Designing and Developing Effective Training Games for the US Navy

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ABSTRACT

Game-based training offers great potential for providing low-cost training systems for learning cognitive and procedural skills within the U.S. Navy. We introduce an effort, sponsored by the Office of Naval Research, to harness, apply and harden this capability by creating validated training games for the Navy. Over the period of fourteen months, our multi-disciplinary team collaborated to develop and validate a flooding control training game to help students at the U.S. Navy Recruit Training Command (RTC) learn to be better sailors. The Flooding Control Trainer (FCT) provides individual training within the simulated interior of an Arleigh-Burke class destroyer. The trainer reinforces damage control skills that the recruits have been exposed to in lectures, but which they have not had a chance to practice in context. In developing the trainer, we focused on both the specific application domain as well as the design methods required to ensure that the trainer was based on relevant learning objectives, incorporated a strong narrative, used an instructional strategy and a game play style that were complementary, and contained embedded assessment capabilities. The FCT is based on the open-source Delta3D engine. To support effective training, we augmented the engine with a task-based instructional infrastructure and a variety of feedback mechanisms, including real-time guidance and feedback as well as after-action debrief. We conducted several empirical tests of the product, including a usability study and a learning validation study using the target recruit population as subjects. The results indicate that the FCT is usable, well-received by recruits and produces a significant improvement in performance across a range of cognitive and procedural skills, including situational awareness, communications, navigation and decision-making. We present our approach, describe the training game design, discuss the studies conducted and their results, and discuss next steps to create Navy training games for use beyond RTC.

ABOUT THE AUTHORS

Dr. Talib S. Hussain is Senior Scientist at BBN with a broad interest in learning and training for both machines and humans. He is currently co-Principal Investigator on the ONR-sponsored Tools for Games-Based Training and Assessment of Human Performance project, which is investigating advances in authoring technology for pedagogically strong game-based training systems and is developing game-based training solutions to support Navy recruit training. He was recently the development lead on the DARPA-sponsored Plan Order Induction by Reasoning from One Trial (POIROT) project, which is applying a broad range of machine learning and artificial intelligence techniques to learn procedural knowledge based on a single observation of a human performing a task.

He was the principal investigator on the DARPA-sponsored Gorman's Gambit project, part of the DARWARS program, which studied the design issues involved in training military teamwork skills using modern multi-player game (MPG) technology. Forty infantrymen from Fort Benning, GA participated in a "capture-the-flag" exercise developed as a scenario within a COTS MPG. Valuable lessons were learned on the requirements for measuring team performance within a game.

Bruce Roberts is a Lead Scientist at BBN Technologies, where he has developed numerous simulation-based intelligent tutoring systems: for Air Force technicians troubleshooting flight-line avionics, for conning officers practicing shiphandling in a virtual environment, and for Air Weapons Officers controlling air-to-air attack aircraft. He is currently co-Principal Investigator on the ONR-sponsored Tools for Games-Based Training and Assessment of Human Performance project, which is investigating advances in authoring technology for pedagogically strong game-based training systems and is developing game-based training solutions to support Navy recruit training. Recently, he was the Principal Investigator for DARWARS architecture and integration, part of DARPA's Training Superiority program, and led the rapid development and successful deployment of DARWARS Ambush!, a widely used multi-player game-based training system.

Dr. Clint Bowers currently resides on the University of Central Florida's Psychology Faculty as well as being Co-Director of the RETRO (Research and Emerging Technology Research Organization) Lab at UCF's Institute for Simulation and Training. Clint's current research interest is in the use of technology to facilitate teamwork. This takes several forms. The first includes basic research on the nature of effective teamwork and the factors that influence it. A second research thrust involves the training of teams. Clint is especially interested in the use of training technologies and simulation in training team skills. Finally, Clint is interested in the use of technology to assist teams in their day-to-day tasks. This includes research in information visualization, groupware, and other hardware/software systems. Besides his interest in team performance, Clint is also involved in several student projects. These include the use of virtual reality to teach deaf children, the neuropsychology of spatial abilities, and the use of warnings to manage predictable non-compliance.

Dr. Janis A. Cannon-Bowers holds M.A. and Ph.D. degrees in Industrial/ Organizational Psychology from the University of South Florida, Tampa, FL. She recently left her position as the Navy's Senior Scientist for Training Systems to join the School of Film and Digital Media at the University of Central Florida, Orlando, FL as an Associate Professor. As the team leader for Advanced Training Research for the Navy, she was involved in a number of research projects directed toward improving performance in complex environments. These included investigation of training needs and design for multi-operator training systems, tactical decision-making under stress, the impact of technology on learning and performance, training for knowledge-rich environments, human-centered design, human performance modeling and development of knowledge structures underlying higher order skills. At UCF, Dr. Cannon-Bowers is continuing her work in technology-enabled learning and human performance modeling. Her goal is to leverage and transition DoD's sizable investment in modeling, simulation and training to other areas such as entertainment, workforce development, life-long learning and education.

