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THESIS

TOWARDS A GAME-BASED PERISCOPE SIMULATOR FOR SUBMARINE OFFICERS TACTICAL TRAINING

by

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June 2016

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13. ABSTRACT

Early in their career, submarine officers must develop and maintain many skills to qualify as periscope operators. This critical position comprises complex tasks, requiring precise steps, accurate mental calculations, and celerity of actions and thoughts, while obeying specific rules to ensure the safety of the submarine and its crew. Currently, gaps in training exist between the professional courses a submarine officer attends over a career to learn and practice these skills. Following an instructional system design process, this thesis developed a 3D, game-based periscope tactical training prototype. This part-task training solution can provide feedback on predetermined performance measures, either automated, real-time, or post-hoc. The second part of this thesis used the prototype environment to investigate the impact of feedback type on performance. Results indicated that participants receiving real-time feedback had significantly better performance than those who received post-hoc feedback during an initial trial. Performance for both groups significantly improved for subsequent trials; by the third trial, however, significant differences were not observed for feedback type. Additionally, results of an exploratory analysis showed feedback type affected performance by age, time in service, and gaming experience. Results of this thesis support the use of game-based simulation as training tools and that feedback type could be tailored to individuals based on factors such as age and experience to optimize training outcomes.

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TOWARDS A GAME-BASED PERISCOPE SIMULATOR FOR SUBMARINE OFFICERS TACTICAL TRAINING

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ABSTRACT

Early in their career, submarine officers must develop and maintain many skills to qualify as periscope operators. This critical position comprises complex tasks, requiring precise steps, accurate mental calculations, and celerity of actions and thoughts, while obeying specific rules to ensure the safety of the submarine and its crew. Currently, gaps in training exist between the professional courses a submarine officer attends over a career to learn and practice these skills. Following an instructional system design process, this thesis developed a 3D, game-based periscope tactical training prototype. This part-task training solution can provide feedback on predetermined performance measures, either automated, real-time, or post-hoc. The second part of this thesis used the prototype environment to investigate the impact of feedback type on performance. Results indicated that participants receiving real-time feedback had significantly better performance than those who received post-hoc feedback during an initial trial. Performance for both groups significantly improved for subsequent trials; by the third trial, however, significant differences were not observed for feedback type. Additionally, results of an exploratory analysis showed feedback type affected performance by age, time in service, and gaming experience. Results of this thesis support the use of game-based simulation as training tools and that feedback type could be tailored to individuals based on factors such as age and experience to optimize training outcomes.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
ADDIE	analysis, design, development, implementation, and evaluation
AOB	angle-on-the-bow
ARL	all round look
ASW	anti-submarine warfare
AT	attack trainer
BNSS	Brazilian Navy Submarine School
CO	contact observation
ECE	earth's curvature effect
FFT	fast Fourier transform
FOV	field-of-view
GDC	go-deep circle
GDR	go-deep range
GODEX	go-deep range exercise
GUI	graphical user interface
ISD	instructional system design
KSA	knowledge, skills, and abilities
LI	look interval
LO	learning objective
OOD	officer of the deck
PD	periscope depth
PDOT	periscope depth operation techniques
PDPS	Preparation for the Duty of Periscope and Sound
PHF	post-hoc feedback
PO	periscope officer
RQ	research question
RTF	real-time feedback
SD	safe depth
SIR	submarine indiscretion ratio
SO	submarine officer

SOO	Submarine Operations for Officers
SOSC	Submarine Officer Specialization Course
STTS	Submarine Tactical Training System
TTP	tactics, techniques, and procedures
YOS	years of service

I.   INTRODUCTION

A.   THESIS STATEMENT

A submarine officer (SO) must develop and maintain a myriad of skills over the course of a successful career. A particularly challenging set of these skills are those required of an officer to become qualified as a periscope operator. Often considered the most important sensor on a submarine, the periscope allows crews to collect crucial information that impact on safety and effectiveness of operations of the ship. Being qualified as periscope operator requires the ability to master complex tasks, which require precise steps, accurate mental calculations, and celerity of actions and thoughts, while recalling and obeying specific rules that ensure the safety of the submarine and its crew.

Currently, the only options for hands-on training are through participation on exercises aboard submarines or scheduled training sessions in a full-scale simulator called attack trainer (AT).

This thesis proposes the use of game-based simulation for training and practicing periscope tasks. To this end, a high-fidelity three-dimensional (3D) environment called Submarine Tactical Training System (STTS) was created with the goal of closing training gaps that exist between career courses for SOs and limited opportunities to participate in AT training sessions and exercises on submarines. Additionally, we conducted an evaluation of game-based feedback during the training session compared to process-based diagnostic feedback provided after the end of the task using the STTS.

B.   MOTIVATION

The knowledge, skills and abilities (KSA) necessary for the proper operation of the periscope are acquired during courses spread across the SO's career. Section II.A provides background information about these career courses. Concepts learned during one course are required for all subsequent courses and retaining the KSAs developed in those courses is the responsibility of the individual officer. When assigned to duties away from submarines or assigned to submarines in long maintenance periods, the AT is the only training solution available. However, individual training opportunities with ATs are

limited because their schedules are normally filled with planned courses, preventive maintenance, and preparation for future courses.

The ubiquity of powerful personal computers and SOs familiarity with computer games suggest that game-based training systems should be explored as a solution for the existing training gap. According to Michael and Chen (2005):

> Advances in computer hardware and software allow games to move into other aspects of education and training. Many skills can be taught only by *doing*, and many lessons can be learned only through failure. Serious games allow training to occur in a non-lethal environment. Routinely, soldiers enter complex, highly detailed simulations with 3D rendering and real-world physics calculations to practice their military training. (p. XVI)

Furthermore, these types of systems can be developed to allow students to train at their own pace, an ideal feature for SOs with busy schedules. However, the self-regulated nature of the proposed solution demands providing trainees with feedback to avoid harmful effects of negative training (Buff & Campbell, 2002). This thesis consists of two main phases. First, following an instructional system design (ISD) process this thesis developed a game-based SO training prototype. Next, this thesis conducted an investigation to determine if different feedback types could increase training effectiveness of the prototype.

C.   RESEARCH QUESTIONS (RQ)

1.   Can a game-based, part-task periscope simulation that incorporates the appropriate cues to train identified knowledge, skills, and abilities be developed to supplement periscope operator training?

2.   Do differences in trainee performance exist when exposed to different feedback types over the course of multiple sessions?

3.   What, if any, differences exist between the real-time feedback (RTF) or post-hoc feedback (PHF) on final trainee performance?

D. HYPOTHESES

A series of hypotheses were developed to investigate the research questions stated above. These include:

(1)   Following an ISD process, the development of a game-based trainer, is addressed in Chapter IV.

(2) $H2_0$: Participants who receive PHF will perform the same as those who receive RTF on the STTS task over repeated trials.

   $H2_a$: Participants who receive PHF will have significant performance differences when compared to those who receive RTF on the STTS task over repeated trials.

