Lowell Institute for Mineral Resources

HARRY'S HARD CHOICES DESIGN EXHIBIT

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1. Game Overview

Based on a paper exercise by Vaught, Hall, and Klein (2009), *Harry's Hard Choices* is a new training tool for mine emergency preparedness (MEP) and self-escape that was designed around best practices in computer gaming (Shelley, 2001; Federoff, 2002; Pinelle, 2008). The simulation immerses trainees in a visually and audibly rich environment that mimics the distractions and chaos of a realistic mine emergency. The game tests players' decision making in response to various disaster events, including fire, smoke, limited visibility, dangerous gas readings, injuries, and roof falls. The game randomizes the disaster events, to present some variation in the story and choices each time the game is played. The game emphasizes consequences and causality, forcing users to think about outcomes basis of collective decision making; in particular, the game fosters a team-oriented mentality by forcing trainees to consider the impacts of specific choices on other crew members. This document will outline the salient features of *Harry's Hard Choices*, including training objectives, game mechanics, user interface, data collection framework, and usability testing.

The story of *Harry's Hard Choices* involves a rapidly spreading fire in an underground coal mine, and a foreman's efforts to get his crew out of the mine as conditions deteriorate. For our application, we have de-serialized and extended the paper exercise to allow for emergent behavior within the game and a variety of additional learning materials and difficult choices dealing with bad ground, defective equipment, explosion events, and crew conflicts. Although we have preserved the basic spirit, decisions, and consequences discussed in the paper scenario, our game allows for a

different flow of events based on trainee's decision making and randomized disaster events. For instance, the location and likelihood of certain triggering events (e.g. such as a breakdown of the mantrip vehicle), the rate of spread of the fire, and the presence of methane will change users' available options and add variety to the game that we hope enhances replayability. A user will encounter different sequences of events and decision options each time the game is played.

The game was developed as part of Dynamic Safety, our "serious games" training initiative at the University of Arizona's Western Mining Safety and Health Training Resource Center. The Unreal Engine (available at <http://www.unrealengine.com>) serves as a technical foundation for this project. The Unreal Engine's AAA game production capabilities include a well-established workflow with high-performance rendering, programmable shaders, robust animation options, and complete physics engine. The game

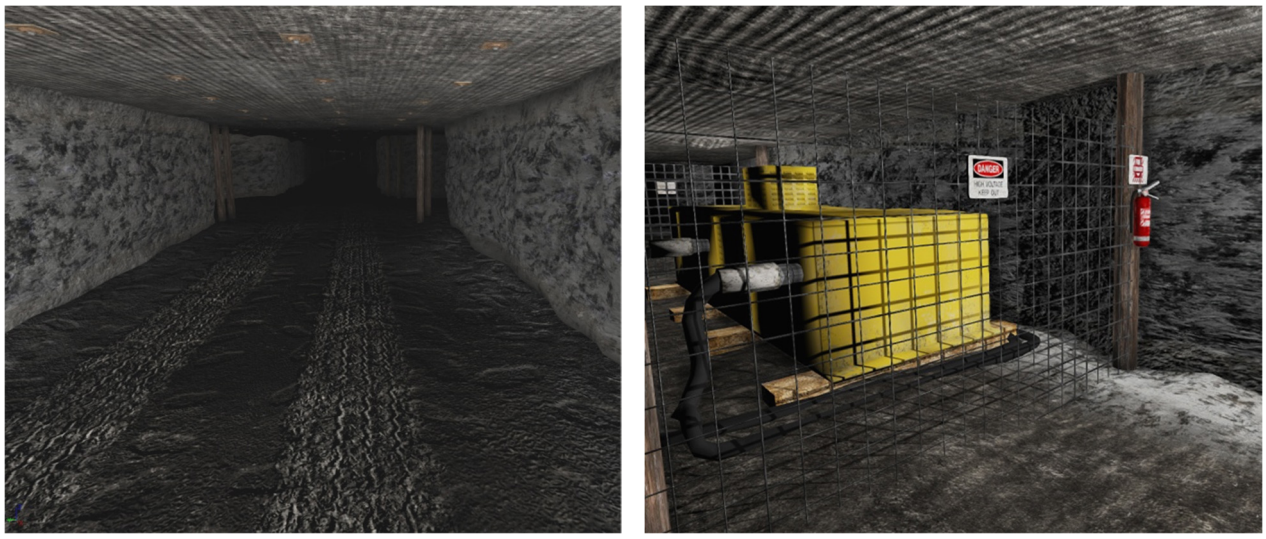

Figure 1. The Bottleneck 3D mine environment. Top: Details include tire tracks, vent tubes, accurate rock dusting, roof grooves and bolts. No two pillars are identical. Bottom: High-detail accessories were added, including translucent check curtains, signage, electrical equipment, and player-usable safety equipment.

also features a greatly enhanced version of the NIOSH “Bottleneck" 3D mine environment, shown in Figure 1, which was developed for the Map Reading Training module (see <http://www.cdc.gov/niosh/mining/works/coversheet1825.html>). With assistance from NIOSH, realistic smoke and fire propagation patterns were developed for this model using computer simulations of air flow and physically-based modeling techniques. A range of fully-operational mine equipment and safety gear are featured in the game.

2. Coverage of MSHA Training Topics

The Mine Safety and Health Administration mandates that specific topics in health, safety, and hazards awareness should be covered in new miner and annual refresher training, *Harry's Hard Choices* brings together a variety of these topics in a comprehensive story centering on a disaster simulation; it compels users to think critically and explore each topic in context. A survey of some of these topics and their in-game coverage is outlined in Table 2.

Table 2. Survey of game mechanics aligned to required MSHA training topics.

Topics in Newly Hired Experienced Miner, Annual Refresher, and New Miner Training	Game Mechanics and Story Elements in *Harry's Hard Choices*
Mandatory health and safety standards	Employs OSHA specs for irrespirable air: carbon dioxide, carbon monoxide exposure have direct impacts on crew health; coal dust and smoke visibly effect crew fatigue; Fire hazards, flammable materials, and fire propagation; Errant ground control, such as unbolted top and collapsed pillars, compels users to survey and be aware of environment
Transportation controls	Selective use of powered haulage: SC24 type shuttle car and diesel-powered pickup truck with appropriate vehicle physics
Communication systems	Hard-wired mine phones at designated map locations and refuge chambers; encourages reporting of crew progress at regular intervals; user response to damaged/inoperative communication systems
Recognition and avoidance of electrical hazards and other hazards	Section power centers and electrical cabling; shorts, downed lines, and other electrocution hazards; battery connections within powered haulage as spark/fire hazards

