Grant Number: 5U60OH10014-03

Western Mining Safety and Health Resource Center: Translating Training to Competency

University of Arizona

Final Report

Project period 9/1/14-8/31/17

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Abstract

The University of Arizona (UA) created the Western Mining Safety and Health Training Resource Center in 2010. The project has changed the way mine safety training is conducted with safety leadership training, active learning, and gaming strategies. We have increased the safety-focused, total-health aware, leadership competency of front-line supervisors, superintendents, and managers representing operations throughout the U.S., spanning all major commodity sectors in surface and underground mining, as well as contractors. The Center has implemented health and safety-focused leadership competencies that respond in near real-time to changing workforce needs and environments of Western U.S operations. Further, we continue increasing the capacity, tools, and methods to reduce miner exposure risks associated with heat, noise, and aerosol particulates. Phase 1 of the Center was conducted from September 1, 2010 to August 31, 2014. Phase 2 of the Center was conducted from September 1, 2014 to August 31, 2017.

We have five aims for Phase 2 of the Center: 1) We propose to network the best mine safety professionals to create the Health and Safety Technical Partnership (HSTP) to assist in writing or reviewing training materials that are based on competencies that will improve transfer of safety learning from the training room to the workplace. 2) We will run a high-level training clinic to train trainers to use these best practices and we will provide a certificate of completion for each level completed. 3) We will measure the effectiveness of the training methods by requesting trainers collect data and follow up with us. 4) We will adapt our computer simulation software platform to measure safety competencies. 5) Our Mine Institute for Supervisor Leadership (MISL) will be modified to include competency measures. All of our materials and training practices will accommodate English Language Learners, low literacy learners, and education disadvantaged learners (e.g. dyslexia). We will have a particular focus on serving the needs of small and medium sized mines.

Some of the key outcomes of past training efforts of the UA Center are: **1)**Trained 3,647 workers and mining professionals from October 2014 to August 2017; total personnel trained since 2010 is over 12,500; **2)** Translated 52 modules of the Part 46 Toolbox Training Modules to Spanish (http://miningsh.arizona.edu); **3)** Created a teaching strategies training program for mining trainers. Phase 1 (first version) of the course, Teaching Strategies for Mine Safety Trainers, was provided to >20 trainers. Phase 2, High Performing Trainer (HPT) Clinic, was provided to 189 trainers; **4)** Developed Mine Institute for Supervisory Leadership (MISL), in which more than 125 supervisors participated over 4 years; **5)** Created the MineSAFE platform and a suite of computer-based training programs, or serious games, called *Learn with Harry*. The first serious game, *Harry's Hard Choices*, is being commercialized in spring 2017, and two others are being readied for use. Furthermore, the platform has been substantially upgraded to support new scenario development, rapid and extensive customization, and integration of evaluation tools. Approximately 338 miners have been trained with Harry's Hard Choices; **6)** Created a network of highly engaged western mine safety professionals

through the Health and Safety Technical Advisory Committee, representing over 30 companies and agencies (now called the Health and Safety Technical Parternship, HSTP); **7)** Disseminated our training materials nationally (175 copies of our Active Learning Handbook for Mine Safety Training and >50 copies of our Handbook for High-level Safety Training). Handbooks are also available on our website (http://miningsh.arizona.edu); **8)** Identified deficiencies in training and safety culture through evaluations. The feedback and input provided by our stakeholders and HSTP have guided each phase of our Center; **9)** Researched validated evaluation tools for training. We tested the Louisiana State University Andragogy in Process Inventory (API) instrument for evaluation of mine safety training and found the survey mechanism to be unworkable for the mining industry. We refocused evaluation in Phase 2 with the use of "clickers" during training to capture evaluation data; and **10)** Created the first mine safety trainer competency model which we are preparing to publish through the United States (US) Department of Labor. **11)** 228 publications, presentations, exhibits, meetings, and training sessions to disseminate our activities and findings.

Section 1 Significant Key Findings

The overall objective of this cooperative research agreement is to reduce the number of injuries and illnesses among workers who are involved in mining operations through a focused, relevant, and comprehensive training program that educates mine workers regarding how best to protect themselves from risks and hazards in the mining environment, and that expands the number of qualified mine safety and health trainers in the U.S.

Our key accomplishments for Phase 2 are:

1. We have created a nearly turn-key training resource for using active learning in new miner and annual refresher training for surface and underground mines in the metal, nonmetal, and coal sectors with trainer (450 pages) and student guides (220 pages) that have lecture materials, activity details, and how-to guidance. These guides accompany the trainer handbook on active learning with more details on activities. We have distributed 175 copies of the active learning handbook and have trained 189 trainers on active learning techniques.
2. We have created the first competency framework for mine safety trainers that will be published through the Department of Labor Employment and Training Administration.
3. Our first serious game, Harry's Hard Choices, is licensed for commercialization. The second generation of the MineSAFE platform is being rewritten to be more flexible and allow for faster game development, multi-player support, and multi-platform functionality. The first game to be released with the new platform is Harry's Hazardous Day.
4. We have developed an evaluation method that allows us to assess active learning in the training classroom without using paper surveys.
5. We have developed a large advisory group called the Health and Safety Technical Partnership that helps us modify our training approaches and products to accommodate rapid changes in the mining industry and ensure our center is not stuck providing the same training materials and approaches.
6. We have built a very large, exceptionally talented research team at the University of Arizona for mine health and safety including engineers, scientists, public health specialists, medical doctors, nurses, economists, training specialists, evaluation specialists, and professional trainers.
7. From 2014 to August 2017 we have provided training to 3,647 mine workers and mining professionals. We have provided active learning training to 189 trainers. We have provided training to 243 mine workers to evaluate effictiveness of active learning. We have trained 338 mine workers with the serious game Harry's Hard Choices. We have provided new miner underground training to 172 workers, annual refresher to 396 workers and specialized safety training including task

training and mine rescue training to 2,284 mining professionals. We provided training to 25 supervisors throught he MISL.

Translation of Findings

Our translation of findings as outputs for Phase 2 include:

- Trainer and student handbooks for active learning of MSHA-mandated new miner and annual refresher for surface, underground, metal, nonmetal, and coal sectors
- Serious gaming software for emergency self-escape training and work place inspections
- Real-time evaluation of trainee learning using active response technology ("clickers") and train the trainer expertise in how to incorporate this technology
- Development of the first competency framework for mine safety training

Outcomes

The Center has created the first competency model for mine safety trainers in the US and is publishing it through the US Department of Labor. 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 how to improve safety training. Our active learning tools include a handbook of active training techniques, serious gaming software, a training clinic, and a supervisor leadership workshop. We have measured the effectiveness of active learning and conclude our methods improve learning transfer to the workplace.

Impacts

The project has changed the way mine safety training is conducted with safety leadership training, active learning, constant industry feedback, rigorous evaluation, and improved communication of state of art and practice between academia, government, and industry. We have increased the safety-focused, total-health aware, leadership competency of front-line supervisors, superintendents, and managers representing operations throughout the U.S., spanning all major commodity sectors in surface and underground mining, as well as contractors. The Center has implemented health and safety-focused leadership competencies that respond in near real-time to changing workforce needs and environments of Western U.S operations.

Section 2 Scientific Report

The University of Arizona (UA) created the Western Mining Safety and Health Training Resource Center in Tucson, AZ initially as a collaboration between the Colorado School of Mines and the UA Lowell Institute for Mineral Resources, the Teaching, Learning and SocioCultural Studies in the College of Education, and the Division of Community, Environment and Policy in the Mel and Enid Zuckerman College of Public Health. The Center utilized the new training facility at the San Xavier Mine owned by the University of Arizona. The Center now operates independently from Colordao School of Mines and has continued to evolve as an interdisciplinary resource center for Western US mine safety training, drawing in experts from several university disciplines and safety professionals from across the mining industry.

The overall objective of this agreement is to reduce the number of injuries and illnesses among workers who are involved in mining operations through a focused, relevant, and comprehensive training program that educates mine workers regarding how best to protect themselves from risks and hazards in the mining environment, and that expands the number of qualified mine safety and health trainers in the U.S.

Since its inception, the Center has recognized the need to educate trainers to use adult education andragogical methods. Active learning is just one part of the need for adult education. As we developed active learning techniques we found that trainers lacked the necessary background in instructional design to modify their training courses to accommodate the elements of adult learning. Over the past seven years we have learned a great deal about the background of trainers, their time pressures, knowledge of adult education, constraints on training time and materials in classrooms, and motivation to change. Thus our approaches have evolved from simply conducting as much training as possible to creating better training materials for adult learners with diverse needs and backgrounds to creating a curriculum to educate trainers in instructional design for adult learners.

As we probed how to best educate miners and trainers we identified the need for more sophisticated and subtle evaluation techniques than quizzes and surveys. Our evaluations have evolved from paper quizzes and end of course surveys to pre- and post-training assessments, active response technology (clickers), and “stealth” assessment imbedded in serious games. We experiemented with a validated but very difficult survey instrument from Louisiana State Univesrity, the Androgocial Process Inventory and found that neither trainers nor trainees had patience for long surveys at the end of long training days. We have found that assessment and evaluation must happen quickly in the course of the training classes and must be embedded as part of training and not as an end of class survey or test. The limitations of training time and the inability to track workers over the course of their jobs restricts the depth of evaluations that we can conduct. We have found that we must empower trainers with easy assessment tools they can implement. Whether trainers can be allowed to share

their evaluations with us depends on the trainers and their employers. In general contract trainers have more flexibility and incentive to modify their training and evaluations and our focus has shifted to engaging more contract trainers and state grants recipients.

We have five aims: 1) We propose to network the best mine safety professionals to create the Health and Safety Technical Partnership (HSTP) to assist in writing or reviewing training materials that are based on competencies that will improve transfer of safety learning from the training room to the workplace. 2) We will run a high-level training clinic to train trainers to use these best practices and we will provide a certificate of completion for each level completed. 3) We will measure the effectiveness of the training methods by requesting trainers collect data and follow up with us. 4) We will adapt our computer simulation software platform to measure safety competencies. 5) Our Mine Institute for Supervisor Leadership (MISL) will be modified to include competency measures. All of our materials and training practices will accommodate English Language Learners, low literacy learners, and education disadvantaged learners (e.g. dyslexia). We will have a particular focus on serving the needs of small and medium sized mines.

Some of the key outcomes of Phase 2 of the UA Center are: **1)**Trained 3,647 mining workers and professionals including supervisors and trainers from September 2014 to August 2017. Overall we have trained nearly 12,500 mine workers and professionals; **2)** Developed Mine Institute for Supervisory Leadership (MISL), in which more than 125 supervisors participated over 5 years; **3)** Created the MineSAFE platform and a suite of computer-based training programs, or serious games, called *Learn with Harry*. The first serious game, *Harry's Hard Choices*, was commercialized in spring 2017, and Harry's Hazardous Day for work place examination and hazard recognition is being readied for use. Furthermore, the platform has been substantially upgraded to support new scenario development, rapid and extensive customization, and integration of evaluation tools; **4)** Created a network of highly engaged western mine safety professionals through the Health and Safety Technical Advisory Committee, representing over 30 companies and agencies (now called the Health and Safety Technical Parternship, HSTP); **5)** Disseminated our training materials nationally (175 copies of our Active Learning Handbook for Mine Safety Training and >50 copies of our Handbook for High-level Safety Training). Handbooks are also available on our website (http://miningsh.arizona.edu); **6)** Researched validated evaluation tools for training. We tested the Louisiana State University Andragogy in Process Inventory (API) instrument for evaluation of mine safety training and found the survey mechanism to be unworkable for the mining industry. We refocused evaluation in Phase 2 with the use of "clickers" during training to capture evaluation data; and **7)** Created the first mine safety trainer competency model which we are preparing to publish through the United States (US) Department of Labor.

Key Accomplishments

Aim 1: Higher Level Trainer Competencies and Curriculum

Challenge: There is no existing competency model for mine safety trainers in the US that is based human resource development research rather than compliance.

Background: The education background of mine workers is dominated by those with a high school education or GED diploma but the stone/sand/gravel sector has the highest percentages (20%) of employees who dropped out of high school before graduation and did not return for a GED (McWilliams et al., 2012; Lutz and Lutz, 2016). Metal mines have the highest percentage of workers with at least some college while coal, sand and gravel have the lowest percentage of college-educated workers (including vocational training). Based on our previous analyses of western mining, a large percentage of miners, particularly contractors and those at sand and gravel operations, are Hispanic and in some cases English language learners (ELL), or have lower eduation attainment. Mines increasingly interact with American Indians through mines on or near reservations Mining is rich with highly specialized vocabulary that is often not easily understood or translated. Further, we have anecdotal evidence that workers with learning challenges and disabilities, such as dyslexia, may self-select mining careers resulting in higher rates than what is found in the general population (~15%). Our training materials were developed to best serve this diverse western workforce.

Lutz and Lutz (2016) analyzed US mine fatalities in 2013. All of the 12 fatality reports noted that the miners killed lacked some type of training. In two of the 12 fatalities, MSHA noted the lack of newly hired experienced miner training. In the remaining 10 fatalities, task training was either completely missing or significant portions of it were missing. While the miners may have believed they had adequate task training, when MSHA reviewed the training, they found aspects of the work being conducted during the fatality were not covered in the original task training. In 2014 there were 11 fatalities in which MSHA investigators noted training was in some way involved in the fatality. In only one case was hazard training noted (loading truck), the remaining fatalities included workers performing tasks they were not trained to do. Like the 2013 fatalities, many of these miners had some task training, but it did not cover the portion of the activity they were doing when the fatality happened. In 2015 there were two fatalities that were training-related. One fatally injured miner did not have any training. In the second fatality the miner was task trained on operating a dredge, but not on dislodging a stuck bucket. The dredge capsized and he drowned.

When reviewing the MSHA investigation reports we found that most of the reports were vague about what type of training had been performed. We analyzed the type of training workers receive based on the 2012 NIOSH surveillance data. The majority of mines use in-house trainers. Of the mines using outside trainers, the stone/sand/gravel sector tends to make more use of the MSHA-funded state grants program than contract trainers. Most trainers in 2012 were using lecture-based training materials that research studies have

shown to be less effective than the active-learning methods we have developed since 2014.

Who needs training? Human Resource Development (HRD) research suggests “the way training is designed, delivered, and implemented can greatly influence its effectiveness (Salas et al, 2012). Our team’s experience working in the mining industry validates that most in-house trainers are subject matter experts and rose through the ranks but do not have the training to design training and evaluate learning. Trainers need more than the minimum MSHA blue card certification to be effective. What type of training is needed? HRD research identifies design, delivery, and implementation as keys to successful training. The right content is integral to effective training as is assessing learning rather than signing off on 5000-23 forms. Workers also need time to implement what they have learned (several fatalities involved task training immediately before performing the task). Does this training exist? We did not find any complete training programs specifically focused on mine trainers.

A competency model is defined as “an integrated set of skills, knowledge, and attributes that enables one to effectively perform the activities of a given occupation or function to the standards expected” (www.ibstpi.org/). We consider the competency model to represent the “collection of multiple competencies that together define successful performance in a defined work setting. A model provides a clear description of what a person needs to know and be able to do to perform well in a specific job, occupation or industry” (US Department of Labor, www.careeronestop.org/CompetencyModel/faq.aspx#q1). Our model is focused on a specific occupation – training (or learning and development). While MSHA speaks of competencies, there are no competency models available for trainers. We have chosen to build our model based on the standards from the Association for Talent Development (ATD, formerly known as the American Society for Training and Development). The ATD standards have been in use for more than 30 years and the 2013 ATD Competency Model provides defined knowledge, skills, abilities, and behaviors for the entire training and development profession (Arneson, Rothwell and Naughton, 2013, p4).

Employers have found that foundational competencies are required for workers to learn industry-specific skills (www.careeronestop.org/CompetencyModel/CareerPathway), including: Tier 1, personal effectiveness-soft skills; Tier 2, academic-cognitive functions and learning styles; and Tier 3, traits and interpersonal styles necessary to function. Additional mining industry-specific competencies are: Tier 4, common mining knowledge and skills; and Tier 5, competencies specific to sectors in the mining industry. Additional occupational competencies include Tier 6 through Tier 9 learning and development which we are combining into one tier using the validated ATD model, which has been systemically validated with diverse industry input. The ATD model provides clearly defined knowledge areas, skills, abilities, and behaviors. The motivation for the competency model was presented at the SME Annual Meeting in Phoenix in February 2016. The full competency model was reviewed by the UA HSTP and unveiled at the National Mining Association Health and Safety session in Las Vegas on September 27

and 28, 2016. To date the model proposed has been well received and we have received many requests for the model and inquiries about the training.

Approach: The base model is comprised of Tiers 1 through 3, Foundational Competencies or Work Readiness Competencies that were developed by the Department of Labor Employment and Training Administration (DOL ETA) in collaboration with industrial/organization psychology experts and represent the essential knowledge and skills for success in school and entry into the workforce. Based on work by the DOL ETA, employers found that foundational competencies "are a prerequisite for workers to learn industry-specific skills" (www.careeronestop.org/CompetencyModel/CareerPathway/CPWGenInstructions.apx) . The Foundational Competencies are: Tier 1 Personal Effectiveness (soft skills); Tier 2 Academic (cognitive functions and learning styles); Tier 3 (traits and interpersonal styles necessary to function). The Mining Industry Competencies are: Tier 4 Knowledge and Skills common across the mining industry; Tier 5 Competencies specific to sectors in the mining industry. The Occupational Competencies include Tier 6 through Tier 9 Learning and Development but we are combining these into one tier using a validated model from the Association for Talent Development (ATD). The ATD model has been in use for more than 30 years and have been systemically validated with diverse industry input. The ATD model provides clearly defined knowledge areas, skills, abilities, and behaviors. The HSTP has reviewed the competency model.

Impact: The motivation for the competency model was presented at the SME Annual Meeting in Phoenix in February 2016. The full competency model was unveiled at the National Mining Association Health and Safety session in Las Vegas on September 27 and 28, 2016. The model will be published through the Department of Labor. The model will form the basis of a revised High Level Training Clinic in 2017.

The competency framework provides a career or skills progression ladder for trainers and a basis for evaluation of knowledge, skills, abilities and other attributes (KSAO) for both trainers and trainees. The power of the competency framework is a shift from compliance by checking off boxes on a form based on seat time and minimal testing to a model that is based on a progression through a KSAO ladder. The framework allows organizations to award badges for mastery of material that fill out their employees career portfolios and motivate future learning and mastery of more content or skills. The competency framework can become an integral part of a safety culture where members of the organization constantly seek to learn and improve.

The model is attached to this report as Appendix A.

Aim 2: High Level Trainer Clinic

Challenge: The main focus of the High Level Trainer (HLT) Clinic is to revolutionize how mandated training is conducted in the mining industry. Our analysis of training related to injuries and fatalities indicates that training is increasingly being used as a corrective action for MSHA citations. Most trainers, however, have no background in instructional design or how to teach. For training to be effective there must be alignment of the competency of the trainer, the content and design of the training materials, and a work environment that re-enforces the training.

Background: When researchers such as Kowalski & Vaught, 2002; Kowalski-Trakofler et al, 2004, call for mine safety training to be more "adult learning oriented" or to "include adult learning principles", they are typically referring to the idea of andragogy or "the art and science of helping adults learn" put forth by Knowles (1990). Andragogy differs from pedagogy in that the focus is on the adult learner, and the teacher or instructors becomes an equal in the learning, i.e. a facilitator, not a director. Knowles built on the work of many early adult education researchers proposing the andragogical framework, which identified the following:

- The need to know – the learner needs to know what they will be learning and why they need to learn it before beginning to learn.
- The concept of the learner – the learner takes responsibility for their lives and hence want control or responsibility for their learning; increasing self-directedness.
- The role of learners' experiences – adult learners come to the classroom with rich experiences that can help them and others learn.
- Readiness to learn – the learner will more readily accept the learning when they are experiencing real-life situations that necessitate it.
- Orientation to learning – adults are problem-, task-, or life-centered on their orientation to learning – not subject-centered.
- Motivation – strongest motivator for adult learners is internal pressure, not external.

These principles were core tenets in the development of a process model to develop educational or training programs for adults. The andragogical process model differs from a typical content-driven model in that the focus lies in procedures that involve the learners, helping them gain the knowledge and skills needed, not merely in delivering content. The eight elements of the andragogical process model, as designed by Knowles, Holton and Swanson (2011), include:

- Preparing learners;
- Setting climate;
- Mutual planning;
- Diagnosing of needs;
- Setting of objectives;
- Designing learning plans;

- Learning activities; and
- Evaluation.

Our process to re-design the mandated training was to focus on the learner. There are several recurring themes in the literature for active learning (e.g. Prince, 2004):

- **Discussion/questioning** – requires the instructor to understand techniques of questioning and strategies and styles for involving discussion. This is an important consideration for our train-the-trainer program since many mine trainers use discussion to engage learners but have limited training on techniques of questioning and strategies for involving participants.

- **Modified lecture** – active lectures involve problem solving, critical thinking, attitude change and motivation for further learning. Both McKeachie et al and Bonwell & Eison (1991) identified active lecturing methods that go beyond discussions and questioning including pausing, immediate tests and quizzes, demonstrations, and alternative formats (mini lectures, guided lectures, and responsive lecture). The modified or active lecture may be a comfortable technique for many trainers and has the potential for greater transfer of learning, something identified as crucial in the ever changing mining environment

- **Peer learning/collaborative learning** - McKeachie et al (1986) found that when immediate knowledge is the measure of effectiveness, lecture is equal to other instructional methods. However, more active and engaging methods are proven to be more effective when the measures are "transfer of knowledge to new situations, or problem solving, thinking attitude change or motivation for further learning" (p. 70). Both McKeachie et al and Bonwell & Eison (1991) identified active lecturing methods that go beyond discussions and questioning including pausing, immediate tests and quizzes, demonstrations, and alternative formats (mini lectures, guided lectures, and responsive lecture). The modified or active lecture may be a comfortable technique for many trainers and has the potential for greater transfer of learning, something identified as crucial in the ever changing mining environment.

- **Cooperative learning** - Cooperative learning is different than collaborative learning in that learners are typically assessed (and rewarded) for their work as a group rather than individually. McKeachie et al (1986) note that cooperative learning has affective impacts, as well as cognitive; and suggest the goals are to develop skills in group membership, leadership, and interpersonal relations. In the research reviewed by McKeachie et al, they note that final exam scores were not affected by student centered teaching, however the studies showed significant impacts to "student adjustment", specifically greater empathy and reductions in prejudice. Johnson, Johnson, and Smith (1991) state for something to be considered "cooperative" learning it must include: positive interdependence, face to face interaction, personal accountability, collaborative skills, and group

processing. The researchers found that cooperative learning activities increased productivity, social support, and self-esteem, as well as development of positive relationships. Similarly, Prince's (2004) review of the literature noted "results are consistently positive" and additionally, he found that "cooperation promotes interpersonal relationships, improves social support, and fosters self-esteem" (p. 5). While cooperative learning may hold great potential for mine training, especially in emergency response situations where research suggests miners act as a group with a leader rising up (Alexander et al, 2010), initial conversations with mine trainers suggest this approach may be hardest to implement because of learner resistance.

- **Simulations/Cases/Games/Problem-based learning** - McKeachie et al (1986) believe the primary goal of the case method is to "develop student ability to solve problems using knowledge concepts and skills relevant to the course" (p. 68) and their review of the literature found that the use of the case method results in the ability to apply knowledge, especially outside the classroom. Bonwell and Eison (1991) found that the use of the case method increased "higher-order thinking" and learner motivation. Additionally, some studies indicated changes in learner attitudes and increased enthusiasm. Prince (2004) identified positive learner attitudes as the most significant (and consistent) outcome of what he calls problem-based learning. His review also found support for long-term knowledge retention, increase of class attendance, use of learning resources and studying for understanding (not short-term recall). Many trainers are already using this approach in their trainings when they present fatalgrams. However, because the case is presented to the learner instead of engaging the learner, the outcome falls far short of its potential. As such, we believe this active learning approach may hold great potential for mine safety and health training.

Ultimately the goal of safety training is to transfer the knowledge, skills, attitudes, and other attributes to the job site. Burke and Hutchins (2007) suggest three primary factors influence transfer of training - learner characteristics, intervention design and delivery, and work environment. Within these factors we further narrowed our search to include those elements that are well-developed constructs with significant empirical research and significant impacts on transfer. These include 1) learner self-efficacy, 2) motivation, and 3) perceived utility/value, as well as 4) learning goals.

1) Several studies suggest that self-efficacy can be increased through training interventions, such as: mastery experiences, supportive feedback, goal setting, and self-management strategies (Gist, 1989; Gist, Stevens & Bavetta, 1991). We believe that learner self-efficacy may be a crucial part of mandated safety and health training success, especially for the new miner being inundated with hours (and days) of new information and vocabulary. Both our active learning methods and our trainers must accommodate this important element.

2) Learner motivation is positively related to learning outcomes including skill acquisition, declarative knowledge, and reactions to and transfer of training

(Colquitt et al, 2000). Stevens and Gist (1997) found that "mastery-oriented trainees would engage in more interim skill-maintenance activities, plan to use more effort, and show more positive affective responses than performance-oriented trainees" (p. 974). Moreover, their study found that a training intervention can affect participants' goal orientations (or motivational dispositions). This research suggests that the structure of our mandatory training should steer participants to mastery of the knowledge, not just to perform well to pass the exam or receive kudos from the instructor.

3) Human resource development research suggests that learners' perceived value of the training can impact whether they will apply the new knowledge they acquired (Baumgartel, Reynolds, & Pathan, 1984; Axtell et al, 1997; Lim & Morris, 2009). Burke & Hutchins (2007) state "Put simply, for maximal transfer, learners should perceive that the new knowledge and skills will improve a relevant aspect of their work performance" (p. 269). We consider this significant since many mandated trainings are framed as an "hour" requirement (I need my 8 hour refresher) rather than being viewed as relevant or important to completing the job.

4) Burke & Hutchins (2007) note that to maximize transfer to the job, trainees must explicitly communicate objectives to the learners. Moreover, some researchers note that goal setting (both directed and participatory) has been found to help participants regulate their behavior, mobilize their effort, and extend their effort over time (Locke & Latham, 2006). We consider this approach to be cost effective and simple measures to increase the likelihood of transfer. It can be included as part of the re-designed course, but trainers must also see the value it can bring post-training.

A summary of the key adult learning design elements is shown in Table 1.

Table 1. Key design elements to improve mine safety training

Elements of adult learning	**Andragogical Process Model**	**Elements of Active Learning**	**Requirements for transfer**
Why they need to know	Prepare the learner	Discussion/questioning	Self-efficacy (mastery)
Learner takes responsibility	Set the climate	Modified lecture	Motivation – competencies and capabilities
Share experiences	Mutual planning	Peer learning	Perceived value – relevance to job, not seat time
Real-life experiences	Diagnose needs	Cooperative learning	Learning goals – for use on the job
Task or life-centered approach	Set objectives	Problem-based learning	
Internal pressure is best motivator	Design learning plans		
	Learn activities		
	Evaluation		

The elements from Table 1 were included in our Effective Mine Safety Training Course (i.e. active learning for trainers) and our Mine Safety Training Handbook: Active Training Tools for Mine Safety Trainers.

For the past seven years, the UA team has worked closely with mine trainers throughout the Western U.S., researching mine safety and health training. When studying the use of adult learning principles or active learning methodologies, mine trainers consistently noted barriers to implementation, such as:

- Lack of training/class time
- Lack of time to revise training materials
- Lack of money to hire consultants or buy curriculum
- Large class sizes
- Hesitance to remove lecture slides/content

Moreover, several trainers have noted in the past that active learning took up “valuable” lecture time/content/slides and that if you weren’t lecturing you were being “lazy” or “slacking”.

Using our knowledge of adult learning principles, active learning methodologies and transfer of training research, we proposed to re-design new miner and annual refresher for surface and underground miners working in metal, nonmetal, and coal sectors.

The first step in re-designing courses was to create a catalog of active learning strategies that could be used in any training course.

The active learning handbook was compiled from activities suggested by safety trainers who are members of our Health and Safety Technical Partnership (HSTP) in the University of Arizona Lowell Institute for Mineral Resources. The members of the HSTP assisting with the handbook represent the following companies:

Resolution Copper Project
Barrick Gold of North America
Coeur Mining
Freeport McMoRan
Salt River Materials Group
Asarco LLC
Vulcan Materials
BHP Billiton
Luminant Mining
Hecla Limited

Activities were modified to apply to multiple commodity sectors and training courses. In addition the project team created new activities. The handbook was reviewed by trainers from BHP Billiton, Freeport McMoRan, Resolution Copper, Salt River Materials Group, Vulcan Materials, and McCraren Safety Compliance.

Approach: We discovered during the HLT Clinic that many trainers did not have a background or understanding of instructional design and difficulty modifying their training programs to accommodate active learning and theories of adult learning. In Phase 3 we are adding a certificate in instructional design that is based on the competency model for mine safety trainers described in Aim 1. The program will include online courses to provide background and an in-residence component where trainers demonstrate their ability to meet the competencies and design training programs that comply with MSHA but meet the best practices established in other fields.

Impact: Improving the ability of trainers to understand how to train and meet the best practice standards that have been established in many fields will improve safety across the mining industry. We have used our best practice active learning training methods with 546 trainees in the mining industry during Phase 2 of the Center. The HLT Clinic has been presented at the Western Mining Safety and Health Conference in Reno, NV in October 2015 and at the SME annual meeting in Phoenix, AZ in February 2016 and

at the NMA MINExpo meeting in Las Vegas in September 2016. We have distributed 175 copies of our Active Learning Handbook to trainers and have made it available on our website. We created the “New Miner and Annual Refresher Training Facilitator Guide” and accompanying student guide. These materials are not intended to wholly replace a company’s training materials but provide a template to show that adult learning practices can be used and still meet the required MSHA training plan in the time allowed. The facilitator guide is 450 pages and the student guide is 202 pages. We have trained 189 trainers to use active learning since the project start.

Figure 1. Active Learning training as part of the High Level Trainer Clinic held at Couer Mining’s Kensington Mine near Juneau, Alaska October 1, 2015.

Aim 3: Assessment and Evaluation of Active Learning

Challenge: We evaluated the only previously validated survey for adult learning in training, the Andragogical Process Inventory (API). The API requires lengthy surveys which were met with resistance by all the trainees (n=295) asked to participate. We needed to develop a new tool for evaluating the effectiveness of training that did not rely on paper surveys. This aim was conducted in collaboration with support from the Alpha Foundation For the Improvement of Mine Safety and Health (grant AFC113-06).

Background: Adult learning principles are foundational to the design and delivery of highly effective training and many researchers and scholars in the mining community have suggested they be incorporated into mine safety and health training courses and teaching practices (Kowalski & Vaught, 2002; Kowalski-Trakofler et al, 2004). To date, there is only one instrument validated to measure these andragogical (adult learning)

principles and their associated process design elements – the Andragogy in Process Inventory (API). The instrument was created and validated by our collaborators at Louisiana State University (LSU) (Holton, Wilson and Bates, 2009). The instrument was distributed to some participants in the control group and all participants in the treatment group in order to test its use in evaluating mine safety training for inclusion of adult learning methods. The completed surveys were sent to Dr. Reid Bates at LSU for analysis and interpretation. The survey is proprietary to Dr. Bates and his colleagues. The instrument can be rented from Dr. Bates on a per copy basis and his team conducts the analysis of the results.

The API does not measure whether training yields a safer miner. It measures whether elements of andragogical learning are present in the training. Active learning for adults has been shown by many researchers to be more effective than passive learning. The API is a powerful tool to assess whether adult learning methods are used in training and contains a measure of Motivation to Improve Safety Through Learning (MTISL). The MTISL is designed to assess an individual's attitude toward safety training, expectations about the value of the training, and for teaching adults during the past 40 years. Defined as the "art and science of helping adults learn" (Knowles, 1990, p. 54), and "an intentional and professionally guided activity that aims at change in an adult person" (Knowles et al., 1998. p. 60), andragogy has become synonymous with the education and training of adult learners. It has been described as "the preeminent and persistent practice-based, instructional method" (Rachal, 2002, p. 211); a "guiding principle on how best to educate adults" (Beder & Carrea, 1998, p. 75); a "set of guidelines for effective instruction of adults" (Feuer & Gerber, 1988, p. 35); and "a way of thinking about working with adult learners" (Merriam & Brockett, 1997, p. 135). their belief in their own capacity to apply the learning on the job.

Andragogical theory suggests a number of design elements that foster adult learning, adult motivation to learn, and outcomes from adult learning. The design elements encompass a range of activities which can occur before, during, and after the learning experience. The API is designed to assess the extent to which the design elements are present in a training program. The scales measuring the design elements are listed and defined in Table 3. The survey instrument reported on in this analysis contained 36 items measuring the eight different design elements.

In the social sciences a scale is a type of composite measure that is composed of several items (in this case survey items) that have a logical or empirical structure among them. Because they are a composite measure scales take advantage of differences in intensity among the indicators of a variable. Scales represent the operationalization of "constructs". The most commonly used scale is the Likert scale which was used here (a 5-point Likert type scale with responses from "strongly agree," to "strongly disagree."

Constructs are approximated units of phenomenon that cannot be observed directly. Put somewhat differently, they are linguistic devices used to specify or describe phenomenon or elements of a phenomenon in which we are interested. For example, the idea of "motivation" is a construct. Constructs are important tools in the social sciences because,

for one reason, they are a central element of theory: Theory describes constructs and the relationships between constructs. To be useful beyond theory we have to be able to measure these unobservable elements. We make constructs observable and measurable through their operationalization as variables (i.e., scales). A scale is an observable entity capable of taking on two or more values. In the present case, our "constructs" of interest (e.g., design of learning activities) represents a component of adult learning theory. We have made these measurable through the creation of a set of survey items represented in the scales by the same name. This measurement process is intended to provide an operational referent for a phenomenon (construct) at a higher level of abstraction. A multidimensional construct is simply one with more than one dimension. These are often useful when it is useful to try to obtain a more complete picture or measurement of a particular phenomenon. We have made these measurable through the creation of a set of survey items represented in the scales by the same name. This measurement process is intended to provide an operational referent for a phenomenon (construct) at a higher level of abstraction.

Table 2: Learning Process Design Scales for Adult Learners

Scale	Definition
Prepare the Learner	The degree to which the learner was prepared for the learning experience through the provision of information or activities and exercises that clarified objectives
Climate Setting	The degree to which the learning climate is perceived to be supportive and fully collaborative.
Mutual Planning	The degree to which the learners perceived themselves to be full partners with other learners and the instructor In planning the learning experience.
Diagnosis of Learning Needs	The degree to which the learner perceived the learning experience provided assistance or opportunities for the learner to diagnose her/his developmental needs.
Setting of Objectives	The degree to which learners had meaningful input and could set or collaborate in the setting of objectives for the learning experience.
Design of the Learning Experience	The degree to which the learning activities were collaboratively designed and adapted to meet individual needs and capabilities.
Design of Learning Activities	The degree to which the learning experience utilized a variety of active learning methods that encouraged learners to engage the task domain and to discover task
Evaluation	The extent to which the evaluation methods used in the learning experience were appropriate and met the learner's needs.

Andragogical theory suggests that integration of these design elements in adult learning settings enhances the learning experience for adults and fosters improved learning-related motivation and outcomes. Therefore, in addition to the design elements associated with adult learning theory (andragogy), the API also included a measure of Motivation to Improve Safety Through Learning (MTISL). MTISL is defined as the motivation to improve work-related safety outcomes by engaging in training or learning activities and using what is learned to perform job functions more safely. It is a multidimensional construct designed to assess an individual's attitudes toward safety training, expectations about the value of that training for improving safe work, beliefs about the his/her capacity to apply learning from safety training, and his/her motivation to learn and apply that learning on the job. The MTISL measure for this project included 17 items on the survey. The MTISL measure was included in the data collection to examine the extent to which andragogical design element present in the safety training courses were associated with the motivation to improve safety through learning of the training participants.

Evaluation is a design element scale that, as defined in Table 1, refers to the extent to which the evaluation methods used in the learning experience were appropriate and met the learner's needs. It is one of the constructs that adult learning theory suggests is important in adult learning contexts and which we have operationalized as a scale here.

The 17 items that measure the Motivation to Improve Safety Through Learning (MTISL) are shown in Figure 2 and include the following on a 6 point Likert scale where 1=strongly disagree and 6=strongly agree. The respondent scores on each of the 17 items in MITSL are summed to yield a single scale score.

1.	I always learn new and important things in safety training. ATT TRNG	1	2	3	4	5	6
2.	My performance improves when I apply at work what I learn in safety training. TEPE	1	2	3	4	5	6
3.	I have no trouble learning new ways to work more safely. SLSE	1	2	3	4	5	6
4.	Safety training programs are a critical part of my work. ATT TRNG	1	2	3	4	5	6
6.	I work hard to learn the material covered in safety training programs. MOT LEARN	1	2	3	4	5	6
7.	I am able to improve safety at work by learning new things. SLSE	1	2	3	4	5	6
8.	I am committed to learning as much as I can in the safety courses I attend. MOT LEARN	1	2	3	4	5	6
9.	Even when it is difficult to learn what is taught in safety training, I keep trying. MOT LEARN	1	2	3	4	5	6
10.	I plan to apply as much of the safety training as possible to my work. MOT TRANSFER	1	2	3	4	5	6
11.	If I want to work more safely I can learn new skills to do so. SLSE	1	2	3	4	5	6
12.	I devote a great deal of time and energy to using on my job what I learn in safety training. MOT TRANSFER	1	2	3	4	5	6
5.	Safety training programs are important for my work-related development. ATT TRNG	1	2	3	4	5	6
13.	I am determined to put into daily practice what I learn in safety training. MOT TRANSFER	1	2	3	4	5	6
14.	My goal is always to use as much of the learning from safety training as I can at work. MOT TRANSFER	1	2	3	4	5	6
15.	The harder I work in safety training the better I do my job. TEPE	1	2	3	4	5	6
16.	When I am confronted with safety problems at work I am confident I can learn what is needed to solve them. SLSE	1	2	3	4	5	6
17.	The more safety training I apply to my job the better my work performance will be. TEPE	1	2	3	4	5	6

Figure 2. MTISL items on the API.

Figure 3. QT2 clicker.

Approach: With the resistance we encountered for collecting paper survey data, we selected a new tool for collecting data and administering assessments. Turning Technologies QT2 (see Figure 3) "clicker" provides an easy to use response technology that allows for assessment during training. The keypad is full-featured and designed to collect more meaningful data than traditional "1-2-3" clickers. We have found the QT2 to increase understanding and communication throughout the teaching and learning process. With the use of this device we have begun collecting data comparing the use of solely lecture based training (control group), versus the effects of active learning (treatment group) on one specific part under the 30 CFR part 48, Fall Protection.