(3) $H3_0$: Participants who receive PHF will perform the same as those who receive RTF on the STTS task.

   $H3_a$: Participants who receive PHF will have significant performance differences when compared to those who receive RTF on the STTS task.

E. SCOPE

This thesis covers only basic, unclassified periscope techniques. Some details of these techniques are different in each navy and most of their practical applications are treated as classified information, which were omitted to avoid classification issues. This thesis will focus only on the basic unclassified definitions and concepts from the techniques, which are explained in the section II.B.1. Section III.A describes the process used to select the appropriate tasks and content to be covered without breaching classified information.

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II.   BACKGROUND

The stealth provided by operating underwater enables submarines to pose a considerable threat to enemy surface ships. An opposing force must commit a substantial amount of anti-submarine warfare (ASW) resources to sweeping vast areas of the ocean to counter a single submarine, accept a high level of risk to operate in an area where submarine presence is possible, or be forced to avoid areas entirely. These are some of the characteristics, which make the submarine a valuable anti-access/area-denial asset.

A submarine is most effective when it is able to remain hidden. When running in deep waters, submarines are virtually undetectable except by very capable ASW forces, which provide safety against attack. Additionally, submarines normally operate submerged at depths significantly greater than the draft of all surface ships. Therefore, once at depth, submarines are effectively immune to collisions with surface ships.

However, some situations force submarines to operate at periscope depth (PD), including performing visual searches, communications, recharging batteries, conducting navigational fixes, ventilating, and preparing to surface. Depending on the task, the submarine is forced to expose one or more of its masts.[1] In these situations, the advantage of stealth is compromised and a submarine can be vulnerable to visual and radar detection. Likewise, while at PD, the submarine's depth is less than the draft of surface ships and the danger of colliding with one exists. To address these risks, submarines must follow a set of procedures, called periscope depth operation techniques (PDOT), to minimize exposure to ASW forces and prevent collisions, while assuring the completion of all the required tasks.

In order to understand this research, additional background information is required in three areas. The first two, current Brazilian SO training and periscope safety, deal specifically with the Brazilian Navy, while the third area is feedback research from instructional research literature.

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[1] Most submarines perform different tasks using multiple masts, such as a periscope, communications mast, snorkel, radar, electronic support measures (ESM), among others.

A.   CURRENT BRAZILIAN SUBMARINE OFFICER TRAINING

Over the course of a career, Brazilian SOs develop KSAs that are required for the different phases of their profession. KSAs are formally taught in a series of specialized courses that are attended as the SOs transition between the phases of their careers. After successful completion of each course, a SO is qualified to perform new duties on board the submarine. As a career progresses, the SO responsibilities graduate from technical/platform-control tasks to more tactically relevant duties. Regardless of phase, each of the formal courses consists of three main parts: (1) theoretical instruction in classrooms, (2) hands-on practice in a full-scale simulator, and (3) a final practical phase aboard a submarine at sea.

The first course SOs participate in is the Submarine Officer Specialization Course (SOSC). This course is required for all SOs prior to joining the submarine fleet. SOSC focuses on the operation and maintenance of the submarine as a platform. Successful completion of the SOSC qualifies the SO to serve in the maneuvering compartment where his duties include maintaining course, depth, and speed as ordered by the Officer of the Deck (OOD). Upon completion of SOSC classroom instruction, students practice skills in a diving simulator. During practice runs in the simulator, an extensive focus is placed on emergency procedures in order to allow trainees to gain experience without the potential consequences of failure that exist aboard a real submarine. After completion of SOSC, trainees report to their first submarine where they become qualified to stand the watch and are able to practice techniques they learned in SOSC while performing their normal duties.

Preparation for the Duty of Periscope and Sound (PDPS) is the second career course a SO attends during his career. This course marks the transition from maneuver officer to OOD. Learning objectives in this second course focus on maintaining the submarine's safety. The primary task trained is how to position properly a submarine to return to PD using passive sonar signals as input. During PDPS, students practice these tasks in the AT. The AT is the simulator SOs will use during all remaining career courses and any other simulation training events they may receive. Although this course contains an introduction to PDOT, those KSAs are taught extensively in the next course.

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The third course a SO takes is Submarine Operations for Officers (SOO), which qualifies them to become a department head on a submarine. This course covers all periscope techniques and focuses on submarine warfare. Students learn to plan and execute a range of different submarine operations, from anti-surface warfare to secondary tasks like visual and electronic reconnaissance and deployment of special operation forces. SOO uses the AT extensively to prepare students for performing on ships and to minimize the shipboard portion of the course, since, unlike the previous courses, SOO requires one or more surface combatant ships to support the tactical missions as an opposing force. The onboard portion of SOO is very costly, and it is imperative that students are prepared prior to the at-sea opportunity because that portion of SOO is generally reserved for final exam purposes instead of training events.

To be assigned commanding officer of a submarine, a SO has to pass the Submarine Commanding Course (SMCC) successfully. This is the final and most challenging of the courses in an SO's career, and is largely based upon the British Royal Navy's Perisher course. According to Mack's (2003, p. 2) description of the Perisher course, "ranging and estimating, mental agility, overall situational awareness, command presence, intellectual honesty, safety, character under pressure" are some of the skills required to succeed in SMCC. At this point, there are very few new topics and the classroom phase is dedicated to refresher training. However, each prospective commanding officer gets significant time in the AT before going to sea, where he will be required to demonstrate that he has mastered the KSAs learned over the course of his career in order to earn command.

These courses are attended as a SO rises in rank from ensign to commander over the course of ten to fifteen years. There is significant time between each course and maintaining the KSAs acquired in them, which are also required for the next, is the responsibility of the SO (Bastos, 2014). As careers progress, SOs are often assigned to duties away from submarines. If an SO is assigned to a unit, which is geographically close to the Brazilian Navy Submarine School (BNSS), he may conduct refresher training in the AT so it is possible to maintain his skills. However, even if an officer is located close to the BNSS, the AT is often unavailable to them because it is being used for

scheduled courses, undergoing preventive maintenance, being prepared for future courses, or recovering from unexpected equipment failures thus limiting an individual SO's access for skill maintenance. Additionally, the use of the AT for individual, non-scheduled, training sessions may not be approved due to the increased maintenance and personnel costs involved in running the system.

During all the three career courses, an experienced instructor closely observes trainees. During live events, if a trainee is operating a periscope, an instructor uses the other periscope to continuously ensure the safety of the submarine. While operating in this tandem, it is commonplace for instructors to provide feedback to the student about their observations during the execution of an exercise. This feedback is given immediately following the execution of a task. For the purposes of this thesis, this type of feedback is defined as real-time feedback (RTF). The most common examples of RTF are the corrections about estimations and measurements made by the student. In the simulators, there is also an experienced instructor who has access to ground truth while operating the instructor console. In this case, the instructor also provides RTF. The amount of feedback provided depends on the instructor's judgement and trainee's performance, varying from constant interventions to none at all.