Barricading/Escape and Emergency evacuation/firefighting plans	Primary focus of simulation: Escape protocols following primary, secondary evacuation routes; lifelines with appropriate line markers and symbols; damaged/unusable lines; decision making process encouraging use of refuge chambers as shelters of last resort; use of fire extinguishers for small fires, e.g. such as engine fire breaking out
Roof/ ground control, ventilation	Ventilation patterns: realistic air flow with designated entry and return air paths supporting appropriate physics model; Fires spread along established ventilation paths according to airflow, encouraging users to consider fire propagation and rate of spread in their evacuation decision making; access doors and ventilators control fire spread and/or enable fire spread when damaged or left unclosed; Vent tubing to face. Roof/Ground control: dynamic roof falls; collapsed pillars may block evacuation routes
First aid	User must consider crew health and fatigue in evacuation strategy and adapt based on current events; Leg injuries: user may assist injured miners in evacuating or getting to shelter; First-aid assistance to miners suffering chest pains, leg injuries, and burns
Prevention of accidents	"Know your ground": roof falls may lead to serious team injuries; various hazards-based real-time risk analysis and decision points: longer evacuation routes and uneven ground increase the risks of leg injuries and increase fatigue; venturing near fires subjects crew to potentially severe burns; gas pockets may lead to explosions; use of vehicles in limited visibility conditions; response to broken escapeway lines
Self-rescue and respiratory devices	Self-rescuers: M-20 SCSR and SRLD, with full donning procedures; game encourages management of usable breathing time and utilization of spares; defective breathing units, cross-checking, and crew response; MineARC refuge chamber
Mine gases	Encourages proficient use of gas meters - oxygen, carbon monoxide, methane levels impact outcomes; possible malfunction of gas sampling equipment; explosions possible
Emergency medical procedures; escapes and emergency evacuation plans; fire warning signals and firefighting procedures	Primary and secondary escapeways with game metrics to encourage adherence to proper protocols; safety tethers and lifelines; response to broken lines and/or blocked escapeways; carbon monoxide alarms, gas meters, and visible smoke as fire indicators; fire extinguishers placed at strategic locations indicated on map; use of goggles and effects of smoke on visibility; crew may become lost or separated in dense smoke; use of fire extinguishers
Health and safety aspects of the tasks to be assigned	Crew health, fatigue, pre-existing conditions factor into outcomes, influence crew morale; risk-analysis required by user to balance fast evacuation versus current environmental hazards
Authority and responsibilities of supervisors and miners' representatives	Communication with designated Responsible Person and emergency response team as part of end-game denouement establishing outcomes
Introduction to the work environment	Four minute prologue introduces the environment and sets up conditions for mine emergency; Pre-game tutorial introducing workplace, crew, situations, and game rules

3. Character-driven Backstory

Harry's Hard Choices provides a comprehensive emergency simulation with relevant back story to enrich the setting and provide plot lines. The game features an variety of 3D characters (Figure 3) and nine distinct personalities. Harry, the Section Foreman, is controlled by the user. Harry is responsible for a crew of eight workers on the Northeast Section of the Bottleneck #1 Mine. The cast may be divided into those which factor directly into the storyline (the primary cast), and auxiliary characters which add depth and color to the scenario (the secondary cast). We have extended the personality profiles in the paper exercise (Vaught 2009) where necessary to suit the needs of our game; character actions in the game will fall in line with this backstory. A summary of each character's personality profile is given below.

Figure 3. Character models in Harry's Hard Choices. The game incorporates a crew of nine miners, each with physical attributes and backstory. Amateur actors provided the dispositions, face models, animations, and voice work for the characters.

3.1 Primary Cast

1. Harry, Foreman, Age 37, 10 years experience, good physical condition. Harry is the section foreman for the Northeast section. He has a wife and two children of middle school age. Harry has been a community volunteer firefighter for more than 15 years. Before entering management, Harry was a fire boss for 5 years. He knows the Bottleneck #1 mine well. The player will control Harry for the duration of the game.

2. Clem (Carlos) , Buggy man, Age 56, 38 years experience, poor physical condition with heart problems. On the job, Clem usually does what is asked of him, but not much more. He recently went through a rocky divorce and bankruptcy filing, and now must support his elderly mother, whose health is declining. As a result, Clem has garnered a defeatist attitude and a perception that life is an eternal crisis.

3. Charlie, Roof bolter, Age 39, 15 years experience, mediocre physical condition. Charlie is opinionated and is quick to offer advice, whether it's wanted or not. His coworkers would characterize him as being somewhat short tempered and argumentative. Charlie has been at Bottleneck for only a few months now. Before that, he worked for another very large operation, but was let go after clashing with management several times.

4. Tom, Roof bolter, Age 62, 44 years experience, Poor physical condition with shortness of breath. Tom has worked nearly every job in the underground coal industry at some point during his long career. He's been with Bottleneck now for nearly 12 years, with much of that time spent running the roof bolter at Bottleneck #1. Tom is also a long time smoker with a passion for pipe tobacco, but had to give it up due to health problems.

3.2 Secondary Cast

5. Bill (Diego), Utility man, Age 23, 2 years experience, good physical condition. Bill completed his red hat training just over 18 months ago. He has learned the job quickly, has a good work ethic, and is quick to volunteer for chores. Bill hopes to become a section foreman someday. Bill has a wife of 5 years and a 4 year old son. Bill is the younger brother of Dave, the Buggy Man.

6. Joe (José), Miner operator, Age 51, 18 years experience, Diabetic. Joe is a longtime employee of the Bottleneck Mining Company. Joe is valued for his expertise in running the miner and nearly always makes his quota. Joe tends to approach situations on the job cautiously, which has helped to keep him accident free for 18 years. Joe is married with three grown children and several infant grand children. In recent times, Joe has developed health problems related to his weight.

7. Larry, Mechanic. Age 38, 5 years experience, mediocre physical condition. Larry is a colorful person who's not always on task; he's been a mechanic at several operations but never stays very long. He just recently arrived at Bottleneck. Larry serves as comic relief.

8. Dave (Emilio), Buggy man, Age 28, 7 years experience, good physical condition. Dave has been at the Bottleneck #1 for his whole career, and with Harry's crew for the majority of that time. Dave is likable and motivated, and most coworkers would describe him as a friend. Dave is very close to his brother Bill, who he recently recommended for a job at the company. Dave has a fiancée that he plans to wed next year.

9. Sam (Samuel), Miner's helper, Age 50, 16 years experience, good physical condition. Sam has been a miner's helper at Bottleneck for several years now, and has shown good aptitude as a substitute miner operator when the need arises. Sam is competitive and eager for a promotion to full-time miner operator – and the better pay that comes with it. Sam has a daughter in college and is an active member of his church.