We ran two training classes for a control group in partnership with McCraren Compliance in Tucson. The control group (n=45) received standard lecture-based training for MSHA new surface miner. The group received a pre-test and post-test for the module on fall protection. We evaluated the tests to look for improvements in understanding of fall protection after receiving the lecture material.

We then ran 11 classes (n=198) with McCraren Compliance using active learning for the fall protection module (see Appendix B for details on training). Some responses had to be removed due to incomplete answers so the treatment group had 131 respondants and the control group had 32. The same pre- and post-test methodology was used. The classes receiving active learning showed a greater improvement in knowledge of fall protection using active learning than those receiving passive learning based on raw data. The average improvement in learning as measured by the percent improvement in correct responses was 7.6% for passive learning versus 8.6% for active learning. We ran statistical tests to determine if the differences in learning were statistically significant.

- Pretest and posttest data were collected from the treatment group sample of 131 participants, with a pretest mean of 15.95, and a posttest mean of 17.98 - thus test score means increased from pretest to posttest. The dependent t test was conducted to determine statistical significance and indicated that the pretest and posttest means were statistically different ($t=6.27$; $df=130$; $p< .05$). Thus the null hypothesis that the test means were the same before and after the lesson was rejected at the 0.05 level of significance.
- Pretest and posttest data were collected from the control group sample of 32 participants, with a pretest mean of 15.63 and a posttest mean of 17.50 -thus test score means increased from pretest to posttest. The dependent t test was conducted to determine statistical significance and indicated that the pretest and posttest means were statistically different ($t=2.59$; $df=31$; $p<.05$). Thus the null hypothesis that the test means were the same before and after the lesson was rejected at the 0.05 level of significance.
- We compared the mean pretest scores of the treatment group and the control group. The independent t test was conducted to determine statistical significance and indicated that the pretest treatment group means were not statistically different from the control group pretest means ($t=0.13$; $df=161$; $p>0.05$), therefore we could not reject the null hypothesis that the pretest means were the same.
- We compared the mean posttest scores of the treatment group and the control group. The independent t test was conducted to determine statistical significance and indicated that the posttest treatment group means were not statistically different from the control group posttest means ($t=0.23$; $df=161$; $p>0.05$), therefore we could not reject the null hypothesis that the posttest means were the same.

This data suggests that both the lecture and active learning worked – participants test scores increased which is to be expected. The analysis also indicates that the control group and treatment group arrived with similar levels of understanding around fall protection (their pretest scores were not significantly different). Since it appears that the control group came with an existing level of knowledge about fall protection, they were able to have learning gains from lecture similar to that of gains made from active learning. This suggests that for our next experiment, we should

ensure people don't have experience with the topic because the research suggests that active learning does better starting from zero, but is equal to lecture when knowledge exists (they have existing mental models).

We will be revising our evaluation methodology for fall protection in Q4 2017 and then applying this methodology to hazard recognition modules in 2018:

- Evaluate new miner training
- Use clickers for all testing to avoid grading tests by hand
- Collect data around years of experience, age ranges, and other demographic data with clickers
- Assign score to questions in Turning Technologies (TT) software so we don't have to resort to raw data.
- Ask instructors to make sure every student has answered before progressing. We had to throw out about 30 students in the treatment groups because they didn't answer all the questions.
- Ask instructors to not have "extra" clickers enrolled in the class. That made TT data "off" because those extra clickers didn't respond – hence why we had to use raw data
- Make sure control group lesson is straight lecture
- Make sure treatment group lesson uses higher level active learning.

As a result of our finding during Phase 2 we will be adjusting Train-the-Trainer (TTT) work to:

• Increase effectiveness of trainers with the Instructional Design and Development Certificate Program.
o Help trainers to more effectively implement adult learning principles and active learning strategies.
o Implement Digital Badging from Continuing and Professional Education (CAPE) at the completion of the program along with a certificate and transcript.
• Continue to offer active learning training and Mine Trainer Handbook.
• Provide TTT to all University of Arizona industry partners and interested parties in order to collect data on active learning versus lecture based training.

Impact: We now have an evaluation methodology that fits within current training, does not involve paper surveys, and can capture impact of active learning. The "clicker" technology has been well-received by trainees and is relatively easy to use. We have demonstrated that active learning can be used in mandated MSHA training courses with no loss of time to cover required content. We have also shown that the clicker technology is a fast and easy method of assessing learning in real time and allows the instructor to adjust the presentation of material to ensure learning and not just complying with time spent on a topic.

Details of the evaluation of active learning for fall protection are included in Appendix B.

Aim 4: Mine SAFE Serious Gaming Software for Mine Safety Training

Challenge: For more than a decade, those in mine safety training and related fields have been calling for changes in the way new and experienced miners are trained. In a review of more than 30 years of research to improve safety and health training in the mining industry, NIOSH researchers have identified two focal points for future training research:

1) Increasing trainee engagement by using more realistic or interactive methods, and
2) Developing and refining methods to evaluate post-training competencies.

Prior research suggests realistic and engaging training is more effective and may result in greater transfer to the job. Researchers have identified the potential of "serious games" using virtual reality to create more realistic and engaging training, noting "the more experience people gain through participating in such role playing simulations, the better prepared they will be to handle real-world events." We have developed MineSAFE (Software Architecture for Mine Safety Education), a new platform to create "serious games" in mine safety education. In designing our platform, we performed a triangulated needs assessment that included: product surveys, feedback from industry stakeholders, and informal user studies of existing training software.

Background: Peters, Vaught, & Mallett (2010, p. 507) summarize the current training dilemma:

> *Collectively, our nation's miners sit through millions of hours of mandated S&H training each year, and mining companies spend millions of dollars to provide this training. Unless effective training materials and methods are used, miners are unlikely to learn what they need to know to actually help reduce their risk of suffering occupational injury and illness. Many miners sit through the same training lectures and films year after year in order to fulfill the requirements of the law. In these situations, their 'training' ends up being a very unfortunate waste of time and resources i.e., a wasted opportunity*.

For more than a decade, training practitioners have been calling for changes in the way new and experienced miners are trained (Kowalski & Vaught, 2002; Brnich *et al*, 2002; Kowalski-Trakofler *et al*, 2004). Research suggests that certain key features and capabilities must be present to facilitate the learning process (Juul, 2003; Malone & Lepper, 1987; Thiagarajan, 1999; Garris, Ahlers, & Driskell, 2002). For instance, Garris suggests a diverse set of attributes that include engaging visual context and themes, clear rules and goals, notable sensory stimuli, difficult challenges, appropriate levels of information complexity, and active learner controls. Wilson *et al*. (2009) expand upon these attributes to include adaptation, assessment, conflict, interaction (equipment, interpersonal, social), language and communication, location, pieces and players, progress and surprise, representation, and safety. Although these studies illustrate the diversity of features and capabilities that are needed to support training, they do not give insight on how, when, or where to deploy such capabilities in a practical training process. The importance of each attribute may depend on the particular field of study, training objectives, and audience. Indeed, Salas *et al*. (2012, p.74) indicate that "properly

designed training works and…the way training is designed, delivered and implemented can greatly influence its effectiveness." In this dissertation, I present insight on this problem by proposing a set of Design Guidelines for Training in Mine Safety. My guidelines are grounded in observations of current, representative training practices, and supported by observations, analyses, and feedback from industry experts.

Furthermore, recent findings point to a gap in how safety is taught in the classroom and the realities of how it is practiced on the worksite (Waibel, Anders, & Kelly 2011; Waibel, Anders, & Zabari, 2012). Addressing this problem may require substantial changes to the classroom, i.e. the training workspace, and the methods used to deliver training content. Indeed, new workspaces will need to capture a proper subset of attributes and capabilities mentioned above in order to be successful vehicles of S&H training. Peters, Vaught, & Mallet (2010) reviewed more than 30 years of work in mine industry-specific S&H, identifying four key areas for improvement:

1. Increasing trainee engagement through active problem solving.
2. Integrating miners' practical knowledge and experience into the S&H curriculum.
3. Using more realistic training centering on high fidelity illustrations.
4. Providing more authentic materials indicative of the real workplace.

These recommendations suggest a need for improvements in both *content* and *delivery*. For example, Bullets 1 and 2 suggest a need for engaging, *practicum-based content*, where users are compelled to assimilate knowledge and think critically about hypothetical situations; Bullets 3 and 4 suggest a need for *contextualized delivery*, where the information is realistic, relevant, and grounded in the users' experience. Indeed, both content and delivery are vital to an effective training curriculum.

The underpinnings of the workspace -- be it a computer-supported workspace or a more traditional classroom -- must be suitable to the range of capabilities needed for training. As a potential vehicle of this process, Peters, Vaught, & Mallet (2010) note the use of “serious games” to create a more realistic and engaging environment. They suggest that, “the more experience people gain through participating in such role-playing simulations, the better prepared they will be to handle real-world events” (p. 507). This view is strongly supported in the findings of both Mallet & Orr (2008) and Alexander *et al.* (2010), who call for the development of “virtual reality theatres” for mine safety and rescue training.

New approaches are needed to improve outcomes for safety training in hazardous industries. Over the past five years we have conducted a detailed needs assessment and field studies of training in the mining industry, developed and validated a new approach for safety training that couples advancements in “serious games” with user interaction techniques to enhance training workflows. By combining these approaches, we can address both content and delivery, resulting in an improved workflow for training. In summary, this aim had four objectives:

1. *Develop guidelines for mine safety training*. The needs of safety training are diverse and complex. To date, they have not been fully characterized as a means to drive application development. In this work, we developed a set of *Design Guidelines for Training in Mine Safety*. We employed field studies and

systematic analysis using a process called Contextual Inquiry and Design to examine the requirements of this domain.

2. *Design an application framework for serious games.* We developed a new approach for training that is based on "serious games." Motivated by the design guidelines, we suggest two extensions: 1) illustrate training content, practices, and outcomes using non-linear stories with consequence-driven game play in a realistic, "sandbox" world; 2) extend conventional game interfaces with complexity management techniques and natural user interfaces to improve the usability of complex data sets. We developed a new platform, MineSAFE, for serious games development.

3. *Evaluate serious games under realistic usage conditions.* We conducted usability studies to evaluate the serious games approach. In particular, our studies center on user acceptance, which the design guidelines suggest is a major obstacle to the success of new training approaches. Our studies characterize acceptance based on standardized metrics, including user satisfaction, ease of use, and willingness to reuse.

4. *Extend to a workspace-level solution.* Some design guidelines are not adequately resolved using only commodity technologies. We have investigated workspace-level extensions that can elevate serious games into an Augmented Virtual Reality, where gestures and a versatile display space drive the gaming experience. Details of these studies and findings are in Dr. Leonard Brown's Ph.D. dissertation (Brown, 2015; 12 chapters, 637 pages) and are papers are being prepared for publication.

Games are difficult to define. What is a game? How are games similar? A survey of the literature suggests that there is no universally agreed upon definition. For example, researchers have attempted to define games based on their underlying structure (de Felix & Johnson, 1993), intrinsic challenges and risks (Baranauskas, Neto, Borges, 1999), and the essence of tasks, roles, and goals (Gredler, 1996). Systems of classification have been proposed, based on the types of experiences provided (Csikszentmihalyi, 1990) and the game's conceptual components (Björk and Holopainen, 2003). A useful summary of game features and classifications may be found in Hays (2005). Wittgenstein (1953, 1958) suggested that there are no properties common to all games and that the collection of activities that we call *games* bear at most a semantic "family resemblance" to one another.

For the purposes of this discussion, we define a *game* based on the analysis of Caillois (2001), as described by Garris, Ahlers, & Driskell (2002):

> *An activity that is voluntary and enjoyable, separate from the real world, uncertain, unproductive in that the activity does not produce any goods of external value, and governed by rules.*

Our interest is restricted to games that can be played on a computer system (including smart phones and tablets) or game console system and feature visual content that responds to player input. Future references to the term *game* will refer to these interactive video games, unless noted otherwise.

Serious games involve the use of games for purposes other than entertainment. Susi, Johannesson, & Backlund (2007) proposed a formal definition for *serious games:*

> *The application of gaming technology, process, and design to the solution of problems faced by businesses and other organizations. Serious games promote the transfer and cross fertilization of game development knowledge and techniques in traditionally non-game markets such as training, product design, sales, marketing, etc.*

Approach: The MineSAFE platform is built atop a commercially available game engine with advanced graphics and interaction capabilities. Our platform uses well-established workflows and software practices employed by the gaming industry to expedite development and reduce costs. MineSAFE games can run on computer hardware ranging from middle-range laptops to higher-end workstations and virtual reality theatres, with support for interface devices that include keyboards, mice, gamepads, touch surfaces, and emerging gesture-enabled interfaces.

Table 3. Entertainment games vs. serious games. (Susi, Johannesson, & Backlund, 2007)

Characteristic	Serious games	Entertainment games
Task vs. rich experience	Problem solving in focus	Rich experiences preferred
Focus	Important elements of learning	To have fun
Simulations	Assumptions necessary for workable simulations	Simplified simulation processes
Communication	Should reflect natural (i.e., non-perfect) communication	Communication is often perfect

Using the MineSAFE platform, we have created a suite of serious games called *Learn with Harry.* Developed in close collaboration with industry, the suite currently contains three games covering important topics in safety training:

- *Harry's Hard Choices*– Our first game, *Harry's Hard Choices* (HHC), is a comprehensive training tool for mine emergency response that is based on a NIOSH paper exercise by Vaught, Hall, & Klein (2009). The game is story-driven and single player. It allows the user to role play as a section foremen tasked with leading a team of miners (non-players) to safety in the midst of an underground coal mine disaster featuring many hazards and tough choices. The game has been thoroughly vetted through multiple levels of formal usability assessments with over 100 miners; testing indicates a high degree of user engagement and a high willingness among users to play (Brown, 2015). HHC has been successfully incorporated into our 40-hour new miner and 8-hour annual refresher training programs and is now being commercialized.

- *Harry's Fatalgram Simulator*–*Harry's Fatalgram Simulator* (HFS) features a series of ten minute "mini games," that allow users to watch the events of accidents and then dive into those accidents to change outcomes. HFS was designed to illustrate the complicated sequences of events that often contribute to fatalities, including communications breakdowns, distractions, and blind spots. HFS can be repurposed to simulate non-fatal accidents and near misses and is easily customized for specific mine sites and mine methods. HFS is our first game to incorporate full multi-player capabilities, allowing teams of users on the same crew to interact within a virtual environment, collaboratively solving safety problems.

- *Harry's Hazardous Day* – Our most recent development, *Harry's Hazardous Day* (HHD) centers on accident prevention through improved situational awareness and hazards recognition. Designed around MSHA's Rules to Live By, HHD is a story-driven game that starts with pre-shift inspection and progresses through normal shift activities as new hazards are introduced into the worksite. To our knowledge, HHD is the first serious game to feature massively multiplayer online (MMO) capabilities. By adapting an MMO approach, HHD can support any number of concurrent users filling different job roles, and include users from the same crew or across multiple crews and worksites. Time is simulated in-game, allowing for multiple work shifts and an ongoing cycle of work days through which the persistent (i.e. non-resetting) virtual world continues to evolve. These game mechanics allow HHD to emphasize situational awareness skills, worker rights and responsibilities, and communications, using more believable world and character dynamics than were feasible in prior iterations of serious games. Furthermore, HHD incorporates a modular world structure and can be used for numerous training roles, from teaching specific hazards or inspection techniques (using one module) to post-session evaluation and daily tailgate training (using the full MMO). The game currently focuses on the stone, sand, and gravel sector and is being readied for training in early 2018.

The *Learn with Harry* suite includes a toolkit for evaluating user performance (Figure 4). Nearly every aspect of a learner's gameplay can be tracked and analyzed. For example, the game logging system records disaster events, user behaviors, decision-making speed, crew interactions, and quality of scenario outcomes. This instrumentation can be remapped and re-purposed for different training activities or metrics. An evaluation dashboard further supports post-session debriefing. It visualizes critical decision points, user travel paths, and major game events in the context of an overview map. Notably, the trainer can step forward or backward through time to watch the action unfold. The dashboard also provides a reporting system to generate handouts such as job action sheets or improvement plans. Finally, the log may be uploaded to a database on an evaluation server (the server may be local or on the internet). The database includes a repository of game logs and tables with performance metrics. A data analytics module is used to interpret the game logs and populate these tables. The analytics module can be hot-swapped in real-time allowing versatility in setting up the evaluation parameters around specific competencies. Using the evaluation server, game performance may be measured across users or cohorts over time.

Studies suggest that well-designed serious games are effective tools for training transfer through learner's self-motivation, critical thinking, and performance tracking (Brown, 2015; Garris et al. 2002; Gee, 2007; Hays, 2005). With the *Learn with Harry* suite of serious games, we can provide a learning environment to teach situational awareness, hazards recognition, worker rights and responsibilities, and communication. Scenarios have been constructed for the Metal/Non-Metal sector, with a focus on Stone, Sand, and Gravel. The modularity of our software platform allows new content to be added with minimal effort. Serious games will be used in this project to both reinforce competency and support the evaluation strategy to measure change in competency in a pre and post-test model for certain segments of the training program.

Impact: In the current project year, we developed the second generation of our MineSAFE platform to address many of the weaknesses of our older game development toolkit. The second generation platform is based on a current, high-end game engine, the Unreal Engine 4 by Epic Games. MineSAFE 2.0 places an greater emphasis on modularity, customization, multi-player cooperation, and evaluation tools. In particular, the evaluation tools include a graphical front end for debriefing and a relational database for logging and tracking users, crews, and cohorts. An analytics module allows the game logs to be

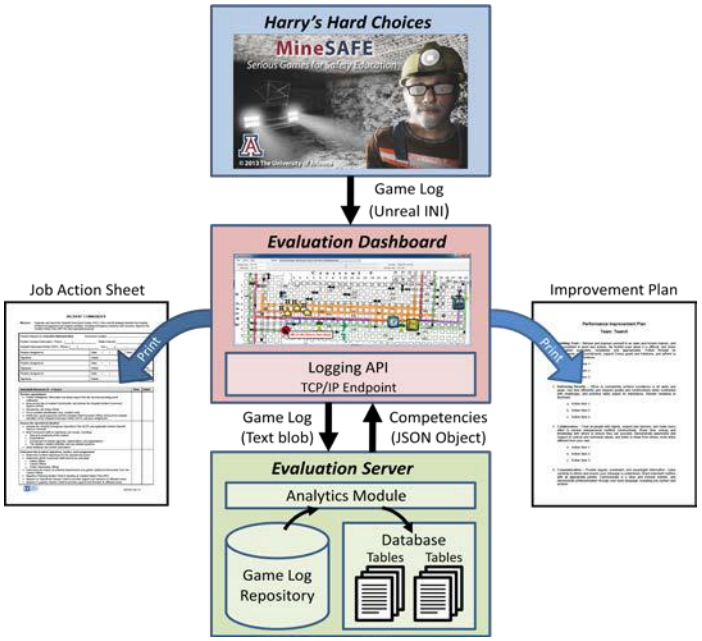

Figure 4: A toolkit for evaluation in serious games.

aligned or realigned to arbitrary competency models. We are currently working toward seamless integration of our serious games and evaluation capabilities with a commercial learning management system (LMS). We are now developing a prototype with an LMS provider in the industry. The evaluation tools will be essential to track safety competencies and future efficacy testing.
We have aggregated more than 7 years of research and development into a comprehensive training solution called Learn with Harry. The solution includes three games: Harry's Hard Choices (mine emergency response), Harry's Hazardous Day (hazards recognition and workplace examination) , and Harry's Fatalgram Simulator (refresher fatalgrams and MSHA best practices). Harry's Hard Choices (HHC) is currently being deployed and/or evaluated for training with 6 industry partners; over 400 miners have been trained with HHC. Harry's Hazardous Day (HHD) addresses situational awareness and workplace examinations. Numerous hazards are being built for the game, based on the Top 15 MSHA citations in each mining sector. The game features environments for sand, gravel, and cement, and it is easily extended for other worksites and mine methods. HHD has been developed in close collaboration with ARPA, McCraren Compliance, and two mine operators. It is now entering the alpha testing stage. The Learn with Harry gaming solution is being commercialized through a startup company that will provide hosting, technical support, and customization services to the mining industry (UA invention disclosure UA17-245). We have given 5 presentations on serious games for training during the current project year. The program is licensed for commercial distribution as of spring 2017 by Desert Saber LLC. We have been collecting log files on user play and are programming a faster method to unpack the files and display the results and parse the information into job action sheets and improvement plans as shown in Figure 6.

We have trained 338 miners on the use of Harry’s Hard Choices.

Details on the gaming software development are included in Appendix C.

Aim 5: Mining Institute for Supervisor Leadership (MISL)

Challenge: The Mining Institute for Supervisor Leadership (MISL) was developed as a result of a needs assessment discussion with our industry technical advisory committee (TAC). The TAC, which is now comprised of over 30 mining safety and health leaders, expressed their frustration in a lack of quality leadership training for supervisors and managers. The MISL course was created for individuals in the field of mining who want to gain a deeper understanding of the characteristics and skills that embody a great leader. “Total health” approach, supervisor roles, legal responsibilities, communication, resiliency, conflict resolution, and time management are just a few of the topics that are covered in the course. The goal of the training is to provide attendees with the tools they need to return to their respective companies and apply these concepts to balance safety with optimized operations as well as drive a culture shift of leadership through example.

Approach: The MISL course has been offered for five years and has evolved through the feedback from attendees and instructors. The content is delivered through modules that

are taught by TAC members, including UA faculty, over 2.5 days. The training employs active learning techniques based on andragogical principles (adult learning techniques), requiring full engagement and interaction between attendees and instructors. At the end of the intensive course, attendees are partnered with a Mentor (from the TAC and UA faculty) who provides guidance and coaching while the participant undertakes a Leadership Project, allowing them to apply their new knowledge and skills in their workplaces. To ensure that attendees receive the most out of the program, each cohort is capped at 25 individuals and they are requested to have a project idea in mind prior to arriving.

The agenda for the 2015 training is shown below in Figure 5.

Time	Topic (Presenter)
8:00 - 11:30	TAC Board Meeting and Knowledge, Skills, Attitudes, and Other Attributes (KSAO) Discussion
11:30 - 12:30	Lunch
12:30 - 12:50	Leadership Introduction (Bassier)
1:00 - 2:10	Team Strategic Planning (Wilson)
2:20 - 3:30	Communication (Beaver)
3:40 - 4:50	Conflict Resolution (Seppela)
5:30	Pub 1922 (MISL Social)

23-Apr-15

Time	Topic (Presenter)
7:00 - 7:20	Accountability (Lutz)
7:30 - 8:40	Regulatory Compliance (Savit)
8:50 - 10:00	Time Management (Fletcher)
10:10 - 11:20	Professional Miner (Lutz)
11:30 - 12:30	Lunch
12:30 - 12:50	Behavior (Fox)
1:00 - 2:10	Hazard Recognition (Gravley/Wegleitner)
2:20 - 3:30	Human Performance Improvement (Johnson)

3:40 - 4:50	Risk Management I (Bishop)
6:30	Tubac Country Club, Stables Ranch Grille (TAC Dinner)

	24-Apr-15
Time	Topic (Presenter)
7:00 - 7:20	Culture (M.Lutz)
7:30 - 8:40	Risk Management II (Wegleitner/Hutchison)
8:50 - 10:00	Compassionate Leadership (Bassier)
10:10 - 11:20	Business Management (Poulton)
11:30 - 12:30	Lunch
12:30 – 5:00	Oral Delivery of Project Objectives Write commitment letter

Figure 5. Agenda for 2015 MISL

Impact: More than 100 attendees have been trained through the MISL course, completing projects spanning a wide range of topics, from the creation of an operation-wide fall protection program to changing company procedures for electrical safety. Extensive evaluation of the course is conducted to assess its effectiveness and to make sure that the program is meeting the needs and expectations of the attendees. One-hundred percent of those who had completed the program in April 22-24, 2015 “agreed” or “strongly agreed” that they would recommend the MISL course to others and 90% reported that the course met their intended needs.

The challenges in continuing to offer MISL are the downturn in metal prices starting in 2013 that have made it challenging for companies to send workers to the course, competition from other NIOSH-funded leadership training courses, and the new emphasis in mining health and safety in the Society of Mining, Metallurgy and Exploration (SME) with the acquisition of the Certified Mine Safety Professional (CMSP) test from the International Society of Mine Safety Professionals Society (ISMSP). So we are considering a range of solutions to leadership training and have proposed a new approach to network mine safety professionals in Phase 3 of the Center.

Center Management

The Western Mine Safety and Health Training Center (Center) was administered through the interdisciplinary UA Lowell Institute for Mineral Resources in collaboration with the Mel and Enid Zuckerman College of Public Health.

Mary Poulton served as Center director until April 2017 prior to her retirement from the UA in May 2017. Drs. Jeff Burgess (Public Health) and Brad Ross (Mining Engineering) were appointed PIs of the project upon Dr. Poulton's departure. Key personnel have included:

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Publications

7 peer reviewed journal publications with 3 in progress
53 conference presentations and exhibitions
4 work products (software, training manuals)
1 dissertation
2 invention disclosures and licenses
113 invited presentations
34 industry partner meetings
11 training classes for serious games

Publications

1. Poplin, G.S., J.L. Burgess, J.R. Hill, H. Chengcheng, H. Miller and J. Sotille (2010). "Development of a Severe Injury Surveillance System for Hazard Identification and Guiding Technological Interventions," *NIOSH Mining*, 2010.

2. Waibel, A., P. Anders, and J. Kelley (2012). "Digging Deeper: Language, Literacy and Learning in the Mine Safety Industry," *Literacy Research Association Yearbook*. Oak Creek, WI: The Literacy Research Association, 2012.

3. Lutz, M and E.A. Lutz (2013). "Training Future Leaders in Mining: Conducting and Evaluating an Action Learning Program", *Action Learning: Research and Practice*, 2013

4. Lutz, M. and E.A. Lutz (2013). "Teaching and Learning in the Mining Community: A Matter of Life and Death", *Proceedings of American Educational Research Association*, 2013.

5. Poplin G.S., H.B. Miller, J. Sotille, C. Hu, J.R. Hill, and J.L. Burgess (2013), "Enhancing Severe Injury Surveillance: The Association Between Severe Injury Events and Fatalities in US Coal Mines," *Journal of Safety Research*; 44:31-35, 2013.

6. Lutz E.A., R.J. Reed, V.S.T. Lee, and J.L. Burgess (2015). "Occupational Exposures to Emissions from Combustion of Diesel and Alternative Fuels in Underground Mining – a Simulated Pilot Study," *Journal of Occupational and Environmental Hygiene*; 12:18-25, 2015.

7. Mehus A.A., R.J. Reed, V.S.T. Lee, S.R. Littau, C.C. Hu, E.A. Lutz, and J.L. Burgess (2015). "Comparison of Acute Health Effects from Exposures to Diesel and Biodiesel Fuel Emissions," *Journal of Occupational and Environmental Medicine*, 57:705-712, 2015.

Publications in Progress

8. Brown, L.D., M. Peltier, and M. Poulton, "Serious Games for Training in Mine Safety." (Submission to *Journal of Mine Engineering.*)

9. Brown, L.D., H. Hua, and M. Poulton. "A New Workflow for Safety and Hazards Recognition Training." (Submission to *Journal of Simulation & Gaming.*)

10. Gowrisankaran, G., He, C., Lutz, E.A., and Burgess, J.L. "Productivity, Safety, and Regulation in Coal Mining: Evidence from Disasters and Fatalities," NBER Working Paper 21129. (Submission to *The Review of Economics and Statistics*.)

Upcoming Conference Presentations

1. Brown, Leonard D. "A Workflow for Mine Safety Training Using Serious Games: Design and Evaluation," *Training Materials Applied to Mining Annual Workshop* (TRAM), MSHA, Beaver, WV, Oct 10-12, 2017.

2. Poulton, Mary M. & Leonard D. Brown. " Improving Hazards Recognition and Situational Awareness Using Serious Games," *Training Materials Applied to Mining Annual Workshop* (TRAM), MSHA, Beaver, WV, Oct 10-12, 2017.

3. Granillo, Brenda & Leonard D. Brown. "Usage Paradigms for Serious Games: Strategies and Lessons Learned," *Training Materials Applied to Mining Annual Workshop* (TRAM), MSHA, Beaver, WV, Oct 10-12, 2017.

4. Brown, Leonard D. & Mary M. Poulton. "Usability Design Guidelines for Training in Mine Safety and Health," *Society for Mining, Metallurgy, & Exploration Annual Conference* (SME), Minneapolis, MN, Feb. 25-28, 2018.

5. Granillo, Brenda & Leonard D. Brown. "Usage Paradigms for Serious Games: Strategies and Lessons Learned," *Society for Mining, Metallurgy, & Exploration Annual Conference* (SME), Minneapolis, MN, Feb. 25-28, 2018.

6. Brown, Leonard D. & Brenda Granillo. "A Framework to Evaluate Safety Competencies Through Serious Games," *Society for Mining, Metallurgy, & Exploration Annual Conference* (SME), Minneapolis, MN, Feb. 25-28, 2018.

Upcoming Invited Presentations

7. Brown, Leonard D. "*Learn with Harry:* An Innovative Training Solution Using Serious Games," Presentation at Safety & Health Workshop, Unimin-Sibelco Corp., Charlotte, NC, Oct. 4, 2017.
8. Brown, Leonard D. "Design, Evaluation, and Extension of Serious Games for Mine Safety," Invited talk at West Virginia University Institute of Technology (WVU-Tech) Computer Science Colloquium, Oct. 19, 2017.

Upcoming Exhibitions

9. *Training Materials Applied to Mining* (TRAM). Will exhibit serious games at UA Institute for Mineral Resources booth. Beaver, WV (MSHA Training Academy), Oct 10-12, 2017.

10. *Mine Safety and Health Conference* (MSHC). Will exhibit serious games at McCraren Compliance, Inc. booth. Reno, NV, Oct. 24-25, 2017.

Presentation at Literacy Research Association (2011)

11. Waibel, A., P. Anders, and J. Kelley (2011). "Digging Deeper: Language, Literacy and Learning in the Mine Safety Industry," *Literacy Research Association Annual Conference*, Jacksonville, FL, Dec. 2011.

Presentations at 7th Annual Western Regional Mine Health and Safety Conference (2011)

12. Brown, L.D., J. Hill, and M. Poulton (2011). "A Platform for Interactive Fatalgram Simulation Using Commodity Gaming Hardware." *7th Annual Western Regional Mine Safety & Health Conference*, Las Vegas, NV, Oct 24-26, 2011.

13. Lutz, E.A. (2011). "Institute for Mineral Resources (IMR) Industrial Hygiene Resources Program," *7th Annual Joint Western Regional Mining Safety and Health Conference*, Henderson, NV, Las Vegas, NV, Oct 24-26, 2011.

14. Anders, P.L., A. Waibel, J. Kelley, and S. Rice (2011). "Teaching Strategies for the Mine Safety Instructor," *7th Annual Western Regional Mine Safety & Health Conference*, Henderson, NV, Oct 24-26, 2011.

15. Newton, S. (2011). "Exposure and Control of Ten High Priority MSHA Contaminants in Metal Mines", *7th Annual Western Regional Mine Safety & Health Conference*, Henderson, NV, Oct 24-26, 2011.

Presentation at Literacy Research Association Annual Meeting (2012)

16. Waibel, A., P.L. Anders, and J. Kelley (2012). "Digging Deeper: Language, Literacy and Learning in the Mine Safety Industry". *Literacy Research Annual Meeting*, San Diego, CA, Nov. 28-Dec. 1, 2012.

Presentation at ISMSP Critical Issues Conference (2012)

17. Lutz, E.A. (2012). "Building Leaders – Mining Institute for Supervisor Leadership (MISL) Program," *ISMSP Critical Issues Conference*, International Society of Mine Safety Professionals, Reno, NV, May, 2012.

Presentations at 8th Annual Western Regional Mine Health and Safety Conference (2012)

18. Brown, L.D. (2012). "Interactive Computer Games for Mine Safety." *8th Annual Western Regional Mine Safety & Health Conference*, Reno, NV, Oct. 22-24, 2012.

19. Lutz, E.A. (2012). "Safety-focused Leadership – Mining Institute for Supervisor Leadership (MISL)," *8th Annual Western Regional Mine Safety & Health Conference*, Reno, NV, Oct. 22-24, 2012.

20. Lutz, E.A. and M. Lutz (2012). "Language and Literacy in the Mining Community," *8th Annual Western Regional Mine Safety & Health Conference*, Reno, NV, Oct. 22-24, 2012.

21. Stobbe T. (2012). "Back Injuries in Western Mines," *8th Annual Western Regional Mine Safety & Health Conference*, Reno, NV, Oct. 22-24, 2012.

Presentation at America Educational Research Association Annual Meeting (2013)

22. Waibel, A., P.L. Anders, and D. Zabari (2013). "Literacy and Pedagogy in Mine Safety Training: The Intersection of Academic and Workplace Domains." Roundtable presentation at the *American Educational Research Association Annual Meeting*, San Francisco, CA, April 27-May 1, 2013.

Presentation at XVII International Seminar on Safety in Mining Operations (2013)

23. Burgess, J.L. (2013). "International Evaluation of Injury Rates in Metal and Coal Mining: A Comparison of Risk and Compliance-based Regulatory Approaches," *XVII International Seminar on Safety in Mining Operations*, Instituto de Seguridad Minera, Lima, Peru, April 25, 2013.

Presentations at 2013 SME Annual Meeting and Exhibit (2013)

24. Brown, L.D., J.R. Hill, & M. Poulton (2013). "MineSAFE: A New Software Architecture for Mine Safety Education," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 24-27, 2013.

25. Lutz, E.A. (2013). "Extract your Full Leadership Potential," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 24-27, 2013.

Presentations at SME Annual Meeting and Exhibit (2014)

26. Brown, L.D. (2014). "MineSAFE: Application and Extension of Serious Games for Mine Safety Education," *SME Annual Meeting and Exhibit*, Salt Lake City, UT, Feb. 23-26, 2014.

27. Lutz, E.A. and R. Reed (2014). "Pilot-Scale Application of Using Traditional and Novel In-Ear Noise Exposure Monitoring in Active Shaft Mining to Evaluate Noise Controls," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Salt Lake City, UT, Feb. 23-26, 2014.

28. Lutz, E.A. and R. Reed (2014). "Occupational Heat Strain in Deep Shaft Metal Mining," *SME Annual Meeting and Exhibit,* Society for Mining, Metallurgy and Exploration, Salt Lake City, UT, Feb. 23-26, 2014.

29. Lutz, M. and J. van Landingham (2014). "Leadership Mentoring in the Mining Community: A Case Study," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Salt Lake City, UT, Feb. 23-26, 2014.

30. Lutz, E.A., T. Regan, X. Liu, and J.L. Burgess (2014). "Age, Injuries, and Costs in the Mining Industry: A Case Study for U.S. Gold and Coal Mines," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Salt Lake City, UT, Feb. 23-26, 2014.

31. Lutz, E.A., C. He, G. Gowrisankaran, and J.L. Burgess (2014). "Fatalities and Disasters in Coal Mining," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Salt Lake City, UT, Feb. 23-26, 2014.

Workshop at 11th Annual Western Regional Mine Health and Safety Conference (2015)

32. Poulton, M. (2015). "High Performance Training – Translating Training to Competency," *11th Annual Western Regional Mine Safety and Health Conference*, Reno, NV, Oct 27-28, 2015.

Presentations at SME Annual Meeting and Exhibit (2015)

33. Lutz, E.A., R. Reed, V. Lee, S. Littau and J.L. Burgess (2015). "Comparison of Diesel and Biodiesel Airborne Exhaust Exposures in an Underground Mine," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 15-17, 2015.

34. Reed, R. and E.A. Lutz (2015). "Broad Associations between MSHA Regulatory Compliance Measures and Injury Outcomes from 1983-2012," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 15-17, 2015.

35. Freeman, P. Highsmith, M. Poulton, M. Karmis, P. van der Veen and M. Hitzman (2015). "The Future of Mining: Our Evolving Role in Global Society - A Roundtable Discussion of Visions for Mineral Recruitment, Education and Talent Development to Better Serve Global Society," *SME Annual Meeting and Exhibit*, Denver, Society for Mining, Metallurgy and Exploration, CO, Feb. 15-17, 2015.

36. Poulton, M (2015). "The New Face of Mining – Industry-University Research Partnerships," *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 15-17, 2015.

Workshop at 12th Annual Western Regional Mine Health and Safety Conference (2016)

37. Granillo, A. (2016). "Competency Framework for Mine Emergency Response," 12*th Annual Western Regional Mine Safety & Health Conference*, Reno, NV, Oct 22-24, 2016.

Presentations at SME Annual Meeting and Exhibit (2016)

38. Lutz, E.A. (2016). "Building a workforce of professional miners to sustain safe production": *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Feb 24, 2016, Phoenix, AZ.

39. Poulton, M., E. Lutz, L. Wilson, and S. Gravley (2016). “Translating Training to Competency: New Approaches to Mine Safety Training,” *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Feb 24, 2016, Phoenix, AZ.

40. Lutz, M., and E. Lutz (2016). “The Future of Training in a Data-driven Mining Industry”, *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Feb 24, 2016, Phoenix, AZ.

41. Reed, R. (2016). “Data Science’s Place at the Mine Safety and Health Table,” *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Feb 24, 2016, Phoenix, AZ.

42. Reed, R. (2016). “Some Like It Hot: Heat Strain Management in Mining,” *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Feb 23, 2016, Phoenix, AZ.

43. Burgess, J. “Risk Management of DPM: Use of Alternative Fuels,” *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Feb 23, 2016, Phoenix, AZ.

Presentations at NMA MINExpo International (2016)

44. Lutz, M. (2016). "Current and Future Trends in Training for the Mining Industry," *MINExpo International 2016*, National Mining Association, Las Vegas, NV, Sept. 26-28, 2016.

45. Poulton, M. (2016). “Higher-Level Training – Translating Safety to Training Competency,” *MINExpo International 2016*, National Mining Association, Las Vegas, NV, Sept. 26-28, 2016.

46. Poulton, M. (2016). “Research-to-Practice: Power of University-Based Research to Improve Profitability and Sustainability," Panel Discussion moderated by Jeffery Kohler, *MINExpo International 2016*, National Mining Association, Las Vegas, NV, Sept. 26-28, 2016.

Presentations SME Annual Meeting and Exhibit (2017)

47. Brown, L.D., M.G. Peltier, and M. Poulton (2017). “Pre-Shift Inspection Training for Industrial Aggregates Using Serious Games,” *SME Annual Meeting and Exhibit,* Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 19-22, 2017.

48. Brown, L.D. and M. Poulton (2017). “A Workflow for Mine Safety Training Using Serious Games: Design and Evaluation,” *SME Annual Meeting and Exhibit*, Society for Mining, Metallurgy and Exploration, Denver, CO, Feb. 19-22, 2017.