Another method to informing students about performance is when an instructor takes note of the errors committed during a run and communicates them to the student after the completion of the task. For this thesis, this type of feedback is defined as post-hoc feedback (PHF).

B. PERISCOPE SAFETY

Performing PDOT involves a trade-off between acquiring important information and exposition. The amount of time that the observation takes is directly proportional to quantity and quality of information that the periscope officer (PO) is able to obtain, but also proportionally increases the risk of counter-detection either visually or by radar. The main goal of the periscope safety procedures is to ensure the crew operates at the optimal ratio between information gathering and time.

There are three main purposes related to periscope's use: navigation, surveillance, and tactical employment. The navigation task is normally done by triangulating three or more bearings obtained from known navigation aids. It is also possible to get distances from reference points for which the height is known. A relatively accurate position can be determined with only one observation of a reference point by taking its bearing and distance at the same observation. The navigation task will not be in the scope of this thesis.

The employment of the periscope for surveillance is accomplished through careful, 360-degree observation around the submarine. When operating at PD, a submarine is exposed to the risk of collision with surface ships, making surveillance a critical task. However, the deliberate use of the periscope for surveillance incurs an increased risk of counter-detection. Therefore, submariners follow a careful set of rules defined to maximize safety while minimizing exposure of the periscope mast in order to reduce the counter-detection risk. These rules and tactical concepts of employment are discussed in the following sections.

C.   PERISCOPE DEPTH OPERATION TECHNIQUES

Originally, the periscope technique arose from the need to fire unguided straight running torpedoes against surface targets using no other data besides images obtained by using the periscope. Even though today the likelihood of successfully performing such attacks is extremely low, the mastery of these techniques remains a requirement in many modern navies because they are useful in many other situations (Bastos, 2014). For example, these techniques are considered essential for the training of a submarine commanding officer, who must know how to position the submarine relative to any contact of interest, using only stopwatches and agile mental calculations (White, 1993).

When operating at PD, submarine crews track all contacts present in the visual spectrum within visual range. Once a contact is detected and tracked, the PO must determine its bearing and heading and constantly update the contact's range, in order to reserve enough time to properly maneuver and to avoid sailing in dangerous situations. The concepts presented in this chapter are a basic, unclassified description of the rules

that allow a PO to maintain the safety of the submarine and crew while maximizing the chances of successfully complete a mission.

Some detailed periscope techniques aspects can vary between navies and are usually found in classified manuals. This thesis will use basic unclassified periscope concepts from the technique.

a.   All-Round Look

The all-round look (ARL) is the periscope technique related to the surveillance task. This observation is used to find new contacts and obtain situation awareness. It is also important to observe the environment and report any changes in the environment, like visibility and rain (Ferguson, 2014). When conducting the ARL, movement of the periscope is continuous around the 360°, without pauses, using a high field of view (zoomed out), and correct lens elevation (sight picture of 1/3 sea, 2/3 sky). The ideal rotation speed while doing the ARL is such that it is not too slow, to avoid counter-detection, and not too fast, to assure the accuracy of the observation and the detection of any visible contact ("Perisher," 2007). The minimum and maximum time limits allowed for this observation can vary from navy to navy.

b.   Safe Depth

Safe depth (SD) can be defined as the minimum depth at which a submarine should dive when close to a surface vessel. At this depth, there is sufficient separation from the keel of the surface ship and the top of the submarine's sail (NATO, 2002). This separation must be increased when operating under heavy weather or high sea states since the keel of a ship may go deeper than its normal draft. When determining SD the type of surface ships expected to be found in the area of operation must be considered. The draft of these ships will contribute to SD calculations. Additionally, the height of the submarine (distance from keel to top of the sail) and the desired separation between the submarine and surface ship are part of this calculation. An example of these factors is shown in Figure 1.
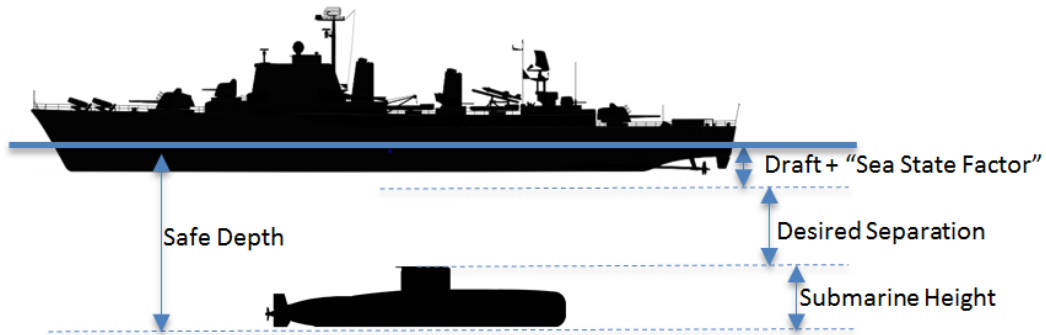
Figure 1. Safe Depth.

c.   Go-Deep Range / Go-Deep Circle

An important goal of operating a submarine is to ensure that the submarine can reach SD prior to a surface ship reaching the submarine's location. Each type of submarine takes some specific amount of time, reported in seconds, to dive from PD to SD (TSD) and has a specific speed during the decent (SpeedSub). Varying the SD will vary TSD proportionally. Go-deep range (GDR) is the distance that a surface ship will be able to travel, relative to the submarine, in TSD seconds. Because a crew wants to ensure that the submarine will be at SD before relative motion causess a surface ship and submarine to occupy the same location at the same time, the ship's maximum speed (MaxSpeedtarget) is used when calculating GDR. Equation (1) is used to calculate the GDR.[2]

$$GDR[yards] = \frac{(Speed_{sub} + MaxSpeed_{target}) \times 100}{180} \times T_{SD}$$

(1)

The go-deep circle (GDC) is a circle centered on the submarine, with a radius of GDR yards ("Perisher," 2007). The GDC is considered the submarine's safe-heaven. A general rule of PDOT is to dive to SD prior to any surface ship entering the GDC (Figure 2-a), which ensures that the submarine will be at SD prior to the surface ship passing overhead (Figure 2-b).

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[2] Throughout this thesis, all distances are in yards, all times are in seconds and all speeds are in knots, unless otherwise noted.
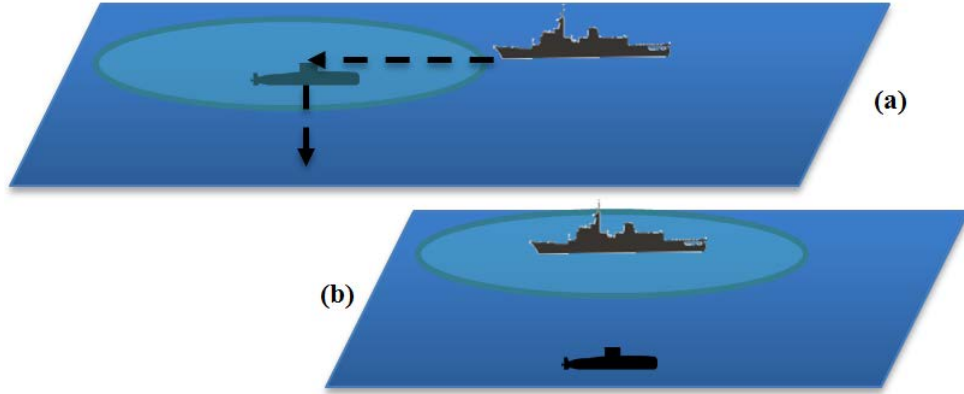
a. The surface ship reaches the GDC; the submarine starts descending.
b. The submarine reaches the SD safely below the surface ship before it reaches the sub.