4. Contextualized Story Telling

The story of *Harry's Hard Choices* is based on an unfolding mine fire disaster (Figure 4) and is divided into 3 Acts. Act 1 involves the prologue, triggering of an emergency, and the first response. Act 1 ends with the first miner's injury. Act 2 involves the struggle to get out of the mine as conditions worsen and team morale wanes. The smoke and gas readings will worsen significantly in Act 2, the miners will become fatigued, and morale will worsen during this time. Act 2 ends when the miners reach the refuge chamber "checkpoint" and argue about what to do next. Act 3 involves the resolution (i.e. the team escapes, shelters in a refuge chamber, or perishes) and denouement. In Act 3, those miners still willing to continue will have to find a way around the spreading mine fire and potential roof falls. Act 3 ends when the player meets up with the Shift Foreman in the mains after having escaped the burning section. At the end of Act 3, Harry will discuss the outcome with the foreman and there will be a cut scene summarizing the user's performance via a dynamically created newspaper headline and game "results" screen.

The game relies heavily on the emergent interactions between characters. Each Act is programmatically divided into blocks of dialog that can be re-assembled at run-time to create situational variation. Each block represents a story-telling narration, crew responses to a triggered events (e.g. traps), or a decision point that requires the user's feedback;

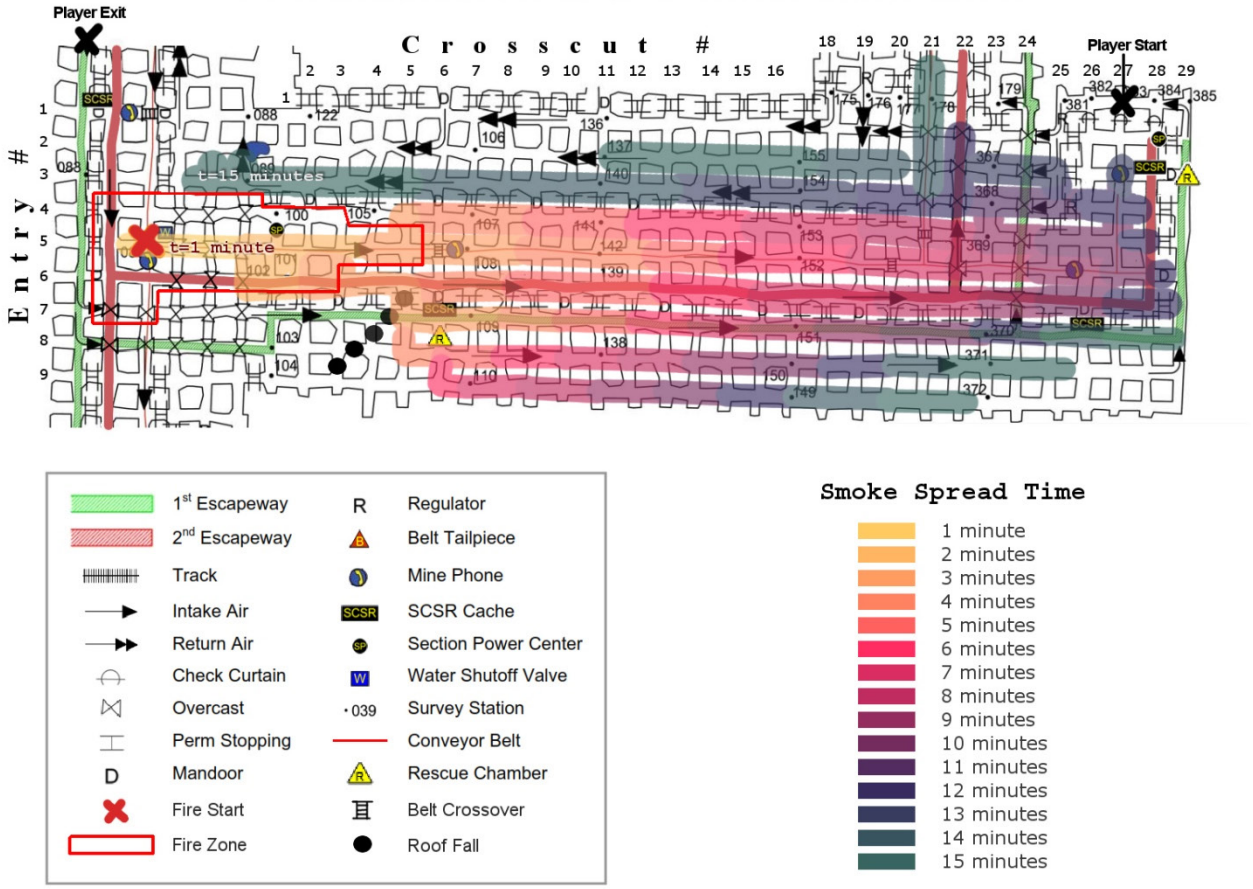

Figure 4. Overview and layout of a fire emergency scenario in *Harry's Hard Choices*, as played out in the Bottleneck #1 Northeast section. Top: a raging fire threatens to trap the crew inside the section. Bottom: Time management is a critical aspect of the game, as fire and smoke propagate realistically along air intakes and returns.

a conversation is composed of one or more of these dialog blocks. In many cases, each line of dialog is itself resolved a list of competing options specified in a set of "General Purpose" (GP) dialog. Characters will say different things each time the game is run, based on the game circumstances, character personality, and group morale. For instance, when the user makes a comically bad decision, like walking into a fire, colorful and humorous interactions can emerge among the nine crew members as they chastise Harry for such poor judgment. In total, there are more than five thousand lines of dialog for each localization; the game is currently available in English, with a Spanish translation also underway.

In *Harry's Hard Choices*, decision points can be both explicit and implicit. Each type of decision point has a specific syntax. Informally, we might think of these two decision types as being related to recognition questions (the conversation-primed decisions) and recall questions (unprimed, remembering spontaneously that something must be done). The objective of using both types of choices is to make the game feel more open, less linear, and also more challenging. The two classes of choices are discussed further below.

Explicit Decision Points. Sometimes the crew will give Harry competing options on what to do next, triggering an explicit decision point. These decision points are situational and often involve arguments or debates between characters -- an aspects of the crew management and emphasis on crew communication that is an underlying theme of the game . Each character represents a specific choice that Harry can make, and Harry makes his decision by agreeing with the appropriate character. For explicit decisions, each crew member will offer a specific option or opinion. These crew members represent the good or bad choices that Harry can make; agreeing with a specific character will then put the crew on a path toward a specific positive or negative outcome. In many cases, there can be more

than two options, and whether an option is "good" or "bad" will depend on the flow of the game story thus far. A frequent game mechanic is that a "bad" choice will eventually bring Harry back to the same decision point again, after a substantial time penalty and some humorous story elements manifesting in failure. For instance, attempting to repair an inoperative vehicle will result in wasted time and a potential engine fire; multiple repair attempts may lead to quarrels amongst crew members as their irritation builds over, or the explosion of the vehicle as a hapless mechanic continues to tinker with smoking engine.