MSHA Spring Thaw Presentations

49. Brown, Leonard D. "Using Serious Games for Training in Mine Safety," *MSHA Spring Thaw Training Workshop*, Rocky Mountain District, Scottsdale, AZ, May 6, 2016.

50. Brown, Leonard D. "Improving Hazards Recognition and Situational Awareness Using Serious Games," *MSHA Spring Thaw Training Workshop*, Rocky Mountain District, Scottsdale, AZ, May 5, 2017.

Training Manuals

1. University of Arizona (2015). Active *Learning Handbook for Mine Safety Training*, Tucson, AZ, 2015.

2. University of Arizona (2016). *Handbook for High-level Safety Training for Trainers and Students*, Tucson AZ, 2016.

Software

3. *Harry's Hard Choices* is now packaged for commercial distribution with a company being formed through TechLaunch Arizona, Desert Saber LLC.

Dissertations

4. Brown, L.D (2015). *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.

Inventions & Licensing

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).

Invited Presentations

1. Poulton, M. (2009). "Overview of the Institute for Mineral Resources," Chemical and Environmental Engineering graduate seminar, Tucson, AZ, Sept. 22, 2009.

2. Burgess, J.L. (2009). "University of Arizona Mining Health and Safety Research," Institute for Mineral Resources Pathways to Sustainable Development Workshop Series, Tucson, AZ Oct. 17, 2009.

3. Poulton, M., M. Barton, and T. Snider (2010). "Lowell Institute for Mineral Resources," Presentation to SFAz and Representative Judy Burges, Feb. 12, 2010.

4. Poulton, M. (2010). "Overview of the Lowell Institute for Mineral Resources," Chemical and Environmental Engineering faculty presentation, March 10, 2010.

5. Poulton, M. (2010). "Overview of the Lowell Institute for Mineral Resources", Presentation to SFAz Board of Directors, March 19, 2010.

6. Poulton, M. (2010). "Mineral Resources Education and Research in the 21st Century: Arizona Leads the Way," Pinal Mountain Section of SME, Globe, AZ, April 20, 2010.

7. Poulton, M. G. Jones, T. Snider, and S. Urquardt (2010). "Arizona's Resourceful Future," Briefing to Terry Goddard, Arizona Attorney General, Phoenix, AZ, May 6, 2010.

8. Poulton, M. (2010). "Overview of the Lowell IMR," Newmont Process Technology Center, Denver, CO, May 18, 2010.

9. Poulton, M. (2010). "IMR and San Xavier Mine," Presentation to the UA Foundation Board, Oct. 8, 2010.

10. Poulton, M. (2010). "Overview of the Lowell IMR," presented to the UA EPA Superfund Project colloquium, Tucson, AZ, Oct. 14, 2010.

11. Hill, J.R. (2010). "Advances in Miner Safety and Health Training and Research at the University of Arizona," ASMIO Fall Mixer, Nov. 2010.

12. Poulton, M and J.R. Hill. Presented the IMR to the MGE Department Industry Leadership Board and provided tours of the San Xavier Training Center, Tucson, AZ, Dec. 3.

13. Poulton, M. and J.R. Hill. Presented to ASARCO training and health and safety staff to discuss collaboration with center. Dec. 13.

14. Poulton, M. and E.A. Lutz. Presented to MSHA Spring Thaw, Rocky Mountain District, Arizona Rock Products Association (ARPA), and Arizona State Mine Inspector, Phoenix, AZ, May.

15. Lutz, E.A. (2010). "University of Arizona Mining Safety and Health Programs," International Society of Mine Safety Professionals – Arizona State Chapter Meeting, Tucson, AZ, 2011.

16. Hill, J. (2011). "Advances in Mine Safety and Health Training and Research at the University of Arizona," Arizona State Mine Inspectors Fall Conference, Phoenix, AZ, Oct. 7, 2011.

17. Poulton, M. and E.A. Lutz (2011). "IMR Mine Safety Research," Joint Meeting of Arizona Rock Products Association and Arizona Mining Association Meeting, Phoenix, AZ, Jan. 13, 2011.

18. Lutz E.A. (2011). "IH Training and Service," International Society of Mine Safety Professionals, Sept. 2011.

19. Lutz, E.A. (2011). Presentation to Mining Institute for Supervisor Leadership (MISL), Tucson, AZ, Dec. 1-2, 2011.

20. Lutz, E.A. "UA and IMR Mining Safety and Health Program," Arizona Mining Association, Feb. 15.

21. Poulton, M. (2011). "Overview of the Lowell IMR," Newmont Process Technology Center, Denver, CO, May 18, 2011.

22. Poulton, M. (2011). "Mining in Arizona: A New Century, A New Story," Arizona Mining Caucus, Tucson, AZ, June 9, 2011.

23. Poulton, M. (2011). "Mining in Arizona: A New Century and a New Story," Arizona Mining Alliance Phoenix Kick Off Meeting, Phoenix, AZ, Aug. 9,2011.

24. Poulton, M.(2011). “The Demographic Earthquake: How to Address Workforce Capacity in the Mineral Resources Professions," Society of Mining Professors Annual Meeting, Arequipa, Peru, Sept. 12, 2011.

25. Poulton, M. (2011). “Creating an Interdisciplinary Research Organization for Sustainable Development of Critical Earth Materials," Society of Mining Professors Annual Meeting, Arequipa, Peru, Sept. 13, 2011.

26. Burgess, J.L. and E.A. Lutz (2012). Invited participation in Alpha Foundation Mining Safety and Health Research Grants Planning Meeting, Charleston, WV, Oct., 2012.

27. Lutz, E.A. (2012). "NIOSH Western Mining Safety and Health Training Resource Center and the Mining Institute for Supervisor Leadership," Arizona Mining Association Safety Committee, Phoenix, AZ, 2012.

28. Poulton, M. (2012). “Technology Advances to Overcome Regulatory Hurdles,” IQPC Mine Automation Summit, Tucson, AZ, Feb. 1, 2012.

29. Poulton, M. (2012). "Overview of the Lowell IMR" (Two presentations plus meeting with Vice President for Research), Colorado School of Mines, Golden, CO, April 15, 2012.

30. Poulton, M. Presented to Preston Chiaro, VP for Innovation at Rio Tinto, Oct. 4.

31. Poulton, M. Interview on ABC affiliate KGUN 9 Morning Show, Oct. 6.

32. Joy, J., M. Byrne and J.L. Burgess (2014). "Material Health and Safety Critical Control Risk Management in ICMM Member Companies," Interim Report to ICMM, London, England, March 24, 2014.

33. Burgess, J.L. (2014). “Comparison of Acute Health Effects from Use of Diesel and Biodiesel Fuels,” Institute of Occupational Medicine, Edinburgh, Scotland, Sept. 3, 2014.

34. Brown, L.D. (2016). "Using Serious Games for Training in Mine Safety," MSHA Spring Thaw, Rocky Mountain District, Scottsdale, AZ, May 6, 2016.

35. Brown, L.D. (2016). "Designing a Serious Game for Workplace Examinations," Meeting of the Arizona Rock Products Association (ARPA), Phoenix, AZ, Aug. 18, 2016.

36. Brown, Leonard D. "Serious Games for Training in Mine Safety," Presentation at Drake Cement, LLC, Scottsdale, AZ, March 4, 2016.

37. Brown, Leonard D. "Designing a Serious Game for Workplace Examinations," Presentation to the Arizona Rock Products Association (ARPA), Phoenix, AZ, Aug. 18, 2016.

38. Brown, Leonard D. "*Learn with Harry:* An Innovative Training Solution Using Serious Games," Presentation to the Mine Training Institute, Freeport-McMoRan Inc. (FMI), Tucson, AZ, July 5, 2017.

Additional 75 presentations mentioning the Center to mining companies, legislators, community groups

Exhibits & Demonstrations

Completed Exhibitions

1. *Mine Safety and Health Conference* (MSHC). Exhibited serious games at UA Institute for Mineral Resources booth. Conducted approximately 35 demonstrations for attendees, including Asst. Secretary of Labor and Head of MSHA, Joe Main; received 14 surveys. Las Vegas, NV, Oct. 24-26, 2016.

2. *MINExpo 2016*. Exhibited serious games at UA Institute for Mineral Resources booth. Conducted approximately 50 demonstrations for attendees; received 33 surveys. Las Vegas, NV, Sept. 26-28, 2016.

3. *Society for Mining, Metallurgy, & Exploration Annual Conference* (SME). Exhibited serious games at UA Institute for Mineral Resources booth. Conducted approximately 25 demonstrations for attendees. Denver, CO, Feb. 19-22, 2017.

Partnerships & Industry Meetings

1. Drake Cement, LLC. Site visit. Partnership on serious game for hazards awareness leading to design of workplace examination component of *Harry's Hazardous Day*. Paulden, AZ, April 11-12, 2016.

2. Red Hammer, LLC. Meeting to discuss data management architecture for evaluation and tracking of site safety and training records. Tucson, AZ, July 12, 2016.

3. New Gold, Inc., Western Mesquite Mine. Teleconference. Meeting to discuss partnership to use *Harry's Hard Choices* in mine emergency response training. Tucson, AZ, Mar. 14, 2017.

4. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Meeting to discuss partnership for customized version of *Harry's Hazardous Day* for CASC. Tucson, AZ, April 10, 2017.

5. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Site Visit. Partnership on customized version of *Harry's Hazardous Day* for CASC. Safford, AZ, April 19, 2017.

6. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Follow-up on development of customized version of *Harry's Hazardous Day* for CASC. Tucson, AZ, May 8, 2017.

7. Energy Fuels, Inc. Teleconference. Discussion of partnership to use *Harry's Hard Choices* for in-house annual refresher training. Tucson, AZ, May 17, 2017.

8. New Gold, Inc., Western Mesquite Mine. Teleconference. Follow-up meeting to discuss partnership to use *Harry's Hard Choices* in mine emergency response training. Tucson, AZ, Mar. 19, 2017.

9. Mining Safety & Learning Systems (MiningSLS), Inc. Teleconference. Meeting to discuss partnership to integrate serious games content with commercial Learning Management System (LMS). Tucson, AZ, May 19, 2017.

10. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Meeting to follow-up on development of customized version of *Harry's Hazardous Day* for CASC. Tucson, AZ, May 24, 2017.

11. Mining Safety & Learning Systems (MiningSLS), Inc. Teleconference. Follow-up on integrating serious games with commercial Learning Management System (LMS). Tucson, AZ, May 31, 2017.

12. McCraren Compliance, Inc. Meeting to discuss partnership to deploy serious games in mine safety compliance courses. Tucson, AZ, June 1, 2017.

13. McCraren Compliance, Inc. Meeting to follow-up on partnership to deploy serious games in mine safety compliance courses. Tucson, AZ, June 6, 2017.

14. Drake Cement, LLC. Teleconference. Meeting to follow-up on development of *Harry's Hazardous Day* workplace examination training. Tucson, AZ, June 14, 2017.

15. Mining Safety & Learning Systems (MiningSLS), Inc. Teleconference. Follow-up on integration of serious games with commercial Learning Management System (LMS): Technical integration challenges. Tucson, AZ, June 21, 2017.

16. Mining Safety & Learning Systems (MiningSLS), Inc. Teleconference. Follow-up on integration of serious games with commercial Learning Management System (LMS): Demonstration of LMS capabilities. Tucson, AZ, June 26, 2017.

17. McCraren Compliance, Inc. Teleconference. Follow-up on game design of *Harry's Hazardous Day* and serious games deployment to compliance training courses. Tucson, AZ, June 29, 2017.

18. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Meeting to follow-up on development of customized version of *Harry's Hazardous Day* for CASC: Proof-of-concept demonstration. Tucson, AZ, June 30, 2017.

19. Unimin-Sibelco, Inc., Schoolhouse Quartz Operations. Teleconference. Meeting to discuss partnership regarding use of *Learn with Harry* serious games in Unimin training courses. Tucson, AZ, June 30, 2017.

20. McCraren Compliance, Inc. Meeting on deployment of serious games for training courses: Live demonstration of *Learn with Harry* serious games. Tucson, AZ, July 5, 2017.

21. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Meeting to follow-up on development of customized version of *Harry's Hazardous Day* for CASC: Game design and proposed safety incidents. Tucson, AZ, July 6, 2017.

22. McCraren Compliance, Inc. Meeting to deploy serious games in mine safety compliance courses: First training class deployment. Tucson, AZ, July 7, 2017.

23. Unimin-Sibelco, Inc., Schoolhouse Quartz Operations. Teleconference. Meeting to discuss partnership regarding use of *Learn with Harry* serious games: Live demonstration of *Learn with Harry*. Tucson, AZ, July 13, 2017.

24. Mining Safety & Learning Systems (MiningSLS), Inc. Teleconference. Follow-up on integration of serious games with commercial Learning Management System (LMS): Workflow prototypes. Tucson, AZ, July 13, 2017.

25. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Teleconference. Follow-up on development of customized version of *Harry's Hazardous Day* for CASC: Strategy for presentation to leadership. Tucson, AZ, July 13, 2017.

26. Intrepid Potash, Inc. Teleconference. Discussion on use of *Harry's Hard Choices* for underground annual refresher training. Tucson, AZ, July 19, 2017.

27. Freeport-McMoRan, Inc., Chemical Analytics Service Center. Follow-up on development of customized version of *Harry's Hazardous Day* for CASC: Design proposal meeting. Tucson, AZ, July 20, 2017.

28. Unimin-Sibelco, Inc., Schoolhouse Quartz Operations. Teleconference. Follow-up to discuss partnership regarding use and customization of *Learn with Harry* serious games: Discussion game customization. Tucson, AZ, July 21, 2017.

29. McCraren Compliance, Inc. Meeting to deploy serious games in mine safety compliance courses: Training use cases. Tucson, AZ, Aug, 8, 2017.

30. McCraren Compliance, Inc. Meeting to deploy serious games in mine safety compliance courses: *Harry's Hard Choices* orientation and tutorial. Tucson, AZ, Aug, 9, 2017.

31. New Gold, Inc., Western Mesquite Mine. Teleconference. Follow-up meeting to discuss partnership to use *Harry's Hard Choices* in mine emergency response training: Discussion of site visit and training curriculum. Tucson, AZ, Aug. 11, 2017.

32. Mining Safety & Learning Systems (MiningSLS), Inc. Teleconference. Follow-up on integration of serious games with commercial Learning Management System (LMS): Drill sheets and reporting. Tucson, AZ, Aug. 11, 2017.

33. Unimin-Sibelco, Inc., Schoolhouse Quartz Operations. Teleconference. Follow-up to discuss partnership regarding use and customization of *Learn with Harry* serious games: of site visit and presentation to leadership. Tucson, AZ, Aug. 18, 2017.

34. McCraren Compliance, Inc. Meeting to deploy serious games in mine safety compliance courses: Installation of *Learn with Harry* serious games using McCraren's classroom technology. Tucson, AZ, Aug, 21, 2017.

Training & Evaluation

1. Reno, NV. Conducted 8 hour mining supervisory leadership workshop at *Mine Safety and Health Conference* (MSHC). Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 10 participants. Oct. 28, 2014.

2. Moundsville, WV. Conducted supplementary mine rescue training at Ohio Valley Mine Rescue Competition. Included 1 hour of training with *Harry's Hard Choices* as active learning for self-rescue training. Trained 21 mine rescue team participants. June 3, 2015.

3. Rock Springs, WY. Conducted active learning workshop with company safety and health leadership. Trained 8 participants. Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 8 participants. June 15, 2015.

4. Sahuarita, AZ. Conducted 40 hour Part 48 underground new miner training. Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 23 participants. Aug. 17, 2015.

5. Lexington, KY. Conducted supplementary mine rescue training at National Mine Rescue Competition. Included 1 hour of training with *Harry's Hard Choices* as active learning for self-rescue training. Trained 49 mine rescue team participants. Sept. 15, 2015.

6. Sahuarita, AZ. Conducted 8 hour Part 48 underground annual refresher training. Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 18 participants. Sept. 26, 2015.

7. Sahuarita, AZ. Conducted 40 hour Part 48 underground new miner training with U.S. Army emergency response teams. Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 18 participants. Aug. 9-10, 2016.

8. Sahuarita, AZ. Conducted 8 hour Part 48 underground annual refresher training. Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 22 participants. Aug. 16, 2016.

9. Las Vegas, NV. Conducted 8 hour workshop on emergency preparedness at annual *Mine Safety and Health Conference* (MSHC). Included 1.5 hours training with *Harry's Hard Choices* as pre/post test. Trained 15 participants. Oct. 24, 2016.

10. Sahuarita, AZ. Conducted 8 hour Part 48 underground annual refresher training with U.S. Army emergency response teams. Included 1 hour of training with *Harry's Hard Choices* as active learning training module. Trained 9 participants. Jan 4, 2017.

11. Sahuarita, AZ. Conducted 40 hour Part 48 underground new miner training with U.S. Army emergency response teams. Included 2.5 hours of training with *Harry's Hard Choices* as pre/post test. Trained 21 participants. Aug. 14-18, 2017.

Materials Available for Other Investigators

Key products and services from this project include the following:

1. Trainer and student handbooks for active learning based MSHA-mandated training for new miner and annual refresher covering surface and underground mining for metal, nonmetal, and coal. Available on Center website
2. Competency framework for mine safety trainers to be published through Department of Labor
3. Part 46 Toolbox in Spanish –available on Center website

4. Trainer Handbook for active learning for required MSHA courses – available on Center website
5. MineSAFE software platform for serious games in mine safety training; training products developed via the platform include *Interactive Fatalgram Simulator* and *Harry's Hard Choices.* Harry's Hard Choices is being commercialized by Desert Saber LLC.
6. Easy to navigate website for access to health and safety resources http://miningsh.arizona.edu/.

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APPENDIX A

Mine Safety Trainer Competency Framework

Tier 9 - Leadership and Management Competencies									
Tier 6 - Learning & Development Knowledge Competencies									
Learning Theory and Psychology of Learning	Learning Technologies	Legal, Regulatory, & Ethical Issues	Instructional Design	Training Delivery	Evalutating Learning Impact	Performance Improvement	Change Management	Knowledge Management	Talent Management
		Tier 5 - Industry-Sector Technical Competencies							
		Metal	Nonmetal	Stone	Sand & Gravel	Coal			
		Tier 4 - Industry-Wide Technical Competencies							
		Geological Concepts	Exploration	Mining Methods	Processing and Refining	Business of Mining			
Tier 3 - Workplace Competencies									
Teamwork	Customer Focus	Planning & Organizing	Creative Thinking	Problem Solving & Decision Making	Scheduling & Coordinating	Checking, Examining & Recording	Business Fundamentals	Sustainable Practices	Health, Safety & Environment
Tier 2 - Academic Competencies									
Reading	Writing		Mathematics	Science & Technology		Communication	Critical & Analytical Thinking		Basic Computer Skills
Tier 1 - Personal Effectiveness Competencies									
Interpersonal Skills	Integrity		Professionalism	Initiative		Dependability & Reliability		Adaptability & Flexibility	Lifelong Learning

Foundational Competencies

Tier 1: Personal Effectiveness Competencies

101. **Interpersonal Skills –** Displaying the skills to work effectively with others from diverse backgrounds.

Demonstrating sensitivity/empathy
- o Show sincere interest in others and their concerns.
- o Demonstrate sensitivity to the needs and feelings of others.
- o Look for ways to help people and deliver assistance.

Demonstrating insight into behavior
- o Recognize and accurately interpret the communications of others as expressed through various formats (e.g., writing, speech, American Sign Language, computers, etc).
- o Recognize when relationships with others are strained.
- o Show understanding of others' behaviors and motives by demonstrating appropriate responses.
- o Demonstrate flexibility for change based on the ideas and actions of others.

Maintaining open relationships
- o Maintain open lines of communication with others.
- o Encourage others to share problems and successes.
- o Establish a high degree of trust and credibility with others.

Respecting diversity
- o Interact respectfully and cooperatively with others who are of a different race, culture, or age, or have different abilities, gender, or sexual orientation.
- o Demonstrate sensitivity, flexibility, and open-mindedness when dealing with different values, beliefs, perspectives, customs, or opinions.
- o Value an environment that supports and accommodates a diversity of people and ideas.

102. **Integrity –** Displaying strong moral principles and work ethic.

Behaving ethically
- o Abide by a strict code of ethics and behavior, even in the face of opposition.
- o Encourage others to behave ethically.
- o Understand that behaving ethically goes beyond what the law requires.
- o Use company time and property responsibly.
- o Perform work-related duties according to laws, regulations, contract provisions, and company policies.

Acting fairly
- o Treat others with honesty, fairness and respect.
- o Make decisions that are objective and reflect the just treatment of others.

Taking responsibility
- o Take responsibility for accomplishing work goals within accepted timeframes.
- o Accept responsibility for one's decisions and actions and for those of one's group, team, or department.

103. **Professionalism –** Maintaining a professional presence.

Demonstrating self-control
- o Maintain composure and keep emotions in check.
- o Deal calmly and effectively with stressful or difficult situations.
- o Accept criticism tactfully and attempt to learn from it.

Foundational Competencies

Professional appearance
- o Maintain a professional demeanor.
- o Dress appropriately for occupational and worksite requirements.
- o Maintain appropriate personal hygiene.

Social responsibility
- o Refrain from lifestyle choices which negatively impact the workplace and individual performance.
- o Remain free from substance abuse.

Maintaining a positive attitude
- o Project a professional image of oneself and the organization.
- o Demonstrate a positive attitude towards work.
- o Take pride in one's work and the work of the organization.

104. **Initiative –** Demonstrating a commitment to effective job performance by taking action on one's own and following through to get the job done.

Persisting
- o Pursue work with drive and a strong accomplishment orientation.
- o Persist to accomplish a task despite difficult conditions, tight deadlines, or obstacles and setbacks.

Taking initiative
- o Go beyond the routine demands of the job to increase its variety and scope.
- o Provide suggestions and/or take actions that result in improved work processes, communications, or task performance.
- o Take initiative to seek out new work challenges, influence events, or originate action.

Setting challenging goals
- o Establish and maintain personally challenging but realistic work goals.
- o Exert effort toward task mastery.
- o Bring issues to closure by pushing forward until a resolution is achieved.

Working independently
- o Develop own ways of working effectively and efficiently.
- o Perform effectively even with minimal direction, support, or approval.
- o Take responsibility for completing one's own work assignments.

Achievement motivation
- o Strive to exceed standards and expectations.
- o Exhibit confidence in capabilities and an expectation to succeed in future activities.

105. **Dependability and Reliability –** Displaying responsible behaviors at work.

Fulfilling obligations
- o Behave consistently and predictably.
- o Is reliable, responsible, and dependable in fulfilling obligations.
- o Diligently follow through on commitments and consistently complete assignments by deadlines.

Foundational Competencies

Attendance and punctuality

- o Come to work on time and as scheduled.
- o Arrive on time for meetings or appointments.
- o Dial in to phone calls and web conferences on time.

Attending to details

- o Diligently check work to ensure that all essential details have been considered.
- o Notice errors or inconsistencies and take prompt, thorough action to correct them.

Following directions

- o Follow directions as communicated in a variety of ways such as writing, speech, American Sign Language, computers, or other formats.
- o Comply with organizational rules, policies, and procedures.
- o Ask appropriate questions to clarify any instructional ambiguities.

106. **Adaptability and Flexibility –** Displaying the capability to adapt to new, different or changing requirements.

Entertaining new ideas

- o Is open to considering new ways of doing things.
- o Actively seek out and carefully consider the merits of new approaches to work.
- o Embrace new approaches when appropriate and discard approaches that are no longer working.

Dealing with change

- o Take proper and effective action when necessary without having all the necessary facts in hand.
- o Easily adapt plans, goals, actions, or priorities in response to unpredictable or unexpected events, pressures, situations, and job demands.
- o Effortlessly shift gears and change direction when working on multiple projects or issues.

107. **Lifelong Learning –** Demonstrating a commitment to self-development and improvement of knowledge and skills.

Demonstrating an interest in learning

- o Take actions showing an interest in personal and professional lifelong learning and development.
- o Seek feedback from multiple sources about how to improve and develop.
- o Modify behavior based on feedback or self-analysis of past mistakes.
- o Learn and accept help from supervisors and co-workers.

Participating in learning activities

- o Identify when it is necessary to acquire new knowledge and skills.
- o Take steps to develop and maintain knowledge, skills, and expertise necessary to perform one's role successfully by participating in relevant training and professional development programs.
- o Actively pursue opportunities to broaden knowledge and skills through seminars, conferences, professional groups, reading publications, job shadowing, and/or continuing education.

Using change as a learning opportunity

- o Anticipate changes in work demands and search for and participate in assignments or training that address these changing demands.
- o Treat unexpected circumstances as opportunities to learn.

Identifying career interests

- o Take charge of personal career development by identifying occupational interests, strengths, options, and opportunities.
- o Make insightful career planning decisions that integrate others' feedback.

Integrating and applying learning

- o Integrate newly learned knowledge and skills with existing knowledge and skills.
- o Use newly learned knowledge and skills to complete tasks, particularly in new or unfamiliar situations.

Foundational Competencies

Tier 2 – Academic Competencies

201. **Reading –** Understanding written sentences, paragraphs, and figures in work-related documents on paper, on computers, or adaptive devices.

Comprehension

- o Locate and understand written information in prose and in documents such as manuals, reports, memos, letters, forms, graphs, charts, tables, calendars, schedules, signs, notices, applications, contracts, regulations, and directions.
- o Understand the purpose of written materials.
- o Comprehend the author's meaning and identify the main ideas expressed in the written material.

Attention to detail

- o Note details and facts.
- o Detect inconsistencies.
- o Identify implied meaning and details.
- o Recognize missing information.

Information analysis

- o Critically evaluate and analyze information in written materials.
- o Review written information for completeness and relevance.
- o Distinguish fact from opinion.
- o Identify trends.
- o Synthesize information from multiple written materials.

Information integration

- o Integrate what is learned from written materials with prior knowledge.
- o Use what is learned from written material to follow instructions and complete tasks.
- o Apply what is learned from written material to new situations.

202. **Writing –** Using standard business English to compile information and prepare written documents on paper, on computers, or adaptive devices.

Organization and development

- o Create documents such as letters, directions, manuals, reports, graphs, spreadsheets, and flow charts.
- o Communicate thoughts, ideas, information, messages and other written information, which may contain technical material, in a logical, organized, and coherent manner.
- o Present well-developed ideas supported by information and examples.
- o Proofread finished documents for errors.
- o Tailor content to appropriate audience and purpose.
- o Distribute written materials appropriately for intended audiences and purposes.

Mechanics

- o Use standard syntax and sentence structure.
- o Use correct spelling, punctuation, and capitalization.
- o Use correct grammar (e.g., correct tense, subject-verb agreement, no missing words).
- o Write legibly when using handwriting to communicate.

Tone

- o Use language appropriate for the target audience.
- o Use a tone and word choice appropriate for the industry and organization (e.g., writing is professional and courteous).
- o Show insight, perception, and depth in writing.

Foundational Competencies

203. **Mathematics –** Using principles of mathematics to express ideas and solve problems on paper, on computers, or adaptive devices.

Computation

- o Add, subtract, multiply, and divide with whole numbers, fractions, decimals, and percents.
- o Calculate averages, ratios, proportions, and rates.
- o Convert decimals to fractions and fractions to decimals.
- o Convert fractions to percents and percents to fractions.
- o Convert decimals to percents and percents to decimals.
- o Understand relationships between numbers and identify and understand patterns.

Measurement and estimation

- o Take measurements of time, temperature, distances, length, width, height, perimeter, area, volume, weight, velocity, and speed.
- o Use and report measurements correctly.
- o Correctly convert from one measurement to another (e.g., from English to metric or International System of Units (SI), or Fahrenheit to Celsius).

Application

- o Use appropriate mathematical formulas and techniques to solve problems.
- o Translate practical problems into useful mathematical expressions.

204. **Science and Technology –** Using scientific rules and methods to express ideas and solve problems on paper, on computers, or adaptive devices.

Comprehension

- o Understand basic scientific principles and uses appropriate technology.
- o Understand the scientific method (i.e., identify problems, collect information, form opinions and draw conclusions).
- o Understand overall intent and proper procedures for set-up and operation of equipment.

Application

- o Apply basic scientific principles and technology to complete tasks.

205. **Communication –** Listening, speaking, and signaling so others can understand using a variety of methods, including hearing, speech, American Sign Language, instant messaging, text-to-speech devices, etc.

Communicating

- o Express relevant information appropriately to individuals or groups taking into account the audience and the nature of the information (e.g., technical or controversial).
- o Convey information clearly, correctly, and succinctly.
- o Use common English conventions including proper grammar, tone, and pace.
- o Effectively establish interpersonal contact with one or more individuals using eye contact, body language and non-verbal expression as appropriate to the person's culture.

Receiving information

- o Attend to, understand, interpret, and respond to messages received in a variety of ways, including hearing, American Sign Language, instant messaging, text-to-speech devices, and other methods.
- o Comprehend complex instructions.
- o Identify feelings and concerns communicated in various formats, such as writing, speech, American Sign Language, computers, etc. and responds appropriately.
- o Consider others' viewpoints and alter opinion when it is appropriate to do so.
- o Apply active interpersonal communication skills using reflection, restatement, questioning, and clarification.
- o Effectively answer questions of others or communicate an inability to do so and suggest other sources of answers.

Observing carefully

- o Notice nonverbal cues and respond appropriately.
- o Attend to visual sources of information (e.g., video).
- o Ascertain relevant visual information and use appropriately.

Foundational Competencies

Persuasion/Influence

- o Influence others.
- o Persuasively present thoughts and ideas.
- o Gain commitment and ensure support for proposed ideas.

206. **Critical and Analytic Thinking –** Using logical thought processes to analyze information and draw conclusions.

Reasoning

- o Possess sufficient inductive and deductive reasoning ability to perform job successfully.
- o Critically review, analyze, synthesize, compare, and interpret information.
- o Draw conclusions from relevant and/or missing information.
- o Understand the principles underlying the relationship among facts and apply this understanding when solving problems.
- o Use logic and reasoning to identify strengths and weaknesses of alternative solutions or approaches to a problem.

Mental agility

- o Identify connections between issues.
- o Quickly understand, orient to, and integrate new information.

207. **Basic Computer Skills –** Using information technology and related applications, including adaptive devices and software, to convey and retrieve information.

Computer basics

- o Understand the basic functions and terminology related to computer hardware, software, information systems, and communication devices.
- o Use basic computer software, hardware, and communication devices to perform tasks.

Using software

- o Use word processing software to compose, organize, edit, and print documents and other business communications.
- o Use spreadsheet software to enter, manipulate, edit, and format text and numerical data.
- o Use presentation software to create, manipulate, edit, and present digital representations of information to an audience.
- o Use database software to manage data.
- o Create and maintain a well-organized electronic file storage system.

Using the Internet and email

- o Use the Internet to search for online information and interact with Web sites.
- o Use the Internet and web-based tools to manage basic workplace tasks (e.g., calendar management, contacts management, and timekeeping).
- o Use electronic mail to communicate in the workplace.
- o Understand the different types of social media and their appropriate workplace and non-workplace uses, and the impact that various social media activities can have on one's personal and professional life.
- o Employ collaborative/groupware applications to facilitate group work.

Ensuring computer security

- o Understand and comply with the organization's privacy policy and information security guidelines.
- o Defend against potential abuses of private information.
- o Recognize and respond appropriately to suspicious vulnerabilities and threats.
- o Use the most recent security software, web browser, and operating system to protect against online threats.
- o Utilize strong passwords, passphrases, and basic encryption.
- o Recognize secure Web addresses.

Tier 3 – Workplace Competencies

Foundational Competencies

301. **Teamwork –** Working cooperatively with others to complete work assignments.

Identifying team membership and role

- o Serve as a leader or a follower, depending on what is needed to achieve the team's goals and objectives.
- o Identify and draw upon team members' strengths and weaknesses to achieve results.
- o Instruct others in learning new skills and learn from other team members.
- o Assist others who have less experience or have heavy workloads.
- o Encourage others to express their ideas and opinions.

Establishing productive relationships

- o Develop constructive and cooperative working relationships with others.
- o Exhibit tact and diplomacy and strive to build consensus.
- o Deliver constructive criticism and voice objections to others' ideas and opinions in a supportive, non-accusatory manner.
- o Respond appropriately to positive and negative feedback.
- o Effectively communicate with all members of the group or team to achieve team goals and objectives.

Meeting team objectives

- o Work as part of a team, contributing to the group's effort to achieve goals.
- o Identify and commit to the goals, norms, values, and customs of the team.
- o Choose behaviors and actions that best support the team and accomplishment of work tasks.
- o Use a group approach to identify problems and develop solutions based on group consensus.

Resolving conflicts

- o Bring others together to reconcile differences.
- o Handle conflicts maturely by exercising "give and take" to achieve positive results for all parties.
- o Reach formal or informal agreements that promote mutual goals and interests, and obtain commitment to those agreements from individuals or groups.

302. **Customer Focus –** Efficiently and effectively addressing the needs of clients/customers.

Understanding customer needs

- o Identify internal and external customers.
- o Attend to what customers are saying and ask questions to identify customer needs, interests, and goals.
- o Anticipate the future needs of the customer.

Providing personalized service

- o Provide prompt, efficient, and personalized assistance to meet the requirements, requests, and concerns of customers.
- o Provide thorough, accurate information to answer customers' questions and inform them of commitment times or performance guarantees.
- o Address customer comments, questions, concerns, and objections with direct, accurate, and timely responses.
- o Identify and propose appropriate solutions and/or services.
- o Establish boundaries as appropriate for unreasonable customer demands.

Acting professionally

- o Is pleasant, courteous, and professional when dealing with internal or external customers.
- o Develop constructive and cooperative working relationships with customers.
- o Is calm and empathetic when dealing with hostile customers.

Foundational Competencies

Keeping customers informed

- o Follow up with customers during projects and following project completion.
- o Keep customers up to date about decisions that affect them.
- o Seek the comments, criticisms, and involvement of customers.
- o Adjust services based on customer feedback.

303. **Planning and Organizing –** Planning and prioritizing work to manage time effectively and accomplish assigned tasks.

Planning

- o Approach work in a methodical manner.
- o Plan and schedule tasks so that work is completed on time.
- o Keep track of details to ensure work is performed accurately and completely.
- o Anticipate obstacles to project completion and develop contingency plans to address them.
- o Find new ways of organizing work area or planning work to accomplish work more efficiently.

Prioritizing

- o Prioritize multiple competing tasks.
- o Perform tasks correctly, quickly, and efficiently according to their relative urgency and importance.

Managing projects

- o Estimate personnel and other resources needed for project completion (e.g., financial material or equipment).
- o Manage activities to meet plans, allocating time and resources effectively.
- o Keep track of and document plans, assignments, changes, and deliverables.
- o Plan for dependencies of one task on another.
- o Coordinate efforts with all affected parties, keeping them informed of progress and all relevant changes to project timelines.
- o Take necessary corrective action when projects go off track.
- o Assure job accommodations are made for personnel who need or request them.

304. **Creative Thinking –** Generating innovative and creative solutions.

Employing unique analyses

- o Use original analyses and generate new, innovative ideas in complex areas.
- o Develop innovative methods of obtaining or using resources when insufficient resources are available.

Generating innovative solutions

- o Integrate seemingly unrelated information to develop creative processes or solutions.
- o Reframe problems in a different light to find fresh approaches.
- o Entertain wide-ranging possibilities and perspectives to develop new solutions.
- o Find new ways to add value to the efforts of a team and organization.

Seeing the big picture

- o Understand the pieces of a system as a whole and appreciate the consequences of actions on other parts of the system.
- o Monitor patterns and trends to see a bigger picture.
- o Modify or design systems to improve performance.

Foundational Competencies

305. **Problem Solving and Decision-Making –** Generating, evaluating, and implementing solutions to problems.

Identifying the problem

- o Anticipate or recognize the existence of a problem.
- o Identify the true nature of the problem and define critical issues.
- o Evaluate the importance and criticality of the problem.
- o Use all available reference systems to locate and obtain information relevant to understanding the problem.
- o Recall previously learned information that is relevant to the problem.

Locating, gathering, and organizing relevant information

- o Effectively use both internal resources (e.g., internal computer networks, company filing systems) and external resources (e.g., internet search engines) to locate and gather information relevant to solving the problem.
- o Examine information obtained for relevance and completeness.
- o Recognize important gaps in existing information and take steps to eliminate those gaps.
- o Organize/reorganize information as appropriate to gain a better understanding of the problem.

Generating alternatives

- o Integrate previously learned and externally obtained information to generate a variety of high-quality alternative approaches to the problem.
- o Skillfully use logic and analysis to identify the strengths and weaknesses, the costs and benefits, and the short- and long-term consequences of different solutions or approaches.

Choosing a solution

- o Decisively choose the best solution after evaluating the relative merits of each possible option.
- o Make difficult decisions even in highly ambiguous or ill-defined situations.

Implementing the solution

- o Commit to a solution in a timely manner.
- o Develop a realistic approach for implementing the chosen solution.
- o Document the problem and corrective actions taken and their outcomes and communicate these to the appropriate parties.
- o Observe and evaluate the outcomes of implementing the solution to assess the need for alternative approaches and to identify lessons learned.

306. **Working with Tools and Technology –** Selecting, using, and maintaining tools and technology, including adaptive tools and technology, to facilitate work activity (with accommodation when necessary).

Using tools

- o Operate tools, technology, and equipment in accordance with established operating procedures and safety standards.
- o Demonstrate appropriate use of tools and technology to complete work functions.

Selecting tools

- o Select and apply appropriate tools or technological solutions to the problem at hand.

Keeping current on tools and technology

- o Demonstrate an interest in learning about new and emerging tools and technologies.
- o Adapt quickly to changes in process or technology.
- o Seek out opportunities to improve knowledge of tools and technologies that may assist in streamlining work and improving productivity.

Troubleshooting and maintenance

- o Learn how to maintain and troubleshoot tools and technologies.
- o Perform routine maintenance on tools, technology, and equipment.
- o Determine causes of errors and take the appropriate corrective action.
- o Develop alternatives to complete a task if desired tool or technology is not available.

Foundational Competencies

307. **Scheduling and Coordinating –**Making arrangements that fulfill all requirements as efficiently and economically as possible.

Arranging and informing

- o Make arrangements (e.g. for meetings or travel) that fulfill all requirements as efficiently and economically as possible.
- o Inform others of arrangements, giving them complete, accurate, and timely information.
- o Ensure that others receive needed materials in time.
- o Handle all aspects of arrangements thoroughly and completely.
- o Respond to the schedules of others affected by arrangements, resolve schedule conflicts or travel issues, and take corrective action.

Coordinating in distributed environments

- o Coordinate schedules of colleagues, co-workers, and clients in regional locations. (i.e., across time zones) to ensure that inconvenience is minimized and productivity is enhanced.
- o Leverage technology (e.g., internet, teleconference) to facilitate information sharing in distributed work environments.
- o Take advantage of team member availability throughout business hours in multiple time zones to enhance productivity.