Dr. Susan L. Coleman, CPT, is the Chief Performance Officer for Intelligent Decision Systems, Inc. Dr. Coleman oversees all phases of human performance analyses, while specializing in instructional systems design processes. She earned a Ph.D. in Instructional Technology and Design and has analyzed performance and designed and developed performance solutions since 1983. She spent the last 18 years analyzing and designing training systems for the military. Dr. Coleman conducts instructional design research, training effectiveness evaluations, design analyses, technology integration front-end analyses, and human performance improvement analyses.

Dr. Alan Koenig is a Senior Research Associate at UCLA/CRESST where he specializes in the application of innovative uses of technology for delivering and assessing instruction. His research focuses on the design and implementation of computer-based games and simulations designed for classroom and/or military training environments. His current work centers on the development of automated assessment systems for high fidelity games and simulations used in the military. Prior to joining CRESST, Dr. Koenig spent 10 years working in the technology sector as both a software developer and mechanical design engineer. Dr. Koenig holds a PhD in

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Dr. John Lee's current research is related to technology-based assessments in a variety of Navy/Marine Corps contexts. He is currently working on the development of a computer-based assessment tool for assessment of Tactical Action Officers (TAO) in a simulated CIC (Combat Information Center) onboard Navy ships called the Multi-Mission Team Trainer (MMTT). He is also working on a simulation-based re-certification assessment of marksmanship coaches' fault checking abillity that delivers just-in-time, individualized instruction that utilizes Bayesian nets for diagnosis and remediation. A third project he is also working on is a game based assessment project for the Navy related to assessment of complex skills (starting with damage control) also using Bayesian nets for real time and after action assessment of skills including situation awareness, decision making and communication. His research interests include data-informed decision making, knowledge mapping, simulation-based assessments, and distance learning.

Dr. Ellen S. Menaker, CPT, is the Chief of Research and Evaluation for Intelligent Decision Systems, Inc. Dr. Menaker has over 30 years of experience in the fields of research and evaluation, cognitive development, and human performance. Dr. Menaker oversees the design, data collection, and analysis phases of research; and various types of analyses and evaluations. She specializes in learning theory, measurement, and instructional systems design. Her academic and industry experiences include conducting research for various military, governmental, and educational entities. Recent studies have focused on implementation of learning strategies, including use of massive multiplayer online games (MMOGs) and the integration of SCORM modules into gaming environments. Recent literature reviews have focused on the application of learning theory, strategies for developing situational awareness, and identification of foundational skills for lifelong learning. Dr. Menaker is an active member of AERA, ISPI, and she serves on the Education Committee for IITSEC.

Curtiss Murphy is a Project Engineer in the AMSTO Operation of Alion Science and Technology. He manages the game-based training and 3D visualization development efforts for a variety of Marine, Navy, and Joint DoD customers. He is a frequent speaker and author and specializes in open source technologies such as the Delta3D Game Engine (www.delta3d.org). He has been developing and managing software projects for 17 years and currently works in Norfolk, VA. Curtiss holds a BS in Computer Science from Virginia Polytechnic University.

Kelly Pounds' multi-dimensional career began as a schoolteacher in Orange County (FL) Public Schools where she spent twelve years as a classroom teacher. Kelly next took her passion for learning and instructional design into the corporate environment as a Technology Designer for the Disney University where she developed computer-based and classroom training products for leaders at the Walt Disney World® Resort. Her next corporate role was at Hard Rock Cafe International as Manager of Organization Development where, as an innovative strategist, she helped the corporate leadership collaboratively develop strategic planning processes and products. Kelly's enthusiasm for learning is currently shared through her role as Vice President of i.d.e.a.s. Learning where she puts her past work experience and her master's degree in Educational Technology to work everyday. i.d.e.a.s. is an innovation studio employing its core competency of storytelling to create entertainment, marketing, and learning products.

Dr. Richard Wainess is a senior researcher with the National Center for Research on Evaluation, Standards, and Student Testing (CRESST) in the University of California Los Angeles' Graduate School of Education and an adjunct associate professor in the University of Southern California's Rossier School of Education. Dr. Wainess' research interests center on the use of games and simulations for training and assessment of adult learners. His most recent work is focused primarily on assessment of problem solving and decision making using computer-based interactive tools. He has authored and co-authored numerous reports, articles, and book chapters and has presented at many conferences on the topic of games and simulations for learning, with a particular emphasis on instructional methods, cognitive load theory, motivation, and learning outcomes. Richard has a B.A. in Radio-Television Production, an MS.Ed in Instructional Technology, and a Ph.D. in Educational Psychology and Technology.

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INTRODUCTION

Immersive training environments based on modern computer game engines are increasingly being used within the U.S. and other militaries to provide training on a range of skills (O'Neil & Perez, 2008; Roman & Brown, 2008), including team convoy operations (Diller et al., 2004; Roberts et al, 2006), route clearance (O'Bea & Beacham, 2008), operationally relevant language skills (Johnson et al., 2007), and small unit tactical operations and mission rehearsal (McDonough, J.P. & Dmochowski, N., 2008). To date, most game-based military training systems have focused on ground or air based operations. However, game-based technologies have the potential to provide valuable training on the ship-based operations of the U.S. Navy. The Office of Naval Research is currently funding research to identify the learning benefits of game-based trainers for naval training, harden the technology and methods for developing game-based training for the Navy, and produce effective training systems that can be deployed in the near term.