Implicit Decision Points. Other decisions are based entirely on the user's recognizing a need for certain actions based on latent environmental conditions or events. Such decisions are often object-oriented. In these cases, the player interacts with the heads-up display (HUD) or a world item to specify a choice. For instance, Harry can decide that he needs to call out on the mine phone to update the responsible person on their location and progress; he can invoke a cache to have the crew pick up spare breathing apparatus if his gas meter indicates rising gas levels. In many of these cases, an implicit (and often bad) choice is to not do anything, or to ignore actionable game objects. However, again, situation dictates the merits of a choice to do or not to do; it would be inadvisable to swap breathing apparatus in an area where dangerous gases are present, when a nearby refuge chamber would provide a safe haven for doing so.

4.1 Trap Framework

Although a mine fire serves as the basis for this emergency simulation, a wide range of additional hazards enhances the excitement of the game and enriches its storyline with additional, compounding subplots. A catalyst of the game is its novel trap framework,

which provides randomized, event-driven triggers. The trap framework allows for a dynamic story structure that can be based on difficulty setting and re-assembled in different configurations (e.g. random frequency and location) each time the game is loaded. Together, the diversity of trap types, realistic in-game portrayal, and randomization allow us to create a "worst case" mine emergency that is beyond anything that could be safely simulated in real-life using traditional role-play techniques.

We have created a variety of traps and hazards that can be placed into the game map. Traps may be triggered based upon user proximity or actions; the triggering semantics are context-dependent for each trap. Several traps have already been deployed using this framework, each has specific negative outcomes when the user fails to recognize the trap and respond accordingly. Samples of bad outcomes are shown in Figure 5. Our game supports the following types of trap conditions and outcomes:

- Irrespirable Gas = Asphyxiation
- Roof Fall = Crushing
- Spreading fire = Blocked egress, burns
- Defective breathing apparatus (SCSR/SRLD) = Asphyxiation
- Inoperative refuge chamber = Asphyxiation, time penalty
- Inoperative mantrip = Time penalty, electrical fire
- Inoperative shuttle car = Electrical fire
- Methane pocket = Explosion
- Broken lifeline = Loss of crew member
- Uneven ground = Stumbling, leg Injury
- Collapsed Pillars = Blocked egress, time penalty
- Damaged wiring = Electrocution
- Damaged power center = Electrocution
- Damaged phones = Loss of communication

Figure 5. A sample of bad outcomes. Top: A roof collapse takes the life of a crew member; Middle: A gas pocket ignites, killing the entire crew; Bottom: Trapped by fire, the crew retreats to a refuge chamber in hopes of a rescue.

4.2 Example: Story Prologue

As an example of this story telling framework, consider the script excerpts in Table 6 and the scenes in Figure 7, which together illustrate part of game's prologue. Many story mechanics are featured here, including triggered events (in block A1.1.2), user decision points (in block A1.2.1), and randomized dialog (in block A1.3).

Table 6. Sample story blocks from Act 1 prologue, part of the 70+ page game script.

Act 1.1.1 Introductory Narrative (Narrator)

Situation: [Fade transition] The camera pans around the scene, cutting to the various activities: the miner, the shuttle car, men working on random chores.

1. Narrator: *"Harry Hamilton is a 37 year old section foreman at a room and pillar mine operation. He has been a community volunteer fireman for more than 15 years. Before taking a management position, he was a fire boss for 5 years. He knows the mine well. "*
2. Narrator: *"Harry has an eight man crew working the face in the Northeast Section. The Section has been driven 29 crosscuts off of the mains. Harry's crew is currently in crosscut 27, just inby of the Northeast Section's #1 entry, turning left into 2 Northeast."*

Act 1.1.2 Harry supervises daily operations (Harry, Joe, and Bill)

Situation: Event sequence is triggered as Harry walks up to Joe. Harry is standing over Joe, looking on as the continuous miner cuts into the face.

1. Joe: *"We should be done with this cut in another 20 minutes or so."*

Joe is kneeling with the miner control box, while the miner runs in the background.

2. Harry: *"Is the seam widening out?"*
3. Joe: *"Yeah, looks good since we made that left turn. Seam's real even – not cutting into so much rock now. "*
4. Harry: *"Bill, see if you can clean up some of this loose coal and slate. Clem (Carlos) should be back for another buggy load soon."*
5. Bill: *"Yep, I'm gonna take care of it."*

Bill comes over with a shovel and starts shoveling coal into a pile.

Act 1.2.1 Clem thinks there's a problem (Harry, Clem, and Charlie)

Situation: [Fade transition] Clem comes back with the shuttle car, parks it, and steps over to Harry.

1. Clem: *"Hey boss, the alarm is going off. I think there's smoke comin' up the belt."*
2. Charlie: *"You sure 'bout that Clem (Carlos)? I don't hear no alarm."*
3. Clem: *"Boss, what should we do?"*

Harry's Decision: Get the crew together and assess situation, or ask Clem to verify what he thinks.

Choice 1: Side with Charlie

4. Harry: "*We're already behind quota today. We don't need more delays. "*

Clem walks off toward conveyor to verify; incurs a significant time penalty.

[Fade transition]

Goto 6.

Choice 2: Side with Clem

5. Harry: *"Clem (Carlos), get the crew together. I'll call the CO room and see what's goin' on. "*

Goto 7.

6. Clem: *"Yeah boss, there's definitely smoke on the belt and it's gettin' pretty thick. Smells like coal."*

Goto 3.

7. Clem: *"Alright. Meet y'all at the power center."*

[Fade Transition] Clem goes to assemble the team. He walks to the vicinity of each mine and yells to get his attention:

8. Random attention query (GP.37)

Act 1.3 Harry calls outside for information (Harry and Operator)

Situation: Triggered as Harry walks over and invokes a phone. Harry picks the receiver and begins to talk.

1. Harry: *"Control room, this is Harry on Northeast."*
2. Harry: Harry calls in current position (GP.12)
3. Harry:*"We're hearing alarms down here and my buggy man says there's smoke comin' up the belt. Can you tell me what's going on?"*
4. Operator: Operator gives fire status and location (GP.30) *."*
5. Harry: "*Alright. I'll phone in and tell you the plan after I talk to the crew."*

GP.12 Harry calls in current position (Harry and Operator)

Harry stands in the vicinity of a mine phone. Note that this conversation is part of a larger phone call that depends on circumstances.