Shiftwork

- o Effectively coordinate the transition of staff at the beginning and end of each work shift.
- o Disseminate crucial information in an organized manner to rapidly bring staff up to speed at the start of their shifts.
- o Ensure that staff is updated on work completed on past shifts and work that still needs to be completed.

308. **Checking, Examining, and Recording –** Entering, transcribing, recording, storing, or maintaining information in written or electronic/digital format, including adaptive devices and software.

Detecting errors

- o Detect and correct errors or inconsistencies, even under time pressure.
- o Identify vague or ambiguous documentation.
- o Route errors to appropriate person to correct documentation.

Completing forms

- o Select and complete appropriate forms quickly and completely.
- o Forward or process forms in a timely and accurate manner.
- o Attend to and follow through on important items requiring action.
- o Expedite forms, orders, or advances that require immediate attention.

Obtaining information

- o Obtain appropriate information, signatures, and approvals promptly.
- o Verify that all information is present and accurate before forwarding materials.
- o Compile, categorize, and verify information or data.
- o Apply systematic techniques for observing and gathering data.

Maintaining logs, records, and files

- o Organize records and files to maintain data.
- o Keep logs, records, and files that are up-to-date and readily accessible (e.g., driver logs, flight records, repair records).
- o Update logs, records, and files, noting important changes.
- o File data and documentation in accordance with organization's requirements.

309. **Business Fundamentals –** Using information on basic business principles, trends, and economics.

Situational awareness

- o Understand the mission, structure, and functions of the organization.
- o Recognize one's role in the functioning of the organization and understand the potential impact one's own performance can have on the success of the organization.
- o Grasp the potential impact of the company's well-being on employees.

Foundational Competencies

Business ethics

- o Demonstrate respect for coworkers, colleagues, and customers.
- o Act in the best interest of the company, the community, and the environment.
- o Comply with applicable laws and rules governing work and report loss, waste, or theft of company property to appropriate personnel.

Market knowledge

- o Understand market trends in the industry and the company's position in the market.
- o Know who the company's primary competitors are and stay current on organizational strategies to maintain competitiveness.
- o Uphold the organization through building and maintaining customer relations.
- o Recognize major challenges faced by the organization and industry, and identify key strategies to address challenges.

310. **Sustainable Practices** – Meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Minimizing environmental impact

- o Use equipment, processes, and systems that minimize environmental impact.
- o Seek to upgrade processes beyond pollution control to pollution prevention.
- o Utilize advances in science and technology to upgrade levels of efficiency and environmental protection.
- o Strive to minimize waste through reuse and recycling, improve efficiency, and reduce resource use.

Complying with standards, laws, and regulations

- o Comply with federal, state, and local laws, regulations, and policies related to environmental impact.
- o Use sustainable business practices consistent with ISO 14001 International Environmental Management Guidance.

311. **Health and Safety** – Complying with procedures for a safe and healthy work environment.

Maintaining a safe environment

- o Follow established personal and jobsite safety practices.
- o Comply with federal, local, and company health and safety regulations.
- o Identify unsafe conditions and take corrective action.
- o Properly handle and dispose of hazardous materials.
- o Follow organizational procedures and protocols for safe evacuation and emergency response.
- o Maintain a sanitary and clutter-free work environment
- o Administer first aid or CPR or summon assistance as needed.

Safeguarding one's person

- o Use equipment and tools safely.
- o Use appropriate personal protective equipment.

Industry Competencies

Tier 4: Industry-Wide Technical Competencies

401. **Geological Concepts** – Understand where and how economic deposits are formed based on fundamental geological concepts and processes that shape the earth.

Earth processes

- Understand the structure of the earth.
- Why economic deposits are where they are
- Earth's history

Basic Rocks and minerals - Understand the relationship between chemical elements, compounds, minerals and rocks.

- Elements, chemical compounds, minerals
- Common rock-forming minerals
- Types of rocks

Economic deposits - Understand the processes that form different types of deposits and how they interact with the enviroment

- Types of deposits and how they are formed
- How rocks are changed by environmental interactions and how these changes affect mining activities
- What negative impacts (Risks) are possible from different types of deposits

402. **Exploration** - Understand how economic deposits are found, identified and evaluated for their development potential.

Prospecting - Methodological, high risk hunt for economic deposits

- Decide on the commodity needed
- Level of acceptable risk in the following areas: political, environmental, infrastructure, transportation, geological, mineralogical that will determination where on earth to start looking
- Library search to gather available geological, mineralogical, and geographic data
- Ground confirmation

Remote large scale - Geophysics, space, airborne and land based

- Satellite data looking for indicator mineralogy and geologic structures
- Airborne surveys of geophysical properties, like: magnetic, density, electric and electromagnetic responses which provide clues about the minerals and rocks present below the ground as well as their depth of burial and areal extent
- Ground confirmation: collect dense geophysical data based on the airborne results

Sampling - Collection of geochemical samples

- Mapping of indicator mineralogy, faults, and folds using the previously collected data as a guide
- Survey of geochemical properties from rock, soil and plant material

Drilling - Drilling sampling of areas of interest

- Drilling samples of represntative areas of the rock mass
- Different types of drill samples are collected for mineralogical, rock mechanic properties and chemical analysis
- All data collected to this point are placed into a three dimensional block model of the property for mine planning purposes
- After every step map data correlations and a continue/non-continue decision is made

403. Mineral Econimics

- Mineral deposits have different types of risks that impact whether the resource can be mined
- Development of a mineral resource depends on the financial calculations that determine profitability
- Price of the mineral is an important part of whether a resource is developed and prices are set different ways for different minerals
- Minerals have different markets
- Companies have different structures to develop resources at different stages - prospectors focus on exploration, junior companies prove the resource is profitable, small to medium companies have 1 or 2 mines, large diversified senior companies have multiple mines, often in many countries and may mine many different types of minerals
- Discuss global trends that impact the mining industry

404. <u>Mining Methods, Operations, and Equipment</u> – Understand a variety of methods and equipment used in both underground and surface mining operations.

Mining cycle

- Explain the typical stages in mining operations - drill, load, blast, muck, haul, dump

Underground mines

- Recognize basic underground mining methods
- Know basic underground mining terminology - stopes, adits, drift, raise, sump, etc.
- Identify common underground mining equipment

Surface mines

- Recognize basic surface mining methods
- Identify common surface mining equipment
- Know basic surface mining terminology - slopes, pushbacks, strip ratio, etc.

405. Processing and Refining - Understand the basic steps in processing and refining a variety of materials.

Blasting

- Most economic method to break rock to the correct size for the mining methods used

Crushing particle size reduction

- Know the typical crushing equipment - gyratory, jaw, and cone crusher, etc.
- Understand what happens to the material during this stage of the process

Grinding even smaller particals

- Know the typical grinding equipment - AG mills, SAG mills, ball mills, etc.
- Understand what happens to the material during this stage of the process

Specific processes retrieving the commodity of interest

- Leaching: Pads or insitu
- Commodity extraction from leaching fluids
- Floatation, for ore concentration or cleaning
- Smelting for metal extraction from concentrates

406. Business of Mining - is the deposit economic with everything considered

- Junior exploration companies conduct high risk exploration to identify and confirm significant economic deposits

- Define geometry of deposit - identify economically viable approaches to mining and processing methods (optimized mine design)
- Economic analysis of project - Social license, capital cost, operational cost, projected revenue, and the tax liability
- Mining of materials of monetary value - mineral products, by-products, and co-products costs from guange minerals
- Processing of mined materials to commercial products of value (commodity)
- Permitting, time required, operations, closure, long term monitoring and maintenance costs

407. Health, Safety, Environment, and Communities

- Mining companies often have community health programs in developing countries and remote locations
- Mining companies take measures to protect workers from exposures that could be harmful to long-term and short-term health
- Mining companies have comprehensive safety programs to protect workers
- Mining companies take steps to prevent contamination of watersheds from such things as acid mine drainage or chemical spills
- Mining companies engineer structures and processes to impound mining residues such as tailings and rock storage facilities
- Mining companies take measures to be compliant with air quality standards including reducing release of CO2
- Mining companies take measures to protect ecosystems
- Mining companies work with local and indigenous communities to ensure development projects are compatible with the community and help obtain social license to operate

Tier 5: Industry-Sector Technical Competencies

501. Metal –

- Types of metallic resources and geographic distribution
- Major types of metallic mineral deposits
- Major producers and producing countries
- Prices of metals
- Types of mining methods - surface and underground - and implications for cost, maintenance, safety
- Types of mining equipment - surface and underground - implications for cost, maintenance, safety
- Types of processing methods
- Critical risks - analysis of safety data
- Mine life
- Environmental stewardship
- Social license to operate including federal, vs state vs private land and permitting processes

- o Workforce - types of jobs, skills, education, demographics

502. Nonmetal –

- o Industrial minerals - types and distribution
- o Markets and transportation issues - including role of changing technologies (e.g. lithium)
- o Types of mining methods
- o Types of mining equipment
- o Types of processing methods
- o Critical risks
- o Mine life
- o Environmental stewardship
- o Health and safety
- o Social license to operate including federal vs state vs private land and permitting processes
- o Workforce - types of jobs, skills, education, demographics

503. Stone, Sand, Gravel & Cement

- o Uses of products and required standards for products
- o How cement and concrete are made
- o Types of mining methods
- o Types of mining equipment
- o Markets and transportation issues
- o Permitting issues
- o Environmental stewardship - working in urban areas
- o Health and Safety
- o Social license to operate - community engagement
- o Workforce - types of jobs, skill, education, demographics

504. Coal, Gas & Oil Sands

a. Types of resources and classification (e.g. peat, lignite, bituminous, anthracite) and quality measures
b. Locations of coal basins and relationship to natural gas and oil

c. Market differences for steam coal, metallurgical coal, natural gas, oil and market trends
d. Surface and underground mining methods and equipment
e. Critical Risks - safety data and health issues
f. Permitting issues
g. Environmental stewardship - reclamation, "clean coal", natural gas
h. Health and safety management
i. Social license to operate
j. Workforce

505. Coal –

- o Surface versus underground operational considerations (i.e., mining and processing methods and technologies)
- o Equipment and associated maintenance (present/future)
- o Critical risk management

- o Mining method and processing optimization, strategic innovation investments
- o Coal pricing structures - producer prices, negotiated prices, independent prices, commodity exchange prices
- o Reserves available, explorations/acquisitions for next project(s), cash availability versus needs

Occupational Competencies

Tier 6, 7 & 8: Trainer Knowledge, Technical Competencies, and Requirements

601. Instructional Design - Design and develop informal and formal learning content using a variety of methods.

Conducts a needs assessment

- Identifies organizational objectives and the learning opportunity
- Identifies target population characeristics and characteristics of the environment
- Gathers and evaluates resources and information, analyzes findings, and incorporates or synthesizes information into the design and development process
- Identifies anticipated constraints or problems affecting desing success or failure, such as equipment deficiencies or lack of support
- Defines basic outcomes of the learning solution to solve the problem or meet the opportunity

Identifies appropriate learning approach

- Selects learning approaches that best address the needs of the learners and the organization

Applies learning theory

- Incorporates sound principles of current learning theory to the practice of instructional design

Collaborates with others

- Builds partnerships and relationships among the participants in a learning design project and establishes sign-off and approval processes for each step of the design process

Designs a curriculum, program, or learning solution

- Uses a variety of techniques for determining instructional content
- Creates or partners with others to plan and design the curriculum, program, or learning solution
- Designs an experience that enables informal learning

Designs instructional material

- Selects, modifies, or creates an appropriate design and development model or plan for a given project
- Identifies and documents measurable learning objectives
- Selects and uses a variety of techniques to define, structure, and sequence the instructional content and strategies
- Designs instructional content to reflect an understanding of the diversity of learners or groups of learners

Occupational Competencies

Analyzes and selects technologies

- Analyzes the characteristics, benefits, and pros/cons associated with existing and emerging technologies, including online learning, blended learning, and informal learning options and their possible application in an instructional environment
- Considers online learning options such as extended books and lectures, extended community, extended expert access, simulations, and embedded help
- Selects technologies based on a needs-driven approach in order to accomplish learning goals and objectives

Integrates technology options

- Integrates existing and emerging technologies to achieve learning goals
- Integrates new material and technologies with existing learning resources to produce a coherent blended solution

Develops instructional materials

- Selects or modifies existing instructional materials or develops new instructional materials
- Conducts review of materials with appropriate parties, such as subject matter experts, design team, and the target audience
- Creates logical learning units/objects as appropriate
- Designs or builds assets to support the learning experience and meet objectives as appropriate
- Develops instructional content to reflect an understanding of the diversity of learners or groups of learners

Evaluates learning design

- Proactively identifies appropriate evaluation techniques and applies them, such as summative and formative evaluation, the four levels, and usability testing
- Conducts appropriate test and revision cycles to assess and test the learning design solution and its impact
- Assesses whether the learning design solution produces positive results, such as a change in learner attitude, skill, knowledge, and/or behavior

602. Training Delivery - Deliver informal and formal learning solutions in a manner that is both engaging and effective.

Manages the learning environment

- Schedules events and users/participants
- Selects facilities conducive to learning
- Prepares agenda/learning objectives in advance
- Organizes materials and mulitimedia equipment
- Ensures access and supplies resources for learning users/participants
- Provides for breaks/refreshments

Prepares for training delivery

- Reviews participant and facilitator materials prior to delivery
- Gathers information about the participants and their characteristics
- Tailors examples and analogies to ensure relevance to participants

Occupational Competencies

Conveys objectives

- Informs users/participants of the goals and purpose of the learning solution
- Ensure that learners have a realistic understanding of what the solution can accomplish

Aligns learning solutions with course objectives and learner needs

- Monitors needs and learning preferences of users/participants to ensure that the learning solutions meet learner and course objectives
- Responds to feedback from learners and make adjustments or enhancements to the learning solution based on this feedback

Establishes credibility as an instructor

- Demonstrates understanding of course content and its relationship to business needs
- Uses appropriate terminology and relevant business examples
- Provides useful information when responding to questions
- Helps participants apply learning to on-the-job situations

Creates a positive learning climate

- Establishes a learning environment where learners feel safe to try new skills and behaviors, where individual differences are respected and confidentiality is support
- Personally models behavior that is consistent with the goals of the program

Delivers various learning methdologies

- Facilitates learning by using various learning delivery methodologies that achieve learning objectives and ensure application, including a combination of lectures, role plays, simulations, technology-delivered training, online learning, and learning technology support tools
- Encourages informal learning approaches such as the development of personal learning networks
- Follows facilitator materials to ensure effective and consistent delivery

Facilitates learning

- Varies delivery style to fit the audience
- Adapts to the needs of learners and adjusts curriculum as needed
- Presents information in a logical sequence
- Uses appropriate visual aids
- Listens and responds to questions and objections
- Leverages the knowledge and experience of participants to facilitate learning
- Manages group dynamics
- Manages time on learning topics

Occupational Competencies

Encourages participation and builds learner motivation

- o Uses techniques and skills to engage all participants in the learning experience
- o Adapts own style to different learner and group styles
- o Makes effort to "bring in" passive participants
- o Creates excitement and commitment to the learning experience
- o Engages learners by providing opportunities for participation and experimentation in the learning process
- o Capitalizes on participant diversity to maximize learning
- o Builds a collaborative learning environment

Delivers constructive feedback

- o Provides behavioral feedback on learners' performance during or after the learning experience
- o Maintains or enhances learners' self-esteem
- o Supports feedback with specific examples of behavior and possible alternatives for improving performance
- o Provides a balance of positive and constructive feedback
- o Creates opportunities for self-discovery and insight

Enhances learning outcomes

- o Ensures the learning objectives are met
- o Integrates or embeds appropriate performance support and assessment techniques to check learner's understanding and to ensure skill and/or knowledge acquisition, on-the-job application, and intended business results

Evaluates solutions

- o Monitors the impact of learning solution to ensure its effectiveness
- o Summarizes and communicates evaluation results

603. Evaluating Learning Impact - Use learning metrics and analytics to measure the impact of learning and performance solutions.

Identifies customer expectations

- o Works with customers or stakeholders to determine why they are interested in measurement and what they hope to accomplish with the results
- o Clearly defines research questions, expectations, resources available, and desired outcomes of the evaluation project
- o Manages unrealistic expectations

Occupational Competencies

Selects appropriate strategies, research design, and measures

- Uses customer questions and expectations to guide the selection of appropriate strategies, research designs, and quantitative and qualitative measurement tools
- Employs a variety of measures and methods to reduce bias and ensure objective conclusions
- Identifies appropriate sample sizes, data tracking methods, and reporting formats
- Balances practical implications of rigor, effort, real-life constraints, and objectivity to create a workable approach
- Identifies information that indicates whether the program is on track

Communicates and gains support for the evaluation plan

- Summarizes measurement approach into a clear plan that can be communicated to a wide range of customers and stakeholders and linked to business goals
- Communicates timelines, roles/responsibilities, and identifies other project management needs
- Gains buy-in for the plan from key partners
- Ensures that all parties understand the approach and their responsibilites

Manages data collection

- Ensures that all data collection methods are applied consistently and objectively
- Monitors ongoing data collection to ensure that assumptions required for statistical inference are being met
- Manages and documents data in a format that can be adequately manipulated during the analysis process

Analyzes and interprets data

- Creates summaries of data in a format that can be readily understood and communicated in order to facilitate decision making
- Adheres to rules of statistical analysis to reduce bias and provide adequate support for conclusions
- Uses a process of creative inquiry to fully explore the data and all of its possible implications and meaning

Applies learning analytics

- Uses a variety of human resource data available through integrated talent management platforms to identify where talent management has the greatest potential for strategic impact
- Uses data to connect learning and development practices to organizational results

Reports findings and makes recommendations to aid decision making

- Presents information in a way that is both clear and compelling to customers and stakeholders (different customers may require different information)
- Bases recommendations and conclusions on sound analysis methods
- Clarifies customer questions and the meaning of the data

Occupational Competencies

604. Managing Learning Programs - Plans, monitors, and adjusts learning and development projects or activities.

Establishes a vision
- o Creates a picture of how the learning function can improve the performance of the business and enable execution of the organization's strategy
- o Partners with business unit leaders to advocate for improving human performance through the learning function

Establishes strategies
- o Develops long-range learning, development, and human performance strategies to implement the vision
- o Understands what drives the business and determines how the learning function can best add value

Implements action plans
- o Converts the learning and development strategies into action plans
- o Balances or reconciles strategy with real-life constraints of the workplace
- o Creates a reasonable timeline that conforms to the expectations of customers/stakeholders

Develops and monitors the budget
- o Ensures budgets are prepared and followed
- o Prepares budget or project reports on a scheduled or as needed basis

Manages staff
- o Recruits, selects, and manages people in the learning function
- o Assigns roles, responsibilities, and projects
- o Conducts performance appraisals
- o Makes compensation decisions

Models leadership in developing people
- o Serve as a role model in own function
- o Provides coaching and mentoring to individuals or groups
- o Supports continuous learning and staff development that enhances performance
- o Builds team capabilities in effectively partnering with line functions to improve business performance

Manages others
- o Directs, assigns, or manages the work of others on the design team to accomplish project goals and objectives

Manages and implements projects
- o Identifies sponsors or champions to help ensure successful project implementation
- o Sources work, budgets, plans and organizes, manages activities, and executes learning design projects

Occupational Competencies

Manages external resources

- Identifies which training-related activities can be outsourced
- Determines external resources available for providing learning and development solutions
- Selects the most appropriate resources for the solution being provided
- Negotiates and manages contracts with external partners
- Maintains contacts with external partners to ensure effective delivery

Ensures compliance with legal, ethical, and regulatory requirements

- Ensures that all delivery complies with relevant legal, ethical, and regulatory requirements
- Monitors compliance and creates reports as needed

605. Performance Improvement - Applies a systematic process of discovering and analyzing human performance gaps.

Identifies the customer

- Identifies the customer and stakeholders
- Determines all groups affected by the performance issue and ensures that each group has a stakeholder representing it
- Determines which stakeholders have resources and decision-making authority

Conducts performance analysis

- Identifies business and performance goals by partnering with appropriate clients
- Compares actual and ideal performance
- Identifies performance gaps or opportunities
- Identifies who is affected by the performance gap and conditions that affect performance

Conducts cause analysis

- Identifies the root cause of a past, present or future performance gaps
- Clarifies the real problem underlying the need for the performance improvement
- Breaks down the components of a larger whole
- Examines work environment for issues or characteristics that affect human performance

Analyzes systems

- Identifies inputs, throughputs, and outputs of a subsystem, system, or suprasystem and applies that information to improe human performance
- Realizes the implications of solutions on many parts of an organization, process, or individual, and takes steps to address any side effects of human performance improvement solutions
- Evaluates how organizational politics may affect performance

Occupational Competencies

Gathers data

- Gathers pertinent information to stimulate insight in individuals and groups through use of general research methods, interviews, and other data-generating techniq

Incorporates customer and stakeholder needs

- Partners with the customer/stakeholder to clarify needs, business goals, and the objectives
- Agrees on desired results and gains agreement on how those results can be achieved efficiently and effectively

Selects solutions

- Recommends appropriate human performance improvement solutions that address the root cause(s) of performance gaps rather than symptoms or side effects
- Presents recommended changes to the client and helps them assess cost, time, and risk considerations

Manages and implements projects

- Identifies key sponsors or champions to help ensure successful project implementation
- Creates a project management plan and ensure stakeholder buy-in while also adhering to cost, schedule, and performance requirements
- Gathers formative evaluation data

Builds and sustains relationships

- Builds credibility and trust with the client based on knowledge and understanding of the business
- Partners and collaborates with the client on an ongoing basis to maintain a sustained business relationship

Evaluates results against organizational goals

- Assesses how well the results of a human performance improvement solution match intentions
- Ensures that goals are converted effectively into actions to close existing or pending performance gaps
- Obtains results despite conflicing priorities, lack of resources, or ambiguity
- Links human performance improvement to organizational goals

Monitors change

- Monitors the human performance improvement solutions as they are being implemented
- Notifies client of any emerging issues and recommends course change/correction

606. Integrated Talent Management - Builds an organization's culture, engagement, capability, and capacity through the implementation and integration of talent acquisition, employee development, retention, and deployment processes.

Aligns talent management to organizational objectives

- Works with leaders and business unit heads to ensure that talent management supports key organizational objectives
- Aligns and integrates learning and development with key talent management processes

Occupational Competencies

Uses talent management systems

- Uses technologies designed to improve talent management processes (for recruiting, developing, training) in order to meet current and future organizational needs
- Stays current on emerging technologies and understands how they work together

Equips managers to develop their people

- Develops managers' performance management skills
- Provides development tools for managers
- Helps managers promote employee engagement
- Holds managers accountable for developing talent
- Enables employees to take responsibility for their own development

Organizes delivery of developmental resources

- Provides flexible access to multiple vehicles for developing talent
- Selects and manages training suppliers and consultants
- Monitors delivery of solutions to ensure successful implementation
- Plans and manages resources to ensure adequate coverage

Promotes high-performance workplaces

- Facilitates recognition and reward of high performance
- Leverages learning opportunities for improving performance
- Balances the investment in developing high-potential talent with providing learning and growth opportunities to all employees

Coordinates workforce and succession planning

- Works with internal clients/stakeholders to design, develop, and implement succession planning or talent mobility programs to fill key positions now and in the future
- Aligns succession plans with business needs and goals
- Uses techniques such as scenario planning and forecasting, job analysis, and competency modeling

Facilitates the career development planning process

- Provides support for identifying skills, aptitudes, interests, values, accomplishments, career goals, realistic opportunities, and preparing developmental plans
- Orchestrates challenging assignments that build skill, knowledge, confidence, and credibility
- Monitors alignment between success profiles and individual development plans
- Manages or conducts career counseling sessions

Occupational Competencies

Facilitates career transitions

- Works with internal customers to provide consulting services and tools to facilitate individual career transitions such as onboarding, job changes, promotions or outplacement
- Prepares managers to carry out employee terminations

Supports engagement and retention efforts

- Integrates learning and development opportunities into the organization's retention strategy
- Measures employee engagement
- Involves experienced employees in coaching and mentoring programs
- Recognizes and leverages generational differences

Implements individual and organizational assessments

- Provides tools and resources to assess individual strengths, development needs, and limits
- Aggregates data to evaluate organizational capabilities
- Offers tools for the enhancement of skills and potential
- Arranges for testing by qualified professionals

Uses talent mangement analytics to show results and impact

- Selects measurement and evaluation criteria that reflects business goals
- Links talent management efforts to key metrics on organizational scorecards

607. Coaching - Uses an interactive process to help individuals develop rapidly and produce results.

Establishes coaching agreement

- Understands what is required in the specific coaching interaction and comes to agreement with the prospective and new client about the coaching process and relationship
- Identifies how the coaching goals link to enhanced business performance

Establishes trust and intimacy with the client

- Creates a safe, supportive environment that produces ongoing mutual respect and trust

Displays coaching presence

- Is fully conscious and creates spontaneous relationship with the client, employing a style that is open, flexible, and confident

Demonstrates active listening

- Focuses completely on what the client is saying and is not saying to understand the meaning of what is said in the context of the client's desires and to support client self-expression

Occupational Competencies

Asks powerful questions
- o Asks questions that reveal the information needed for maximum benefit to the coaching relationship and the client

Uses direct communication
- o Communicates effectively during coaching sessions and uses language that has the greatest positive impact on the client

Creates awareness
- o Integrates and accurately evaluates multiple sources of information and makes interpretations that help the client to gain awareness and thereby achieve agreed-upon results

Designs learning opportunities
- o Creates with the client opportunities for ongoing learning, during coaching and in work/life situations, and for taking new actions that will most effectively lead to agree-upon coaching results

Develops goals and plans
- o Develops and maintains an effective coaching plan with the client

Manages progress and accountability
- o Holds attention on what is important for the client and leaves responsibility with the client to take action

Meets ethical guidelines and professional standards
- o Understands coaching ethics and standards and applies them appropriately in all coaching situations

608. Knowledge Management (KM) - Captures, distributes, and archives intellectual capital in a way that encourages knowledge sharing and collaboration in the

Advocates knowledge management (KM)
- o Develops the KM vision and strategy ensuring it integrates with the organization's business strategy
- o Helps the organization understand the concept and value of effective knowledge creation, sharing, and reuse

Uses talent management systems
- o Uses technologies designed to improve talent management processes (for recruiting, developing, training) in order to meet current and future organizational needs
- o Stays current on emerging technologies and understands how they work together

Occupational Competencies

Equips managers to develop their people

- Develops managers' performance management skills
- Provides development tools for managers
- Helps managers promote employee engagement
- Holds managers accountable for developing talent
- Enables employees to take responsibility for their own development

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609. Change Management (CM) - Applies structured approaches to shift individuals, teams, and organization from a current state to a desired state.

Establishes sponsorship and ownership for change

- Clarifies case for change and desired outcomes
- Facilitates client sponsorship of expected outcomes
- Engages stakeholders to build critical mass of support

Build involvement

- Involves people to raise awareness and gathers input on the best course of action
- Helps clients and change leaders build involvement and ownership in the change process
- Helps clients create a communication plan that generates buy-in and commitment
- Facilitates effective two-way communications to ensure understanding, commitment, and behavior change

Creates a contract for change

- Helps clients contract for change, clarify outcomes, and establish realistic expectations for change
- Identifies boundaries for change
- Clarifies relationships, roles, and ethical parameters
- Creates conditions for success

Occupational Competencies

Conducts diagnostic assessments

- Determines which data are needed to clarify issues, including stakeholder expectations
- Collects information to pinpoint initial steps
- Diagnoses problems as well as perceptions favoring change
- Assesses current reality against business/organizational strategy and desired outcomes to define change efforts needed
- Identifies formal and informal power networks
- Establishes design requirements for future state

Provides feedback

- Prepares clients/stakeholders for receiving the results of data gathering and diagnosis
- Provides feedback to people in position to influence with course corrections on change strategy
- Articulates what is happening and what needs to happen in a complex system
- Builds an impetus to support change

Facilitates strategic planning for change

- Facilitates creation of overall change strategy with sponsor and key change leaders
- Clarifies what must change, how to minimize the human impact and optimize buy-in
- Helps identify all technical, organizational, cultural, and people-related change initiatives
- Shapes the best process and conditions to accomplish results
- Designs appropriate change process plans to be time efficient and responsive to needs

Supports the change intervention

- Helps clients design, assess impacts, plan and implement the change effort and strategy
- Identifies innovative ways to structure the system
- Creates new approaches or models of programs as appropriate
- Offers advice and support for managing complex projects as needed
- Refines change strategy
- Supports learning and course correction

Encourages integration of change into organizational culture

- Fosters chared mindset in support of change
- Supports alignment of all systems, policies, and processes of the organization to match and support the change
- Supports integration and mastery of change effort so that it becomes the norm

Occupational Competencies

Manages consequences

- Creates strategy to reduce human trauma
- Manages reactions to the change and the unanticipated consequences of the change
- Surfaces and resolves conflict
- Helps clients overcome resistance
- Influences those who react negatively to support the change

Evaluates change results

- Facilitates information sharing during the change to ensure that results match intentions
- Collects information about the impact of the change
- Communicates results and best practices to interested stakeholders

Management Competencies

Tier 9: Management Competencies

901. **Staffing**

Planning

- Effectively engage in staff planning and help to ensure that work unit is appropriately staffed to accomplish its goals.
- Anticipate obstacles to staff planning, such as shifting economic and political climates, and make appropriate contingency plans for these possibilities.
- Understand how to provide reasonable accommodations to jobseekers and workers with disabilities during the hiring process and in the workplace.

Identifying required skills

- Accurately and comprehensively identify candidate skills needed to perform in vacant positions.

Assessing qualifications

- Assess candidate qualifications thoroughly and accurately, recognizing and hiring /promoting those who possess the skills needed to fulfill vacant positions.

902. **Informing**

Gathering and disseminating

- Continually gather data from diverse sources to determine what information employees need to perform their work.
- Disseminate information to employees in a timely, efficient manner.

Keeping employees informed

- Keep employees well-informed through a variety of means, including productive and informative group and individual meetings and targeted written communications.
- Highlight important information in communications and avoid flooding employees with irrelevant information.

Updating information

- Monitor internal and external environments to determine if additional information is required for employees to perform tasks.
- Inform employees when changes occur that affect them and distribute updated information when necessary.
- Provide information to peers and subordinates in a timely way that maintains cooperative relationships among people.

903. **Delegating**

Delegating efficiently

- Efficiently delegate tasks so that organizational goals are met within established timelines.
- Delegate tasks that are not central to the leader's role and which allow the leader to use his/her time more effectively.

Delegating appropriately

- Make delegation decisions that take into account the size of the task, whether an employee has the necessary background and skills to complete the task, and the sensitivity and importance of the task.
- Delegate tasks that are challenging but not overwhelming.
- Delegate tasks that develop and extend employee skills.

Monitoring

- Monitor accomplishment of delegated tasks, and provides constructive, timely feedback.
- Provide support and assistance for goal accomplishment, and make mistakes a learning experience.

Management Competencies

904. **Networking**

Building relationships

- o Seek opportunities to make contacts and build relationships, including through organizational events, social events, external organizations, and professional activities.

Partnering

- o Establish strong and lasting partnerships with business contacts.
- o Proactively seek ways of increasing business opportunities with contacts.
- o Skillfully influence and negotiate with partners to create opportunities that increase the competitive position of both parties.

Leveraging contacts

- o Leverage contacts to obtain information relevant to the health and continued growth of the organization, including enhanced perspectives and feedback on organizational performance.

905. **Monitoring Work**

Identifying performance criteria

- o Identify work-related performance criteria that need to be measured for individual and team performance, and determine a means of measuring these criteria.

Measuring progress

- o Measure progress against timelines set for performance of tasks.
- o Ask questions of subordinates and team members to check for problems in work processes.
- o Encourage subordinates and team members to report problems and mistakes by creating a non-threatening environment for discussion of problems.

Reviewing work

- o Conduct frequent progress review meetings with subordinates and team members to discuss progress and any barriers to progress.
- o Conduct after-reviews upon task completion to identify lessons learned and generate ideas for more effective task completion in the future.

Soliciting feedback

- o Solicit feedback from multiple sources during and following task completion to ensure employee tasks are performed correctly, and to learn how employee and team performance can be improved.
- o Conscientiously monitor downstream consequences of work to ensure tasks are completed correctly and have intended consequences.

906. **Entrepreneurship**

Thinking innovatively

- o Constantly search for new ways of improving existing processes and doing things more efficiently.
- o Strive to understand what is missing from current product stream, and search for new ideas for product improvement everywhere.
- o Attempt to address product gaps and build the business by creating innovative and unique solutions.

Influencing decision makers

- o Know which organizational leaders to influence to win support for new ideas and skillfully persuade key decision makers to invest appropriate resources to transform new ideas into reality.
- o Woo venture capitalists, and other extra-organizational constituents to seek financial support for new ideas.

Encouraging entrepreneurial activity

- o Encourage innovation and entrepreneurial activity in team members.
- o Challenge teams to take calculated risks for innovation, and ensure teams have time to pursue their ideas for new and improved products or processes.

- Hold regular team meetings to solicit bold new ideas.

Championing great ideas

- Advance and promote the best ideas, even in the face of organizational resistance.
- Shield the team from bureaucratic processes that interfere with an innovative climate, and work to change processes that interfere with growth and innovation.

Rewarding innovation

- Recognize the contributions of those who have enabled positive change, and give appropriate rewards for extraordinary achievements.

907. **Supporting Others**

Demonstrating positive regard

- Show acceptance and positive regard for employees.
- Maintain a pleasant, cheerful disposition.
- Provide support and sympathy when others are anxious or upset.

Counseling

- Counsel and encourage employees who have motivational or performance problems.
- Indicate a desire to help subordinates learn from mistakes and overcome performance problems.

Advocating

- Publicly affirm the importance and value of individual and group tasks in order to minimize the effect of budget cuts or other constraints on resources.
- Skillfully advocate on behalf of employees, teams, and their work.
- Work hard to increase the prominence of employee's or team's work within organization.

Helping

- Pitch in to help support subordinates when workload is high.
- Minimize disruptions and help employees overcome bureaucratic work obstacles.
- Work with leaders in other organizational units to keep work flowing smoothly.

908. **Motivating and Inspiring**

Generating enthusiasm

- Generate enthusiasm for task objectives and team accomplishment through standard and creative-influence techniques.
- Focus team effort and enthusiasm on goal attainment.
- Secure behavioral commitment of team members for goal attainment.

Recognizing

- Recognize contributions and achievements of all types, among people in high- and low-visibility jobs alike.
- Actively search for contributions to recognize.
- Recognize improvements in performance as well as commendable efforts that failed.

Rewarding

- Reward employees for high performance.
- Take the time to determine what is rewarding for individual employees, and fairly and objectively dispense rewards based on performance indicators that reflect a person's effort and competence.

Management Competencies

Setting an example

- o Set an example for others by acting in ways that are consistent with organizational goals and objectives.
- o Confront behavior that undermines the reputation of the organization.

909. **Developing and Mentoring**

Encouraging self-assessment

- o Help employees identify skill deficiencies.
- o Create a safe environment that promotes self disclosure of a disability to request a reasonable accommodation if needed.
- o Develop mechanisms that elicit feedback from multiple perspectives, and encourage employees to solicit feedback from others about strengths and weaknesses.
- o Mentor employees by giving specific, constructive feedback on how performance can be improved.

Enhancing skills on the job

- o Provide opportunities for skill development on the job.
- o Plan for and seek out developmental opportunities and stretch assignments that simultaneously develop employees and help the organization reach its goals.
- o When appropriate, give employees opportunities to mentor more junior employees.

Promoting training

- o Encourage employees to attend relevant training and workshops to broaden skills.
- o Explain why training is relevant to employee's career and work with employees to identify training goals.

Supporting learning

- o Provide support and encouragement during learning process.
- o Express confidence that employees will be able to learn a new procedure or skill.

Preparing for the future

- o Anticipate future changes in work tasks due to changing economic and/or political climates.
- o Provide employees with developmental opportunities that prepare them for these changes.

Identifying career issues

- o Provide career advice.
- o Help employees identify career problems including lack of advancement, interpersonal conflicts, and burnout.
- o Help employees identify career paths and promotion opportunities in the organization.

910. **Strategic Planning/Action**

Establishing objectives

- o Establish long-range objectives and specify the strategies and actions necessary to achieve those objectives.
- o Identify the most probable short- and long-term consequences of implementing various strategies.
- o Strategically analyze the risks, benefits, and opportunities of various strategies.

Implementing strategies

- o Confidently implement chosen strategies, despite difficulty and resistance from others.
- o Collaborate across organizational units to ensure buy-in and follow-through on strategies.
- o Skillfully obtain commitment from affected parties to transform strategic vision into reality.

Management Competencies

Capitalizing on alliances

- o Recognize alliances, either internal or external to the organization, that are complementary and benefit the competitive position of multiple parties.
- o Strategically shifts orientation to capitalize on these alliances.

Recognizing and dealing with obstacles

- o Comprehensively consider a wide range of problems that could affect the entire work unit.
- o Strategically identify ways to address or capitalize on these problems.

Identifying emerging trends

- o Identify emerging trends and form strategic plans to address them.

911. **Preparing and Evaluating Budgets**

Gathering information

- o Study all relevant budget material and anticipate future needs by gathering data on forthcoming plans.
- o Ensure that budget proposals incorporate all elements.
- o Translate organizational objectives, priorities, and analysis of current resources into accurate budget proposals.

Preparing

- o Prepare highly accurate and precise estimates of costs.
- o Obtain the most recent cost estimates from vendors or catalogs.

Ensuring accuracy

- o Recognize and correct misstatements or errors of omission in budget proposals.
- o Effectively consolidate budget requests and proposals of multiple units.

Ensuring completeness

- o Prepare budget justifications and proposals that reflect the needs of the office.
- o Submit proposals that are thorough and accurate, and that receive management acceptance with little or no questioning.

912. **Clarifying Roles and Objectives**

Explaining job duties

- o Clearly explain job duties, responsibilities, and priorities.
- o Inform employees of the work for which they will be responsible and help them establish priorities.
- o Check to ensure that employees understand duties and responsibilities.

Instructing

- o Provide instruction on how to accomplish an assignment.
- o Explain correct and incorrect ways to accomplish tasks.
- o Provide timely and effective feedback about whether task is being performed correctly.

Setting performance goals

- o Help employees set performance goals.
- o In consultation with employees, set goals that are clear, specific, and attainable.
- o Inform employees of deadlines for goal attainment.

Management Competencies

Linking tasks to organizational objectives

- o Explain relationship between individual work tasks and overall organizational objectives.
- o Continually rethink job duties and responsibilities as organizational objectives shift, and communicate new roles and responsibilities to employees as appropriate.

913. **Managing Conflict and Team Building**

Gathering information

- o Identify sources of conflicts, and provide parties with an opportunity to express their point of view.
- o Remain impartial in gathering and verifying information relevant to the conflict.