We introduce a training game developed to reinforce the skills needed in controlling flooding on board a ship. The Flooding Control Trainer (FCT) was developed in collaboration with the Naval Service Training Command to serve three purposes: (1) supplement classroom instruction at the Navy Recruit Training Command (RTC) to produce better-trained recruits; (2) reduce the demand on current and anticipated training resources, and (3) produce a training platform that can be used across the Navy technical schools and, eventually, in the fleet.

Over the period of fourteen months, starting in February 2008, our multi-disciplinary research and development team conceived, developed and validated a 3D immersive training game for flooding control. The FCT is built using the open-source Delta3D game engine (www.delta3d.org, Darken et al., 2005, Murphy et al. 2008) and runs on a typical modern desktop computer. During our effort, a strong emphasis was placed upon drawing together the best practices of training game design from several disciplines, including instructional system design, narrative design, formative and summative assessment, and game design and development. In this process, we identified a number of lessons learned and made good progress towards identifying cohesive and consistent design and development methods for game-based training systems (Hussain et al., in press).

The FCT provides individual training on flooding control skills within the interior of a simulated Arleigh-Burke class destroyer. It focuses on learning objectives that directly support the RTC curriculum and embeds the training within a story that promotes core values, provides a relevant context and reinforces the culture of the service. The game reinforces decision-making, communication protocol, flooding control procedures and situational awareness. It provides information resources and feedback designed to help students of different levels and backgrounds succeed.

To ensure the relevance and success of the training game, we conducted multiple tests using the target recruit population as subjects, and enhanced the system iteratively based on the results. In April 2009, we conducted a validation study that demonstrated learning transfer from the game environment to a real physical environment. Significant performance improvements were observed across almost all the skills taught in the game.

We present some details on the design approach used, introduce the final game design, discuss the studies conducted and their results, and discuss our next steps.

BACKGROUND

Navy Recruit Training

The U.S. Navy's boot camp, the Recruit Training Command (RTC) at Great Lakes, Illinois, currently trains 40,000 recruits per year, drawn from diverse socioeconomic, cultural and educational backgrounds. Recruits undergo eight weeks of training, delivered primarily via classroom lectures and drill instruction by recruit division commanders. There are some computer based training labs and a few hands-on training labs, such as fire fighting, using self-contained breathing apparatus and line handling. At the end of their training, recruit performance is evaluated in an intense ten-hour capstone evaluation event, Battle Stations 21 (BS21). BS21 is a physical simulation, in a building, of an Arleigh-Burke class destroyer, complete with a simulated dock and ship exterior, as well as several internal decks. The ship is named the U.S.S. Trayer. During the event, recruits complete seventeen different training scenarios, ranging from routine (moving stores, standing bridge watch) to critical (flooding control, fire fighting) to extreme (dealing with injured shipmates during a mass casualty caused by an explosion).

The scale and diversity of the RTC training population provide ongoing training challenges. Currently, recruits face significant cognitive overload in BS21 due to limited opportunities to practice the skills they have been taught, spatial disorientation from never before having been on board a ship, the need to learn significant new material once they are in the BS21 exercise, and a high degree of stress due to being evaluated on unfamiliar skills (HPC, 2008). In particular, these issues can be seen in damage control situations. Further, the recruit population's diversity is increasing with time and current requirements call for an increase to over 46,000 recruits per year by 2011 with no increase in funding. As a result of these challenges, RTC is exploring the use of advanced training technologies, such as game-based training, to augment and enhance the training they provide.

Battle Stations 21 represents a high performance environment, characterized by rapidly evolving and changing scenarios, severe time pressure, serious consequences for error, command and peer pressure, fatigue, and a need for complex coordination of action. As such, BS21 requires highly complex performance that combines both individual and team level skills.

Research into optimizing performance in such environments has been ongoing for several years. Overall, findings suggest that, in order to be successful, individuals must be able to execute mission essential skills quickly and without hesitation. More specifically, the research literature suggests:

1. Complex performance must be broken down into requisite components so that individual knowledge and skills can be isolated and trained to proficiency before introducing the full complexity of the task. (Goldstein, 1993)
2. Under stress, performance is most resilient when it becomes automatic or habitual. This can be accomplished most efficiently by allowing trainees to practice until skills are over-learned (i.e., practiced beyond the point where performance is learned so that it becomes habitual and requires little active cognitive processing for successful accomplishment). (Kirlik et al., 1998)
3. Training for complex skills requires hands-on practice and feedback to be most effective. (Salas & Cannon-Bowers, 2001)
4. Synthetic learning environments, including simulations and games, are excellent environments in which to provide learners with realistic tasks so that they can practice essential skills. (Cannon-Bowers et al., 2008)
5. Trainees who are confident in their knowledge and skills are more likely to perform without hesitation. (Wurtele, 1986)

