are no issues, yellow and orange represent progressively worse effects, and red indicates severe health issues.

Aim 3: Develop new technologically driven training products. Working in collaboration with industry partners, we have developed a "Continuum of Training Resources" to accommodate a variety of training needs, trainer capabilities, and classroom requirements. A new research group, the Hybrid Applications Working Collaboration (HAWC), was established to facilitate development of eight new training resources, including tabletop games, app-based games, and computer-based SLEs. Technologies developed under this aim provide a foundation to improve training, augment data collection and reporting practices, improve controls hierarchies and risk management processes, and ultimately reduce injuries and exposures across the mining industry. Significant outputs included the following:

Harry's Hazardous Day: Streaming Workplace Examinations (HHD). HHD is a story-driven SLE which emphasizes multi-player teamwork, situational awareness, and recognizing the consequences of bad decisions. Testing with industry partners revealed a need for shorter, more modular training activities that better fit into annual refreshers, tailgates, and other time-compressed training sessions. A new module was developed to improve workplace examination training and features crushers, conveyors, and mobile equipment. The module's content can be broken into 10-minute segments to facilitate integration into short trainings. Furthermore, testing with industry partners revealed a need to improve game accessibility in classrooms, which frequently lacked gaming computers. To overcome this technological limitation, we developed a prototype streaming mode for HHD, enabling it to be played at any location with basic computers and an internet connection with >400 Kbps downstream bandwidth (e.g., a connection capable of streaming a 720p video).

Mobile and Hybrid Gaming Apps. Two new app-based games were developed that include *Coming Home Alive* (CHA) and *MSHA Football*. CHA is a multiplayer cooperative game motivated by *Among Us*, a successful game for entertainment that features a novel "Imposter" game mechanic. In CHA, learners must work together to meet a "safe tons" quota and discover

unsafe workers (*Imposters*) that are compromising the safety of the worksite, while completing a series of minigames covering training content (e.g., traffic controls, communication, worker rights, blasting, etc.). *MSHA Football* is a team-based, competitive tabletop game used for training synthesis. The game's rules mirror American Football; teams gain yards by correctly answering quiz questions. Although primarily played with a deck of cards, the game also features a digital "Scoreboard" app showing team possession, ball location, time clock, and score. Activity time for each game ranges from 15-30 minutes. By using adopting simple, popular game mechanics and targeting widely available low-cost computers and mobile devices (e.g. Android, iOS), these technologies increase accessibility of games as tools for S&H training.

Dynamic Safety: Cloud-based Data Tracking & Analytics. We have developed a cloud-based framework to correlate lagging indicators (i.e., MSHA reportables) with leading indicators in our partners' S&H datasets. Based on partner needs, leading indicators were considered for injuries to six body parts, including ankle, back, eye, hand, knee, and shoulder. In collaboration with Dr. Brianna Eiter at NIOSH Spokane Mining Research Division, a new analytical framework was developed which included: 1) A meta-model exploring the correlation between risk factors and incidents; 2) A performance assessment of popular classifiers for labelling potential injuries in safety reports; and 3) Association rules which provide insight into leading indicators of injuries. In a transfer learning experiment, four popular machine models (classifiers) were trained on the MSHA accidents and injuries dataset, and then used to predict potential injuries from non-reportable safety interaction reports in two partners' Safety Management Systems. The machine models demonstrated accuracy rates that were 97.5% as good as human experts in the best-case and 80.9% as good in the worst case.

Translation of Findings

The intrinsic design of the LLs program facilitates Research to Practice (r2p). Each industry LL partner provides a testbed in which to evaluate new and current training resources "*in vivo*", rather than *in vitro*. Built in collaboration with industry partners and mentors, we have also developed a "Continuum" of in-house and shared S&H training resources and evaluated them through the LLs program, using a robust competency model and our cloud-based data framework. Training resources are disseminated broadly via our website and cloud services, while visibility is increased through presentations at LL quarterly meetings, professional conferences and symposia (i.e., 37 talks this period), and social media (i.e., LinkedIn, Discord). In this way, we continue to expand our partner network, continuum of training resources, and training impact.

Research Outcomes/Impact

This program has resulted in positive changes to mine workplace safety culture, worker competency, and S&H outcomes:

Changes in training and safety culture. Our needs assessments suggest that operators recognize the value of active learning and the added capabilities of our technology-based training resources, and are thus more willing to invest resources in these initiatives as a step toward sustainable improvements in S&H. For example, two mine operators transitioned from lecture-based to hands-on training methods after surveying our resources and instructional design programs. After observing the capabilities of computer-based games, seven operators recently deployed SLEs in their new miner training. The use of our computer-based games increased 4x, to over 3,000 miners, during this phase of our program.

Improvement in worker competency. Workers have demonstrated improvements in competency using our active learning resources, as measured with pre- to post-test assessments. For example, in studies with seven new miner cohorts (n = 148) using our computer-based SLEs, there were substantial improvements in hazard recognition – as high as 50% for some hazard types.

Improvement in S&H outcomes. Case studies of our training interventions have indicated reductions in both the frequency and severity of workplace injuries. For example, a partnering worksite reported pre- to post-intervention decreases in average injuries and days lost per 100,000 hours worked at 23.6% and 72.5%, respectively. This outcome compares favorably to the 100% increase and 27.7% decrease in the same measures, respectively, at the operator's other worksites, which were not using our training programs. Average reductions in days lost exceeded 60% across all operators using our programs – a favorable outcome versus the sector trend, which showed only a marginal reduction of 3.6% over the period.

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