Encouraging resolution

- o Make healthy use of conflict and disagreement to promote learning and expand team perspectives.
- o Encourage parties to work together towards problem resolution.
- o Work with parties to identify a range of acceptable solutions.
- o When appropriate, propose effective compromises that satisfy some of each parties' needs.
- o Ensure mutual commitment to a solution.

Discouraging unproductive behavior

- o Express concern for improving relations among team members.
- o Explain how dispute is affecting others.
- o Discourage non-productive behavior such as threats, insults, stereotyping, or exaggerations.

Building cooperative teams

- o Encourage and build mutual trust, respect, and cooperation among team members.
- o Seize opportunities and utilize creative methods to build team cooperation and cohesion.

914. **Developing an Organizational Vision**

Developing a vision

- o Develop a strategic vision for the future of the organization or unit.

Generating excitement

- o Identify fundamental values and beliefs to guide the organization into the future.
- o Generate excitement, enthusiasm, and commitment for the vision.

Gaining commitment

- o Skillfully gain commitment to make organizational vision a reality.
- o Create a belief that vision can be achieved.

Inspiring others

- o Embody organizational vision and demonstrate conviction in vision in order to inspire others.

Management Competencies

915. **Monitoring and Controlling Resources**

Identifying resources

- o Continually seek to identify resources (e.g. staffing, training, and monetary resources), both internal and external, that can be useful to unit and assist in work accomplishment.
- o Proactively work to secure additional resources for work unit.

Informing

- o Develop strategic plans for making a wide array of resources available.
- o Ensure that knowledge of those resources is spread throughout organization.

Monitoring

- o Develop strategic plans to anticipate future resource needs, and accurately identifies, tracks, and prioritizes existing resource needs.
- o Monitor resource availability and make contingency plans to ensure the availability of adequate resources in the event of unforeseen circumstances.

Creating efficiencies

- o Consistently seek to perform work unit tasks in a cost-efficient manner.
- o Identify ways to produce the same level and quality of work while utilizing fewer resources.
- o Create an organizational climate in which cost effectiveness is valued and rewarded.

APPENDIX B

Evaluation Data

Treatment Group

Date Assessed	*Number of Participants	Pre Assessment										Post Assessment										
		Q1	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Average*	*Average %*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Average%*	*Average %*	*Difference*
		% Correct	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*Incorrect*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*% Correct*	*Correct*	*Incorrect*	
5-Jan	15	64.29	S/A	92.86	100.00	S/A	S/A	78.57	S/A	83.93	16.07	76.92	S/A	84.62	92.31	S/A	S/A	92.31	S/A	86.54	13.46	2.61
6-Jan	24	65.22	S/A	95.83	100.00	S/A	S/A	70.83	S/A	82.97	17.03	86.96	S/A	100.00	100.00	S/A	S/A	95.65	S/A	95.65	4.35	12.68
27-Jan	20	55.56	S/A	95.00	90.00	S/A	S/A	66.67	S/A	76.81	23.19	83.33	S/A	88.89	89.47	S/A	S/A	83.33	S/A	86.26	13.75	9.45
10-Feb	19	66.67	S/A	100.00	94.44	S/A	S/A	61.11	S/A	80.56	19.45	88.89	S/A	94.44	94.44	S/A	S/A	94.44	S/A	93.05	6.95	12.50
24-Feb	15	69.23	S/A	85.71	92.86	S/A	S/A	69.23	S/A	79.26	20.74	84.62	S/A	92.86	100.00	S/A	S/A	85.71	S/A	90.80	9.20	11.54
6-Mar	5	60.00	S/A	100.00	100.00	S/A	S/A	0.00	S/A	65.00	35.00	0.00	S/A	100.00	100.00	S/A	S/A	40.00	S/A	60.00	40.00	-5.00
31-Mar	23	73.91	S/A	95.45	90.91	S/A	S/A	45.45	S/A	76.43	23.57	90.48	S/A	85.00	100.00	S/A	S/A	80.95	S/A	89.11	10.89	12.68
6-Apr	23	73.91	S/A	95.65	91.30	S/A	S/A	45.45	S/A	76.58	23.42	90.91	S/A	95.65	100.00	S/A	S/A	86.96	S/A	93.38	6.62	16.80
28-Oct	12	75.00	S/A	100.00	100.00	S/A	S/A	54.55	S/A	82.39	17.61	75.00		90.91	100.00			70.00		83.98	16.02	1.59
4-Nov	23	68.42	S/A	70.00	95.00	S/A	S/A	94.74	S/A	82.04	17.96	61.90	S/A	100.00	100.00	S/A	S/A	94.74	S/A	89.16	10.84	7.12
18-Nov	12	54.55	S/A	90.91	81.82	S/A	S/A	70.00	S/A	74.32	25.68	63.64	S/A	100.00	100.00	S/A	S/A	81.82	S/A	86.37	13.64	12.05

	Total number of participants for	
S/A = Short Answer	198 **treatment group**	**Average Difference** 8.55

Control Group

Date Assessed	*Number of Participants	Pre Assessment									Post Assessment									
		Q1	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Average*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*	*Q8*	*Average*	*Difference*
16-Dec	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		
28-Apr	26	68		83.33		100	S/A	S/A	42.86	S/A	73.5475	68	S/A	100	95.83	S/A	S/A	68	S/A	81.0755	7.528
10-Feb	19	44.44		94.12		94.12	S/A	S/A	100	S/A	83.17	70.59	S/A	100	100	S/A	S/A	100	S/A	90.752	7.582

	Total number of participants for control	
	45 **group**	**Average Difference** 7.555

Total study number of participants 243

**All numbers are percentages

Working at Heights

General Hazard Awareness

Pre-Test

In the workplace, more falls occur from heights than from the same level.

A. True

B. False

List **3** ways in which slips and trips can be prevented.

A fall hazard exists in photo #1.

A. True
B. False

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A fall hazard exists in photo #2.

A. True
B. False

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List **3** ways to control the hazard in photo #1.

List **3** ways to control the hazard in photo #2

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Which photo shows the worker in a properly donned harness?

A. Picture A
B. Picture B
C. Picture C
D. None
E. All

Mary is walking to a meeting in the mill and walks by the following situation in photo #3. What should Mary do? List the appropriate steps Mary should take.

Types of Falls

- Falls from same level (about 60% of falls)
  - Slips
  - Trips
- Falls from heights (about 40% of falls)

Preventing Slips and Trips

- Housekeeping
- Maintain clear, tidy work areas
- Keep walkways well-lit, free of clutter
- Store materials and equipment in orderly manner
- Clear walkways of slippery materials
- Do not run

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Ladders

- Employees on ladders may work without protection if:
  - No more than six feet from the ground
  - Ladder steps are dry and clean
  - Ladder is placed on a level surface
  - Employee has controlled remaining risks

Working at Heights

- When you must work without guarding:
  - Work permit
  - Job Safety Analysis
  - Risk Analysis
  - Open-hole permit
  - Wear fall protection

Barricading and Guarding

- Guarding by standard railing
- Proper warning signs
- Passage provided by swinging gate/chains
- Barricades tagged
- Floor openings covered

Hazard Awareness/Inspection

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Post Test

In the workplace, more falls occur from heights than from the same level.

A. True

B. False

List **3** ways in which slips and trips can be prevented.

A fall hazard exists in photo #1.

A. True
B. False

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A fall hazard exists in photo #2.

A. True
B. False

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List **3** ways to control the hazard in photo #1.

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D. None
E. All

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Remediation

- Activity Harness Inspection

Working at Heights

General Hazard Awareness

Testing Effect

- A message to the learners: Pre-Test
  - It is not what you know, but how you can apply it to a real world scenario.

Self Efficacy

- You have been successful in the past when taking on new tasks/skills or you wouldn't be here today; you will be successful in completing this too.

Goal Orientation

- The important part of this test is not a grade but to be able to apply what you learned.

Pre-Test

In the workplace, more falls occur from heights than from the same level.

A. True

B. False

List **3** ways in which slips and trips can be prevented.

A fall hazard exists in photo #1.

A. True
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A fall hazard exists in photo #2.

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  - Risk Analysis
  - Open-hole permit
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Barricading and Guarding

- Guarding by standard railing
- Proper warning signs
- Passage provided by swinging gate/chains
- Barricades tagged
- Floor openings covered

Hazard Awareness/Inspection

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Activity

Self Regulation

- Is everyone prepared to take the test right now?

Post Test

In the workplace, more falls occur from heights than from the same level.

A. True

B. False

List **3** ways in which slips and trips can be prevented.

A fall hazard exists in photo #1.

A. True
B. False

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A fall hazard exists in photo #2.

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APPENDIX C

Serious Gaming Software Details

Aim 4: Design, Evaluation, & Extension of Serious Games for Training in Mine Safety

In previous work, we developed a platform called MineSAFE -- the Software Architecture for Education -- that enables the UA team to create a variety of "serious games" for training in mine safety. During the last project year, substantial progress was made to develop and evaluate new computer-based training applications using the MineSAFE platform. This work resulted in the successful completion of a Ph.D. dissertation in Computer Science (Brown, 2015; 12 chapters, 637 pages). In this report, we will summarize our activities and principal findings during the last project year, including (1) our on-going needs assessment, (2) platform extension and prototype development, and (3) multiple levels of usability testing with end users. A detailed discussion of these activities and findings may be found in Brown (2015).

Needs Assessment

As part of an on-going needs assessment for computer-based training applications, we have conducted a series of structured field studies (Courage & Baxter, 2005, p. 565) examining the teaching media and methods used in mine safety training. A summary of this needs assessment was reported in the annual report for the 2014 project year. In the 2015 project year, we performed a detailed analysis based on a usability engineering approach called Contextual Inquiry and Design (Beyer & Holtzblatt, 1998). Our objectives were two-fold: first, we wanted to gain a holistic view of the training process -- how the individual parts of the training regimen came together to shape the miners' understanding of Safety & Health (S&H); second, we wanted to examine the protocols, data sets, and information flows that miners experienced while covering important training topics. From this analysis, we identified several need and deficiencies that may be addressed using a "serious games" approach (Brown, 2015, Ch. 6).

Our field studies looked at areas of training which were noted by our Safety & Health Technical Advisory Committee as being particularly problematic. In all, five applications were surveyed to touch upon a variety of MSHA-required training topics. During our studies, we collected a considerable volume of empirical data. More than one thousand individual pieces of evidence were collected, in addition to a large body of sample media. Taken together, the field studies are representative of the current media and methods used for S&H training in the mining industry for new miner, annual refresher, and site practicum training. A detailed survey of our field studies may be found in Brown (2015, Ch. 3).

Model Consolidation

Model consolidation is an important first step in Contextual Design (Beyer & Holtzblatt, 1998). It allows us to go from individual observations to a coherent characterization of safety training applications. The consolidation process resulted in several models: an **Affinity Diagram** describes the major themes of usability problems from the bottom up, while a set of consolidated work models provides a high-level overview of domain users, tasks, and information from the top down. The two types of models were developed independently, using complementary inductive techniques as defined by Beyer and Holtzblatt (1998). Brown (2015, Ch. 4) provides a detailed discussion of the model consolidation process. The abridged Affinity Diagram may be found in Fig. 1, while Appendix A provides the full diagram with corresponding evidence. Similarly, Appendix B provides the eight consolidated work models that were developed based on our field studies.

Furthermore, the Affinity Diagram was cross-referenced with the specific indications in the consolidated work models. The mapping considers four categories of problems, based on the design themes outlined in the Affinity Diagram (Appendix A). Appendix C illustrates this mapping for each problem category,

Figure 1. Abridged Affinity Diagram

Table 1. Design Guidelines for Training in Mine Safety.

ACCESSIBLE **Make activities and media accessible to a target audience that includes mine workers and safety trainers.**	
DG1	Choose technologies that promote acceptance of new curricula across sites and demographics.
DG2	Remediate skills through custom tutorials that incorporate best practices in training pedagogy.
DG3	Allow novices to manipulate all relevant data easily and synonymously.
DG4	Streamline context switches and the flow of information to support dynamic task needs.
DG5	Promote hands-on interaction with equipment through realistic forms, constraints, and usage.
CONTEXTUAL **Provide a meaningful context for training that includes suitable details and perspective relative to the user's experience.**	
DG6	Support a range of effective training media and presentation needs on demand.
DG7	Make information available to users when and where they need it, at a suitable level of detail.
DG8	Provide suitable perspective on the environment, with clear relationships between important data.
DG9	Use realistic, site-relevant examples that ground information in the user's experience.
CONSEQUENT **Illustrate the consequences of choices relative to ambient features and activities in the workplace.**	
DG10	Underscore the progression of time and correlate events across media.
DG11	Incorporate dynamic exercises and media that require tough choices in hypothetical situations.
DG12	Provide users with timely, context-relevant feedback on their progress, actions, and decisions.
PRACTICAL **Develop communities of practice in safety training through situated, story-driven games.**	
DG13	Use story-driven scenarios and evolving content to engage users and encourage participation.
DG14	Encourage team activities that allow for dynamic discourse among users.
DG15	Use an apprenticeship model that couples situated learning with competency-based evaluation.

with example evidence. Note that the lack of an indication in a consolidated work model does not necessarily dismiss a problem; rather, it means that the consolidated model simply failed to capture the problem at a high level. In general, the problem categories revealed by the Affinity Diagram were well-represented in the consolidated work models, with 38 of the 45 (84%) Affinity Diagram problem categories reflected in at least one consolidated model.

Design Guidelines

Based on the consolidated models, we propose a set of 15 design guidelines to address systemic usability problems in mine safety training. By convention, a problem had to reflect in *both* the Affinity Diagram and the consolidated work models to be considered in our guidelines. In many cases, several problem categories in the Affinity Diagram pointed to one high-level guideline, and in one case, a single problem category (e.g. "Clumsy context switches") warranted its own guideline, since that problem was reflected across a large number of consolidated work models and had sweeping impact. In general, each design guideline addresses a coherent and coordinated usability problem that was observed in our field studies. Appendix C illustrates the mapping of the design guidelines to the consolidated models. A detailed derivation of the guidelines may be found in Brown (2015, Ch. 5).

The **Design Guidelines for Training in Mine Safety** are summarized in Table 1. Through these guidelines, we propose that applications in mine safety should be ACCESSIBLE, CONTEXTUAL, CONSEQUENT, and PRACTICAL. These design themes address the Affinity Diagram problems of "Limited Accessibility," "Lack of Context," "Lack of Consequences," and "Absence of Practicum," respectively.

Game Development

In the current project year, we made numerous technical improvements and extended the capabilities of our development platform, MineSAFE. Principal technical work focused on three main issues: the development of a Learner's Clipboard system for expert feedback, a new story language called DDFS2, and a new game prototype for hazards recognition training. Each of these technical components is summarized below.

Learner's Clipboard

In collaboration with Mr. Michael Brnich and the Mine Emergency Systems group at NIOSH, we have developed a "Learner's Clipboard" capability to provide interactive feedback. Specifically, the Learner's Clipboard provides a log of game events (i.e. a "Game History") that displays each choice as it is made during the game, coupled with expert perspective (i.e. "Learning Points") as to why that choice was good or bad in context. The game history and learning points are cumulative and may be accessed by the learner at any time. The Learner's Clipboard is shown in Fig. 2. A detailed discussion of the Learner's Clipboard interface and proposed usage patterns may be found in Brown (2015, Ch. 7.1).

The Learner's Clipboard has been demonstrated in *Harry's Hard Choices* (*HHC*), a game for mine emergency preparedness which is based on a paper scenario by Vaught, Hall, and Klein (2009). A discussion of the *HHC* serious game may be found in Brown (2015, Ch. 8). The Learner's Clipboard was debuted during a usability study at the 2015 National Mine Rescue Competition in Lexington, KY, where it received excellent feedback from mine rescue teams. In Fig. 3, the Learner's Clipboard is shown at the far right in an ultra-widescreen configuration of *HHC* which was demonstrated at the mine rescue competition.

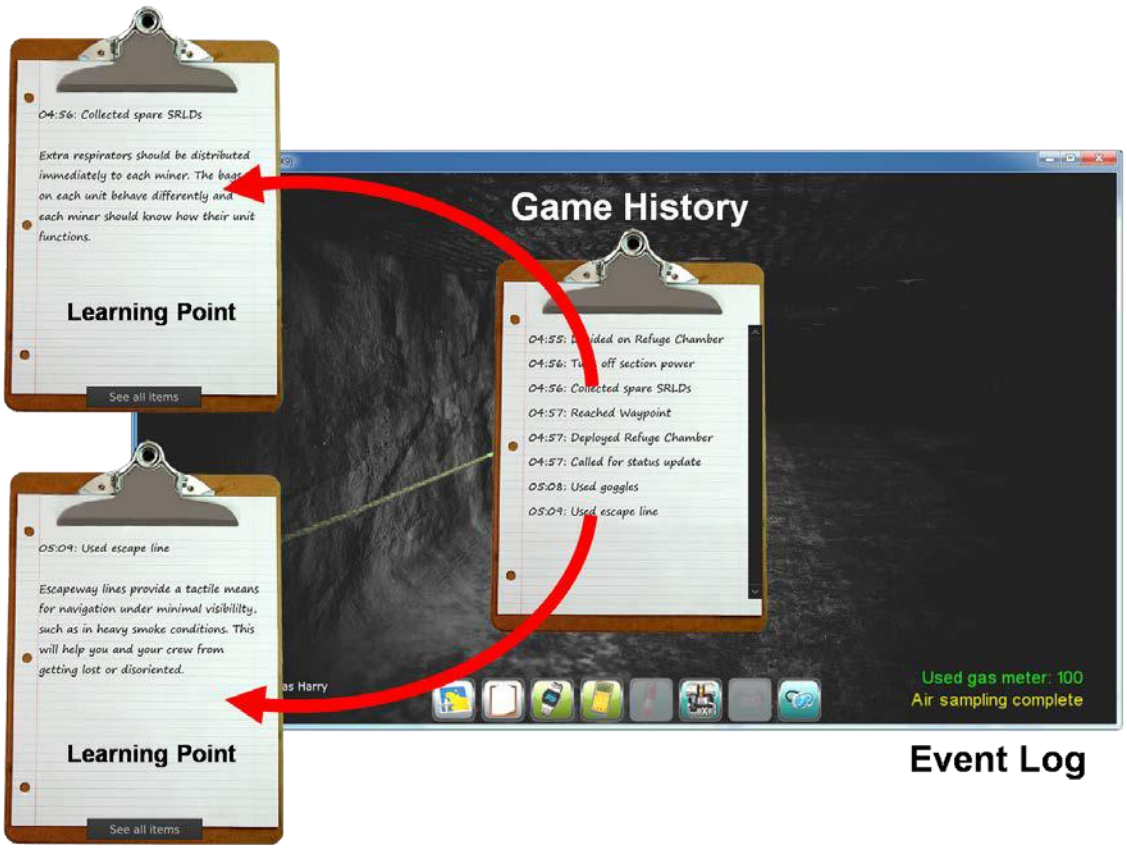

Figure 2. The Learner's Clipboard featuring Game History and associated Learning Points.

Figure 3. Experimental setup for the Ultra Wide Screen (UWS) condition.

Table 2. Learning Points: Sample choices and actions with associated feedback in Learner's Clipboard.

Choice / Action	Feedback and Analysis
Procrastinating	In a mine fire, fires double in size every 15 minutes. Also, crewmates are stressed and will want to take action immediately.
Go to Refuge	There is little indication that you cannot evacuate; going to a refuge chamber should be your last resort.
Evacuate	Evacuation is always the best choice.
Walk out (Low CH4)	There is debate whether a vehicle should be operated in a fire because of the possibility of an explosion. It is less strain on stressed crewmates who may have trouble breathing with an SCSR.
Walk out (Med CH4)	This is a judgment call given the current methane levels. Vehicles risk an explosion, but could save walking time. It is less strain on stressed crewmates who may have trouble breathing with an SCSR.
Walk out (High CH4)	This is probably the best option since the methane levels are high and using the truck could risk an explosion.
Drive out (Low CH4)	There is debate whether a vehicle should be operated in a fire because of the possibility of an explosion. It is less strain on stressed crewmates who may have trouble breathing with an SCSR.
Drive out (Med CH4)	This is a judgment call given the current methane levels. Vehicles risk an explosion, but could save walking time. It is less strain on stressed crewmates who may have trouble breathing from an SCSR.
Drive out (High CH4)	This is potentially a bad decision. The methane levels are high and you risk an explosion by using the truck.
Call outside	Keep the responsible person informed of your location and intentions as it will help him facilitate a rescue.
Annoy the operator	Repeatedly calling the operator without any appreciable change in status wastes valuable time and ties up communications resources. Be clear and efficient in communicating during an emergency.
Attempt vehicle repair	Choosing to fix the truck is a risky decision that could cost precious time.
Abandon inoperative vehicle	Unless the repair is trivial, you should never waste time you could be using to get out on a repair attempt.
Miner leg injury	Injuries are likely to occur under conditions that include physical stress, poor visibility, and uneven ground.
Assist miner	You should make every effort to encourage crewmates to evacuate the mine.
Abandon miner	Separated from the group and unable to walk unassisted, the abandoned crewman has little hope to escape. Furthermore, some crewmen may find it morally reprehensible to abandon a crew mate.
Assist miner to refuge	Assisting a miner to a refuge chamber can increase the injured miner's chances of survival and will improve crew morale.
Used refuge chamber	Refuge chambers offer air, communication with the outside, and an option for injured crewmates to await rescue.
Used inoperative refuge	The red strobe light indicates that this refuge chamber is non-functional. You should know how to activate the chamber and recognize its status modes, so that you can react quickly in an emergency. For details, consult the documentation for the refuge alternatives used in your workplace.
Left refuge chamber	This is potentially a good decision: evacuation is always the best choice.
Donned self-rescuer	Even if there is little CO present, it can build up quickly when there is little or no smoke. Chemical-oxygen units may become difficult to breathe through, as if breathing through a straw, as resistance increases over time.
Self-rescuer expired	Faith in self rescuers is a known issue. You should note the time that self rescuers are donned so that you can assure crewmates that they are working.

Miner quits group	Being attentive to your crew's concerns helps keep anxiety and panic low.
Miner lost	Keep a close account of your crew. A miner became lost, either because he was not using a lifeline or was allowed to fall too far behind.
Failed to see ground control	Helmet signals are an important method of communication in toxic atmosphere. You should always maintain awareness of your surroundings in hazardous situations.
Miner trapped	Evacuation is always the best option, as it is uncertain whether a trapped crewmate can be rescued before he runs out of breathable air.
Failed to use multi-meter	Vehicle use should always be contingent on the current methane levels, because of the risk of an explosion.
Collected spare self-rescuer	Extra respirators should be distributed immediately to each miner. The bags on each unit behave differently and each miner should know how their unit functions.
Used multi-meter	CO checks should be made as often as possible; it can build up with little or no smoke.
Used goggles	Goggles protect the eyes from smoke and toxic gasses, but can fog up due to perspiration, decreasing visibility.
Tethered to escapeway line	Escapeway lines provide a tactile means for navigation under minimal visibility, such as in heavy smoke conditions. This will help you and your crew from getting lost or disoriented.
Turned on section power	Never turn on a power system when fire or smoke is reported in the mine.
Turned off section power	Always turn off power to sections of the mine containing a fire.
Removed mouthpiece	Atmosphere >= 50ppm of CO is irrespirable. At 35ppm, you may talk but run the risk of inhaling smoke and other contaminants a meter may not detect.
Picked up inoperative multi-meter	You have swapped out your working gas meter for a defective one. What were you thinking?
Picked up operative multi-meter	You have swapped out your defective gas meter for one that actually functions. This, in general, is a good idea because it will allow you to resume checking critical gas levels.

Initial text for each Learning Point was derived from the paper scenario by Vaught, Hall, and Klein (2009). Note that the interactive game *HHC* greatly extends the scope of the original paper scenario to include new mine emergency events and story elements. As such, we are collaborating with the Mine Emergency Systems group to develop expert perspectives for these new Learning Points. A partial list of game choices and actions, with their associated feedback, may be found in Table 2.

Story Scripting Language

The first iteration of our story scripting language, the Data Driven Function Script (DDFS), suffered from several notable limitations. For instance, DDFS lacked portability across game engines; it was prone to high coupling that reduced modularity across games; instructions were necessarily interpreted in real time, leading to performance issues; it relied on a cryptic syntax that had a high learning curve for new developers; and it lacked error checking capabilities that would facilitate debugging. In the current project year, we have developed a second generation scripting language, DDFS 2.0, which addresses many of these limitations. A synopsis of DDFS 2.0 capabilities is provided in Table 3.

A particular strength of DDFS 2.0 rests in its substantially improved modularity. Through DDFS 2.0, each component of a game can be implemented as a discrete module, which can be added to

our master library, i.e. the Creation Toolkit. For instance, a module can define a piece of equipment, a character, a learning point, or graphical interface element. As the size of the Toolkit increases, the development time for future games will decrease. Furthermore, existing games can be updated easily, based on individual needs. Indeed, DDFS 2.0 allows game stories to modified

Table3. Summary of capabilities of the second generation Data Driven Function Script (DDFS 2.0).

Design Goal	Description
Autonomy	DDFS 2.0 is an independent scripting engine that can be linked from arbitrary host software to provide scripting/sequencing services. The ability to independently link to other external libraries will also be provided. In addition, the DDFS 2.0 toolset will include an executable stub that allows DDFS to operate without host software as a stand-alone scripting language.
Modularity	Code written in DDFS 2.0 is modular, allowing a variety of features or functional packages to be included or excluded at runtime. This allows game dynamics to be significantly altered without recompiling or reissuing the host software. This modular feature also allows libraries of source code to be written that can be dropped into new projects.
Familiarity	DDFS 2.0 uses C++ syntax and grammar, which is familiar to many game developers and reduces training overhead. Many existing C++ routines and methods may be easily ported to DDFS 2.0.
Efficiency	Source scripts are precompiled or compiled at initialization (runtime) into an Executable Object Tree (EOT), which provides significantly faster execution over interpreted models, yet offers source flexibility often associated with interpreted models.
Multithreading	DDFS 2.0 maintains an autonomous thread pool, which provides true multithreading independent of the host software. This allows DDFS 2.0 to operate efficiently without parasitic use of the host software's threads.
Routed Logging	DDFS 2.0 includes a routed logging system that allows messages of various classes to be routed to multiple software/hardware endpoints in realtime based on class. Messages can be routed locally to activity logs or a HUD, or even over a network or wireless connection to other devices providing realtime monitoring of a remote session. This logging system is also available to the

easily from session to session and site to site.

Technical Overview. The execution model of DDFS 2.0 is given in Fig. 4(left). All aspects of the language are represented with scoped objects, including namespaces, classes, functions, variables, and loops. Each scoped object contains an environment template, which holds variables and other instance-specific data, a list of executable object trees (EOT), and a list of child scope objects as part of a recursive structure. Each EOT is assembled from small and efficient executable object (EO) classes that are built by the compiler. As an example, Fig. 4(right) provides an EOT for a sample instruction, N = X + 2. When a scope is instanced and executed, the Environment Template is cloned as instance-specific data and handed to each EOT as it is executed. Some EOs will execute additional child scopes or spawn new threads as the process propagates.

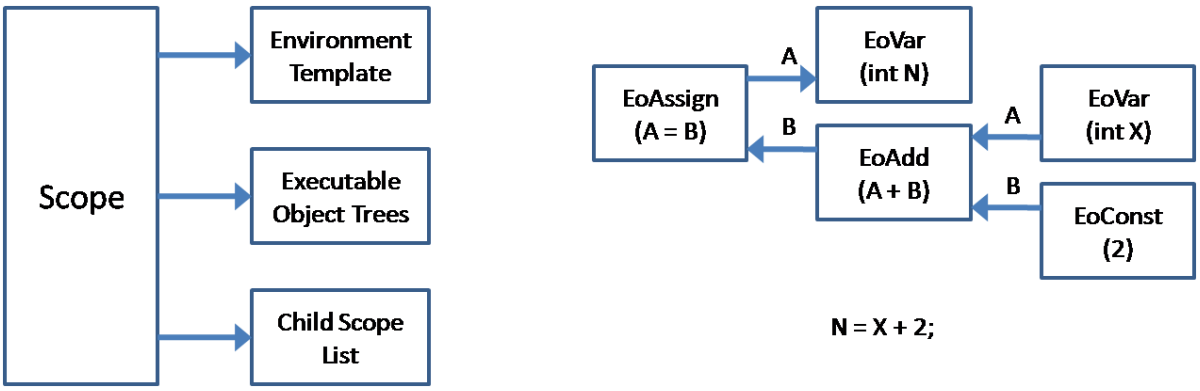

Figure 4. Technical framework of DDFS 2.0. Left: Execution model; Right: An Executable Object Tree.

DDFS 2.0 can be implemented using a Just In Time (JIT) compilation model. The JIT compiler consists of a C++ preprocessor, a lexical token parser, and a recursive parser. The preprocessor configures the source code for requested features, by performing conditional substitutions and inclusions of source code. The lexical parser is a linear parser that separates the output of the preprocessor into discrete tokens for the recursive parser. The recursive parser processes the list of tokens in order of precedence and builds the executable objects consisting of scopes, environment templates, and EOTs described above. After the runtime objects are built, the XML serializer can convert the executable objects to an equivalent XML representation that can be stored as a precompiled version of the code. If a precompiled version of the code is available, the software can load the runtime objects directly from XML. A utility is provided to run the JIT compiler outside of the host software to prepare precompiled modules.

Hazards Recognition Prototype

To demonstrate the capabilities of the new story scripting language, we have created a hazards recognition game called *San Xavier Challenge* (*SXC*). In *SXC* prototype, users are required to recognize hazards while performing a series of domain tasks requiring high cognitive overhead. This game design was motivated by our field studies, in which trainers emphasized a need for better hazards recognition and situational awareness *in context*. Supporting comments from trainers included #220 ("'Tunnel vision' is common -- focusing on some aspects of work but not others"), #299 ("A real mine is constantly changing"), and #465 ("I want to evaluate users in real situations, not highly controlled ones") in the Affinity Diagram (Appendix A). A detailed discussion of the *SXC* prototype may be found in Brown (2015, Ch. 7.2).

Game and Hazards Design. The game uses the San Xavier Mine Laboratory dataset and features a 4-level shaft mine for overhead stope mining of small ore veins. The data set incorporates a heterogeneous collection of 2D and 3D maps, schematics, equipment, and instrument readings. As a unique feature of this application, the 3D map better illustrates the vertical structure and connectivity between levels, through shafts and raises; this information is typically not available on 2D maps and serves as a navigational aid to the learner.

The *SXC* game is an attempt to frame hazards awareness within the context of workplace tasks requiring high cognitive overhead. The game circumstances are designed to be analogous to real-life situations that a new miner, or new experienced miner, may face in acclimating to a new job site; a miner must concentrate on orienting himself (or herself) within the workplace, while

performing job tasks and maintaining a sufficient level of environmental and situational awareness. Providing an adequate testbed for hazards training is not feasible with existing training approaches. The game further incorporates secondary tasks which are meant to exercise domain skills and distract the learner from hazards recognition. Example screen shots of the *SXC* application are given in Fig. 5.

There are presently four programmatic classes of hazards, which include missing objects, dislodged objects, misplaced objects, incorrectly oriented objects, inoperative objects, broken objects, and errant ventilation. Each has a different visual representation and behavior. For instance, an inoperative object may not work even though it presents no outward signs of damage, while a broken object may have visible dents or twisted parts. Similarly, a misplaced object may be moved to the wrong location, while a

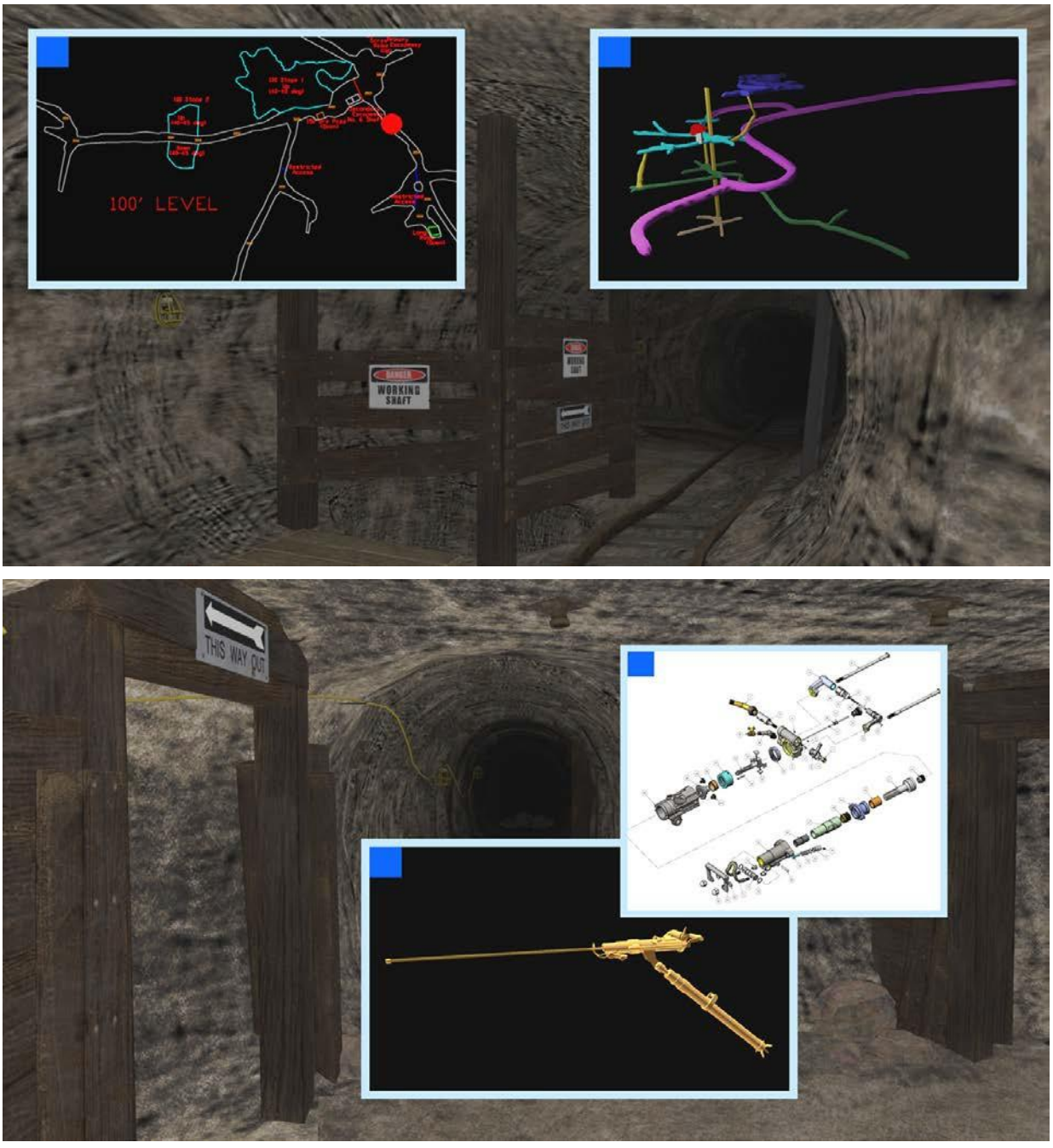

Figure 5. Screen shots of the *San Xavier Challenge*, illustrating game environment and data. Top: Mine maps used in navigation tasks; Bottom: Equipment and schematics used for inspection tasks.

dislodged object may fall down when the user comes too close. Table 4 provides a list of the hazards that have been realized for the *SXC* game.

Hazards are randomly injected into the environment. Specific hazards selected at run-time from the list of all possible hazards. Each hazard is accompanied by constraints that define how many instances of that hazard should appear in the game (minimum and maximum). The hazard list and constraints are defined in an initialization file which is loaded at run time. Note that, in addition to type and location, hazards may also be randomized in *time*; some hazards may be pre-placed at game start-up (latent hazards), while others subtly "appear" when the user is not looking (dynamic hazards). Dynamic hazards present a very real danger in the workplace; they often represent the unintended consequences of other, concurrent work activities. Dynamic hazards are an emphasis for our hazards recognition training, since they are difficult to illustrate effectively with other training media.

User Feedback. We have conducted a formative assessment of the *San Xavier Challenge*. Feedback was solicited from attendees of the Mine Safety & Health Conference in Reno, NV in October, 2015. For these tests, we used a consumer Head-Mounted Display (HMD), the Oculus Rift DK2, as it offered a higher level of immersion than was possible with a traditional desktop setup. An Xbox 360 gamepad was used for gaze-directed travel (Bowman *et al.*, 2004, p. 200). Eight subjects participated in this study. All eight users were safety trainers or members of management at mine sites in the western United States. As such, the users were knowledgeable of mine safety and workplace hazards. Each user played the game for 20 minutes, completing several domain tasks while also searching for mine hazards.

The virtual environment's level of detail and realism were very well received. Users commented that it was the most realistic "fake" mine they had ever seen and that the presentation was comparable to production games for entertainment. The level of immersion provided by the Oculus Rift was also praised. Users liked the ability to move their heads, indicating that it was helpful for navigation and awareness tasks. However, more than half of the users also mentioned that the HMD made them feel nauseous or dizzy. This is concerning, since the game session lasted only 20 minutes. Future work will need to identify and reduce the causes of the nausea and dizziness.

In terms of the game tasks and story, users liked the hazards concept, particularly its randomized aspects, but felt that the virtual environment was too stagnant to represent a real situation. Three users specifically commented on the need for more people and more work activity. Another user commented that the game would be more fun if it provided a way to tally "score" for the hazards that were discovered. Users also wanted the hazards to have tangible consequences, such as a roof collapsing due to bad ground control or a blast that was sparked by a buildup of flammable gas. In general, users wanted the game to be more fun -- "a balance between teaching simulation and game." Asked if they would be willing to play the game in their spare time, the users generally indicated that they wouldn't choose to do so; one commented that it's "useful for training but not very fun." Another suggested that it needed to be more like a "survival game" or to have a "gamer mode" to increase its play value. Indeed, the game would likely benefit from game mechanics such as scores, traps, and outcomes, which were not tested in this prototype but will be added to future hazards recognition games.