Game-Based Training Technology

The use of games and game-based technology for education and training has been increasing over the past few years (O'Neil & Perez, 2008; Smith, 2008). Computer game-based training systems share a number of potential characteristics with effective instructional tools and therefore have a great potential to affect learning. For example,

1. Games provide interactive experiences in a task-based environment with repeated exposure to important cue patterns. This is consistent with the development of expertise (Glaser, 1989; Chi et al., 1988; Bransford et al., 1999), anchored instruction (e.g., Bransford et al., 1990; CGTV, 1992; 1997; 2000) and active learning (Rothman, 1999; Chi, 2000; Mayer, 2001; Vogel et al., 2006).
2. Games provide a model-based world in which students may manipulate variables, view phenomena from multiple perspectives, observe system behavior over time, draw and test hypotheses and compare their mental models with representations in the external word. These features are consistent with the model-based reasoning concepts advocated by learning researchers (Gentner, 1983; Raghavan et al., 1997; 1998; Leher & Schauble , 2000; Cartier & Stewart, 2000; Zimmerman et al., 2003; Stewart et al., 2005).
3. Games provide successive tasks to help players make progress towards concrete, specific and timely goals. Goal setting in instruction enhances learning (Locke et al., 1981; Locke & Latham, 1990; Schunk & Ertmer, 1999).
4. Well designed training games also provide a variety of elements that can enhance motivation and learning, such as a sense of accomplishment (Bandura, 1977; 1986; Gist et al., 1989; 1991); informative feedback (Bransford et al., 1999; Salas & Cannon-Bowers, 2000) and a sense of challenge or competition (Epstein & Harackiewicz, 1992; Reeve & Deci, 1996).

Hence, properly designed training games can provide engaging learning environments that result in high time-on-task, reproducible learning outcomes and low human and system resource requirements.

However, the empirical evidence supporting the effectiveness of games for learning has generally been mixed (O'Neil et al., 2005). This has been due largely to a poor understanding in the field of how to effectively design games to support training (Gunter et al., 2006; Hussain & Ferguson, 2005; Hussain & Feurzeig, 2008), and an associated lack of empirical evidence for what effects different elements of a game-based training system have upon learning outcomes (Wilson et al., 2009). Some evidence has been presented indicating that game-based technology "is most effective as part of a blended training solution," and that using games for mission rehearsal prior to undergoing live training "makes live training more effective and efficient" (Roman & Brown, 2008). However, very few studies have been conducted to demonstrate the reliable transfer of learning, in a military domain, across a range of cognitive and procedural behaviors from a game-based training system to a physical environment.

Using modern learning theory as a basis, we put forth that game-based training should be able to create a strong positive learning effect with minimal instructor involvement. To prove this hypothesis, we developed the Flooding Control Trainer using proven instructional principles and modern game design. We then ran U.S. Navy recruits through a near transfer study to validate our hypothesis. The results were both compelling and conclusive.

FLOODING CONTROL TRAINER OVERVIEW

In order to address the training challenges in the Navy and at RTC in particular, we developed a prototype training game that teaches the basic skills necessary to control flooding on board a ship. Over the course of fourteen months, starting in February 2008, we designed, developed and validated the Flooding Control Trainer. Details on the design and development process, including lessons learned, are given in Hussain et al. (in press).

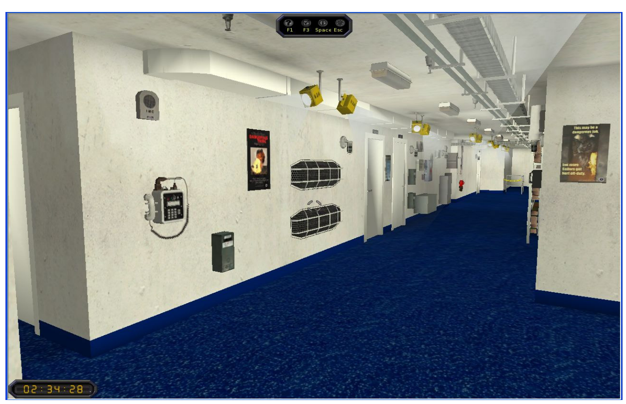

Figure 1: Simulated ship interior

Gaming Experience

The FCT is a single-player game that uses a first-person perspective. The 3D virtual environment models the interior of an Arleigh-Burke class destroyer with compartments of different types and appropriate fixtures and equipment (see Figure 1). The passageways resemble those of the U.S.S. Trayer at BS21. The player navigates the ship in a first-person perspective using the mouse and keyboard. The player interacts with the virtual world using the mouse to perform typical game actions, such as opening doors, inspecting objects, collecting personal protective equipment, and using damage control tools. There are no animated characters in the game, but the player can interact with virtual characters via dialogs over a communications device. Dialogs appear as a pop-up window in which the player can respond to a virtual character by choosing from several alternatives (see Figure 2).