Figure 2. Go-Deep Circle.

Although this method for GDR calculation is the safest for the submarine, it comes with a cost in the flexibility: unless the surface ship is directly ahead of the submarine and heading straight for it, the GDR will be greater than need be, and the submariner will have to dive earlier than actually required. A more detailed GDR calculation can be accomplished by dividing the circle around the submarine into sectors. When a contact is approaching from a different relative bearing (θ), the submarine's component of the relative motion can be estimated more accurately. This is shown in Equation (2).

$$GDR[yards] = \frac{[(Speed_{sub} \times \cos\theta) + MaxSpeed_{target}] \times 100}{180} \times T_{SD} \tag{2}$$

The exact angles used to reduce the GDC by sectors are a specific decision made by each navy and are normally classified information.

d.   All Round Look Interval

ARL Interval is the "acceptable time interval between two ARLs" when the "worst case scenario is considered: a new contact appears just after the periscope looks toward its direction" (Bastos, 2014, p. 16). ARL assumes that the surface contact approaches with its maximum speed and is on a collision course. The ARL interval must be such that is always smaller than the time that a contact will take to reach the GDR.

This assures that all contacts, even in the worst-case scenario, will always be detected before reaching the GDR.

e.   Look Interval

When a contact is observed and its range determined, and after the periscope is lowered, a PO must again consider the worst-case scenario based on the information that he has collected. This case usually means considering that the surface contact has instantaneously turned towards the submarine and has increased to its maximum speed. Based on this worst-case scenario, the look interval (LI) is defined as the time required for that individual ship to get from its present position to the GDR. Immediately after the periscope is lowered, the PO must calculate the LI and before this time is reached, the PO must determine the contact's range again to ensure that it is further than the GDR ("Perisher," 2007).

Each contact in the visual range must have its LI calculated and controlled. If the LI expires before the vessel is ranged again, emergency procedures require the PO to order an urgent dive to SD. The calculation to determine LI is shown in Equation (3).

$$LI_{[sec onds]} = \frac{Range_{target} - GDR}{MaxSpeed_{target} + Speed_{sub}} \times \frac{180}{100}$$
(3)

f.   Angle-on-the-Bow

The angle-on-the-bow (AOB) is defined as the relative bearing of the submarine when observed by the target. It can be compared to what the surface sailors usually call target angle, but with the difference that AOB must include the side of the target and the angle is between 0° and 180°, while target angle is simply the clockwise angle from the target's bow. The difference between AoB and target angle is illustrated in Figure 3.
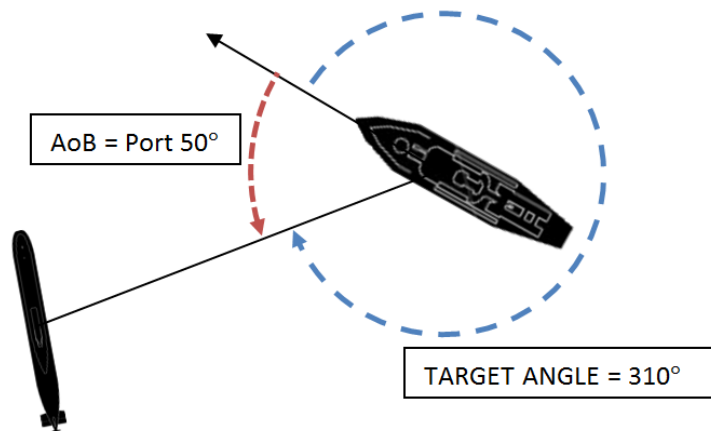
Figure 3. Angle-on-the-Bow and Target Angle Compared.

g.   *Contact Observation*

The contact observation (CO) is the technique used when observing the contact for the first time or when maneuvering close to a contact and tracking it with a stadimetric plot. It is designed to obtain the maximum amount of information from a contact in a minimum time, and is always done in the same order to avoid confusion. During a CO, the PO should mark the contact's bearing, range (by the use of stadimeter built into the periscope or other ranging system), and after lowering the periscope, inform the AOB, and mentally calculate the LI based on the range observed. Table 1 illustrates this sequence and phraseology for a contact observation.

Table 1.   Contact Observation Phraseology.

"Observation - contact 03"	State type of observation and the contact to observe
"Raise the one"	Order to raise the appropriate periscope
"Bearing 030"	Report bearing reading
"Distance 2300 yards"	Report distance reading
"Lower"	Order to lower the periscope
"Angle-on-the-bow, Port 60"	Report side and value estimation for AoB
"Look Interval, 1 minute and 20 seconds"	Report the mentally calculated look interval for the observed distance.

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The time that a contact observation lasts should be as short as possible but the maximum limit allowed can vary depending on the country.

D.   TYPES OF FEEDBACK

The role that feedback plays in the learning process is a controversial topic. Buff and Campbell (2002) define feedback as a mean for the learner to alter his understanding of a task, by confirming adding, overwriting tuning or reconstructing previous knowledge basis. Cohen (1985, p. 33) stated that feedback "is one of the more instructionally powerful and least understood features in instructional design." Ilgen, Fisher, and Taylor, (1979) concluded that feedback is a crucial piece in the learning process. Despite the evidences that feedback is useful, there is still a debate on the kind of feedback or what type of information should be delivered to better help in the learning process. This thesis explored several types of feedback and associated with improved performance.

1.   Outcome-based Feedback

Outcome-based feedback is based only in the student's achieved performance in that training session. Normally, outcome-based feedback is provided as percentages and in messages such as: "You were accurate 85% of the time when performing this task." This type of feedback is only delivered after the training is complete. Numerous studies examining the effect of outcome-based feedback on trainee performance (see: Todd and Hammond [1965], Summers, Taliaferro and Fletcher [1970], Hammond [1971], and Deane, Hammond, and Summers [1972]) failed to find significant increase in performance for subjects exposed to outcome-based feedback.

2.   Process-based Feedback

Process-based feedback delivers information to the trainee about how well they performed on the task, without informing ways to improve the performance (Kluger & DeNisi, 1996).

There are two ways to present the feedback on a process-based evaluation. *Non-diagnostic feedback* does not reference the trainee's performance but only describes an expert solution for that task. "A general strategy used by an expert in this field is…" or

"To achieve this goal, an expert takes this or that approach…" are possible declarations providing non-diagnostic process-based feedback. Sadler (1989) suggests that when assessing effective ways of teaching, feedback is only effective when it addresses the gap between what was understood by the student and the actual learning target.