1. Harry: "*We're currently near …* ___
2. Harry: *"and* ___."

Note: blanks are filled with "*Entry [1-9]*" and "*Crosscut [1-29]*"

GP.12.2 Entry names

1. Harry: "*Entry [1-9]*" (9 lines)

GP.12.3 Crosscut names

1. Harry: "Crosscut *[1-29]*" (29 lines)

GP.30.1 Operator gives status (Operator and Responsible Person)

1. Operator: *"Harry, the CO monitors have gone off all along the belt on Northeast. We're checking it out now."*
2. Operator: *"We think there's a fire...it's somewhere in the Northeast mains."*
3. Operator: *"We're currently assessing the situation. Try to stay away from the Northeast section."*
4. Operator: *"We think there's a fire ...It's somewhere in the Northeast mains. We're checking on it."*
5. Operator: *"Harry, that fire looks to be at the belt transfer in #1 Northeast mains. "*
6. Operator: *"It's still not under control."*
7. Operator: *"Harry, that fire looks to be around the head drive in entry 5 Northeast mains. "*
8. Operator: *"It's still not under control and it is spreading."*
9. Operator: *"It's still not under control and likely spreading into your section."*
10. Operator: *" If you're gonna move, you better do it now."*
11. Operator: *"You're running out of time."*

12. Responsible Person: *"Harry, this is the RP. That fire is still out of control and it may take several hours at least before I can get rescue teams in."*
13. Responsible Person: *"It's looking pretty bad. You may be hemmed in at this point. I suggest you find a refuge chamber"*
14. Responsible Person: *"Your section may be blocked off at this point, so I advise you to stay in a refuge chamber until we can get the situation under control. "*
15. Responsible Person: *"The fire is still not under control. There's no way out of the section at this point. Do you read?"*
16. Responsible Person: *"The situation is grim. You're trapped and the fire is spreading toward you. Why did you waste so much time? "*

GP.30.2 Operator reprimands (Operator)

Spoken with belligerent tone.

1. Operator: *"Stop calling me unless you have a status change!"*
2. Operator: *"Harry, quit screwing around on the phone and get your men out! What the hell is wrong with you?"*
3. Operator: *"If you keep wasting time on the phone we'll have to put Larry in charge! Now get your men out!"*
4. Operator: *"Are you trying to get killed, Harry? There's a fire! Get off the phone and get your men out of there!"*

Figure 7. Scenes from the Prologue of Harry's Hard Choices. The section foreman (Harry) supervises the miner operator and his assistant at the face (top), while a shuttle car has just dropped off a load and is returning for another cut (center). When the alarms go off and smoke is detected, Harry calls outside to discuss the problem (bottom).

5. Game Stats and Role Playing

Game mechanics such as timers and scoring mechanics make *Harry's Hard Choices* exciting, competitive, and memorable. Points are awarded or deducted from the game score based on choices that are relevant to the story context. For example, a user would lose points by choosing to retreat to a refuge chamber when all available information suggests that the crew could safely evacuate the section since this choice violates a prime objective of self rescue. Conversely, a user would be awarded points for using safety equipment at the proper times, such as checking gas readings and donning breathing apparatus. The merits of a choice are often based on the situation; for instance, activating a refuge chamber may be a good choice (and thus awarded points) if the user finds that escape routes have been blocked by substantial hazards (such as by roof fall). Time is another critical factor, as it is with any underground mine emergency, due to the rapid spread of fire and dangerous gases, and time penalties are enforced for bad or slow decision making. Respirators will also expire and irrespirable gases will grow more concentrated. Procrastination and slow decision making may lead to unwinnable conditions as the fire consumes the section.

Furthermore, the game incorporates role-playing mechanics which compel users to think about their choices within the context of the larger group. An example is shown in Figure 8. In this game, other characters in the crew are controlled by computer-based intelligent agents. In addition to the personalities and back stories outlined in Sec. 3, the non-player characters (NPC) also have stats governing fitness, fatigue, and morale, and their willingness to go along with the user's decisions will be gauged by these stats. Fatigue will increase with prolonged exertion and exposure to dangerous gases, but will decrease

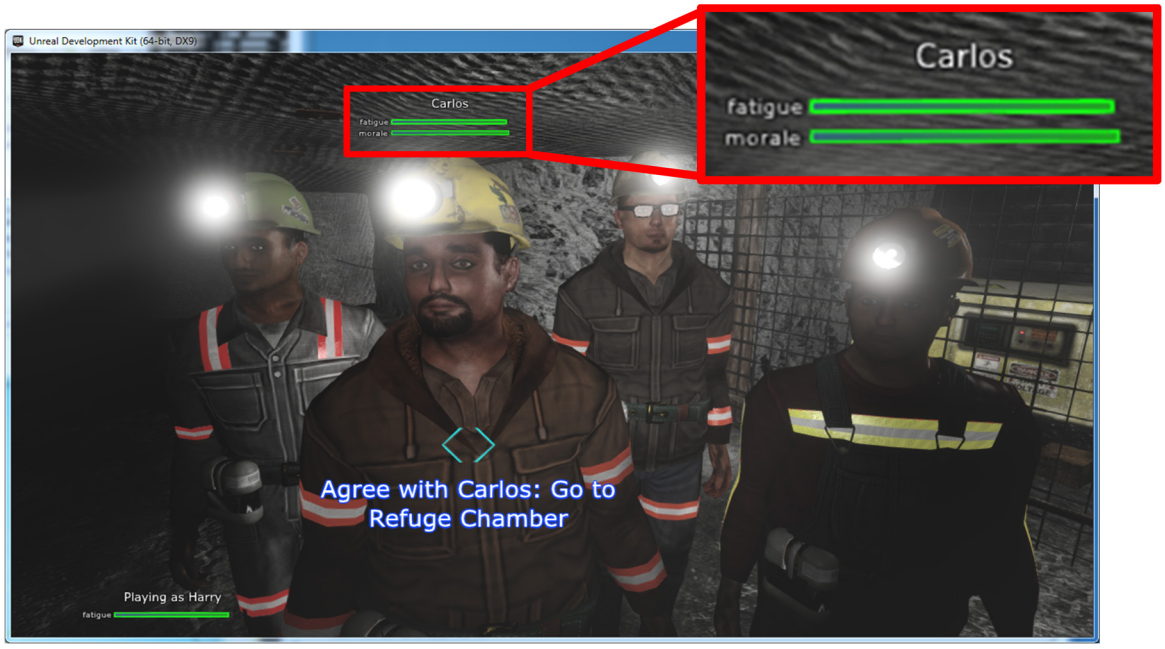

Figure 8. The game emphasizes crew-oriented decision making and gameplay mechanics.

with rest in designated shelters. As morale will change for better or worse depending on the user's decisions and interactions with each character. NPC that are extremely fatigued or low in morale may be more prone to become argumentative and plead for retreat to a refuge chamber, rather than continuing the difficult journey out of the mine. They may chastise Harry (the user) for making poor decisions. Some characters may even be injured during the course of the story. As shown in Figure 9, crew members exhibit visual signs of distress through facial expressions, sweating, and level of dirtiness that are dependent on the situation; all of these visual effects would be expected in a highly stressful, real mine emergency. The party can lose NPCs through attrition – miners can become separated and lost in the thickening smoke and confusion, they may be purposefully left in designated refuge shelters if unable or unwilling to continue, or they may perish outright due to physical injury or asphyxiation. Safety equipment must be precisely deployed and used

Figure 9. Miners in distress. Left: A miner sweats from exertion and exhaustion. Center: An injured miner is surrounded by crew members. Right: A miner is covered by soot, dust, and dirt.

within this context (Figure 10). To our knowledge, none of these game mechanics or graphical capabilities have been featured in mine safety training simulations to date.