Usability Studies

Our field studies suggested that user acceptance was a major obstacle to good training outcomes. A new training approach must overcome barriers due to age, work experience, computer literacy,

and a variety of other factors (DG1 in Table 1). Indeed, the work of Garris, Ahlers, & Driskell, (2002) and Gee (2004) suggest that user motivation and engagement are major factors in successful computer-based training applications. During the last project year, we undertook a

Table 4. Hazards in *San Xavier Challenge.*

Hazard Type	Examples
Ground control	Bad ground control: Cracks in ceiling, debris hanging down, roof bolt dislodged, hanging out; Rib (side) sloughed off, creating an obstacle partly blocking the escapeway; Timber support damage: Cross pieces are buckled in the middle and bent down in "V" shape; back is bulging downward; Fall of material: Top has an obvious gap in it where debris have fallen out, with small pile of pulverized rubble below
Stumbling, Falling	Open/Broken/missing doors on main shaft (to access ladder; to access skip); Open/Broken/missing door on ore pass; Broken ladder: rung missing or cracked; Multiple ground fall events in decline; Ore pass door is open/missing; Vertical Ladder in corkscrew or long raise is replaced with knotted rope; Ground clutter; Lower stope not properly blocked off; missing landings in shaft
Electrical	Damaged/scorched electrical panel/box ; Electrical harness along wall is frayed through insulation; Bulb in light broken, sparking; Broken water pipe above light; sparking electrical wires; smoke emanating from electrical box
Equipment	Ore car off track in a blind curve; Broken tools -- broken shovels, pick axes, damaged jackleg drill shaft; Steel (drill bit) jammed in rib, sticking out by 18"; Miscellaneous bore holes throughout area, blasting cap subtlety protruding from one; Broken rail in blind curve; Safety cache locked; Safety cache blocked by tools/timbers; Damaged ore car; Empty or out-of-place safety cache; dysfunctional mine phone
Escape way	Equipment partially blocking secondary escapeway; Pile of timber balanced precariously against rib near escapeway line ; Escapeway arrow (exit signage) pointing up or down (as if sign were knocked out of proper orientation); Escapeway and cache signage sporadically missing; Broken bulkhead door latches; flickering lights in escape way; escapeway cordoned off
Explosion, Fire	Blasting caps laying in crew rest area; Pack of cigarettes and lighter randomly placed; Open/unlocked door to explosive (ANFO) cache/ detonator cache; Open whiskey bottle sitting on table near lunch pail; Shotgun shells laying on ground in explosives cache
Ventilation	Open/Broken/Missing door on bulkhead; Bulkhead door is jammed shut Check curtain partially pulled down; Inoperative or squealing ventilation fans; Gas multi-meter alarms in certain areas

series of usability studies to examine user acceptance (DG1) of our serious games approach.

Study Overview. Four usability studies were conducted (Brown, 2015, Ch. 9-10). A pilot study (**Level 1**) considered a small group of users having a range of domain experience. The pilot study represented the first time that a domain audience had used a MineSAFE application for practical training objectives. The pilot study was conducted to probe for individual weaknesses in the application design and to provide direction for future studies. Based on this experience, a larger study (**Level 2**) was conducted, focusing specifically on users' acceptance, ease of use, and satisfaction with the new serious games approach. The Level 2 study included two cohorts of users representing extreme ends of the spectrum in terms of domain expertise. The results of these two cohorts were compared, and significant differences were found in their opinions on key issues relating to the user interface and presentation.

The Level 2 usability study suggested that the level of domain expertise played a factor in users' ratings of our serious games for both satisfaction and ease of use. In particular, users that were new to mining (i.e. novices) scored the serious game significantly lower on most ease of use metrics in comparison to domain experts. The apparent differences in ratings may have been due to the overhead of learning the game, the interface, and the domain information all at the same time. The novice users had a particularly hard time figuring out what they were supposed to do next and finding their way around the game environment. Such tasks are strongly influenced by domain knowledge and experience. Increased levels of frustration among novices, when compared to the experts, also give credence to this hypothesis.

Improvements in the user interface and display capabilities may help to alleviate many of the problems observed in the Level 2 studies and lead to improved acceptance of serious games among novices. To this end, we conducted two additional levels of usability tests focusing on the computer infrastructure used to support serious games. Individual studies were conducted to examine interface conditions (**Level 3**) and display conditions (**Level 4**); Level 3 looked at factors that included ease of use, perceived difficulty, and expressive power of the user interface, while the Level 4 tests addressed presentation-oriented factors, such as perceived presence, spatial awareness, and usefulness of the data set and work objects. Through these usability tests, we hoped to gain insight on the infrastructure requirements for future training workspaces.

Study Apparatus. For our usability tests, we used the mine emergency simulation, *Harry's Hard Choices* (*HHC*). *HHC* is a practical training application that implements several important training objectives end-to-end, with potential utility across a spectrum of safety courses and programs, from new miner to mine rescue training. *HHC* was chosen because it is both a robust domain application, making it task-relevant for domain users, and a suitable testbed of our serious games approach, having been closely designed around the Design Guidelines for Training in Mine Safety (Table 1). Thus *HHC* represents the most mature and "best case" application developed to date using the MineSAFE platform. Furthermore, the game supports many options for display, presentation, and interaction, making it a useful testbed to explore infrastructure needs.

In conducting these usability studies, it was important to solicit a representative sample of domain users. In total, 95 users participated at four testing sites throughout the United States. Human subjects were solicited from both eastern (42 subjects) and western mining regions (53 subjects), and included attendees of new miner (23), annual refresher (18), and mine rescue competitions (42). The users' skill levels ranged from novice to expert in the practices of mine safety. Additionally, 16 of our subjects indicated that they were professional trainers in the mining industry.

Level 1: Pilot Study

The results of the pilot study were reported in the 2014 annual report and are omitted from this discussion.

Level 2: Experts versus Novices

Although there are no specific metrics to gauge user acceptance, it is largely indicated by user opinions and preferences, which are shaped by collective life experience (Yusoff, 2010, p. 65). In this study, user acceptance was examined in terms of the Technology Acceptance Model (Yusoff, 2010, p. 63). The Technology Acceptance Model incorporates standardized metrics for satisfaction, ease of use, and willingness to replay. A serious game must succeed in all of these characteristics if it is to be an effective as a vehicle for training.

A key aspect of this study is that it considered both ends of the user spectrum in terms of domain expertise. Cohort 1 consisted of domain experts, while Cohort 2 was made up of domain novices. Since we hope to use serious games to improve a range of training courses involving both new and experienced miners, we wanted to look at users with a range of domain expertise to see if their opinions were consistent on our serious games approach. In summary, we hoped to gain insight into the following four hypotheses relating to user satisfaction and acceptance:

L2-H1: Users will be satisfied with the overall game experience.
L2-H2: Users will rate the serious games as being easy to use.
L2-H3: Users will want to play games to receive training content.
L2-H4: Experts and novices will have similar opinions.

Results. Table 5 provides a summary of users' game performance, while Table 6 itemizes trap trigger frequencies; note that some trap types, including electrocution and failed breathing apparatus, were not enabled for this difficulty level (i.e. level 3 of 5). Nonetheless, Table 6 illustrates the diversity of game events that may be encountered even in a relatively short playing time. Note that on these quantitative metrics, a logging error caused one log file to be overwritten in each session. Thus, a total of n = 20 experts and n = 22 novices were considered in these measurements.

The Level 2 post-session questionnaire is summarized in Table 7, while user responses are given in Table 8. The questionnaire used 7-point Likert scales. Note that the post-questionnaire also included a "Training Needs Assessment" (L2-Q12), which asked curriculum-oriented questions that were targeted toward trainers. The Training Needs Assessment is beyond the scope of this study and is therefore omitted from these results.

Analysis. One of our principal interests in conducting this study was to examine differences of opinion between groups with differing levels of domain experience. For this analysis, the

Table 5. Level 2 summary task performance metrics (n = 20 for experts; n = 22 for novices).

Metric	Cohort1 (Experts)				Cohort 2 (Novices)			
	Mean	Stdev	Min	Max	Mean	Stdev	Min	Max
Rescued	1.70	2.49	0	7	0.50	1.17	0	4
Final Score	-249.15	1521.91	-2400	2465	-655.83	729.23	-1885	805
Time (m:s)	22:57	9:56	3:46	45:59	17:30	6:58	5:57	31:00
Sim. Time	27:32	9:26	3:54	50:28	30:34	9:58	15:57	52:02 [7]
Distance (x1000 ft)	4.25	1.77	1.21	7.19	3.33	1.70	1.15	6.31

Table 6. Frequency of trap triggers. Values given in percentages (%).

Trap Type	Cohort 1 (Experts)	Cohort 2 (Novices)
Roof fall	65.0	77.3
Lifeline break	75.0	81.8
Burned to death	20.0	50.0
Asphyxiated	20.0	50.0
Gas explosion	5.0	9.1
Broken refuge	0.0	18.2
SCSR expired	20.0	18.2
Sprained ankle	70.0	25.0
Truck breakdown	30.0	25.0

Wilcoxon rank sum test was used to look for significant differences between Cohorts. At the $p < 0.5$ level, the test indicated significant differences for both user satisfaction and ease of use questions; these differences are illustrated by red dotted boxes in Table 8.

Experts (Cohort 1) generally graded the game higher than novices (Cohort 2) on most metrics. In terms of user satisfaction (Fig. 6), the Wilcoxon rank sum test indicated significant differences between cohorts on three of four questions. Experts graded the game higher than novices for both L2-Q1A, "Terrible versus Wonderful," and L2-Q1B, "Frustrating versus Satisfying." A marginally significant difference was suggested for L2-Q1C, "Dull versus Exciting," with experts finding the game more exciting. Interestingly, there was no significant difference in the Cohorts for L2-Q1D, "Easy versus Challenging"; both Cohorts reported that the game was similarly challenging.

Experts rated the game significantly higher on the ease of use metrics (Fig. 7), including L2-Q2, "Learning to play," and L2-Q3, "Exploring new features." Experts also gave higher ratings in response to L2-Q5, "I knew what I was supposed to do," and L2-Q6, "It was easy to find my way around." There was no significant difference on L2-Q4, with both cohorts finding gameplay to be clear and consistent (mean = 4.98). On willingness to replay (Fig. 8), there was no significant difference in cohorts for L2-Q7 or L2-Q8; both cohorts indicated that they felt the game made the training content more effective (L2-Q7) and were similarly enthusiastic to play the game again (L2-Q8). On these questions, scores leaned toward "strongly agree," with means of 5.30 and 6.18, respectively.

In response to the short answer questions, users provided a range of comments on the game experience. In response to questions L2-Q9 ("What surprised you most?") and L2-Q10 ("What did you like most?"), there were several common responses. Across both cohorts, common themes included level of challenge (24 responses), level of realism (18 responses), breadth of experience (15 responses) gaming elements (10 responses), and crew interactions (5 responses).

Looking at the two cohorts independently, the experts cited the levels of realism and challenge as things they liked most, while novices liked the variety of options, level of challenge, and gaming aspects (e.g. scoring, humor, deaths). For question L2-Q11 ("What would you suggest to improve the game?"), users mentioned a need for better in-game tutorials (8 responses), better maps (4 responses), higher fidelity interaction with equipment (4 responses), and better navigation controls (3 responses).

Table 7. Level 2 Post-Session Questionnaire. Ratings were gauged using 7-point Likert scales.

Question	Description
L2-Q1	Overall, this "serious game" was…
A	Terrible vs. Wonderful
B	Frustrating vs. Satisfying
C	Dull vs. Exciting
D	Easy vs. Challenging
L2-Q2	Learning to play this game was… (difficult vs. easy)
L2-Q3	Exploring new features by trial and error was (difficult vs. easy)
L2-Q4	Game play was clear and consistent.
L2-Q5	I always knew what I was supposed to do next.
L2-Q6	It was easy to find my way around the game environment.
L2-Q7	The game made the training content more effective.
L2-Q8	I would play this game again for training.
L2-Q9	What part of the game surprised you most?
L2-Q10	What part of the game did you like most?
L2-Q11	What would you suggest to improve the game?
L2-Q12	Training Needs Assessment [OMITTED]

Table 8. User ratings of serious game in Level 2 study (higher is better). Shaded cells with dotted outlines indicate significant differences between cohorts, based on Wilcoxon rank sum test ($p < 0.05$).

Question	Cohort 1 (Experts)				Cohort 2 (Novices)			
	Mean	Stdev	Med	Mode	Mean	Stdev	Med	Mode
L2-Q1A	6.05	0.97	6	7	5.29	0.96	5	6
L2-Q1B	5.24	1.41	5	6	4.13	1.48	4	3
L2-Q1C	5.62	1.43	6	6	5.17	1.01	5	5
L2-Q1D	6.00	1.38	7	7	5.75	1.65	6	7
L2-Q2	5.48	0.93	5	5	4.17	1.66	4	5
L2-Q3	4.95	1.20	5	5	3.38	1.38	3	3
L2-Q4	5.29	1.15	5	6	4.71	1.43	5	5
L2-Q5	3.91	1.38	4	3	2.77	1.34	3	2
L2-Q6	5.10	1.48	5	7	3.71	1.49	3	3
L2-Q7	5.24	1.55	5	5	5.38	1.06	6	6
L2-Q8	6.29	1.23	7	7	6.13	1.04	6	7

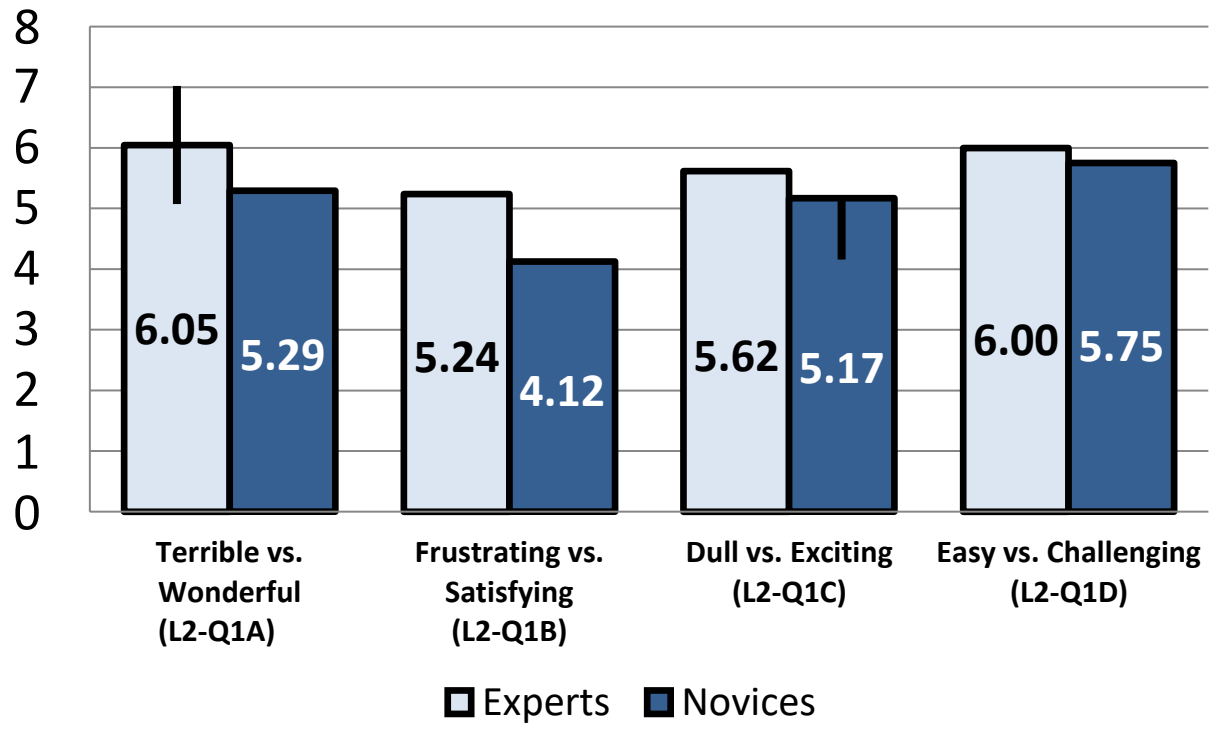

Figure 6. User satisfaction ratings (mean) for serious game in Level 2 study.

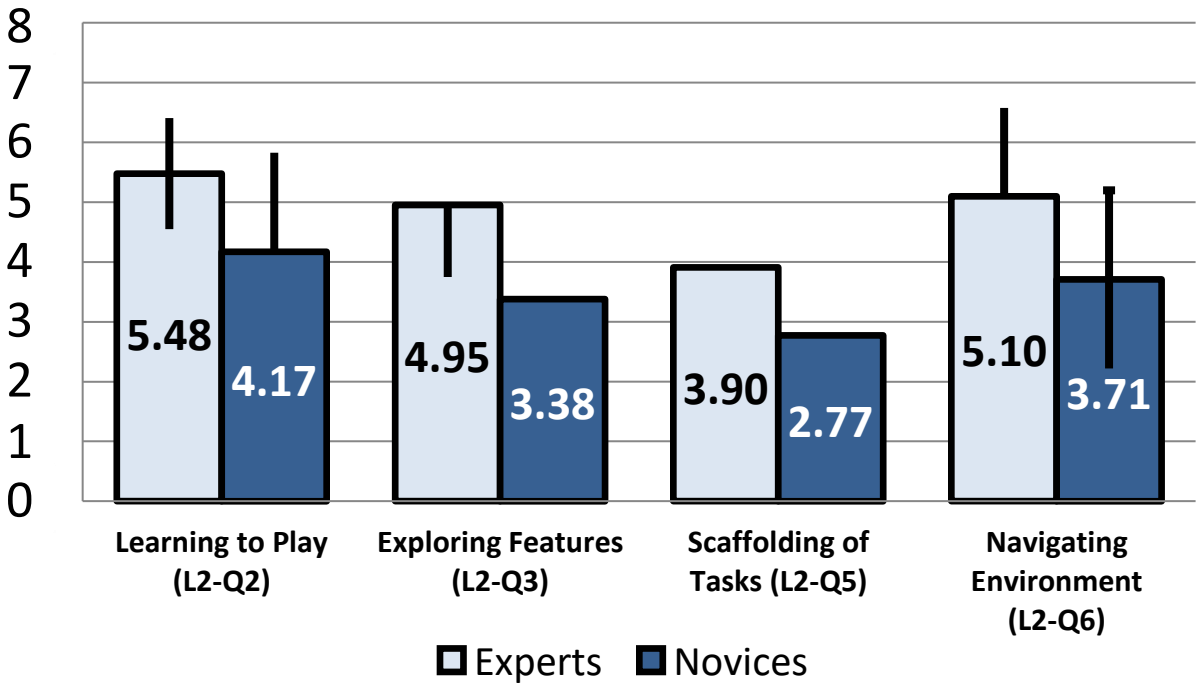

Figure 7. Ease of use ratings (mean) for serious game in Level 2 study.

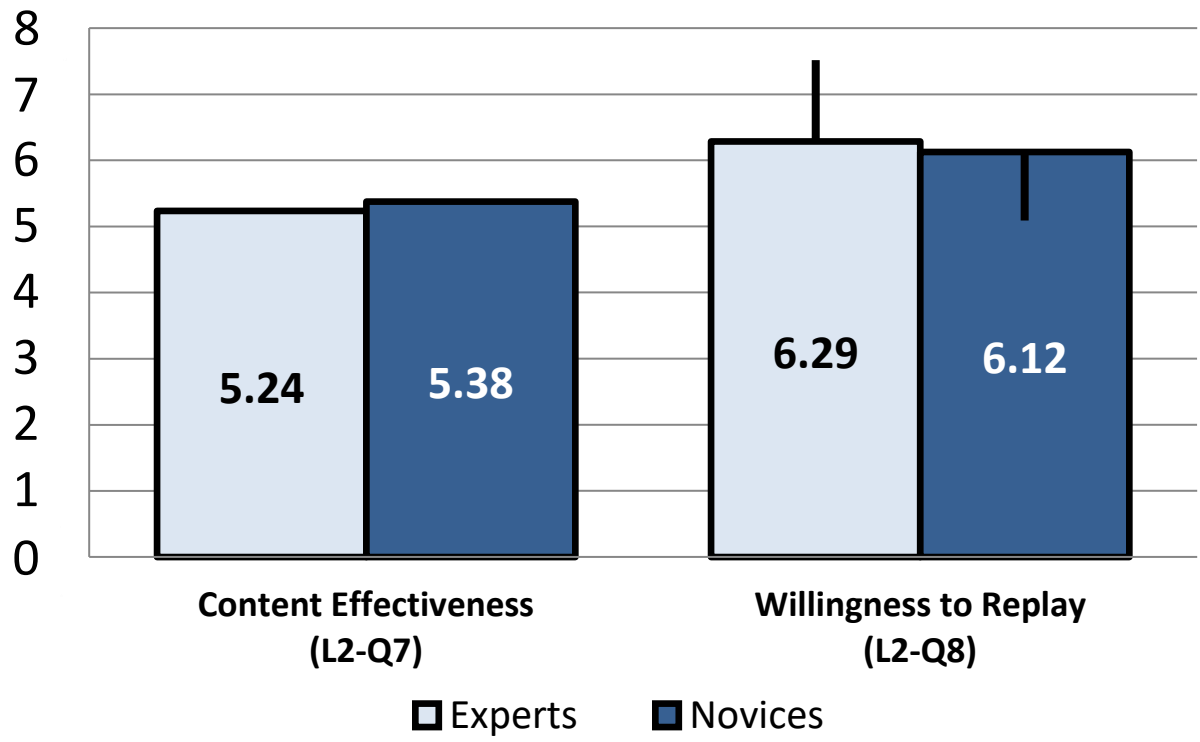

Figure 8. Willingness to play ratings (mean) of serious game in Level 2 study.

Discussion. User responses to the game were generally positive. The game scored well on most of the 7-point Likert metrics for user satisfaction. The median and mode were above 5 for all parts of question L2-Q1 (satisfaction); the mean was above 5 for all but L2-Q1C (Frustrating versus Satisfying), where novices rated the game slightly more frustrating than experts (mean = 4.04 versus mean = 5.24, respectively). As the scores were above the "no opinion" level (4) in all cases, the evidence suggests that hypothesis L2-H1 is confirmed. Furthermore, users rated their willingness to replay the game (L2-Q8) as very high, with mean and mode of 7, indicating "Strongly Agree" (mean = 6.18). In fact, question L2-Q8 showed the highest rating of any question in our survey. Furthermore, the results were similar for both cohorts, suggesting a high degree of acceptance of the new approach among users and confirming hypothesis L2-H3.

We noted lower scores on the ease of use metrics (L2-Q2 through L2-Q6). Novices in particular rated the game lower than experts on all of the ease of use metrics except L2-Q4 ("Game play was clear and consistent"). L2-Q4 was also the highest rated ease of use metric (mean = 4.98, median = 5, mode = 6 toward "Strongly agree"). The other questions, including L2-Q2, "Learning to play," and L2-Q3, "Exploring new features," scored median values of 5 on both metrics among experts, but only 4 and 3, respectively, among novices. Furthermore, the novices rated L2-Q5, "I always knew what I was supposed to do next," and L2-Q6, "It was easy finding my way around," particularly low (toward "Strongly disagree"). The median and mode were 3 for both of these metrics. The lower scores on ease of use and are rejected. Further analysis is needed to understand these trends.

We might interpret the differences in opinions in terms of the cognitive overhead that was required to perform the tasks. The overhead was substantially higher for novices, such that they

may have felt overwhelmed. The domain tasks were themselves very challenging, and the game provided only limited clues about what users should do at each step of the evacuation. The limits on information were by design, to compel users to think critically and to make decisions based on incomplete knowledge. The experts were familiar with evacuation protocols and knew how to react in a mine emergency, even with limited information. In contrast, the level of available information may have been too low for novices. It is notable to mention that the perceived level of challenge was not rated significantly different between the cohorts (L2-Q1D).

Level 3: Interaction Techniques

In this study, we explored aspects of the user interface which can play a central role in making the application more accessible to domain users. The relationship between interaction and Accessibility is codified by specific Design Guidelines for Training in Mine Safety, namely DG1, DG3, and DG4 (Table 1). With the flexibility of our platform, we can support a variety of different user interface techniques and devices, including traditional keyboard and mouse, gamepad, and touch surfaces. All are common interfaces which are popular for different types of applications. We considered their effects in terms of ease of use and interaction capabilities for domain tasks. In summary, the following two hypotheses were considered:

L3-H1: The gesture interface is the most accessible in terms of (a) perceived difficulty to learn and (b) ease of use.

L3-H2: The game controller is the most accepted method in terms of (a) overall satisfaction and (b) overall preference.

In this experiment, there was one variable, the interface device, with three conditions: KB+MOUSE, GAMEPAD, and GESTURE. The three conditions were as follows:

1. Keyboard and mouse (KB+MOUSE): A standard keyboard and mouse user interface. A mouse was used to manipulate head orientation while the W-A-S-D keys were used for travel. Where possible, key mapping conventions where chosen that were similar to existing FPS games.
2. Gamepad (GAMEPAD): A hand-held game controller. For this study, we used a Microsoft Xbox 360 controller, as it is among the most popular game controllers currently available. The interface mapping was selected to be similar to the default mapping used in many console-based FPS games
3. Gesture (GESTURE): An experimental gesture-based interface using a touch-enabled tablet computer. We attempted to make the gesture interface as intuitive as possible through direct-touch manipulation for all on-screen elements, with a gesture language that is common to "apps" on handheld computing devices.

Results. A summary of the post-session questionnaire may be found in Table 9, while user responses are given in Table 10. Questions incorporated 7-point Likert scales. In Table 10, the median and mode are given for each question; means are excluded due to space limitations and the small sample size of the Likert data. Note that significant effects for the interface condition are highlighted with dotted boxes (red). Tests of significance used one-way (1x3) within subjects rank ANOVA, at the $p < 0.05$ threshold.

Analysis. Rank ANOVA indicated significant differences in user satisfaction for both L3-Q1A, "Terrible versus Wonderful" and L3-Q1B, "Frustrating versus Satisfying." Post hoc analysis with

the Student-Newman-Keuls (SNK) test indicated two statistical groupings for "Terrible versus Wonderful," with the GESTURE condition rating significantly lower than the KB+MOUSE and GAMEPAD. The ratings for KB+MOUSE and GAMEPAD were not statistically different. For L3-Q1B, the SNK test suggested that the KB+MOUSE condition rated significantly better than

Table 9. Level 3 Post-Session Questionnaire. Ratings were gauged using 7-point Likert scales.

Question	Description
L3-Q1	Overall, how would you rate each interface technique?
A	Terrible vs. Wonderful
B	Frustrating vs. Satisfying
C	Hard to use vs. Easy to use
L3-Q2	Learning to use this interface technique. (difficult vs. easy)
L3-Q3	Exploring new features by trial and error, without using a manual.
L3-Q4	Remembering interface mappings, like keys, gestures, or actions.
L3-Q5	I could interact with all of the information in a clear and consistent way.
L3-Q6	The interface technique was familiar and intuitive.
L3-Q7	The interface did what I needed for the training tasks.
L3-Q8	Physical demands of the interface. (tiring vs. not tiring)
L3-Q9	Given the choice, I would use this interface technique again.
L3-Q10	The interface technique made the training tasks easier.
L3-Q11	Rate the following types of interaction: Ease of Use & Effectiveness
A	Navigating my viewpoint in the virtual environment.
B	Interacting with people and objects in the virtual environment.
C	Manipulating information on the Heads-up Display (HUD).
D	Using the game mini-map.
L3-Q12	Which interface technique did you like the most? Why?
L3-Q13	Which interface technique did you like the least? Why?

GESTURE, while GAMEPAD was similar to both

Table 10. User ratings of three interface conditions in the Level 3 study (higher is better). Shaded cells with dotted outlines indicate significant differences based one-way rank ANOVA ($p < 0.05$).

Ouestion	KB+MOUSE		GAMEPAD		GESTURE	
	Median	Mode	Median	Mode	Median	Mode
L3-Q1A	6	6	6	6	4	5
L3-Q1B	6	6	5	5	3	3
L3-Q1C	6	6	6	7	5	6
L3-Q2	6	7	6	7	5	7
L3-Q3	4	6	5	4	5	7
L3-Q4	5	5	5	7	6	7
L3-Q5	6	6	6	7	6	6
L3-Q6	6	7	6	7	6	6
L3-Q7	6	7	7	7	6	6
L3-Q8	7	7	7	7	6	7
L3-Q9	7	7	7	7	4	1
L3-Q10	6	7	7	7	5	5
L3-Q11A						
Ease of Use	6	6	5	7	6	7
Effectiveness	6	7	6	7	7	7
L3-Q11B						
Ease of Use	6	7	5	7	7	7
Effectiveness	7	7	6	7	7	7
L3-Q11C						
Ease of Use	6	7	6	7	6	7
Effectiveness	7	7	6	7	6	7
L3-Q11D						
Ease of Use	6	7	6	7	3	2
Effectiveness	7	7	7	7	4	3

KB+MOUSE and GESTURE. The three conditions were not significantly different for L3-Q1C, "Hard to Use versus Easy to Use." On question L3-Q7, "The interface did what I needed for the task," the SNK post hoc test indicated that GESTURE rated significantly worse than KB+MOUSE and GAMEPAD. Such a result suggests that the implementation of the GESTURE interface did not have sufficient expressive power for the types of interaction needed in the game tasks. There was no significant difference between KB+MOUSE and GAMEPAD.

In an interesting reversal of trends, the GESTURE condition rated favorably for certain types of component interaction (L3-Q11). For ease of use, one-way rank ANOVA indicated a marginally significant difference in the conditions for L3-Q11A, "Navigating my viewpoint," and L3-Q11B, "Interacting with people and objects." Post hoc testing with SNK suggests GESTURE was rated slightly better than both KB+MOUSE and GAMEPAD. Users' ratings for "Effectiveness" were not statistically significant. The GESTURE condition's use of direct touch for selection and pose manipulation may have played a factor in making it the preferred method for object manipulation and navigation in the virtual world.

Another area where the GESTURE condition showed promise rested in the cognitive overhead needed to remember the interface mappings. The use of direct touch manipulation, coupled with repeated use of tap and drag gestures, may have reduced the perceived load on users' memory. Indeed, rank ANOVA indicated a significant difference in the means for L3-Q4, "Remembering interface mappings" ($F_{2,34} = 3.35$, $p = 0.0469$), with post hoc SNK showing GESTURE to rank higher than both GAMEPAD and KB+MOUSE in this regard. Informal observations supported this notion; during the experiment, we observed that users rarely looked at the reference card (i.e. "cheat sheet") in the GESTURE condition, whereas users appeared to reference the cards more frequently in both the GAMEPAD and KB+MOUSE conditions.

In terms of use acceptance, one-way rank ANOVA indicated a significant effect for interface condition on question L3-Q9, "I would use this interface again"; SNK post hoc tests suggested that the GESTURE condition was again ranked lower than both KB+MOUSE and GAMEPAD, which were similar. There was no significant effect of the interface condition on question L3-Q10, "The interface made the training tasks easier." In the short answer questions, users indicated that they liked GAMEPAD (50%, 9 of 18 users), followed by KB+MOUSE (39%, 7 of 18 users). Two users, both self-identified as non-gamers, preferred the GESTURE interface over the other conditions, although a majority of the users (61%, 11 of 18 users) rated the GESTURE condition as their least favorite. Common criticisms of the GESTURE condition included unfamiliarity (4 responses), limited responsiveness (4 responses), and lack of expressive power (3 responses). Indeed, the user responses illustrated a wide range of opinions and preferences.

Discussion. The results of the Level 3 study were mixed on the performance of the GESTURE condition, which scored lowest overall on the satisfaction ratings and was the least preferred method. However, GESTURE did show some promise for perceived ease of learning and ease of use. Although users felt it was overall no easier or more difficult to learn that the other methods, they did rate it easiest to remember commands and interface mappings. The low memory overhead makes sense, given the small set of gesture commands and reliance on direct tap and swipe gestures for common interactions. However, the answers to the learning questions are not in agreement, so we cannot confirm or reject L3-H1(a) based on this study. In terms of ease of use, GESTURE was rated easiest for certain types of common interactions, including navigation and object manipulation, even if it was substantially worse for manipulating certain work objects on the HUD. The conflicting results suggest that L3-H1(b) also needs further study. Furthermore,

user comments suggested that awkwardness in the implementation was partly at fault, otherwise GESTURE may have rated considerably better overall. Further studies are necessary to investigate gesture-based techniques as a means to increase the accessibility of serious games for domain users (hypothesis L3-H1).

In contrast to GESTURE, the GAMEPAD condition scored more consistently. It was ranked in a tie with KB+MOUSE on most satisfaction and ease of use metrics. Furthermore, users strongly preferred GAMEPAD when asked for their favorite. Several users cited familiarity as a reason for their choices. Therefore, evidence suggests that hypothesis L3-H2 is proven. Curiously, the KB+MOUSE condition scored substantially better in this study than in our pilot. In nearly all respects, it scored similarly to GAMEPAD -- except for overall user preference, in which users picked GAMEPAD by a simple majority. Based on this evidence, the GAMEPAD appears to be the best option at present to interact with serious games. It is the most established and refined input device, being purpose-built for gaming, and is familiar to a large portion of the user base. However, many users do have issues with the control mappings and it is less than ideal for many domain-oriented manipulation tasks.

Level 4: Display Techniques

Notable problems were also observed in our Level 2 studies relating to users' understanding of the data sets. The issues with information synthesis were particularly evident among domain novices. For example, novices were easily overwhelmed by the game experience and had difficulty in determining what to do next. Despite the availability of hints and waypoints, they rated the game significantly lower than experts in regard to task scaffolding (e.g. L2-Q5). They also tended to get spatially disoriented and lost their way more readily (e.g. L2-Q6). Such problems may be due, in part, to the game's presentation, given the limited display technology used in the Level 2 studies (e.g. standard LCD monitors). This study will look at ways to address specific presentation problems using enhanced display technologies.

The Contextual theme of the Design Guidelines for Training in Mine Safety (Table 1) makes specific recommendations that include supporting a range of presentation needs (DG6) and helping users understand spatial relationships (DG8). Increasing the level of immersion (Bowman & McMahon, 2007) has been proposed as a method to address the usability problems of heterogeneous data sets similar to those observed in mine safety applications (Brown, 2015, Ch. 2.3). Toward this goal, the MineSAFE platform supports extended display capabilities that can enhance the level of immersion offered by serious games. In this usability study, we examined two of these display capabilities -- stereoscopic 3D and ultra wide screen -- which are currently popular among gaming enthusiasts. Note that “ultra wide screen” is gaming parlance for a multi-monitor surround configuration. In summary, the Level 4 study was designed to test two hypotheses:

L4-H1: Both ultra-wide and stereoscopic3D display will enhance the game experience through (a) greater environmental presence and (b) better spatial awareness.

L4-H2: The ultra-wide display will be the highest rated viewing condition in terms of (a) user satisfaction and (b) overall preference.

The Level 4 study considers one variable with three conditions: STANDARD, STEREO and UWS. All three display conditions were presented using a desktop workstation. The STEREO and UWS conditions examine specific aspects of the "desktop VR" gaming experience. Furthermore, each display condition

was designed to be a "best case" configuration given the available technology. In summary, the three conditions were as follows:

1. Standard (STANDARD): A standard PC monitor. A baseline for this usability study, the PC monitor is a common configuration for computer-based training applications and is reflective of the display setup used in our earlier Level 2 tests. The field of view (FOV) of the virtual camera was set to 80°.
2. Stereoscopic (STEREO): A stereoscopic 3D display. The stereoscopic display affords an additional depth cue which can help users understand the 3D structure of a scene. The stereoscopic effect was achieved using a frame-sequential view plane method with active shutter glasses.
3. Ultra-wide screen (UWS): A three-panel surround display with wide virtual FOV. The UWS condition enabled two capabilities: it provided substantially greater peripheral vision and offered more screen space for users to manipulate supplementary data. The UWS featured a FOV of 150°. The experimental setup for UWS condition is illustrated in Fig. 3.

Results. A summary of the post-session questionnaire may be found in Table 11, while users responses are given in Table 12. In Table 12, the median and mode are given for each question; means are excluded due to space limitations and the small sample size of the Likert data. Note that significant effects for the interface condition are highlighted with dotted boxes (red). Tests of significance used one-way (1x3) within subjects rank ANOVA, at the $p < 0.05$ threshold..

Analysis. Overall satisfaction was rated similarly for all three conditions. Rank ANOVA indicated that there was no significant effect for display condition on the ratings for either L4-Q1A, "Terrible versus Wonderful," or L4-Q1C, "Dull versus Exciting"; there was a marginally significant effect on the ratings for L4-Q1B, "Frustrating or Satisfying." On this question, post hoc SNK suggested that the STANDARD and STEREO conditions were similar and rated as slightly more frustrating than UWS.

On question L4-Q2, rank ANOVA indicated a significant difference in the three display conditions. Post hoc SNK tests indicated that the UWS condition was rated significantly better than both STANDARD and STEREO, while the STANDARD and STEREO conditions were not statistically different. Furthermore, there was a significant effect of display condition on users' perceived ability to navigate the in environment, L4-Q3. Surprisingly, post hoc testing suggested that the UWS and STANDARD conditions were both considered better than the STEREO condition for navigation. There was no significant difference in the ratings for UWS and STANDARD, despite the higher median rating for UWS (6 for UWS versus 5 for STANDARD). There was also a significant effect of display condition on the users' perceived understanding of spatial relationships, L4-Q4. Post hoc SNK suggests that UWS rated significantly better than STEREO and STANDARD.

There was no significant effect for display condition on user acceptance. At the $p < 0.05$ level, rank ANOVA did not indicate differences in the means for either L4-Q5, "the display technique made the training tasks easier," or L4-Q6, "I would use this display technique again." Nonetheless, users rated the UWS condition as a favorite on question L4-Q11, by a large percentage (69%, 11 of 16). Thirty-nine percent of users mentioned the advantages of peripheral vision as the reason they preferred UWS, while 22% indicated the additional screen space as their reason for liking it. Conversely, only a small percentage of users (13%, 2 of 16), listed UWS as their least favorite on question L4-Q12. The STEREO condition was a distant second in

preference, with 25% (4 of 16) of users indicating it as their favorite. The STEREO condition was also the most disliked, with 63% (10 of 16) listing it as their least favorite. In all, there was a consensus for the UWS being either a good or best solution, while users typically had strong opinions one way or the other for the STEREO condition (88%, 14 of 16, rated it either best or worst). Note that 5 users did not report preferences.

Informally, we noticed a marked difference in the usage of the Learner's Clipboard across the conditions. Recall that the clipboard provides helpful feedback and hints on decisions making, based on game context. The behavior of the clipboard was such that it was brought on screen when the first learning point appeared and stayed on screen dismissed by the user. In the STANDARD and STEREO conditions, the clipboard took up virtually the entire space of the display, making it impossible to view the virtual

Table 11. Level 4 Post-Session Questionnaire. Ratings were gauged using 7-point Likert scales.

Question	Description
L4-Q1	Overall, how would you rate each display technique?
A	Terrible vs. Wonderful
B	Frustrating vs. Satisfying
C	Dull vs. Exciting
L4-Q2	The display technique made me feel immersed in the game, like I was there.
L4-Q3	The display technique made it easy to navigate in the game environment.
L4-Q4	The display technique helped me to understand spatial relationships.
L4-Q5	The display technique made the training tasks easier.
L4-Q6	Given the choice, I would use this display technique again.
L4-Q7	The HUD was clearly organized.
L4-Q8	The HUD was easy to understand.
L4-Q9	The HUD was helpful in the training tasks.
L4-Q10	How often did you look at or use each piece of data? (never vs. all the time)
L4-Q11	Which display technique did you like the most? Why?
L4-Q12	Which display technique did you like the least? Why?