Diagnostic feedback presents the trainee not only the expert solution, but also the difference between what was executed by the student and the ideal outcome. "Your outcome to this task was … while the expert found …," "You took in consideration …. aspects to your decision, while the expert normally focus in … aspects." are some examples of diagnostic process-based feedback.

In their 2002 investigation, Buff and Campbell assessed learning improvements between sessions with subjects exposed to outcome-based and the two processed-based forms of feedback cited above. The feedback was presented in the intervals between sessions. They found that there was a significant increase in performance when students received non-diagnostic feedback, only a marginally significant improvement when using diagnostic feedback, and no significant differences in performance when provided with outcome-based feedback. The control group in their study also had no significant increase in performance without receiving feedback.

3.   Normative Feedback

Normative is another type of feedback, which provides individuals with a comparison about their performance related to all others in their particular group. (Smither, Wohlers, & London, 1995). "You are in the 90th percentile. 10% of all the participants performed better than you" is a typical example of this type of feedback.

Astwood and Van Buskirk, Cornejo, and Dalton (2008) conducted an experiment comparing process, normative, outcome and none (control) feedback. Using a modified version of the Forward Observer Personal Computer-based Simulator (FOPCSIM) developed at the Naval Postgraduate School, they compared the performance of participants randomly assigned to all four groups, side-by-side. Their results suggest that process feedback group was statistically more likely to perform better than the other three groups. Although the study could not find significant difference between normative and

outcome feedback, the authors suggested that their findings might have been attributed to a potential limitation in the form of the power of the study.

4. Velocity Feedback

Velocity feedback is the comparison of trainee's performance with his own prior performances on the task. It is considered a self-referenced evaluation. The term velocity is used as an analogy to the "physical concept of change in distance over time", or the trainee's changing state towards the goal (Kozlowski et al., 2001). The advantage of velocity feedback is that the trainee can rate his progress and compare it to a predefined goal. An example of velocity feedback statement could be: "You got ten answers correct; this is a 25% improvement over your last attempt." Landsberg, Van Buskirk, and Astwood (2010) investigated the comparison between process feedback, velocity feedback, and no feedback for control. This study revealed that females achieved better performance when receiving process feedback, while males who received velocity feedback, outperformed those given process feedback.

The research cited above used scenarios where feedback was provided between trials during the training sessions. Ilgen, Fisher, and Taylor (1979) define feedback as "information regarding the correctness of past performance." How long in the past? Would it be better to provide the feedback closer to the action that generated it?

The advent of game-based training systems and the availability of powerful personal computers provide the tools to investigate these questions. By using game mechanics such as competitive scoring, pop-up messages, and auditory feedback, it is possible to deliver feedback closer to the actions that generated the outcomes. It is even possible to provide this feedback immediately after the performance of an action that resulted in a specific outcome. The ability to program systems capable of recording, assessing, and interacting with trainees based on individual actions during a training event has been recognized as a revolutionary leap for training. As summarized by Kozlowski et al. (citing Anderson, 1987), "Feedback about errors should be provided immediately if the goal is to develop rapidly a strong procedural knowledge base" (2001,

p. 40) and "Feedback should be provided frequently to facilitate the development of self-efficacy during training for a complex task" (Gist & Mitchell, 1992).

III. SYSTEM DESIGN PROCESS

The instructional system design (ISD) model used to guide the creation of STTS was based on the traditional five phases of analysis, design, development, implementation, and evaluation (ADDIE) which was developed at Florida State University for the U.S. Army in 1975 (Branson et al., 1975). This chapter will cover the analysis and design phases.

A. TASK ANALYSIS

A task analysis was performed during the early stages of this thesis in order to define the appropriate type of mission to be simulated. The task analysis was also used to determine which set of mission sub-tasks were feasible to be integrated into the STTS. Other analysis were performed considering limitations imposed by classification issues, technical restrictions, and time constraints.

Submarine operations are complex, diverse, and involve many different types of missions. Each mission relies on specific equipment, tactics, techniques, and procedures (TTP), and each TTP was a potential area to be trained in the simulation. Initially, the potential areas were narrowed to unclassified operations. This was mandated by the desire to build a simulator that SOs could use in a wide variety of locations, and including classified operations would severely limit the areas where the STTS could be used. Given that most submarine operations are classified, this culled the majority of potential missions.

Likewise, the subjects for the experiment were not going to be Brazilian SOs, so this meant that it was impossible to assume a basic level of knowledge of the participants. This further limited this research to missions which could be explained quickly and that a novice could achieve a basic level of proficiency within a reasonable amount of time. Since many submarine operations are fairly complex, this again reduced the list of potential missions.

Therefore, an acceptable mission was one that could be covered at an unclassified level and taught quickly. Additionally, the mission had to consider that the experimental

sample would come from a population of mainly novices. With these limitations in mind, the mission selected would still need to be meaningful if applied to actual SOs. Finally, the technical requirements to build such a trainer had to be achievable within the scope of a thesis at the Naval Postgraduate School.

The mission selected for task analysis was the Go-Deep Range Exercise (GODEX). A major factor in the decision to use GODEX was founded on the fact that it relies heavily on operations performed while a submarine is at PD. Tasks performed in the GODEX mission after evolving to SD were not considered. The skills acquired by training for the GODEX mission form the basis for many of the other tactical missions that submariners perform throughout their careers. Finally, simulating the view out of the periscope does not require sonar propagation models, most of which are classified.

Bastos (2014) addressed similar task analysis, focused on the GODEX mission. Figure 4 presents the overall hierarchical task tree decomposition for the GODEX mission. His part-task trainer was developed for training on the ARL task. This session will analyze the whole GODEX mission with focus on the contact observation.
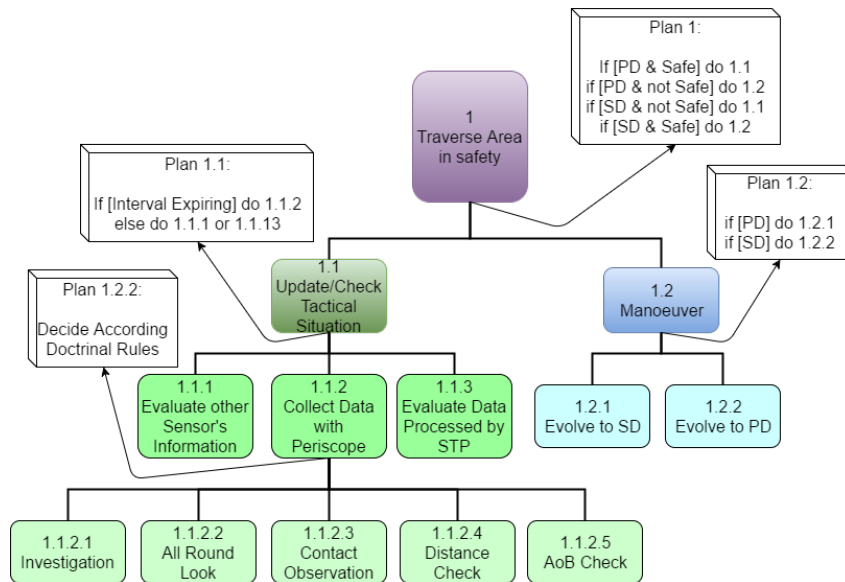
Figure 4. Hierarchical Task Tree. Adapted from Bastos (2014).