In line with a true computer gaming approach, a core element of *Harry's Hard Choices* rests in the use of these game statistics and stat modifiers as drivers of user progress and story outcomes. We chose to build statistic assessments that reflect the reality of a mine emergency - such as morale of the crew, demeanor and likeability of individual crew members - as these factors greatly impact decision making. Here we describe in detail the fatigue level and exertion rate statistics; these descriptions serve to demonstrate how the other statistics and modifiers are calculated in the simulation.

5.1 Fatigue Level

The base statistic in this game is called Fatigue Level. Every character, both user and NPC, starts the game with 0 Fatigue points. Through the course of the game, the Fatigue Level will increase or decrease based Stat Modifiers (see next section) and the current instantaneous Exertion Rate. Physical work and stress cause the Fatigue Level to

increase, whereas resting causes the Fatigue Level to decrease. When the Fatigue Level reaches 100, the character has entered a state of extreme exhaustion and/or severe stress leading to unconsciousness. The Fatigue Level stat affects all aspects of a character's behavior. The Levels are shown in Table 11 and impacted by the following mechanics:

1. Characters gain Fatigue points by exerting themselves and reduce Fatigue points by resting. Resting is enhanced in designated safe areas such as Refuge Chambers, but at the expense of time.
2. Characters fall unconscious when their Fatigue meters reach 100. Characters cannot recover from a fully Fatigued state (100) – they are effectively "dead."
3. Character composure is related to Fatigue level as given in Table 11. Composure state effects both physical appearance and the impact of decision-making on morale.

Figure 10. Donning the M-20 Self-Contained Self-Rescuer (SCSR). MSHA protocols are used for all mine emergency equipment. For example, the in-game donning procedure for the M-20 (left) was frame-wise reconstructed in 3D from MSHA training videos (right).

Table 11. Fatigue level definitions.

Fatigue Level	Morale Multiplier	Composure State
0-60	1.00	Alert
61-80	1.50	Tired
81-99	2.00	Exhausted
100	N/A	Unconscious

The Fatigue Level is updated every 1s for each character, based on his or her instantaneous Exertion Rate (discussed below). The current Fatigue Level (F) is computed as

$$F' = F + T*E$$

In this equation, T is the time stepping (s) and E is the current instantaneous exertion rate (pts/s). The rate of increase in Fatigue points depends on the severity of physical exertion and relevant environmental stresses, which are characterized by the instantaneous Exertion Rate (E) given in Eq. (1). We calculate Exertion Rate using by a summary formula that considers several modifiers, most of which are penalties. This formula is motivated by the intuition that various conditions will compound and increase the rate at which characters become fatigued. For instance, a character that is running will become fatigued much faster than a character that is walking. A character that has poor health and that is breathing air saturated in CO_2 will become fatigued many times faster than a character that is walking, has good health, and is breathing good air. Thus a character's Exertion Rate includes modifiers for Activity Type (A), Fitness Penalty (F), Breathing Penalty (B) and Injury Penalty (Damage, D) and is computed as follows:

$$E = E_0 * ((1 - [I]_{Rest}) * (A * (1+B) * (1+F) * (1+D * H)) + [I]_{Rest} * (R * (1-B) * (1-F)))$$

where A = Activity Type, F = Fitness Penalty, B = Breathing Penalty,
D = Injury Penalty, H = Injury Assistance, R = Rest Bonus,
$[I]$ = Indicator variable for Resting state

5.2 Breathing Penalties

Most significantly, the Breathing Penalty (B) is used to indicate factors affecting the character's air quality and ease of breathing. The breathing penalty directly affects exertion rate. In extreme cases (i.e. lethal gas levels), the penalty can be higher than 1, leading to rapid loss of consciousness and acute poisoning of the character (and, intentionally, even while in the Resting state). The factors covered by the Breathing Penalty include respiration through an SCSR, which requires additional breathing labor, and respiration of dangerous gases in the surrounding air, which include abnormal levels of CO

Figure 12. A gas multi-meter. Users must interpret gas readings and manage their time on apparatus. Gas levels become increasingly lethal and breathing apparatus will expire after designated usage times.

Table 13. Breathing penalties (exertion rate) as a function of gas concentration.

Carbon Monoxide (< ppm)	Exertion Rate Multiplier
35	0.00
100	0.25
200	0.50
400	2.00
800	5.00
1,600	10.00
3,200	40.00
6,400	60.00
12,800	400.00
>12,800	4,800.00

Carbon Dioxide (< %)	Exertion Rate Multiplier
0.50	0.00
1.00	0.25
2.00	0.50
3.00	2.00
4.00	10.00
5.00	20.00
7.00	40.00
10.00	250.00
30.00	500.00
>30.00	5000.00

and CO_2. The SCSR and gas penalties are mutually exclusive, in that the character uses the SCSR to avoid breathing bad air. As such, the SCSR penalty can be substantially less than the penalty for bad air. These penalty modifiers are summarized in the tables below. The relative values of gas readings and penalty rates given in these tables were derived from reference materials on the effects of these gases in humans at the given concentrations. In cases when there are dangerous levels of multiple gases present (i.e. CO and CO_2), we simply take the highest penalty value.

Gas levels are both time and position dependent. They can be sampled in real-time with a virtual gas multi-meter as shown in Figure 12. For each type of gas, a concentration is computed for each nearby emitter as a polynomial function of time. The gas levels affecting each character will then depend on the proximity of that character to each nearby smoke/gas emitter; a weighted interpolation function considers the n-closest emitters along each cardinal direction. Impacts on character stats, i.e. penalty multipliers, are given

in Table 13 and are based on OSHA research into the effects of gas concentrations on humans (e.g. symptoms and lethality).

6. The User Interface

A good user interface is vital for effective game design (Federoff 02; Shelley 08). *Harry's Hard Choices* provides a user interface with substantial flexibility, in terms of both interface hardware and on-screen presentation, to support different playing styles and classroom capabilities. Supported interface hardware includes keyboard, mouse, gamepad, touch screen, and gesture-based hand tracking. The default gamepad interface is given in Figure 14. A corresponding Heads Up Display (HUD) shows vital game status information and serves as an interface to various safety equipment. See Figure 15. The HUD information