Table 12. User ratings of three display conditions in the Level 4 study (higher is better). Shaded cells with dotted outlines indicate significant differences based one-way rank ANOVA ($p < 0.05$).

Question	STANDARD		STEREO		UWS	
	Median	Mode	Median	Mode	Median	Mode
L4-Q1A	5	5	5	6	6	7
L4-Q1B	5	4	5	6	6	7
L4-Q1C	5	7	5	5	6	7
L4-Q2	5	6	6	6	6	7
L4-Q3	5	6	5	4	6	7
L4-Q4	6	6	5	4	6	6
L4-Q5	5	6	5	5	6	7
L4-Q6	6	7	6	7	7	7

environment at the same time. For this reason, users typically dismissed the clipboard quickly and simply forgot about it thereafter. In contrast, clipboard usage was markedly different for the UWS condition. In this condition, the clipboard was attached to the right side of the ultra-wide screen, out of the direct line of site. Users overwhelmingly chose to leave the clipboard visible in the UWS view rather than dismissing it. Post hoc analysis of game logs indicates that the clipboard was on screen significantly more than in the STANDARD and STEREO, with a visible time that was almost as long as the mini-map.

Discussion. The results of the Level 4 tests suggest the benefits of enhanced display techniques. The UWS was rated as good or better than both STANDARD and STEREO for enhancing presence and increasing spatial awareness. Opinions of STEREO were mixed, as it typically scored no better than STANDARD and, in one case (L4-Q3), worse. These results suggest that hypothesis L4-H1 is proven for UWS and disproven for STEREO. However, it is possible that the implementation and specific choices of hardware played a factor in the poor results. For instance, the stereoscopic images were prone to ghosting.

In terms of user preferences, UWS was listed as a favorite for the majority of users. Although UWS did not score substantially better on overall satisfaction, users strongly preferred it in their comments and almost never listed it as the least preferred (i.e. only 2 users of 16 listed UWS as their least preferred). These results suggest L4-H2(a) requires further study, while L4-H2(b) is accepted. Furthermore, user comments also suggest that the dual utility of UWS -- increasing peripheral vision while simultaneously affording more screen space to manipulate data -- played a factor in user preferences. Overall, the evidence supports hypothesis L4-H2.

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Appendix A: Affinity Diagram

Legend

Application		Evidence Type	
MRB	Map Reading Basics	O	Observation
MNC	Mine Navigation Challenge	C	Comment
RFG	Refresher Fatalgrams	I	Inference
MES	Mine Emergency Simulation		
MED	Mine Evacuation Drill		

ID	Description	Type	App	Task
LIMITED ACCESSIBILITY (ACCESSIBLE)				
Obstacles to acceptance				
The age gap				
1	"Old guy, not a gamer."	C	MNC	
2	Computer keyboard causes some users anxiety	I	MNC	
3	"I work for old school people that haven't embraced the computer age"	C	RFG	
4	"Most younger miners play games"	C	MES	
5	"Younger miners would prefer to play games on an iPad; older miners prefer paper."	C	MES	
6	Older miners will be less interested in playing video games or doing graphical simulations	I	MES	
Aversion to (new) technology				
7	"PowerPoints are easy"	C	RFG	
8	Training slides are readily available from MSHA	O	RFG	
9	Trainers often stick to things they know, but would be willing to change if results are verifiably better	I	RFG	

10	Training sites often lack sophisticated technology	I	RFG	
11	Handouts are objects that users can touch, take home.	I	RFG	
12	Expensive simulators often sit around unused	I	MES	
13	Perception of simulators being narrowly scoped, limited use for more safety training applications	I	MES	
14	"Trainers don't like to deal with IT"	C	MES	
15	Needs to be a complete system package to make it adoptable	I	MES	
16	Audience acceptance is a factor in using computer-based software in the classroom	I	MES	
17	Audience knows phones, handhelds, touch interfaces, but may not be literate in business computing systems	I	MES	
18	Concerns about acceptance of computer-based training by management, workers	I	MES	
The time it takes				
19	"Timing is important." May not have time to go through everything in great detail.	C	RFG	
~~20~~	"Simulation takes too long"	C	MES	
~~21~~	"Any way to speed up training?"	C	MES	
~~22~~	Should fit within existing curriculum	I	MES	
23	Production downtime can last for several hours per shift	I	MED	
24	Time pressures mean the drill must be finished as quickly as possible	I	MED	
Ergonomic risk factors				
~~25~~	Drill does not condition miners to the physical demands of equipment or emergency	I	MED	
~~26~~	Goggles are cumbersome, take getting used to	O	MED	
~~27~~	Users may not speak up if they have trouble donning SCSRs	I	MED	5
~~28~~	May not include guidance or practice of breathing control or realistic resistance breathing	O	MED	5

29	Walk out is physically demanding with potential for real injury	O	MED	7
Beyond the user's skill level				
Difficult tasks				
30	"Need apps with support for different personalities"	O	MRB	
31	"Need simpler game, with levels to get better."	C	MNC	
32	User is completely on his/her own	O	MNC	
33	"The tasks are too difficult"	C	MNC	
34	Users would like to have difficulty settings	O	MES	
35	"Would be better to have less choices for easy level, more choices for hard level"	C	MES	
Cognitive overload				
36	Lots of new terminology and symbols presented in a short amount of time, requiring rote memorization	O	MRB	3-5
37	Teams of trainees worked together to figure out what was said, where to go, and shortest path to get there	O	MNC	2-4
38	"Are there simpler games available? Could move up as [workplace] literacy increases."	C	MNC	
39	High task overhead due to directions that are difficult for novices to understand and remember	I	MNC	2-3
40	Depth and breadth of information can be saturating	I	RFG	4-5
41	Accidents involve complex sequences of events, which can be difficult to understand	I	RFG	4
42	Too many best practices to memorize	I	RFG	7
43	"It's hard to tell if miners are actually 'getting it'"	C	RFG	7
44	Summary slides are used as a take-away message	C	RFG	7
45	The tutorial presents a lot of information on the user interface and simulation mechanics	O	MES	2

46	Less experienced users have a hard time remembering everything presented in the stream of tutorial videos	I	MED	2,3,4
Lack of remediation				
47	No hints are given for direction or waypoints	O	MNC	2-3
48	No hints are given for terminology	O	MNC	2-3
49	No legend provided for the map	O	MNC	2-3
50	Limited opportunities in structured drills to help miners that don't understand procedures	I	MED	
51	Review sessions may not allocate the time or structure to tutor individuals, especially on Refuges, Firefighting	O	MED	2,3,4
Limited language and workplace literacy				
A multi-lingual audience				
52	"Need Navajo, Spanish versions in the West"	C	MRB	
53	Many first languages (English, Spanish, Navajo, etc), dialects, and accents in audience	I	RFG	
54	Wide variation in language understanding across audiences	I	RFG	
Limited understanding of the language				
55	Definitions are formal English -- don't use layman wording.	O	MRB	3-5
56	No usage examples	O	MRB	3,4,5
57	Lack of pronunciation example for terminology	O	MRB	3,4,5
58	No language localization	O	MRB	
59	Instructions are limited to spoken form	O	MNC	2
60	Instructions are not repeated	O	MNC	2
61	Non-native speakers may not be able to follow discussion and analysis	I	RFG	5
62	Trainees may be reluctant to speak up if they do not understand	I	RFG	5
63	Backstory is conveyed only by spoken narrative	O	MES	1

64	Videos difficult to hear, understand, even for native speakers	I	MED	2,3,4
65	Evacuation route is given in spoken narrative	O	MED	7
66	Locations and directions may be confusing if not looking at a map	I	MED	7
Presumption of workplace literacy				
67	One definition may rely on understanding of other definitions.	O	MRB	3-5
68	Many terms are used without sufficient background to orient user	I	MRB	3-5
69	Barrage of technical terminology can be overwhelming for new miners	I	MNC	
70	Technical summaries assume fluency in English and technical terms	O	RFG	
71	Trainees may be reluctant to speak up if they do not understand	I	RFG	5
72	Narratives assume users understand technical terminology	O	MES	1
73	No support for remedial learning of technical terminology	O	MES	
74	Videos include step by step breakdown of processes including terms used in manual instructions	O	MED	2-4
75	Diagrams, manuals, and instruction sheets may use technical terminology	O	MED	
76	Maps use many domain-specific symbols	O	MED	
Variation across work sites				
77	Should account for differences in dialect, pronunciation across mine sites	I	MRB	3-5
78	Tutorials are tailored for coal; metal (hard rock) terms are very different	I	MRB	3-5
79	"Could we use my mine site and maps?"	C	MES	
80	"We do some things differently at my company."	C	MES	
81	Mine maps may include site and method-specific symbols and variations in symbol usage	O	MED	

82	There are differences across companies, mine methods, and in states' laws.	I	MED	

Difficult for novice user

Apparent learning curve

83	"I lack the extensive computer skills needed to use it"	C	MRB	
84	Novice users and non-gamers struggle to learn how to navigate the environment, and fumble around quite a bit	I	MNC	
85	Teams of 2 trainees typically work together to control one game avatar	C	MNC	3-4
86	Trying to deal with the interface for navigation distracted some users from the real goals	I	MNC	2-3
87	"Keyboard interface is challenging to use for less computer literate"	C	MES	
88	"Gamepad may be better choice and likely a 'must' for young workers"	C	MES	
89	Novices and non-gamers: Much time wasted learning, fumbling with the controls	I	MES	
90	Simpler interface would be desirable for casual users	I	MES	

The need for technology tutorials

91	Very little orientation is provided for control schemes	O	MNC	1
92	No opportunity to practice UI tutorial elements as they show up	O	MES	
93	Tutorial is not interactive: restricted to text on signs in environment	O	MES	
94	"I need pointers on how to play this"	C	MES	
95	No instructions on navigational controls or heads up display	O	MES	
96	Cannot practice game tutorial elements as they show up	O	MES	2
97	Tutorial is presented as a series of billboards in 3D game lobby environment	O	MES	2

98	Tutorial has no instruction on user interface, including navigational controls and heads up display	O	MES	2
99	No hints on user interface controls or heads up display once in game	O	MES	3-7
A multitude of standards				
100	Tutorial uses a WIMP interface with embedded slide show	O	MRB	
101	Control scheme differs across Introduction, Quick Start, Manual, and Tutorial	O	MRB	1
102	Pseudo-standard FPS computer game interface splits degrees of freedom for travel, head pose across devices	O	MNC	
103	MNC (non-WIMP) uses different interface than MRB (WIMP)	O	MNC	
~~104~~	fatalgrams use slide shows and paper handouts	O	RFG	
105	Pseudo-standard FPS computer game interface splits degrees of freedom for travel, head pose across devices	O	MES	
106	Simulation (non-WIMP) uses different interface than Debrief (WIMP)	O	MES	
107	Drills use videos, equipment, and paper handouts, some of which may be carried during the evacuation segment	O	MED	
Lack of concise mechanics				
108	Interface actions are not always obvious: hovering over some elements changes output, but not others	I	MRB	
~~109~~	WIMP: "The interface is confusing"	C	MRB	
110	User interface requires clicking through small text links distributed around page making it easy to miss parts of the tutorial	I	MRB	3-5
~~111~~	Users randomly click on everything	O	MRB	
~~112~~	The splitting of travel and head pose controls is awkward for novice users	I	MNC	
~~113~~	The user gets stressed and visibly frustrated that he cannot orient himself during navigation	I	MNC	

114	Two users team up to control navigation in tandem, by splitting the travel and pose manipulation tasks	O	MNC	
115	Users find tandem navigation to be easier	I	MNC	
116	"Map is inconvenient to use"	C	MNC	
117	No clean way to terminate or restart tasks or simulation	O	MNC	
118	The splitting of travel and head pose controls is awkward for novice users	I	MES	
119	Mouse-based pan and zoom implementation is tedious on the debrief map, especially during interactive discussion	I	MES	8
120	The user is unclear how to interact with world or what to interact with	I	MES	
121	Non-gamer: "Controls weren't intuitive"	C	MES	
Clumsy context switches				
122	Learning component (MRB) and evaluation component (MNC) use different software & presentation	O	MRB	
123	The overview map and 3D mine environment (walkthrough) cannot be viewed at same time; map fills entire screen	O	MNC	
124	Task involves a three-way context switch and high cognitive overhead for novice to plan a route: interpret instructions, read map, find location and direction	O	MNC	2-3
125	"The map was cumbersome, so I didn't use it very much"	C	MNC	
126	Every fatalgram is presented in a separate set of slides	O	RFG	
127	Trainers sometimes have to flip back and forth through slides to find relevant pictures or diagrams.	O	RFG	6-7
128	Photos are sometimes duplicated for reference to discuss best practices	O	RFG	7

129	The tutorial occurs in a 3D lobby environment; must exit the lobby to load the actual game environment	O	MES	2
130	The game lobby looks nothing like game environment	O	MES	2
131	The Debrief is a separate program from the simulation.	C	MES	8
132	"Switching between all of the [3] programs can be disruptive"	C	MES	

Overly limited interface mechanics

Artificial constraints

133	Control scheme artificially limits degrees-of-freedom of viewpoint pose	I	MNC	
~~134~~	Limited options to interact with environment	I	MNC	
~~135~~	"I want to pick stuff up"	C	MNC	
136	Control setup (keyboard+mouse) is not remappable	O	MNC	
137	fatalgrams cannot be manipulated by end users -- trainer only has control	O	RFG	
138	Holding of lifeline has no visual indication in 3D mine environment	O	MES	7
~~139~~	Lifeline coupling is cumbersome	I	MES	7
140	Control scheme artificially limits degrees-of-freedom of viewpoint pose	I	MES	
141	Does not promote or allow for proper equipment donning, usage procedures	O	MES	4
~~142~~	Crew tethers are not actually used for anything	O	MES	
143	Interface to safety equipment is limited, unrealistic	O	MES	
144	Control setup (keyboard+mouse) is not remappable	O	MES	

Necessity of tactile feedback				
145	Proprioceptive cues, like turning head, moving body, and stepping, are essential in navigation underground	I	MNC	4
146	Tactile cues, like touching ribs and lines, are essential in navigation underground	I	MNC	4
147	No support for natural proprioceptive cues	O	MNC	
148	Tactile cues are not supported	O	MNC	4
149	No support for popular UI devices: gamepads, touch surfaces	O	MNC	
~~150~~	No support for natural proprioceptive cues	O	MES	
~~151~~	Tactile cues are not supported	O	MES	7
152	No support for popular UI devices: gamepads, touch surfaces	O	MES	
~~153~~	"Game controller might make it easier"	C	MES	
~~154~~	"Miners learn by doing"	C	MES	
155	"Would like to use something like [Microsoft Xbox] Kinect"	C	MES	
156	Drill involves real manipulation of real/dummy equipment	O	MED	5-6
~~157~~	Donning practice for SCSR is required by MSHA	O	MED	5
158	In drill, navigation is natural, with full body and sensory cues employed while walking real escapeways	O	MED	7-8
LACK OF CONTEXT (CONTEXTUAL)				
Media do not meet needs of task				
Problems with computer-based media				
~~159~~	Limited display resolution makes 3D mine environment and map look pixelated	O	MNC	
~~160~~	Field of view and peripheral vision restricted by display hardware (23" LCD panel)	O	MNC	

161	Limited and incomplete depth cues: no stereoscopic cues, limited depth of field, ambiguous shadowing	O	MNC	
162	Difficult to read small text	O	RFG	
163	Limited display resolution makes 3D mine environment look pixelated	O	MES	
164	Limited display resolution makes it hard to read the tutorial text in the 3D lobby environment	O	MES	2
165	Field of view and peripheral vision restricted by display hardware (23" LCD panel)	O	MES	7
166	Limited and incomplete depth cues: no stereoscopic cues, limited depth of field, ambiguous shadowing	O	MES	
167	Videos have limited contrast	O	MED	2-4
Problems with print and other media				
168	Paper maps may be optionally printed as a reference for the navigation challenge	O	MNC	1
169	Printer does not appear to be readily available in classroom to print software manual or maps	O	MNC	1
170	Summary handouts are given for fatality statistics, best practices	O	RFG	
171	Users jostle handouts, trying to follow trainer	O	RFG	
172	Notes are often discarded shortly after the session	I	RFG	
173	Paper maps posted underground in crew break areas and caches for reference	O	MED	
174	Signage is vital to indicate escapeways, egress directions, caches, refuges, and phones	I	MED	
175	Instruction sheets are made available for safety equipment such as refuge chamber	I	MED	3
176	Utter darkness is chief limitation on visual acuity, except in areas with secondary lighting	O	MED	7-8
177	Instruction labels on equipment can be covered in dust and dirt, difficult to read	O	MED	7-8
178	Evacuation drill plans are printed to paper and may be carried underground by the foreman	O	MED	7-8

179	Printed maps have small details which can be difficult to see	O	MED	7-8
180	Notes may be lost or sullied	I	MED	7-8
181	Instruments and papers may be difficult to read in smoke conditions	I	MED	
Details do not meet needs of task				
Missing or unavailable data				
182	Not clear which map symbols relate to each map or piece of media	I	MRB	3,4
183	Cannot view the 2D overview map and 3D virtual environment at the same time	O	MNC	3
184	No visual indications of goals or progress	O	MNC	3-4
185	"Not enough information to make decisions"	O	MES	5
186	No map to use for reference -- not how it would normally be in practice	O	MES	5-6
187	Mustering point is inconspicuously marked: only shown during the tutorial phase, in the lobby. No way to access in game environment itself	C	MES	6
188	"What is the mustering point? Usually it's safety cache"	C	MES	6
189	Cannot use 3D virtual mine environment as a frame of reference for debrief	O	MES	8
190	Difficult to find the map details needed for debriefing discussion	I	MES	8
191	Hard to point out problems or techniques after fact	I	MED	9
Too little detail				
192	Mine model geometry is repetitive, simplistic	O	MNC	
193	Missing important workplace-specific details (e.g. vent tubes, electricals, signage) that are required to be code compliant	I	MNC	
194	Verbal instructions reference objects and equipment that are hard to make out	O	MNC	2
195	Unrealistic underground lighting and lack of shadows	O	MNC	

196	Models are low polygon count and textures are low resolution by current game standards	O	MNC	
197	Instructional text is missing for most of the navigation tasks -- verbal only	O	MNC	
198	Simulated mine environment is repetitive and simplistic, offering few distinct reference points for navigation	I	MNC	3
199	Models are low polygon count and textures are low resolution by current game standards	O	MES	
200	Visual fidelity of safety equipment is very limited, reduces meaningfulness of checking it	I	MES	4
201	"Safety equipment is limited, not very realistic"	C	MES	
202	Unrealistic underground lighting and lack of shadows	O	MES	
203	Avatars of team members have limited fidelity or uniqueness, making identification difficult	I	MES	4, 5
204	"Difficult to tell who controls which avatar"	C	MES	
205	"Simulated" emergency is a very limited experience: few if any visual cues	I	MED	7-8
Too much detail				
206	Map icons difficult to read due size, display resolution	O	MNC	
207	Lots of important mine features to consider at once -- beltways, airflows, crossovers, doors, pillars, etc	O	MNC	2-4
208	Difficult to see path lines on small map	O	MNC	5
209	Accident scene is complex in both time and space	O	RFG	4
210	Depth and breadth of information can be saturating	I	RFG	4
211	Map can become cluttered, making it difficult to follow debrief	I	MES	8
212	Difficult to tell overlapping symbols, paths in debrief	O	MES	8

Lack of spatial awareness				
Limited point of view				
213	Photographs often have narrow field of view, don't give a lot of perspective on surrounds	O	MRB	3-5
214	Not presented from same point-of-view as would be seen in real workplace	O	MRB	3
215	Lack of useful frames of reference	I	MRB	4
216	"Not being able to see the full view makes it harder to find my way around"	C	MNC	4
217	Few illustrations - can be difficult to understand setup from textual descriptions alone	I	RFG	4-5
218	Discussion not clear on placement of people and things	I	RFG	4
219	Difficult to understand visibility and field-of-view factors	I	RFG	4
220	"'Tunnel vision' is common -- focusing on some aspects of work but not others"	C	RFG	
221	Can be difficult to understand side-effects of actions	I	RFG	5
Disorienting workplace structure				
222	References and directions seem ambiguous to novices	O	MRB	3-4
223	No hints to indicate direction or waypoints	O	MNC	3
224	Difficult to understand what we're looking for based on the spoken instructions	I	MNC	2-3
225	User must figure out where he is before he can figure out where he should go	O	MNC	3
226	Even experienced trainees can become disoriented, confused in navigation task	I	MNC	3-4
227	"No way to tell my orientation in unfamiliar mine"	C	MNC	
228	Understanding the mine setup -- airflows, escapeways, and known hazards -- is vital to plot an escape	I	MES	5-6

229	Mine is repeating grid pattern where every cross section looks the same	O	MES	6-7
230	Navigation is difficult without a map	I	MES	6-7
231	Fidelity of virtual mine environment offers few distinct points of reference for navigation task	I	MES	6-7
232	Difficult to recall which locations aligned with map features	I	MES	8
233	Locations and directions may be confusing	I	MED	7
234	Workplace can be difficult to navigate	I	MED	7-8
235	Escapeway maps are provided to workers and posted at strategic locations	O	MED	

Users cannot relate

Stylized or abstract

236	Terminology is presented in a slide show	O	MRB	
237	Stylized line drawings used to illustrate mine layout terms	O	MRB	3
238	Textbook definitions instead of layman interpretations	O	MRB	3-5
239	Diagrams and stylized line drawings used to illustrate many terms	I	MRB	3-5
240	No realistic photos or models to illustrate many terms	I	MRB	3-5
241	"Must balance realism with abstraction"	C	MRB	
242	Navigation terms are defined using 2D overview maps	O	MRB	4
243	Each navigation term is discussed separately from other related terms	O	MRB	4
244	Safety guidelines are presented in generic format	O	RFG	7
245	Refuge refresher is not tied to emergency circumstances	O	MED	3
246	Donning occurs in controlled, sterile situation	O	MED	5
247	Fire conditions are isolated and tightly controlled for safety	O	MED	6

Lack of real world examples				
248	Many examples are map-only in scope: does not consider how mine features might look in a real mine	O	MRB	3
249	Some equipment types are presented without reference to corresponding map symbols	O	MRB	5
250	Examples do not account for real-life complexities, variations, counter-examples, or adequately portray subject matter within its typical surrounds (e.g. a close-up picture of a mine door)	O	MRB	3-5
251	Lack of spoken examples or usage	O	MRB	3-5
252	Navigation tasks cover only a small portion of the topics in MRB	O	MNC	2-3
253	Matter-of-fact presentation may not sufficiently illustrate human factors	I	RFG	4
254	Simulation lacks much of the visceral sights, sounds, and confusion that would be present in real mine disaster	I		
~~255~~	"We use different refuge chambers"	C	MES	
256	"We need training scenarios for mill, moly, pit and the crusher"	C	MES	
~~257~~	"Everything is focused on underground coal."	C	MES	
258	Lack of visual references makes it difficult to illustrate problems with techniques or evacuation route	I	MED	9
Unauthentic usage of equipment				
259	Safety guidelines are presented in a generic format without specific consideration for trainee's workplace	I	RFG	7
~~260~~	"In real life, equipment can fail"	C	MES	
~~261~~	Multi-meter instruments can run low on battery, malfunction	I	MES	
262	Safety equipment has few effects: breathing apparatus does nothing, goggles do not change visibility; safety tethers have no in-game purpose	O	MES	4

263	The interface to each piece of safety equipment is set up as a toggle switch with "on" and "off" settings	O	MES	4
264	Lack of correct helmet lamp visibility constraints: unrealistic underground lighting and lack of shadows, dynamic range	O	MES	
265	User indicates multi-meter seemingly failed to alarm at appropriate gas concentrations	O	MES	
266	Users get irritated when devices don't work as they expect based on real life experience	I	MES	
267	Mouthpiece seating may not be vetted for correctness	O	MED	2
268	Refuge refresher is not tied to emergency circumstances	O	MED	3
269	Cannot practice refuge deployment techniques or evaluate performance due to logistics	I	MED	3
270	Donning occurs in controlled, sterile situation	O	MED	5
271	No practice of time management while under apparatus	O	MED	5
272	Fire conditions are isolated and tightly controlled for safety	O	MED	6
LACK OF CONSEQUENCES (CONSEQUENT)				
No cause-and-effect				
Unclear rules and boundaries				
273	Cannot die by breathing bad air or standing in fire	O	MES	
274	Players willfully break rules without consequence	O	MES	
275	"I'm tempted to try things just to see what can and can't be done"	C	MES	
276	Drill rules and constraints may be forgotten	I	MED	7-8
277	Escapeway route and out of bounds areas may be forgotten if not clearly marked, reminded	I	MED	7-8
Confusing timelines and events				
278	Accident scene is complex in both time and space	O	RFG	4

279	Sequences of events may be difficult to understand	I	RFG	4
280	Discussion may not clearly illustrate movement of people and things	I	RFG	4
281	Trainer does not spend a lot of time trying to explain accident circumstances, instead quickly jumping to preventative practices	O	RFG	4-7
282	Difficult to convey relationships of side effects and latent factors	I	RFG	5
283	Preconditions may not be well illustrated or sufficiently linked to discussion	I	RFG	5
284	No visual evidence or coordinated backstory; story is entirely spoken narrative	O	MES	1
285	Simulation of safety equipment has minimal fidelity: breathing apparatus has no effect, goggles do not significantly change visibility; safety tethers have no in-game purpose	O	MES	4
286	Mine environment is relatively static, with few changing or dynamic components: only smoke and gas readings ever change	O	MES	5
287	Damaged areas do not change	O	MES	5
288	Fires do not spread over time	O	MES	5
289	User actions do not impact other crew members	O	MES	3-7
290	Cannot die by breathing bad air or standing in fire	O	MES	7
291	When things go wrong: "I can't die?"	O	MES	
292	Not apparent how, when, or why pillars collapsed	C	MES	7
293	"Making bad decisions and seeing the results would help training"	O	MES	8
294	No logistically feasible way to simulate a dynamic event using current drill practices	C	MED	
295	"Drilling practices don't really push miners to think critically about the situation"	I	MED	
296	When should we use this equipment? What environmental conditions are triggers?	C	MED	2-4

Scenarios that are static or inflexible				
No workplace dynamics				
297	Virtual environment is static: no apparent work or commotion that you would normally find in a mine workplace	I	MNC	
298	"There's nothing much happening in this mine"	C	MNC	
299	"A real mine is constantly changing."	C	MNC	
300	"It was a pretty dull experience"	C	MES	
301	Damaged areas do not change	O	MES	5
302	Unbolted top does not fall	O	MES	5
303	Flammable items do not catch fire	O	MES	5
304	Walkout is a monotonous and limited experience with few if any dynamic happenings	I	MED	7
Lack of hypotheticals				
305	Simulation has one, fixed set of (3) objectives	O	MNC	
306	Does not cover latent hazards or cautions (e.g. unbolted ground) that are mentioned in MRB	O	MNC	
307	"Horrible things can happen in emergencies and accidents"	C	RFG	
308	Trainer: "I'd like to make the decisions"	C	RFG	
309	"Can't address what-if scenarios or variations"	C	RFG	
310	Difficult to incorporate what-if scenarios, variations, differences in outcomes	I	RFG	5
311	Mine environment is relatively static, with few changing or dynamic components: only smoke and gas readings ever change	O	MES	5
312	Fires do not spread in response to changes in ventilation	O	MES	5
313	No ground fall injuries	O	MES	5
314	It'd be nice to have more gameplay options"	O	MES	
315	"Making bad decisions and seeing the results would help training"	C	MES	

316	"Element of surprise would reinforce learning"	C	MES	
317	"Consider randomizing, so users have to think about it"	C	MES	
318	"In real life, equipment can fail"	C	MES	
319	"Failure paves the way to success"	C	MES	
320	No fault checks or improper donning	O	MES	7
321	Outcomes are always positive: no way to be killed, injured, or trapped.	O	MES	8
322	Refuge options are not tied to emergency circumstances	O	MED	3
323	Doesn't consider or illustrate behavior of faulty or non-working equipment	O	MED	2-4
324	Refuge refresher does not cover circumstances for when users should deploy refuge alternatives	O	MED	3
325	Emergency does not evolve beyond the evacuation procedure specified in the drill plan	O	MED	7-8
326	Evacuation drill has limited ability to simulate real emergency circumstances and conditions	I	MED	7-8
Confusion about task progress				
Where do I go?				
327	References and directions are confusing for novices	I	MNC	2
328	Even experienced trainees can become disoriented, confused in navigation task	I	MNC	3-4
329	"Messages should prompt you to do something if you are lost"	C	MES	
330	"I spent a lot of time wandering around the mine alone"	C	MES	
331	Hard to decide where to go or what to look for	I	MES	3-7
What do I do?				
332	Information flow is confusing: task focus moves across contexts and windows	I	MRB	

333	Task objects are ambiguously assigned; no indication that objects were transferred or received	O	MNC	2
334	No visual indications of goals or progress	O	MNC	3-4
335	Am I progressing toward my goal? User doesn't know	I	MNC	3-4
336	Interface tutorial provides no guidance beyond floor plan of lobby (I follow the arrows on floor?)	I	MES	2
337	Game has little structure or story	O	MES	
338	Users not clear what to do next for much of the simulation	I	MES	
339	"Needs better flow"	C	MES	

ABSENCE OF PRACTICUM (PRACTICAL)

Inadequate story

Standardized content

340	Thoroughness of orientation tutorial depends entirely on trainer	O	MNC	1
341	Storyline and narrative can be uneven, inconsistent; dependent on trainer's imagination	I	MES	1
342	No visual evidence or coordinated backstory; story is entirely spoken narrative	O	MES	1
343	Drill content depends largely on available resources and logistics	O	MED	5-8
344	"Drill isn't consistent across sites and shifts"	C	MED	
345	Some elements may be missing from drill, such as wearing of breathing apparatus, deployment of refuges, use of lifelines, use of fire suppression	O	MED	5-8
346	Drills may or may not include diversions and detours	O	MED	7-8
347	Logging and assessment of drill varies across companies, sites, and trainers	I	MED	8

Believable delivery

348	Spoken accents are not reflective of real mine sites	I	MNC	2

349	"Need western accents"	C	MNC	2
350	"Needs to be less formal"	C	MRB	
351	Textbook definitions instead of layman interpretations	O	MRB	3-5
352	Lack of colloquial terminology, references	O	MRB	3-5
353	Matter-of-fact presentation may not sufficiently illustrate human factors	I	RFG	
354	Workplace and mine methods in fatalgram can be very different from user's experience	I	RFG	1-2
355	Specific outcomes may not have clear and obvious application to learners' workplace	I	RFG	7-8
356	Safety guidelines are presented in generic format that may be difficult for learners to relate to	I	RFG	8
357	Familiarity with mine would reinforce learning	I	MES	
358	"Make it personal."	C	MES	
359	"Give names and faces to characters."	C	MES	
360	Players face ambiguous situation: no concrete backstory to ground the situation or conditions	O	MES	1
Lack of motivation				
Boredom among users				
361	Players have limited motivation to finish game, and some don't	O	MNC	
362	No positive reinforcement upon completion of tasks	O	MNC	3
363	Slow, tedious pace of task is discouraging	I	MNC	4
364	The MSHA-sanctioned media promote a non-interactive, lecture-based format	I	RFG	
365	Users appear disinterested after a few slides	I	RFG	
366	Limited opportunity for reinforcing social interactions among learners or feedback from learners to trainer	O	RFG	
367	"Speed of operation and transition -- timing is important."	C	RFG	

368	"It's a pretty boring experience."	C	MES	
369	"I spent a lot of time wandering around the mine alone"	C	MES	
370	"Really needs a ticking clock"	C	MES	
371	"More options would make it more fun"	C	MES	
372	"Might be useful for training, but not very fun"	C	MES	
373	"Could use an element of surprise"	C	MES	
374	"Nothing ever happens"	C	MES	
375	Slow and monotonous pace lacks excitement and misses visceral sights, sounds, and confusion of real mine disaster	I	MES	
376	Drills are compliance-oriented; same review is done each quarter with little variation in process or media	I	MED	
377	Videos are dated, have been seen many times	O	MED	1,4
378	Drill practicum is sterile, controlled	I	MED	5-8
379	Walkout is a monotonous and limited experience with few if any visual cues	I	MED	7
Users as competitors				
380	"We want to compare how well we did"	C	MNC	
381	"Miners are a competitive bunch"	C	RFG	
382	Users ask their friends how they did	O	MES	
383	Users want to watch their friends make mistakes	O	MES	
384	No rewards for good decisions or penalties for bad ones	O	MES	
385	Outcomes are identical for all users, regardless of performance	O	MES	8
386	"Most younger miners play games"	C	MES	
387	"Miners want 'bragging rights'"	C	MES	
388	"Miners look out for each other"	C	MES	

Limited opportunity for crew interaction			
Importance of team activities			
389	"Want multiple actors"	C	MNC
390	"Crew interactions would add a useful dimension to training"	C	MNC
391	"Miners learn better with mentoring"	C	RFG
392	Many activities on the work site at the same time; many different people working in the same area on different tasks	O	RFG
393	Most fatal accidents involve a collection of mistakes and oversights by multiple parties	I	RFG
394	Miners should understand responsibilities, including marking and reporting hazards	I	RFG
395	"Multiplayer is optimal"	C	MES
396	"Miners look out for each other"	C	MES
397	Leadership is a vital skill and should be tested in emergency situations	I	MES
398	Some safety activities require group participation, such as cross checking of breathing apparatus	I	MES
399	Evacuation and mine rescue are crew-based activities	I	MES
400	Section crews are typically 7 to 15 people, depending on the mine site and shift	I	MED
401	Most activities underground involve multiple workers -- rarely is a crew member alone	I	MED
402	New miners and new experienced miners are never left alone during their "red hat" period -- always supervised while underground	I	MED
403	Ground crews constantly track the locations of crew members while underground	I	MED
Few opportunities for team activities			
404	Tutorial is predominately an independent study with wrap-around training, which limits one-on-one interaction	O	MRB

405	Introduction and tutorial afford only chance for interaction with trainer	O	MNC	1
406	Navigation challenge does not have any explicit game mechanics for multi-user; designed as single-player experience	O	MNC	
407	Teams of trainees typically worked together to control one game avatar	O	MNC	
408	Virtual environment is empty, no teams or coworkers, as would be in a real workplace	O	MNC	2-3
409	The MSHA-sanctioned media promote a non-interactive, lecture-based format	I	RFG	
410	Lecture format limits opportunity for interactions among learners or feedback from learners to trainer	O	RFG	
411	Trainer pauses for some feedback on root causes, solicits some discussion	O	RFG	5
412	Once teamed up, a leader may spontaneously arise to delegate tasks and manage the group	O	MES	
413	Much of the game is spent wandering around the mine alone	O	MES	
414	Miners participate in all drills with rest of their shift crew	O	MED	

Hard to communicate

Problems with verbal communication

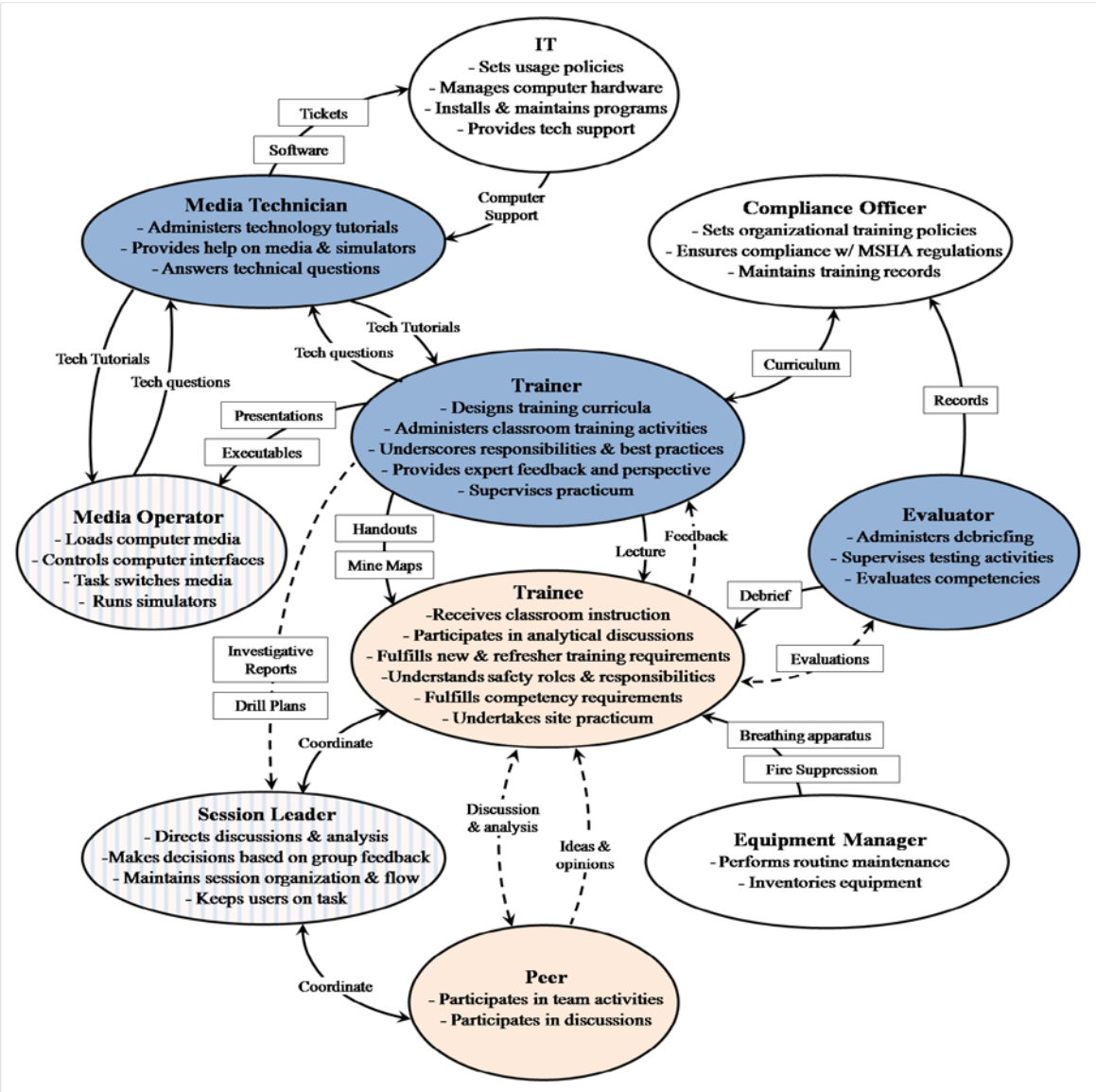
415	Trainer pauses for some feedback on root causes, solicits some discussion	O	RFG	5
416	Limited means to communicate in game: restricted to on-screen text commands (preset list)	O	MES	
417	"We need to be able to discuss the situation to come up with ideas"	C	MES	
418	Discussion of action plan must be held outside of game environment	O	MES	5
419	"Should emulate communication breakdowns"	C	MES	
420	Avatars of team members have limited fidelity or uniqueness, making identification difficult	O	MES	4, 5