Figure 2: Dialog mechanism, providing multiple response options from which to select

The game-play is based on completing a sequence of missions. There are three missions in the game, including a tutorial that teaches the player how to play the game itself. Each mission starts with a briefing that gives the player the key mission goals and puts them in the context of the underlying narrative. Each mission requires the player to achieve a set of tasks related to damage control. Some of these tasks are given to the player at the beginning of the mission and some are given during the course of the mission based on their actions. During a mission, the player has relatively free rein to interact with the virtual world. However certain actions may be prevented until the player has completed a particular task. Progress in the game is achieved by completing tasks that have been assigned to them.

Learning Experience

The FCT is designed to be played without assistance from a human instructor. It weaves instruction throughout the gaming experience, and varies its instruction based on the performance of the student. Different missions focus upon different learning objectives, and successive missions get increasingly complex and difficult. In each mission briefing, the student is explicitly given directions that relate to the learning objectives for that mission. During a mission, the player is given guidance and feedback based on their actions. Content support is provided to players through access to the "Navypedia" help system (see Figure 3). For example, they can go to the Navypedia to find out what safety equipment they need when fighting a flood. Critical errors can result in penalties or failure. At the end of each mission, a debriefing on their performance is given.

Figure 3: Navypedia mechanism, providing didactic content within the game on request

Technology

The FCT is built using Delta3D, an open-source game engine, and an open-source instructional logic engine also developed as part of the project. The instructional logic engine is part of a platform-independent pedagogy middleware that interacts in real-time with the game engine to control the instruction. It communicates game events to a separate process which executes explicitly defined instructional and assessment logic and, in turn, directs certain pedagogical actions within the game, such as providing feedback. While details of the middleware are beyond the scope of this paper, a key capability to note is that the instructional logic is authorable using a visual logic editor that supports rapid prototyping and modification of the instruction.

TRAINING DOMAIN

The key training goals of the system are to:

- Develop flooding control skills
- Develop cognitive skills and a sound and robust mental model in the areas of situational awareness, communication and decision-making
- Establish patterns for adaptive thinking

Further, a key ability that applies across all shipboard activities is an understanding of one's location on the ship and navigating efficiently between different locations. Due to the spatial disorientation experienced by students in BS21, training shipboard navigation was an additional training objective.

The FCT targets students that are novices who have declarative knowledge about ships and basic damage control procedures. The FCT design assumes that students have been through formal training to acquire the declarative knowledge, but that they have not been required to apply this information or to draw on this information to solve problems. In other words, the recruits have classroom instruction, but very little hands-on experience with flooding control and related skills. The expectation is that learners may not fully understand the information and that they require practice in realistic contexts to build sound mental models (HPC, 2008).

As such, the FCT focuses upon novice-level skills and upon reinforcing the types of decisions a novice would make in the Navy fleet. On board a ship, key damage control decisions are made by personnel in Damage Control Central (DCC). DCC receives damage reports from across the ship and has the key responsibility to coordinate repair operations and ensure the safety of the ship as a whole and its sailors. In general, DCC will make key decisions regarding how to combat a particular casualty, based on a thorough understanding of the affected systems and a higher-level understanding of what is happening on the ship. In particular, certain key actions require permission from DCC due to the potentially negative consequences to the sailor and/or to the ship. It is a role requiring significant expertise, and hence decisions specific to DCC are not trained in the game. Rather, emphasis is placed upon the student's interaction with the environment, use of repair equipment, and communication with superiors and DCC.

The flooding control skills required of a sailor include the actions and processes followed in preparation for a potentially dangerous situation, the ability to detect and identify flooding situations, the communication and coordination skills required to ensure that appropriate members of the ship are appropriately informed at appropriate times, following correct personal and ship safety protocols, and following the correct repair and follow-up procedures.

In a flooding situation, it is important to identify the source and type of the flooding. For example, the flooding may be due to a leaking pipe or a hull breach; the fluid may be fresh water, salt water, oil or fuel; and the flooding may range from minor to severe. Different types of damage require different types of repairs, such as patching a pipe, plugging a hole or shoring up the hull. It is also critical to maintain the watertight integrity of the ship. Throughout the ship are watertight doors. In a flooding situation, it is important to keep those doors closed to avoid the risk of a flood spreading through the ship. As a result, opening certain doors may require permission from DCC.

In addition to these basic flooding control skills, it is also important for a sailor to understand general damage control processes, general communication skills and protocols, and the relationship between their actions and events elsewhere on the ship. To ensure their safety in a real or potential damage control situation, sailors must always don the appropriate personal protective equipment (PPE). PPE can include boots, gloves, helmets, fire fighting gear, breathing gear and more depending on the situation. For communications in particular, clarity and accuracy is critical. To avoid miscommunications, all interactions should include the identities of the participants, and all instructions should be confirmed by repeating them back verbatim. In addition to mitigating interference caused by noise and other activities, repeating back instructions ensures that no misunderstanding has occurred and provides an opportunity for correction.

On a Navy ship, a specific coordinate system is used to identify locations. All doors, compartments and passageways, as well as certain equipment, are identified using three coordinates that indicate their deck, frame number (position forward to aft) and position port to starboard.