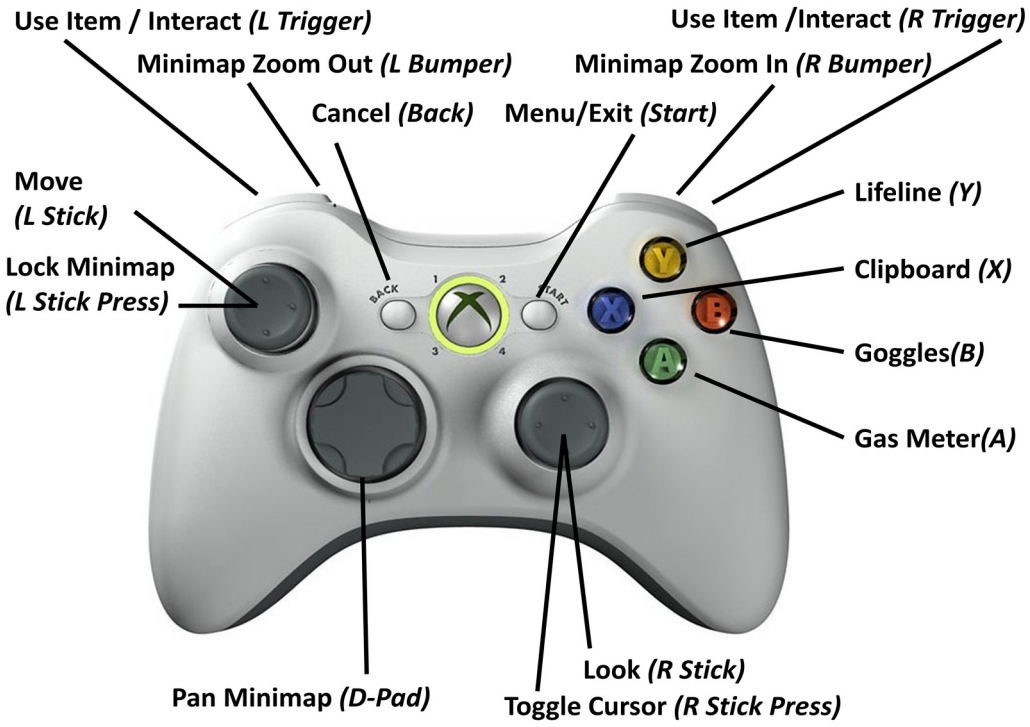

Figure 14. Default control scheme for the popular XBox 360 gamepad. The controls may be remapped by the user.

Figure 15. The Heads-Up Display (HUD). Note the inclusion of memorable game elements, such as score, timer, and health bar, all of which are impacted by the situational context and user actions.

can also be customized to suit user needs through the addition of map navigation aids, equipment tool tips, learning objectives and gaming hints. By default, the HUD offers the following types of information, which can be turned on or off as necessary:

1. Game Stats, including Morale and Fatigue bars, floating above each non-player character's (NPC) head.
2. An Event Log displaying situational context and dialogue. For convenience, a secondary "Clipboard" interface couples the event history with context-relevant learning points.

3. An Action Bar displaying equipment status. These items include a mine map, clipboard, pocket watch, gas multi-meter, fire extinguisher, SCSR, safety tether, and goggles.
4. A Mini Map featuring pan and zoom controls, plus status icons to designate look direction and active waypoints.
5. A Game Score indicating the user's cumulative points, based on good and bad choices. Colors are used for reinforcement -- game scores are green when positive and red when negative.
6. A Simulation Time, showing the game clock since the start of the emergency.
7. Tooltips providing context help when the user hovers over a HUD icon, such as the name of the icon and the action it performs.
8. A Fatigue Level bar indicating the current health of the user's character (i.e. Harry).

7. Usability Studies

Through a series of focus groups and qualitative pilot studies, our game software has been tested with 32 users at three sites. Test participants included students, professors, certified trainers, and professional miners. Overall opinions of the software have been highly favorable, with users providing summary feedback that it is a "Great simulation," and "A fun learning experience." Users mentioned that they were "Surprised by the level of accuracy," and added that the games were "Very real," with "lots of options" and "graphics were pretty good." In a recent evaluation of Harry's Hard Choices, participants graded their overall game experience using 7-point Likert scales, rating the game as significantly better than the "No Opinion" level (4) on 3 of 4 metrics (Figure 16). The lowest rated metric, "Frustrating or Satisfying," scored only slightly better than 4 and

with high standard deviation, which were attributed through user comments to a latent bug in the path following algorithm; that has since been fixed. Moreover, all participants in the study replied in the affirmative when asked if they would like to play the game again.

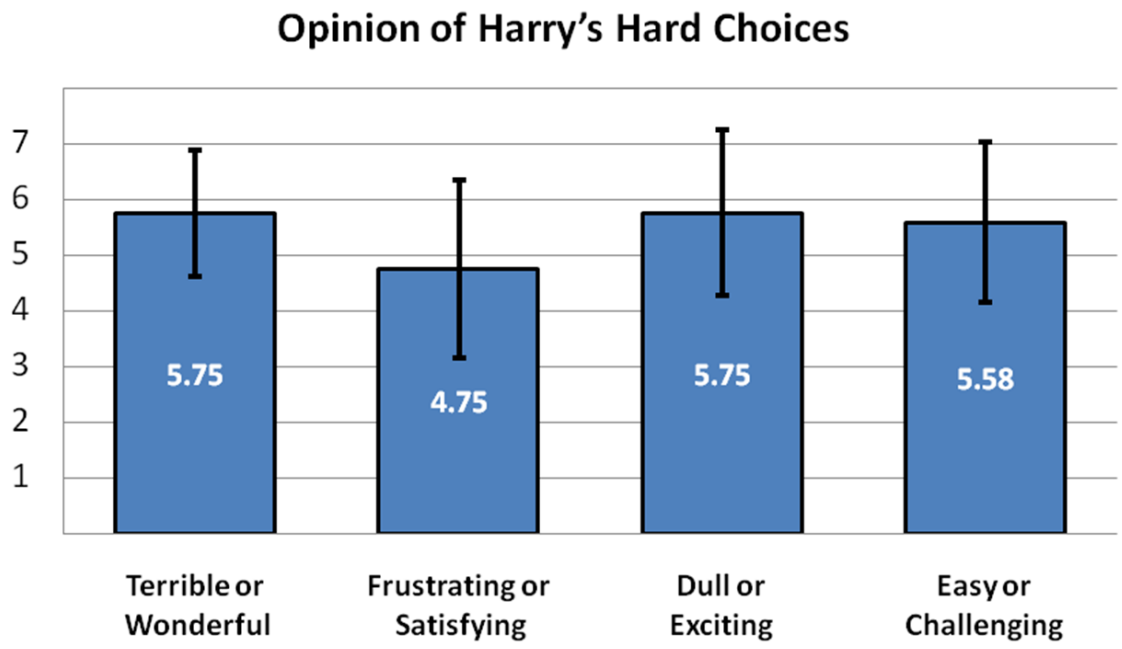

Figure 16. User opinions of Harry's Hard Choices, as reported by test participants (p=12) via 7-point Likert scales. Higher scores are better. Evaluation instrument based on (Chin 1988).