This hierarchical, high-level representation of tasks allows a detailed sub-tasks analysis. Figure 5 illustrates the series of decision points and new subtasks added to the analysis. Figure 6 details the hierarchical tasks that compose the contact observation.
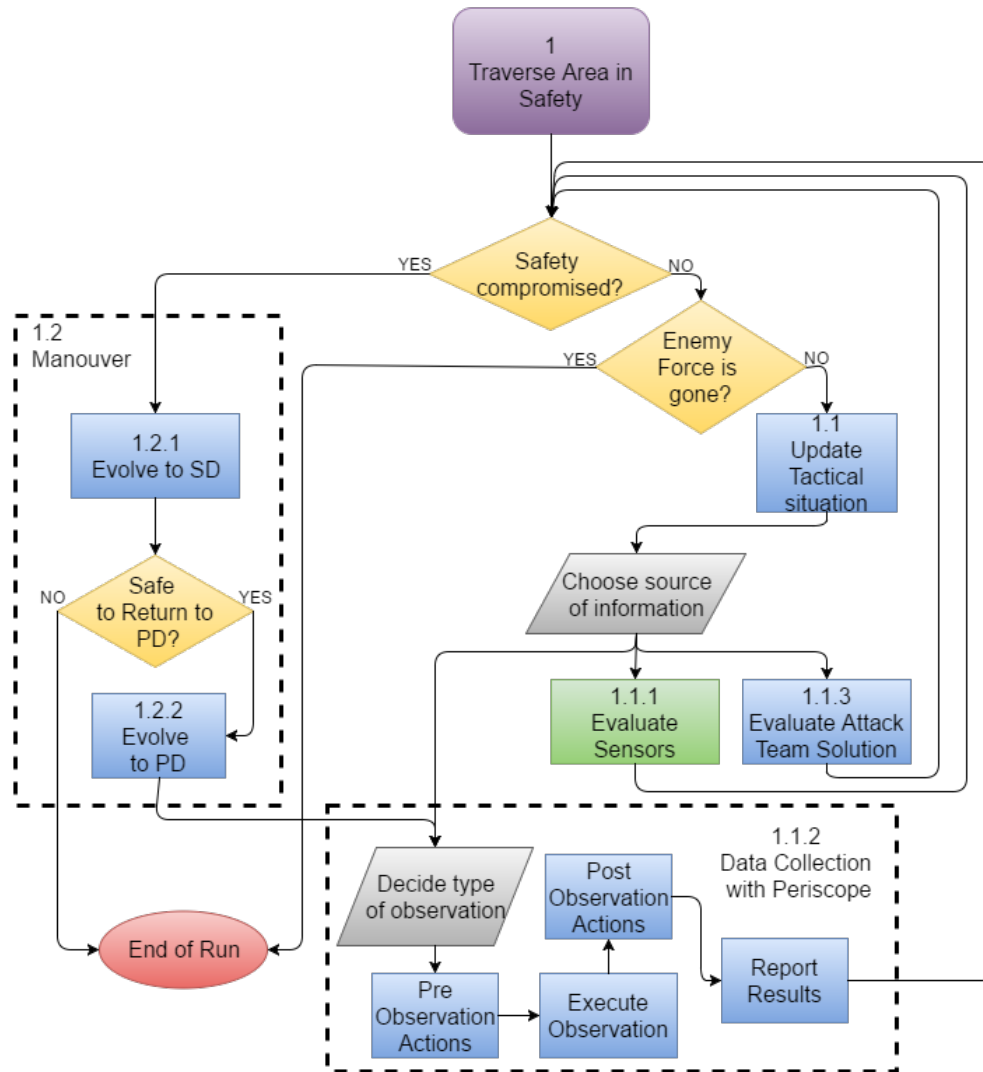
Figure 5. Summarized Procedural Diagram. Adapted from Bastos (2014).
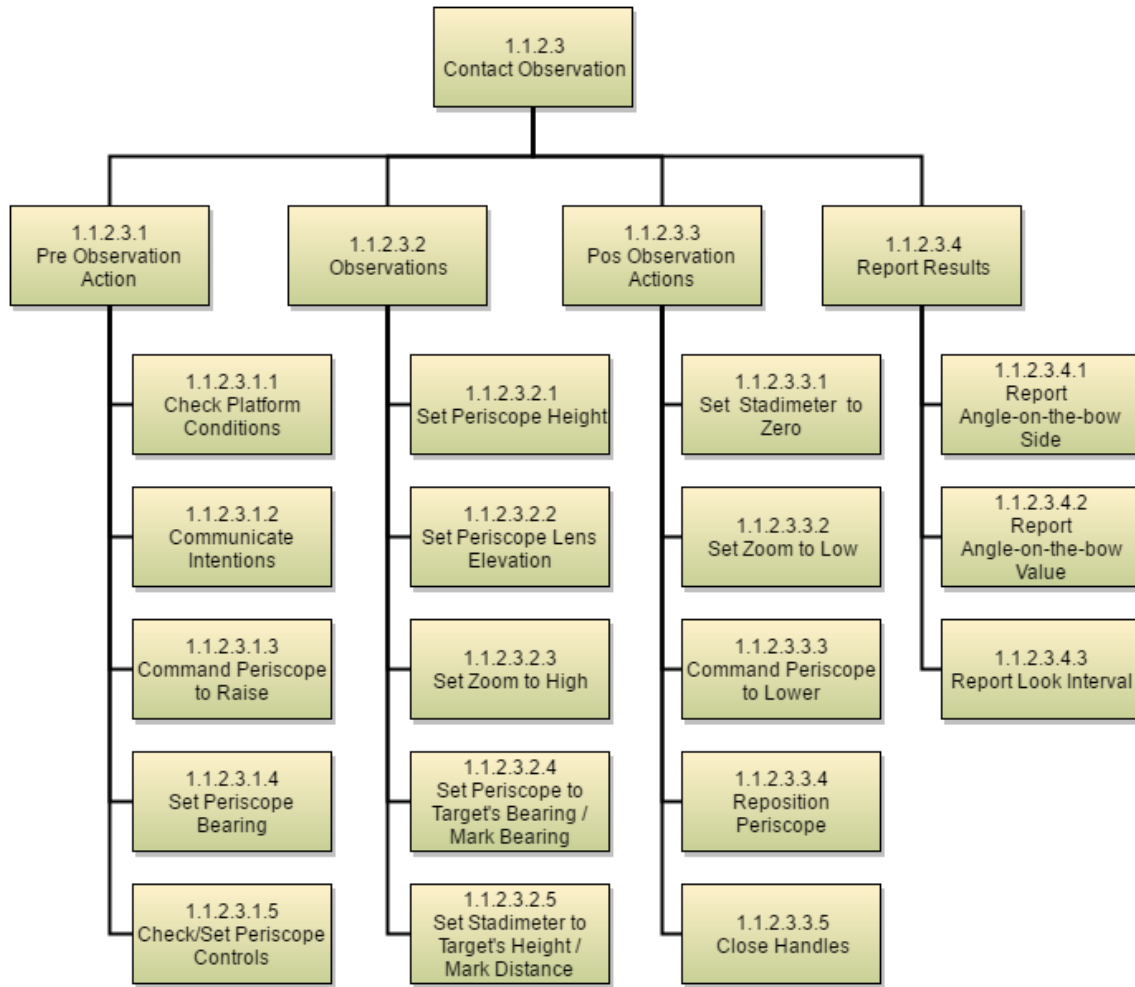
Figure 6. Hierarchical Task Tree for Contact Observation.