421	"Difficult to tell who controls which avatar"	C	MES	
422	Leaky feeder systems, mobile radios, and ID tags allow crews to stay in constant communication	I	MED	
Lack of workplace-specific forms				
423	Helmet signals can be vital to warn someone away from dangers -- stop, go back, or come toward me	I	MES	
424	"Helmet signals are used frequently underground"	C		
425	Cannot use non-verbal forms of communication, i.e. hand gestures or helmet signals, as recommended by MSHA for mine emergencies	I	MES	
426	Limited means to communicate in game: restricted to six stock text commands (preset only)	O	MES	
427	Most of the communication occurs offline, outside of game environment	O	MES	
428	Crews would keep in constant contact with the surface during a mine emergency	I	MES	
~~429~~	No simulated communication with surface	O	MES	
430	Leaky feeder systems, mobile radios, and ID tags allow crews to stay in constant communication; this also lets ground crews track the locations of crew members while underground	C	MED	
431	Miners will often use hand gestures or signals while under apparatus	I	MED	5
~~432~~	No practice of communication under apparatus	O	MED	5
Need for hands-on experimentation				
Few opportunities to practice technique				
~~433~~	Cannot practice terms interactively	O	MRB	3-5
~~434~~	No evaluation or practicum	O	RFG	
~~435~~	Some fatalgrams have limited applicability to this job site	C	RFG	
~~436~~	"There is a need for good simulations"	C	RFG	
~~437~~	"Miners learn better with mentoring"	C	RFG	
~~438~~	"Miners learn by doing"	C	MES	

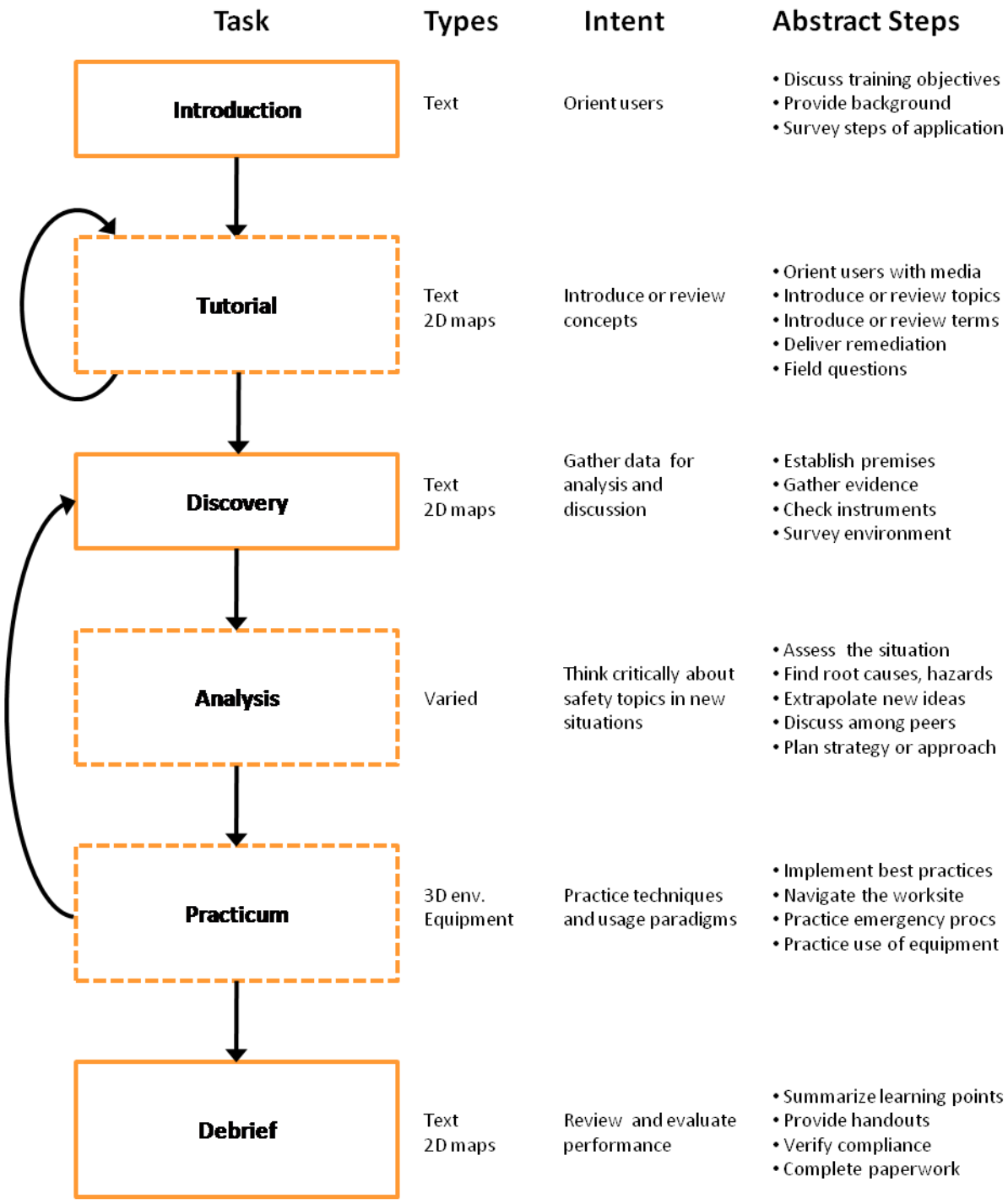
439	Simulation of safety equipment has minimal fidelity: breathing apparatus has no effect, goggles do not significantly change visibility; safety tethers have no in-game purpose	O	MES	4
440	Does not promote or allow for proper equipment donning, usage procedures	O	MES	4
441	Drill does not condition miners to the physical demands of equipment and mine emergency	I	MED	
442	No practice of time management while under apparatus	O	MED	2
443	Cannot practice refuge deployment techniques or evaluate performance due to logistics such as placement and availability	I	MED	3
444	SCSR practice requires all users to go through entire donning procedure.	O	MED	5
445	May not include guidance or practice of breathing control or realistic resistance breathing	O	MED	5
446	No practice of communication while under apparatus	O	MED	5
Lack of substantive feedback				
447	No interactive feedback on quiz answers, i.e. what was wrong and why	O	MRB	2,6
~~448~~	"How many more [tasks] to go?"	C	MNC	2
~~449~~	No indication of progress toward goal	O	MNC	3-4
~~450~~	No reinforcement or rewards for task completion	O	MNC	3-4
~~451~~	No results-based denouement	O	MNC	4
~~452~~	"Did I win or lose? I don't know."	C	MNC	5
~~453~~	Users have no idea if their result is good or bad	I	MNC	5
~~454~~	No indication of progress toward goal	O	MES	7
~~455~~	Users want scoring metrics so that they know how they well did	I	MES	8
Limited means to evaluate competency				
~~456~~	Pre- and Post-test "knowledge checks" presented in multiple choice quiz	O	MRB	2,6

457	Easy to guess correctly while being functionally illiterate in domain terminology	I	MRB	2,6
458	Pre- and Post-test "knowledge checks" offers limited coverage of topics, do not cover direction finding or navigation	O	MRB	2,6
459	No interactive feedback on quiz answers, i.e. what was wrong and why	O	MRB	2, 6
460	Post-test is identical to pre-test	O	MRB	2,6
461	Does not cover all the topics of in MRB (e.g. hazards, air flow patterns, equipment)	O	MNC	
462	Effectiveness of MNC is uneven, dependent on trainer interpret, discuss results	I	MNC	
463	What metrics adequately quantify performance? Difficult to answer.	I	MNC	5
464	Difficult to examine travel efficiency, areas of confusion within tasks	I	MNC	5
465	"I want to evaluate users in real situations, not highly controlled ones"	C	RFG	
466	fatalgram "evaluation" is based only on attendance, not comprehension	O	RFG	7
467	"Discussion helps new miners understand their mistakes"	C	MES	8
468	No standardized competency metrics	I	MED	
469	Deployment, use of refuge alternatives often not vetted due to logistics	I	MED	3
470	May or may not evaluate fire suppression	O	MED	4
471	Trainers observe, correct users for problems in donning process	O	MED	5
472	Mouthpiece seating may not be vetted for correctness	O	MED	5
473	Session metrics and evaluation are uneven, vary by company, site, and trainer	I	MED	9

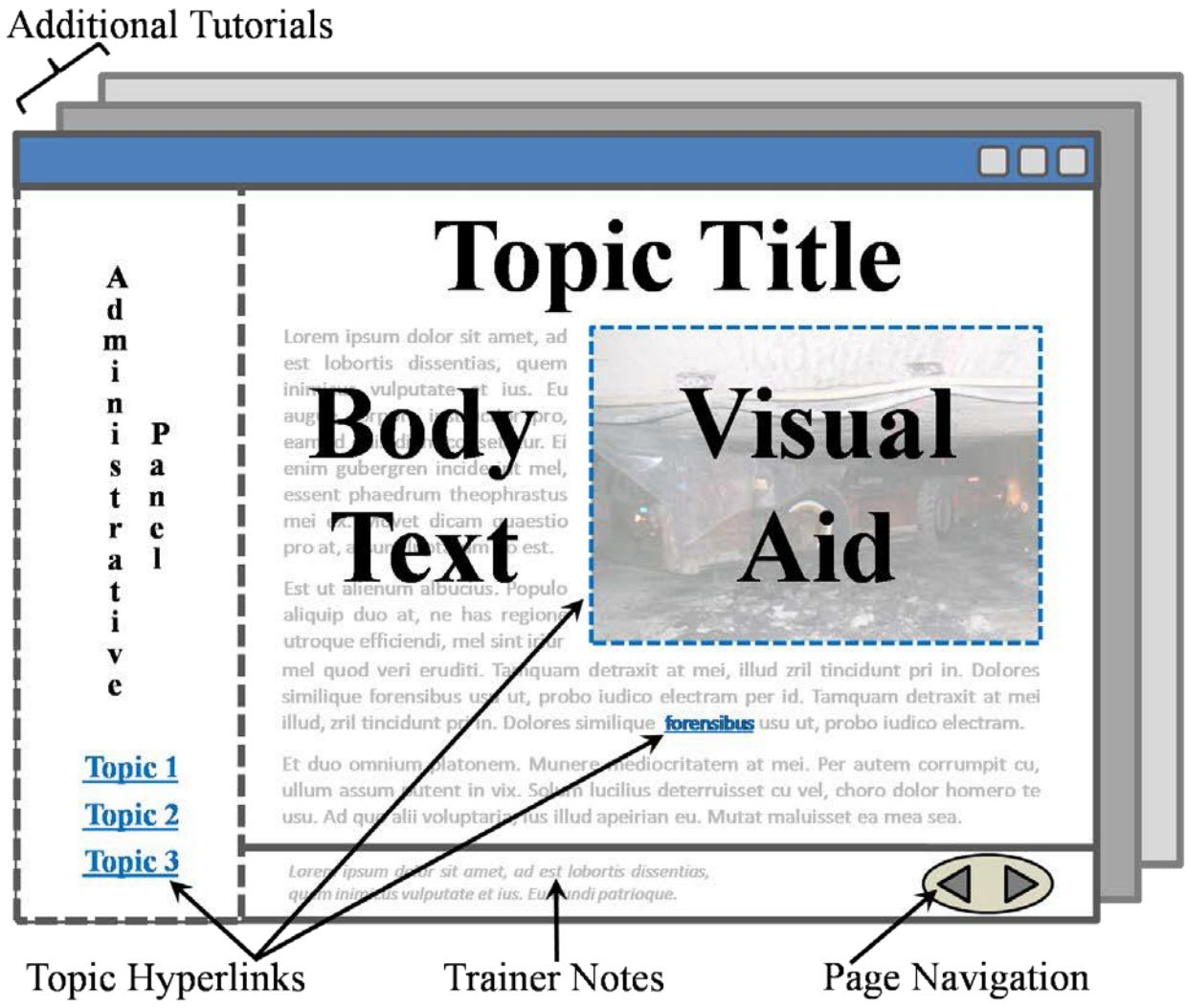
Appendix B: Consolidated Work Models



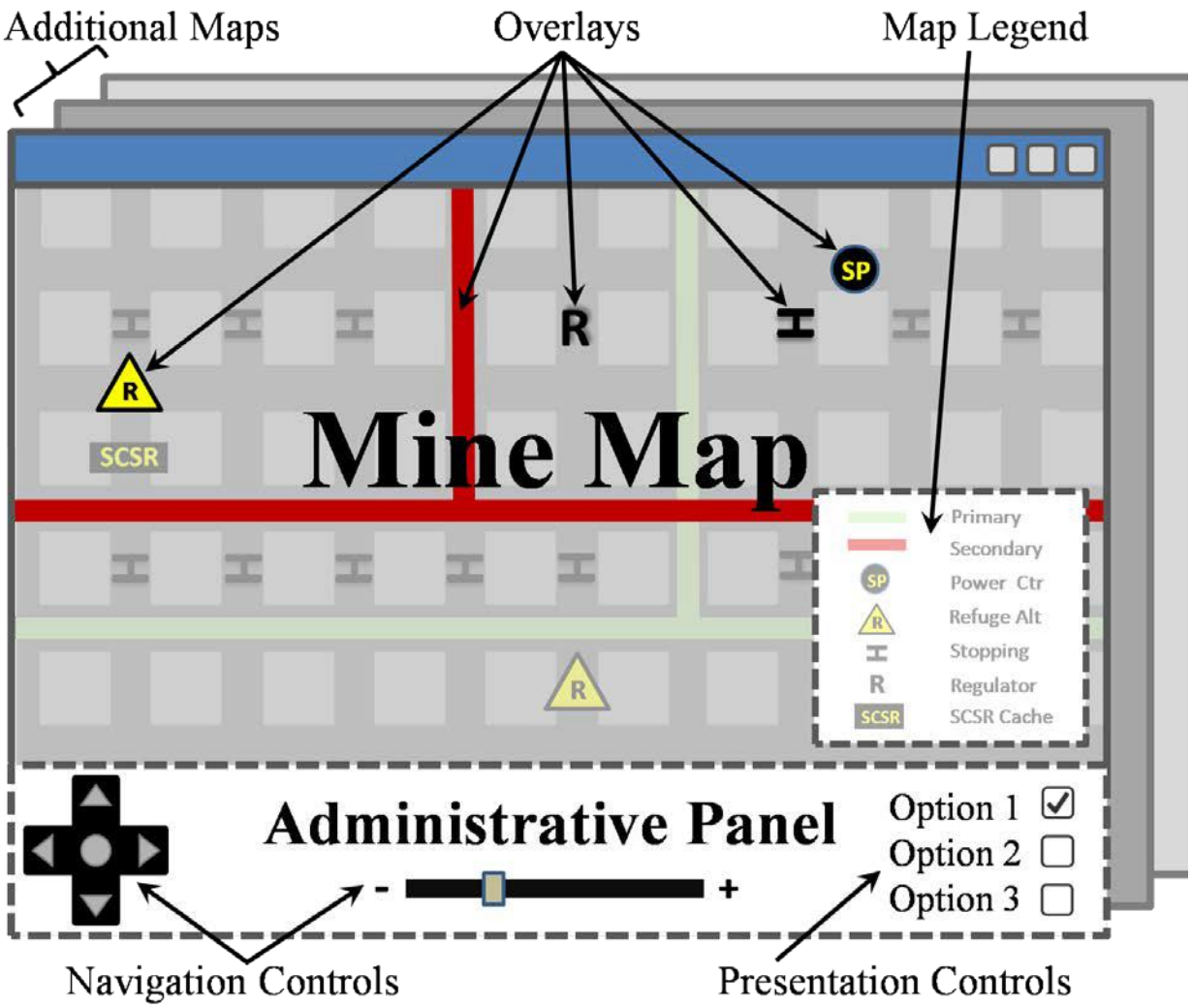
Consolidated flow model.



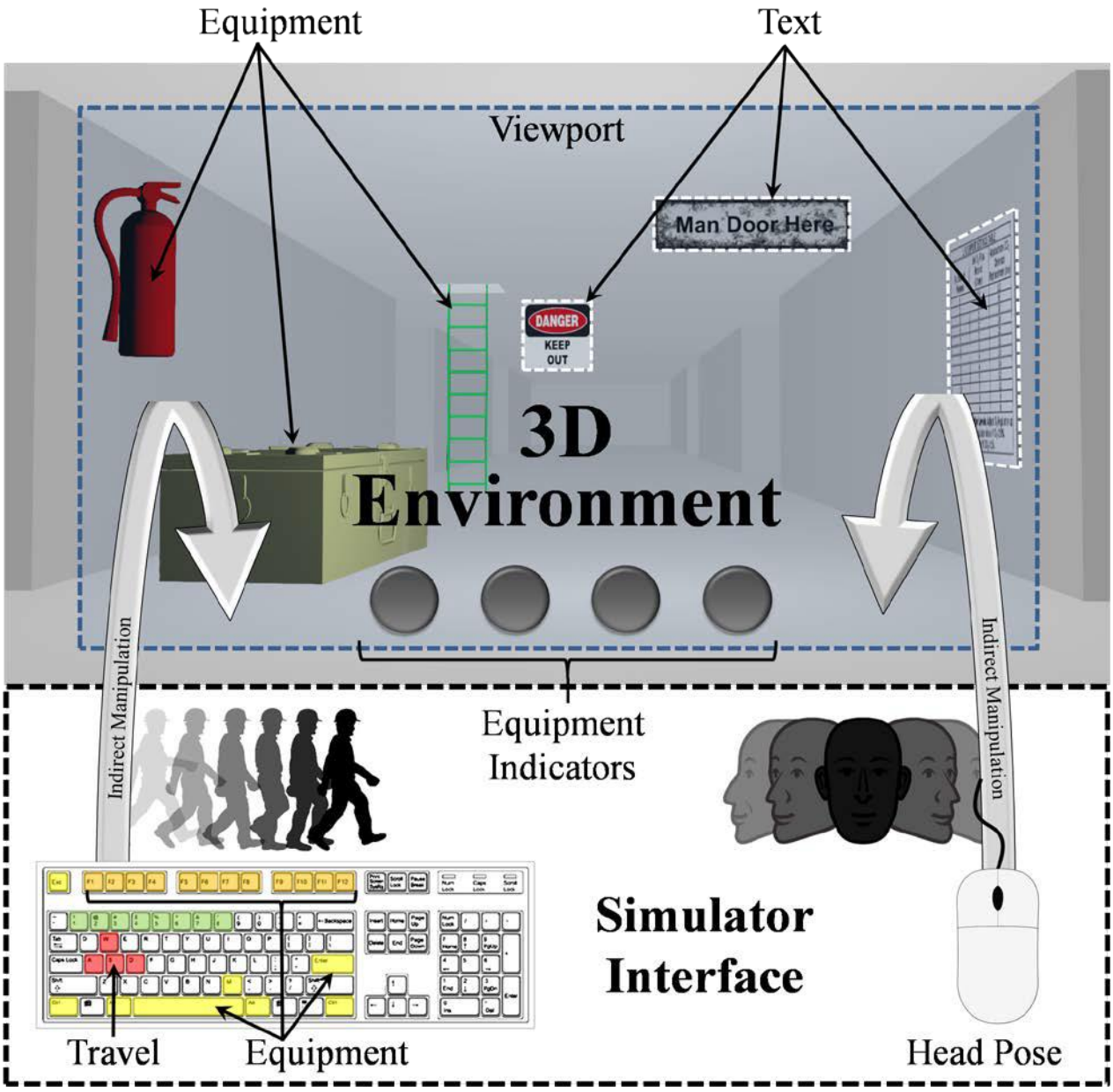
Consolidated task sequence model.



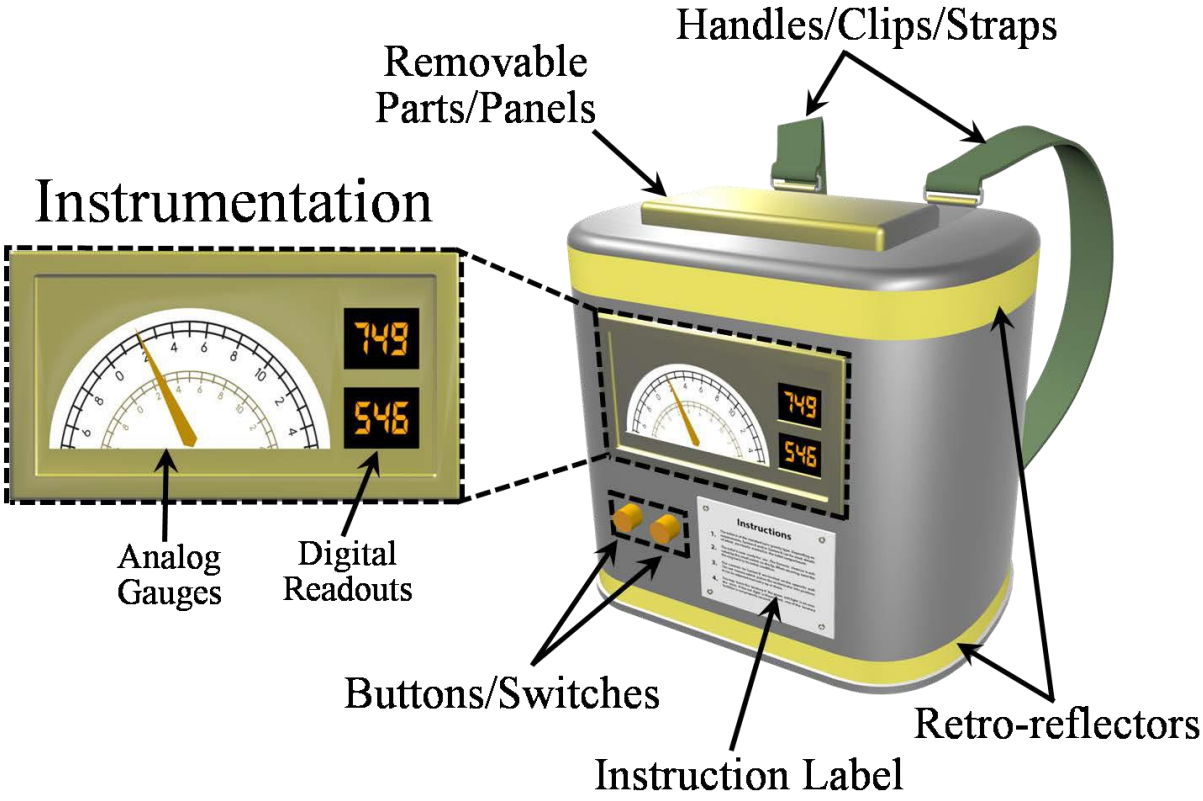
Consolidated artifact model: Tutorial.



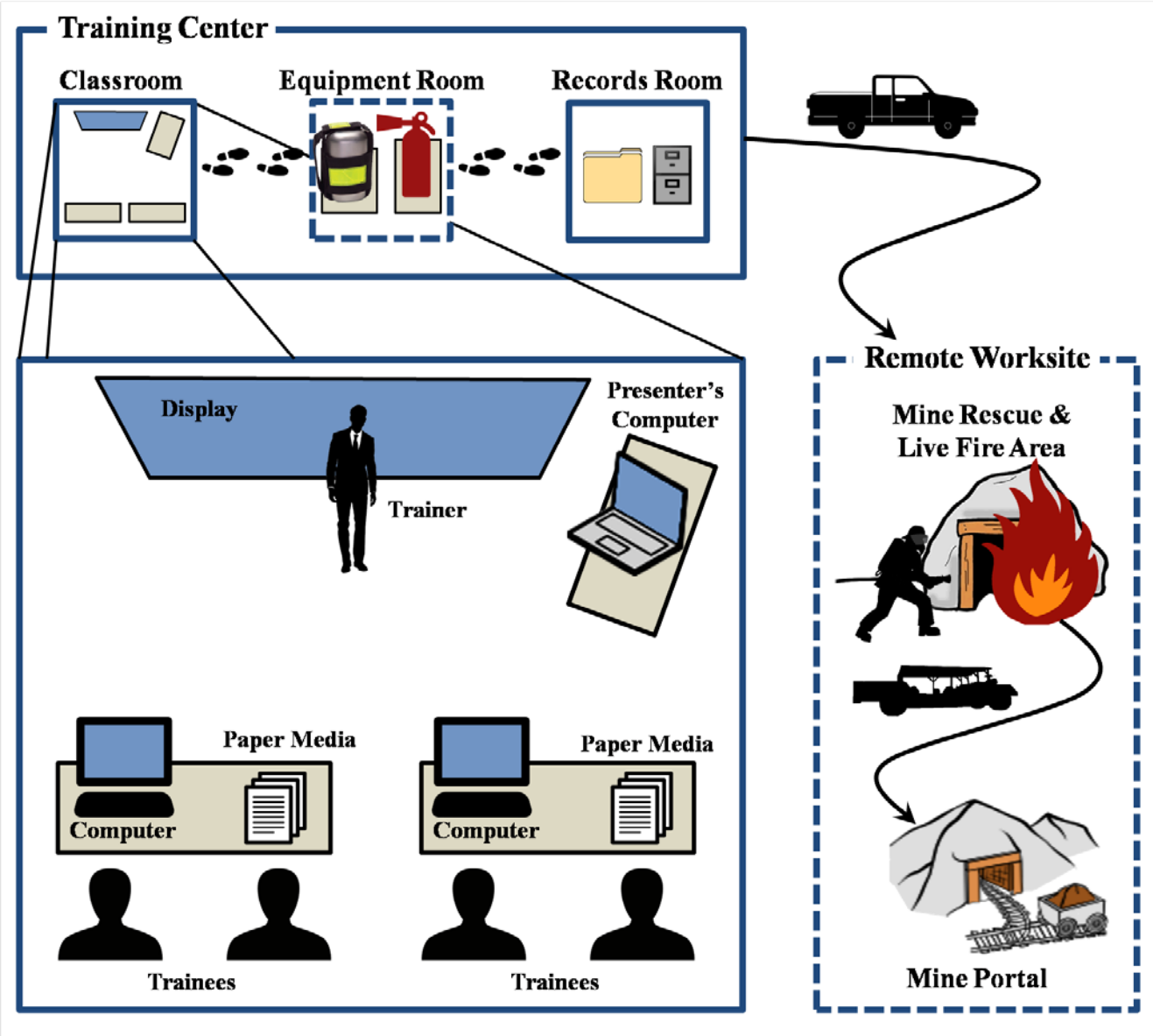
Consolidated artifact model: Mine Map.



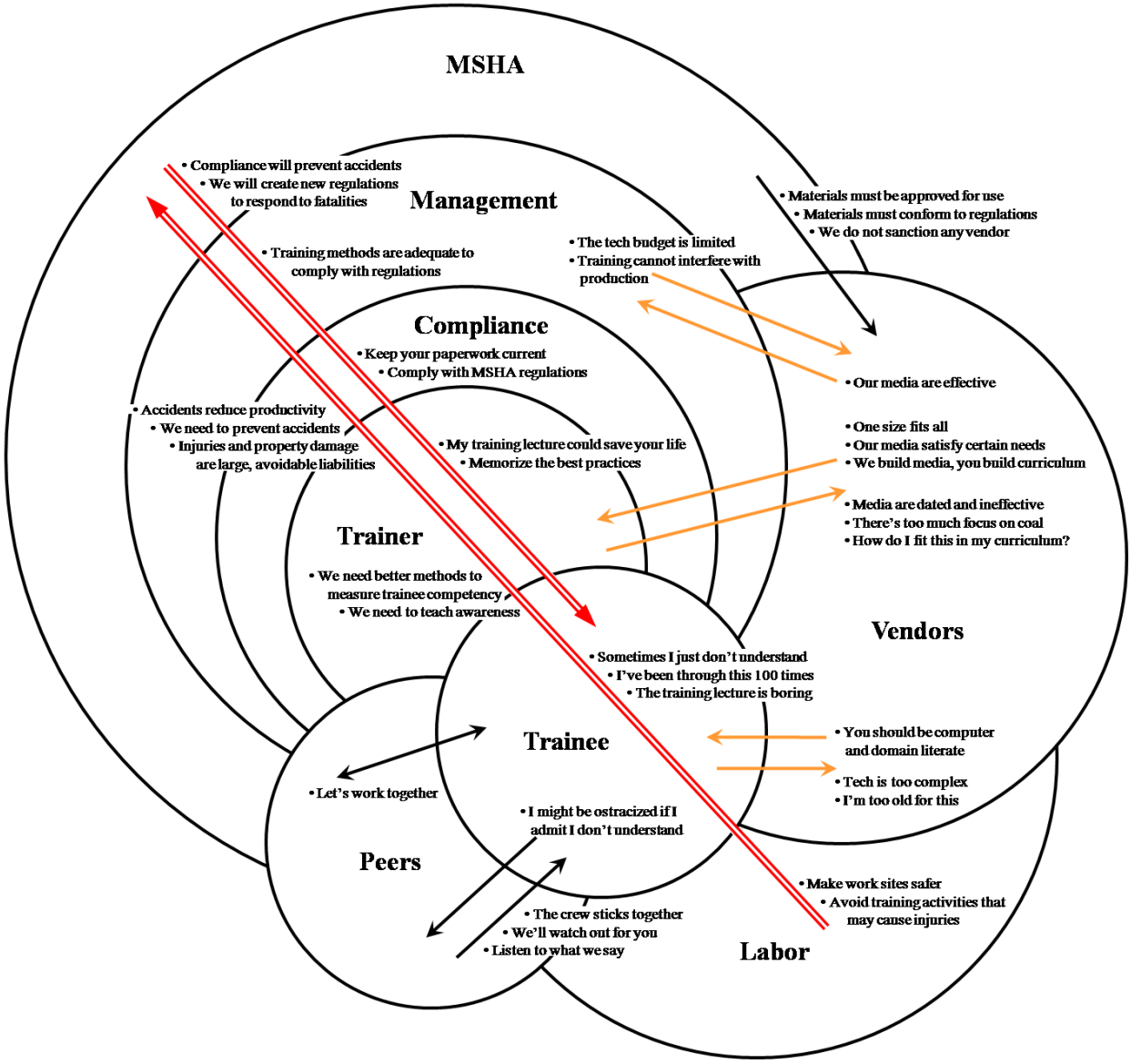
Consolidated artifact model: Environment.



Consolidated artifact model: Equipment.



Consolidated physical model.



Consolidated cultural model.

Appendix C: Usability Theme Mappings

Mapping of Affinity Diagram to consolidated models for CONSEQUENT theme.

Problem Category	Example Evidence	Model & Indications		
Cause-and-effect		**No clear progression, correlation of events across media**		DG10
Unclear rules and boundaries	• Players will break rules (#274) • "I'm tempted to try things to see what can, can't be done" (#275)	--	--	
Confusing timelines and events	• Event sequences are difficult to understand (#279) • Hard to illustrate movement of people, things (#280) • Difficult to convey side effects, latent factors (#282)	Artifact Task	• Heterogeneous data • Analysis task	
Scenarios that are static or inflexible		**Curriculum is generic, compliance-oriented**		
Workplace dynamics	• Static: no usual activities (#297) • "Mine constantly changes" (#299)	Artifact	• Level of detail	
Lack of hypotheticals	• No what-if scenarios, variations, alternate outcomes (#310) • "Making bad decision and seeing result would help training" (#315) • "In reality equipment fails (#318) • No way to be killed, injured, or trapped (#321)	Cultural Flow	• Pushback: Trainer • Role Strain: Trainer	
Confusion about task progress		**No clear feedback on user actions, decisions**		DG12
Where do I go?	• Even experienced workers get disoriented, confused (#328) • "I spent a lot of time wandering around" (#330)	Artifact	• Level of detail	
What do I do?	• Task objects ambiguously assigned w/o indication (#333) • No indication of task goals or progress (#334)	Artifact	• Level of detail	

Mapping Affinity Diagram to consolidated models for ACCESSIBLE theme.

Problem Category	Example Evidence	Model & Indications		
Obstacles to acceptance		**Pushback on technology**		DG1
The age gap	• "Old guy, not a gamer" (#2)	Cultural	• Pushback: Trainee	
Aversion to (new) technology	• "Power Points are easy" (#7)	Cultural	• Pushback: Trainer	
The time it takes	• Time pressures mean drills must be finished quickly (#24)	Cultural	• Pushback: Management	
Ergonomic factors	• Physically demanding (#29)	--	--	
Limited language, workplace literacy		**Pushback on curriculum**		
Multi-lingual users	• "Need Navajo, Spanish" (#52)	--	--	
Limited language understanding	• No usage examples (#56) • Instructions not repeated (#60)	Cultural	• Pushback: Trainee	
Presumption of workplace literacy	• Manuals use tech. terms (#75)	Cultural	• Pushback: Trainee	
Site variation	• "We do things differently" (#80)	Cultural	• Pushback: Trainer	
Beyond user's skill		**Inadequate, unresponsive tutorials**		DG2
Difficult tasks	• Need difficulty levels (#34)	--	--	
Cognitive overload	• Lots of rote memorization (#36)	Task	• Tutorial design	
Lack of remediation	• No hints to help user (#47, #48) • No time for tutoring (#51)	Task	• Tutorial design	
Difficult for novice		**Complicated, clumsy interaction**		DG3
Learning curve	• "I lack computer skills" (#83) • Novices need simple UI (#90)	Flow	• Role strain: Operator	
Need for technology tutorials	• "I need pointers" (#94)	Flow	• Role strain: Technician	
A multitude of standards	• MNC, MRB use diff. UI (#103) • Game, Debrief use diff. UI (#106)	Artifact	• Heterogeneous data • Control scheme	
Lack of concise mechanics	• Users click everything (#111) • Split nav. controls (#118)	Artifact	• Heterogeneous data • Control scheme	
Clumsy context switches	• Can't see map w/ mine (#123) • Multi-way context switch (#124) • Trainers flip back & forth (#127)	Task Flow Artifact Physical	• Task transition • Bottleneck: Operator • Heterogeneous data • Partitioned space	DG4
Overly limited interface mechanics		**Interaction limited by technology, logistics**		DG5
Artificial constraints	• "I want to pick stuff up" (#135) • Equipment UI is limited (#143)	Artifact	• Control scheme	
Necessity of tactile feedback	• Proprioceptive, tactile cues are vital in mining tasks (#145, #146) • "Miners learn by doing" (#154)	Artifact	• Control scheme	

Mapping of Affinity Diagram to consolidated models for CONTEXTUAL theme.

Problem Category	Example Evidence	Model & Indications		
Media do not match task		**Lack of adequate display media, technology for data types**		
Problems with computer media	• Limited display resolution (#159) • Difficult to read small text (#162)	Artifact	• Heterogeneous data	
Problems with print and other media	• Small print hard to read (#179) • Notes may be lost, sullied (#180)	Artifact	• Heterogeneous data	
Details do not match task		**Data type, details not aligned to task**		DG7
Too much detail	• Accident scene is complex in time and space (#209) • Maps can be cluttered (#211)	Artifact	• Level of detail	
Too little detail	• Repetitive, simple models (#192) • Missing workplace details (#193) • Virtual env. is low fidelity (#199)	Artifact	• Level of detail	
Unavailable data	• "Not enough information" (#185) • No map for reference (#186) • Need 3D as reference (#189) • Missing map details (#190)	Artifact	• Heterogeneous data	
Spatial awareness		**Inadequate perspective on scene structure, relationships**		
Limited point of view	• Photos have narrow FOV (#213) • Can't see what others see (#219) • Tunnel vision is common (#220)	Artifact	• Level of immersion	
Disorienting mine structure	• Even experienced users can become disoriented (#226) • No points of reference (#231)	Artifact	• Heterogeneous data	
Users cannot relate		**Media not grounded in relevant workplace context**		DG9
Stylized or abstract	• Diagrams, line drawings illustrate many terms (#239) • Guidelines are generic (#244)	--	--	
Lack of real world examples	• Does not account for real life complexities, variations (#250) • Missing important scenarios for other mining methods (#256)	Cultural	• Pushback: Trainer	
Unauthentic equipment behavior	• Equipment has no effect (#262) • Users get irritated if device doesn't work as expected (#266) • Cannot practice deployment in real conditions (#269, #270)	Artifact	• Level of detail	

Mapping of Affinity Diagram to consolidated models for PRACTICAL theme.

Problem Category	Example Evidence	Model & Indications	
Inadequate story		**Stale, compliance-oriented curriculum**	
Standardized content	• Stories require imagination (#341) • Need resources, logistics (#343) • "Inconsistent, repetitive" (#344)	Cultural	• Compliance culture • Pushback: Multiple
Believable delivery	• "Need to be less formal" (#350) • Not applicable to user's work (#355) • "Make it personal" (#358)	Flow	• Role Strain: Trainer
Lack of motivation		**Stale, compliance-oriented curriculum**	
Boredom of users	• Media are lecture-based (#364) • Slow, monotonous pace (#375) • Compliance based, repetitive (#376)	Cultural	• Compliance culture • Pushback: Trainees
Users as competitors	• "Miners are competitive" (#381) • "Young miners play games" (#386)	--	--
Limited opportunity for crew interaction		**Limited support for community activities**	
Importance of team-based activities	• "Crew interactions add a useful dimension to training" (#390) • Evacuation, mine rescue are crew-based activities (#399)	Cultural	• Influence: Peers
Few opportunities for teamwork	• Simulation devoid of people (#408) • Lectures limit discussion (#410) • Live drills are crew oriented (#414)	Cultural Flow	• Compliance culture • Role Strain: Leader
Hard for users to communicate		**Limited support for community discourse**	
Problems with verbal communication	• Restricted to text presets (#416) • Avatars difficult to tell apart (#421)	Flow Artifact	• Bottleneck: Leader • Level of detail
Lack of workplace-specific forms	• "Helmet signals are frequent" (#424) • Non-verbal forms are recommended by MSHA for emergencies (#425)	--	--
Need for hands-on experimentation		**Lack of practicum and feedback**	
Few opportunities to practice technique	• No evaluation or practicum (#434) • "Miners learn by mentoring" (#437) • No equipment donning, use (#440)	Task Cultural	• Practicum design • Compliance culture
Lack of substantive feedback	• No reinforcement or rewards (#450) • No results-based denouement (#451) • Are my results good or bad? (#453)	Task	• Debrief design
Limited means to evaluate competency	• Easy to guess right answers (#457) • "Evaluate in real situations" (#465) • Based solely on attendance (#466) • No standardized metrics (#468)	Cultural	• Compliance culture

DG15