Learning Objectives

The game reinforces a basic "Assess-Report-Act" approach to flooding control. Three high-level categories of learning objectives related to cognitive readiness are used as an organizing principle.

- Situational Awareness: The ability to recognize cues, interpret cues and predict consequences.
- Communication: The ability to know whom to contact, when to contact, and how to report.
- Decision-making: The ability to follow appropriate protocols, follow orders and take initiative to complete a mission.

Table 1 summarizes the specific terminal and enabling objectives of one of the missions in the Flooding Control Trainer, organized by cognitive readiness categories.

Table 1: Learning Objectives

Terminal Objective	**Enabling Objective**
Situational Awareness	
Recognize abnormal condition	Use cues to detect flooding situation
Assess flooding situation	Recognize source and type of leak
Recognize shipboard navigation cues	Recognize and interpret compartment identifiers
Anticipate consequences of actions	Anticipate consequences of securing the fire main valve
Communication	
Recognize when situation warrants communication	Report flooding conditions in a timely manner
	Request permission to enter compartment
	Report when repair actions are complete
Report appropriate information	Report relevant information to DCC
Report information accurately	Report information accurately to DCC
Repeat back accurately	Repeat back DCC instructions accurately
Decision-Making	
Maintain watertight integrity	Enter compartment with permission
	Secure compartment doors as required
Follow safety protocols	Don appropriate PPE
Take proper actions to combat flooding	Follow directed orders
	Select correct patch repair items
	Position patch properly during application
	Use wrench to tighten patch
Use compartment identifiers to navigate ship	Successfully navigate using compartment identifiers

TRAINING SYSTEM DESIGN

Design Overview

A highly iterative design process was followed (Hussain et al., in press) in developing the Flooding Control Trainer, during which a variety of different instructional, narrative, assessment and gaming elements were considered. The final training system has four key components. The first component is a supporting story that evolves as play progresses. The second component is an environment with high physical fidelity (realistic simulation of DDG ship interior) and simple interaction methods that were tested for usability. The third component is a progression of increasingly challenging game levels, each forming a distinct "mission" to be accomplished by the student. Specifically, the FCT contains three missions, one of which provides a tutorial on how to use the game and two others which provide training on navigation and flooding control skills. The fourth component is a rich suite of mechanisms and associated instructional logic that provide different types of guidance and feedback to the student under different situations and performance outcomes.

Narrative

The game's backstory begins following graduation from RTC as the sailor is posted to an Arleigh-Burke class destroyer. The ship's mission is to provide support in the Middle East. The ship has left port and is approaching its station near Abu Dhabi. Upon starting the game, an introductory movie (i.e., cut-scene) relates this backstory. At the end of the cut-scene, the student is encouraged to behave with Honor, Courage and Commitment, the core values of the U.S. Navy.

The training is delivered in multiple game levels. To reinforce military protocol, each level is given as a mission to perform. Each mission begins with a briefing relating the objectives of the mission, and ends with a debriefing summarizing what happened in the mission.

The first mission (the tutorial) begins in a heightened state of readiness as the ship is preparing for an underway replenishment (UNREP). During the first and second missions, the student helps prepare the ship for UNREP by securing compartments, verifying the status of equipment and moving equipment. During the underway replenishment, however, a collision occurs between the two ships. A second cut-scene is used to show the collision as it happens, with the goal of making the story tensions more apparent and immersive. As the third mission starts, the ship is at general quarters and the sailor is ordered to investigate potential flooding. As the mission develops, a leaking pipe is discovered that requires patching.

This narrative arc was chosen to make the training experience highly relevant to our target audience, to provide motivation by stressing the core principles of the U.S. Navy, and to provide a context in which a wide variety of casualties could occur. In addition to using cut-scenes to introduce and develop the story, dialogs within a mission are also used to advance the story.

Instructional Design

The Flooding Control Trainer, generally, applies a guided discovery instructional strategy. In such a strategy, it is important to balance the desire to give students explicit advance information to ensure they are properly prepared for the events they encounter with the desire to allow the students to learn on their own by making mistakes and using feedback after the fact to ensure they reflect appropriately on their performance. It is also important, as a game-based trainer, to use instructional interactions with the student that seek to avoid interrupting the flow of the game or providing information that is out of context with the narrative and immersive context of the game.

The FCT uses a variety of methods to communicate instructive information to the student. In general, our approach is to provide both non-interruptive and interruptive guidance and feedback of varying detail depending on the nature of the mistake made while keeping the player immersed in the story as much as possible (see Tables 2 and 3). Some situations requiring new skills may result in some unsolicited guidance provided in a small pop-up window (see Figure 4). Minor errors will generally result in some feedback in the same window. The guidance and feedback can take the form of a hint, question or instruction. Conversely, when the student makes a critical error, a demerit will interrupt gameplay visually and aurally with a specific message about the error and a warning sound (see Figure 5). For both hints and demerits, the initial message will be somewhat general. If an error is repeated, subsequent messages will be more detailed. Errors of omission or delay, as well as errors of commission are addressed.