The results of a detailed analysis of each sub-task component of GODEX mission are shown in Table 2. Some adaptions were required to this complete model to address the limitations related to classification and lack of previous experience of the population. Additionally, some subtasks listed are related to the operation of the equipment itself and they were not represented. The tasks not simulated in STTS are marked in Table 2 with an asterisk.

Table 2.   Detailed Description of Tasks. Adapted from Bastos (2014).

Step	Task	Task Description	Remarks
1	Traverse Area in Safety / Stay as long as possible in the PD	This is the overall goal. The PO must traverse an area where the transit of an enemy task force is expected. PO should keep the submarine as long as possible at PD, without changing course or speed	PO should use the periscope the little as possible to avoid exposure and counter-detection, while constantly assessing the current safety status.
1.1	Update Tactical Situation	PO performs the most adequate technique to obtain information about the surrounding tactical situation.	The PO must assess the source of information to be evaluated based on his mental model of the situation and on the time available before the next observation is due.
1.2	Maneuver	PO performs a depth change.	
1.2.1	Evolve to SD	PO announces orally the type of depth change and the previously defined SD value.	E.g., "Emergency 40 meters"
1.2.2*	Evolve to PD	PO announces orally the type of depth change and the final desired depth at PD.	E.g., "Depth, 15 meters"
1.1.1*	Evaluation of Sensors' Information	PO obtains information of the contacts straight from sensors' displays or from supervisors.	PO checks if the information from sensors is consistent with his model of the situation.
1.1.3*	Evaluate data processed by attack team	PO checks the previous calculated solutions, obtained by the Attack Team, managed by the Executive Officer.	PO compares solutions with his own mental models

Step	Task	Task Description	Remarks
1.1.2	Data Collection with Periscope	PO obtains information of the contacts performing a periscope observation.	PO must judge which type of periscope observation is appropriate based on the data he needs to obtain and the time he has to do it.
1.1.2.3	Contact Observation	PO performs a Contact Observation	
1.1.2.3.1	Pre Observation Action	Set of tasks performed to make the periscope ready for an observation. Comprises all actions taken from the decision to raise the periscope to when the PO puts his eyes on the eyepieces.	
1.1.2.3.1.1	Check Platform Conditions	Submarine's conditions to be checked every time before the periscope is raised	Each condition should be checked "at a glance." Depending on conditions like the depth of the keel, speed over ground, or hull inclination (trim), the AO may decide to not raise the periscope until corrections are made on the platform conditions.
1.1.2.3.1.2	Communicate intentions	After deciding that all conditions allow for periscope raising, the AO announces orally to Attack Team what kind of observation he will do.	E.g., "Observation of Contact 03"
1.1.2.3.1.3	Command periscope to Raise	PO commands the periscope he will use to be raised	E.g., "Raise the One (or Two)" After the PO commands the periscope to be raised, an auxiliary supervisor orally announces the estimated bearing of the target to be observed.

Step	Task	Task Description	Remarks
1.1.2.3.1.4	Set Periscope Bearing	PO turns the periscope to the bearing where he expects to begin his observation.	Assessing his mental model and the information just received, the PO decides what is the most probable target's bearing. As periscope comes closer to the floor limit, the PO crouches. As the periscope handles become reachable near the floor, the PO opens them and turns the periscope to the chosen bearing.
1.1.2.3.1.5*	Check/Set Periscope Controls	PO manually sets the periscope controls while it is being raised	To save time, the PO must crouch and do these settings as soon as he can reach the periscope controls near the floor, while he still cannot reach the eyepieces with his eyes. For Contact Observation PO sets / checks the height of target's point to be observed on the periscope's front panel and checks the zoom level is set to lower.
1.1.2.3.2	Observation	PO performs the chosen type of observation	
1.1.2.3.2.1	Set Periscope Height	PO sets the periscope height	PO evaluates, according to his own height and sea state, a height for the periscope in which it is possible to execute the observation, exposing just the sufficient amount of mast.

Step	Task	Task Description	Remarks
1.1.2.3.2.2	Set Periscope Lens Elevation	PO uses periscope controls to set the best lens elevation to execute the observation.	PO will execute this throughout the observation looking for keep the target in the center of periscope screen, compensating inclinations caused by the sea state.
1.1.2.3.2.3	Set Zoom To High	PO sets the periscope zoom to high.	Only set zoom to high if the target to be observed is close to the center of the periscope screen
1.1.2.3.2.4	Set Periscope to Target's Bearing / Mark Bearing	PO rotates the periscope to align the vertical line in the screen to the center of the target, press the mark bearing button to send the current bearing to the combat system, and disseminate orally the bearing reading.	E.g., "Bearing 040" PO should be careful to always take the bearing form the same point of the target.
1.1.2.3.2.5	Set Stadimeter to Target's Height / Mark Distance	PO rotates the stadimeter's wheel to the point where the reference point of the target is aligned to the ship's water line, press the mark distance button to send the current range reading to the combat system, and disseminate orally the range reading.	E.g., "Distance 3500 yards" PO should compensate for distant contacts (more than 4 kyds) where the ship's water line cannot be seen, due to earth's curvature.
1.1.2.3.3*	Post Observation Actions	PO takes actions to prepare the periscope for the next observation before lowering it.	According to the current tactical situation, the PO must predict what is his next step, and decide to lower the periscope all the way down or just enough to break its exposition ("flood") allowing for a faster raising afterwards.