Through a triangulated needs assessment, we identified accessibility as a major objective in designing our gaming software. Specifically, serious games should be usable and engaging for an audience with broad demographics, including both new and experienced miners, as well as users with varying degrees of computer and workplace literacy. Our user studies suggest that Dynamic Safety games have the potential to achieve this goal. In evaluating *Harry's Hard Choices Interactive*, Users indicated high degrees of both satisfaction with the user interface (Figure 17, Top) and ease of use (Figure 17, Bottom), with scores consistently at or above 5 for most metrics; higher scores indicated 6,

"Strongly Agree." Experimenter observations suggest that most users were quick to pick up the gameplay controls and could comfortably interact with the game within a few minutes. Results were similar for users identifying themselves as gamers and non-gamers.

We noted that game outcomes also improved significantly as users played through several iterations of the game. Improvements were reflected in final scores, where higher scores meant "better" decisions, and in the number of crew members evacuated from the mine. In a typical first play iteration, users often made "bad" decisions in the face of game hazards that would lead to point deductions and/or crew members being injured, lost, or killed. In subsequent play iterations, users were typically able to avoid the same mistakes, leading to better game outcomes. We should note that the game randomized hazards and decision events, such that users could not improve their outcomes simply by anticipating events or by using rote sequences of actions; the randomization was meant to enforce critical thinking based on the current situation. User's results improved from 0 or 1 crew members successfully evacuated in the first iteration to a mean of 3.80 (out of 9 maximum) on the player's best attempt, which was typically the last iteration of play. Game scores showed a similar, monotonic improvement over subsequent attempts for most users. Although the mean scores were relatively low versus the ideal solution, the game was meant to be challenging; it simulated a "worst case" mine emergency where compounding hazards and bad luck led to many difficult choices. We observed two users that evacuated almost their crew (8 of 9) and ended the game with benchmark high scores by making excellent choices and efficient use of time and crew resources.

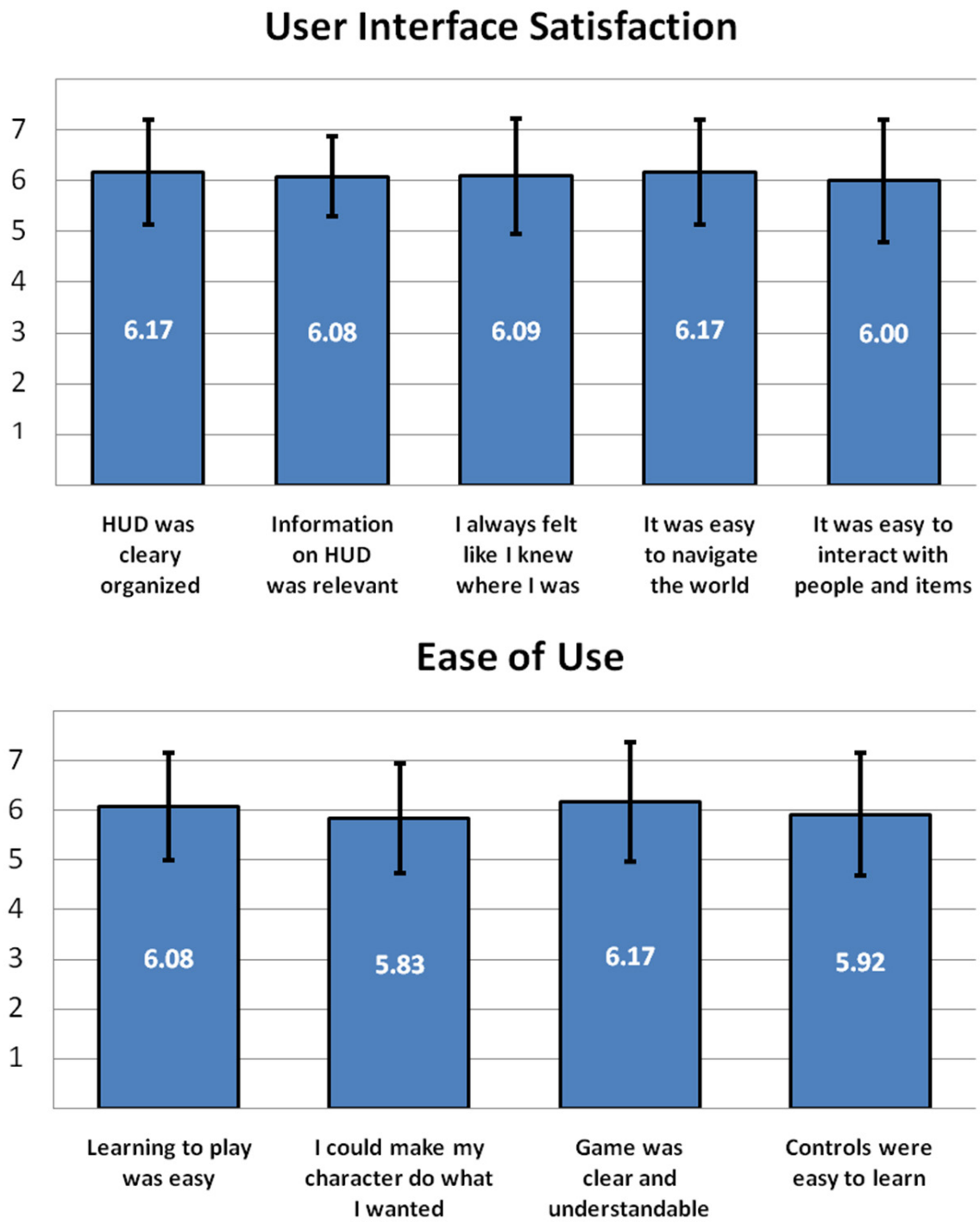

Figure 17. User evaluation of Harry's Hard Choices, as reported by test participants (p=12) via 7-point Likert scales. Higher scores are better, indicating "Strongly Agree." Evaluation instruments based on (Chin 1988; Davis 1989; Federoff 2002).

8. Conclusions

Harry's Hard Choices is a "serious game" for mine safety education covering a broad range of MSHA training topics. Detailed characters and backstory provide color, humor, and personal investment, while a variety of crew-based (NPC) interactions, such as conversations and arguments, foster team-oriented thinking and decision making. A novel system of hazards, traps, and event triggers randomizes gameplay and allows for dynamic story structure. In summary, *Harry's Hard Choices* supplements best practices in training pedagogy by emphasizing five core features: (1) contextualized learning via a dynamic and suspenseful story; (2) reinforcement through persistent consequences and chains of cause-and-effect; (3) competitive gameplay, with scoring and outcomes based on quality of decisions; (5) promotion of leadership skills in cooperative, team-oriented role-playing; and (4) enhanced accessibility for all generations of miners through versatile gaming interfaces. Brought together, these elements yield a new type of training tool with a level of breadth and capability that are new to the mining industry. Initial user testing has been promising and suggest user's enthusiasm for the new approach. Future work will explore the efficacy the software in more detail, by deploying *Harry's Hard Choices* to the classroom as part of a comprehensive training program.

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