Table 2: Instructional Guidance Mechanisms

Guidance mechanism	Purpose
Embedded information	Enable the student to examine objects in the environment and receive information about those objects and how to use them (mouse-over, inspect).
Advance priming	Provide students with directions and a summary of learning goals prior to start of mission ("briefing")
Current objectives list	Provide students with explicit information about the mission objectives they should be pursuing and which objectives they have achieved.
In-dialog hints	Use the natural dialog of the game to provide the student with suggestions or detailed information
Explicit instructions	Use a pop-up suggestion to explain the details of a procedure to the student prior to performing a task involving that procedure.
Explicit cues	Use a pop-up suggestion provide short cues or questions to promote thinking on part of student
In-game priming	Provide students with a just-in-time reminder to ensure they enter the event focused on the correct behaviors.
Visual aid	Provide students with a minimap to assist in spatial orientation
Didactic reference	Provide students with access to written and visual explanations of different aspects of ship operations and damage control ("Navypedia")

Figure 4: Example of a suggestion being provided in a pop-up window (see top left)

Table 3: Instructional Feedback Mechanisms

Feedback mechanism	Purpose
On screen cumulative performance bars	Immediate implicit performance feedback. A green merit bar increases as tasks are completed. A red demerit bar increases as errors are made. When the demerit bar reaches maximum, a failure occurs.
Natural consequences	Demonstrate the consequences of an error without ending gameplay and implicitly show why performing correctly was important.
Non-interrupting feedback	Alert student to a positive or negative behavior using the natural interactions of the game (e.g., dialog with DCC).
Interrupting feedback	Alert student to performance above expectations or critical errors and interrupt gameplay to ensure that students receive specific information explaining the alert.
Catastrophic end of the level	Teach the student that the behavior that caused the catastrophic event is not acceptable in any way. This is reserved for actions that can bring immediate/fatal danger to self or ship.
Ranking	Provide student with a rank (out of 5) indicating performance against ideal.
Debrief at the end of level	Explicitly summarize strengths and weakness of the student's performance and provide appropriate guidance.

Figure 5: Example of a demerit message being given in a pop-up window (see bottom-right)

Throughout a mission, the student's actions are assessed to determine whether they are demonstrating appropriate intent and/or accuracy. The student's performance against every terminal objective is assessed automatically via the student's actions in the game and choices in dialogs. Dialog interactions form a key method for assessing user performance against a variety of communication and situation awareness learning objectives. These assessments are context-sensitive (i.e., the same dialog choice may be correct or incorrect depending upon prior user actions). A single dialog interaction can result in errors against different objectives (e.g., reporting appropriate versus accurate information), and different types of feedback (e.g., dialog responses versus demerits).

The FCT uses scaffolding techniques to minimize cognitive load while providing effective practice and training on the learning objectives. In the earlier levels, the student is provided with a fairly limited number of gameplay options and is constrained to follow a highly linear path through the mission tasks. In the later levels, the students are allowed increased free-play and some mission tasks may be varied in order. For example, in the tutorial, the passageways are blocked to prevent the student from going too far from the initial location and getting lost. In the third mission, the student has free rein of the ship.

Figure 6: Example of a cut-scene showing the catastrophic consequences of a critical error

Finally, the FCT gradually introduces complexity in order to minimize cognitive load. In the earlier levels, the student has few tasks to perform and cannot make any critical errors leading to failure (though they can make too many minor errors and thereby fail). In the later levels, the student has several tasks to perform at the same time, and can make several catastrophic errors without any advance warning. For instance, an important requirement in damage control is requesting permission before securing a valve. As part of the story development in FCT, the student is aware that there is a fire being fought on elsewhere on the ship. If the student attempts to repair a leaking fire main by securing the valve, a shipmate elsewhere on the ship gets injured when the water to his hose is cut-off and the fire he was fighting goes out of control. The importance of this consequence is emphasized using a short cut-scene shown from the perspective of the shipmate fighting the fire (see Figure 6).

EVALUATION

The effectiveness of the Flooding Control Trainer was evaluated in two key studies - a usability study and a validation study - conducted with students from RTC. Prior to each study, a pilot was held. Following each study, the FCT was enhanced based on feedback.

Usability Study

A usability study was conducted in October 2008 with seventy subjects. The subjects were drawn from a population of recent graduates from RTC who had not yet deployed to their first posting (i.e., they had completed Battle Stations 21). The vast majority (92%) of respondents described their comfort with computers as average or above. Participation was voluntary. Each participant had approximately two hours available to play the Flooding Control Trainer. Performance was observed and rated by several trained observers during gameplay. Following gameplay, the subjects completed customized versions of two usability forms: the Questionnaire for User Interface Satisfaction (QUIS) (Chin et al., 1988) and the System Usability Scale (Brooke, 1996; Copyright Digital Equipment Corporation, 1986). Usability results were very positive; most subjects rated the game as 7 or higher on a scale of 0 to 9, with 9 being a strong positive rating (see Table 4). There were no differences associated with any background variable.

For the usability study, the FCT only had two missions - a tutorial and a flooding mission requiring a fire main pipe to be patched. During the usability study, we noticed that the students were having trouble navigating around the ship and introduced a condition in which one group of subjects was given a short verbal refresher on interpreting compartment identifiers and a reference sheet to use while playing. While the treatment group showed no differences in the QUIS items, they made significantly fewer navigation errors and were less likely to fail (Bowers et al., 2009). In response to this result, we identified the need for an additional training level focusing on navigation. This became a level between the tutorial and flooding missions.

Table 4: Overall Usability Responses (0=low rating, 9=high rating)

Rating	Overall reaction to game	The game was stimulating	It was easy to play the game	The instructions were clear
0	0%	2%	0%	0%
1	0%	2%	2%	0%
2	2%	0%	0%	0%
3	0%	2%	0%	0%
4	3%	2%	0%	0%
5	6%	11%	3%	4%
6	15%	7%	6%	3%
7	25%	27%	13%	12%
8	25%	18%	16%	19%
9	25%	30%	60%	62%

Validation Study

In April 2009, a validation study was conducted to test the benefits of the Flooding Control Trainer (FCT) on individual performance within a flooding control test scenario in the Battle Stations 21 environment. Thirty-one recruits participated in the study. These recruits had completed RTC training but had not yet done the BS21 capstone evaluation. Sixteen of the participants formed the control group, and fifteen formed the treatment group. The treatment group played the FCT for one hour and then took the test scenario two days later. The control group had no extra training and took the same test scenario.

In the test scenario, an individual recruit was given orders to report to DCC by a primary facilitator. DCC (played by another RTC facilitator) ordered them to dress out and report to a specific location to investigate potential flooding. The recruit needed to perform the appropriate actions, find the compartment and communicate appropriately. At the indicated compartment, the recruit needed to safely investigate the compartment for flooding, report the situation and, upon receiving orders, patch a leaking pipe with a jubilee patch. The recruit needed to perform all their tasks with no help from the facilitators.

The recruits were assessed on a number of behaviors related to communications, decision-making, situational awareness and navigation within the ship. Performance differences between the groups were striking. Decision making errors were reduced by 50%. Communication errors were reduced by up to 80%. Situational Awareness and Navigation skills were improved by 50%.

Table 5: Performance Differences between Control Group and Treatment (Game) Group

Error / Correct Behavior	Control	Treatment
Entered the flooding compartment without appropriate PPE	67%	28%
Identified themselves on first contact with damage control	7%	93%
Repeated back commands from DCC	7%	57%
Described the leak correctly	16%	36%
Went to the wrong deck	33%	0%

A full description of the validation study and results will be presented elsewhere (in preparation). Differences on some of the key behaviors are given in Table 5. The treatment group performed significantly better in each case.

In addition to these specific measures, the behaviors of the two groups were visibly quite different in terms of their stress level and independence. The individuals in the control group generally appeared confused as to what they should do and made frequent requests for help. The individuals in the treatment group were generally confident in their actions, made few requests for help and appeared to be enjoying the challenge of the test.

CONCLUSIONS

By working actively to weave together the instructional, narrative, gaming and assessment elements into a cohesive whole, we developed a flooding control training game for the U.S. Navy that demonstrates significant learning benefits and transfer of learned skills. Given the strong benefit of the Flooding Control Trainer game for improving communication, decision-making, situational awareness and navigation skills in individuals, we are confident that the game will have a strong effect on team performance within the Battle Stations 21 capstone evaluation. We predict that trainees who train using the game prior to BS21 will demonstrate significant improvements in the skills that are practiced directly in the game, higher-order skills that can become the focus of the trainee's attention, and overall performance due to higher confidence in their ability to cope with the challenge. Further, though the game provides practice on skills needed in the BS21 flooding control scenario, many of the skills reinforced in the game are relevant to a number of additional BS21 scenarios as well. Thus, we predict that the trainees who train using the game will show improvements across a variety of BS21 scenarios, not just the flooding scenario. The FCT is currently in the process of being deployed at RTC, and we hope to have additional results on the effectiveness of our system before the end of the year.

We are currently in the second year of a three year effort and have several enhancements to our trainer planned. We are currently enhancing the FCT with an additional level that includes a complex flooding situation requiring a higher degree of prioritization and more complex safety protocols. The additional level will provide a strong challenge for recruits, and will bring the Flooding Control Trainer to a level of complexity that begins to address the training needs of the Navy's technical schools.

We are also currently extending our training system to train fire fighting skills. As with flooding control, a suite of several missions of increasing complexity are planned. In our final year of effort, we plan to create several scenarios addressing skills required in combating a mass casualty situation. Together, these three domains will provide a solid foundation in shipboard damage control that is suitable for recruits and for sailors at technical schools.

Our long-term vision is that games such as the FCT will form a regular part of the training that occurs in the schoolhouses and in the fleet. Damage control is a critical skill set required of all sailors, and one that must be kept fresh throughout a sailor's career. We believe it is an ideal domain for demonstrating the utility and effectiveness of game-based training for the Navy.

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