Step	Task	Task Description	Remarks
1.1.2.3.3.1	Set Stadimeter to Zero	PO rotates the stadimeter's wheel all the way back to the point where the images of both eyepieces are aligned.	Range reading shows 16000 yds.
1.1.2.3.3.2	Set Zoom to Low	PO sets the zoom back to low.	
1.1.2.3.3.3	Command Periscope to Lower	PO commands orally to lower or "flood" the periscope	E.g., "Lower the One (or Two)" or "Flood"
1.1.2.3.3.4	Reposition Periscope	While the periscope is being lowered, the PO quickly turns it to the start bearing of the next observation	PO must plan one step ahead, choosing the next observation to be done, and set the periscope bearing to the direction of the next observation. This movement must be done quickly, without looking at the eyepieces.
1.1.2.3.3.5*	Close Handles	PO close periscope handles.	
1.1.2.3.4	Report Results	PO recall from memory the data about the observation, calculates and orally reports the results	
1.1.2.3.4.1	Report Angle-on-the-bow Side	PO orally reports the side of the target that he saw during the observation.	If the target is pointing directly to the submarine, no side should be informed.
1.1.2.3.4.2	Report Angle-on-the-bow Value	PO orally reports the angle from the target's bow to the bearing where the submarine is.	E.g., "Angle-on-the-bow Starboard 40"
1.1.2.3.4.3*	Report Look Interval	PO mentally calculates the LI, based on the observed target's range.	E.g., "Look Interval 2 minutes and 30 seconds"

Figure 7 illustrates the final procedural diagram for STTS, after all the considerations listed previously.
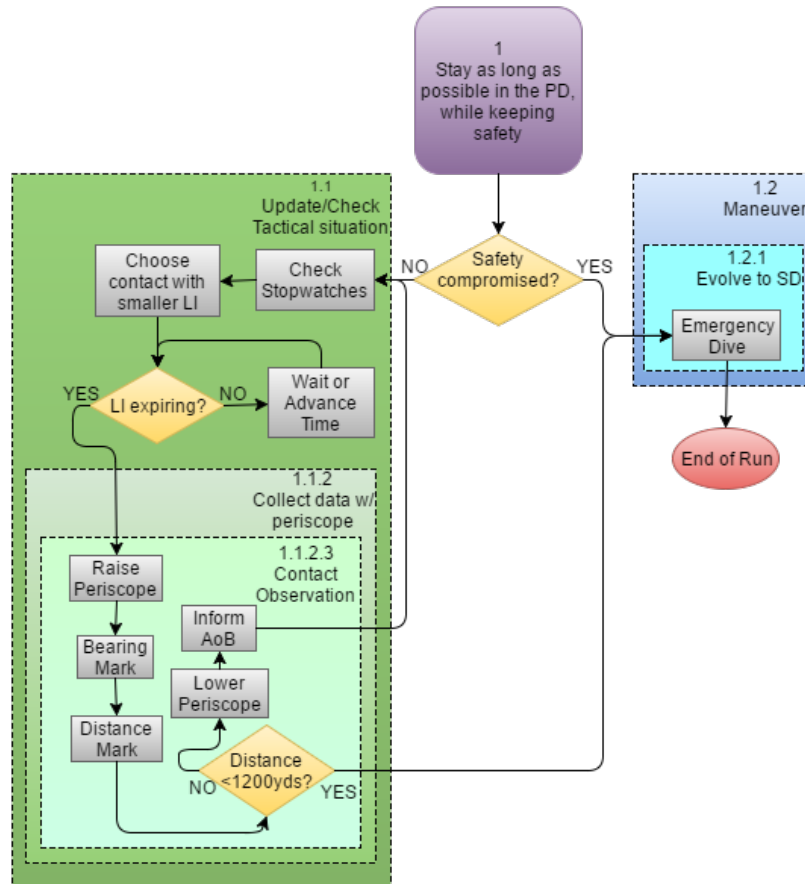
Figure 7. STTS Procedural Diagram.

B.   LEARNING OBJECTIVES

After a training section on STTS, a participant should be able to:

- Enumerate the correct sequence of movements for each contact observation.

- List the pre-observation required actions.

- Describe the process of taking a contact's bearing.

- Describe the process of taking a contact's distance;

- Enumerate the actions to prepare the periscope for the next observation, before lowering it.

- Explain what the AOB is and how it is disseminated.

- Report the criteria for a correct emergency call.

These learning objectives reflect only the set of KSA intended to be assimilated by a participant on this study. Of all knowledge required for the GODEX mission, this simulation addresses only the basic unclassified process.

C.   SYSTEM REQUIREMENTS

In order to achieve the desired learning objectives, STTS should be able to meet the following requirements:

1. Simulate the virtual environment outside the submarine

    a. Sea surface and its movements

    b. Sky

2. Simulate the virtual environment inside the submarine (control room)

    a. Periscope 3D Model representation

    b. Periscope rotation while not completely raise

    c. Depth indication

    d. Trim indication

3. Simulate the visual through the periscope screen

    a. Built-in true bearing indicator

    b. Built-in relative bearing indicator

    c. Built-in stadimetric range indicator

4. Simulate the periscope equipment

    a. Horizontal rotation with at least two speeds (fine and coarse)

    b. Vertical rotation of the lenses

    c. Vertical raise and lower movements

      d. Stadimeter

      e. Zoom levels

5. Simulate enemy surface ships and their movements

6. Simulate orders and reports made by PO

7. Organize experiment by three trials

8. Score management

9. Automatically assign participants to groups keeping balanced experience scores

10. Provide feedback according to assigned group

IV. SYSTEM DEVELOPMENT

A. OVERVIEW

The intent of this thesis was to build a realistic simulation for submarine officer tactical training and a suitable platform for testing the hypothesis. Contact Observation was the task selected during the task analysis, based mainly on unclassified part-tasks that could be taught in a short window of time for non-submariners. However, additional factors steered the system development towards distinct goals. The main constraint on the development of a tactically realistic system lies on classification of some concepts of the task. It was also necessary to adapt and simplify the execution of the task. Some adaptations had to be made to the actual procedure so that participants with no previous knowledge would be able to accomplish the GODEX task. One example is the calculation of look intervals: in reality, this calculation must accomplished mentally in a very short timeframe after lowering the periscope, considering the distance observed for the contact, the maximum speed of a particular type of ship, and the go-deep range for the bearing sector where the contact is located. On this version of STTS, the LI is calculated automatically and a stopwatch correspondent to that contact is automatically updated to reflect the LI. This chapter describes the process used for developing a version of STTS that is flexible for use as an unclassified experimental testbed as well as a basis for the future development of a more tactically realistic training tool.

B. SOFTWARE USED

1. Unity

Unity 3D is a popular game engine developed by Unity Technologies from Denmark. It is a cross-platform solution, which allows developers to build their games in one development environment and release them for multiple platforms, such as different consoles, numerous operating systems, smartphones, and web-browsers ("Unity," n.d.).

Numerous reasons guided the selection of Unity for the development of the STTS. The first is that Unity allows scripting in either C# or UnityScript (a language based on JavaScript). C# is very similar to JAVA programming language, which the author has

significant previous experience, allowing an easy transition. The second reason is that the popularity of this game engine has produced a large and collaborative developer community, which uses a several forums and blogs that facilitate the process of learning Unity for new developers. Similarly, online documentation is complete, easily accessible, and includes implementation examples. Additionally, the Unity Asset Store is an online repository where any developer can publish or sell their solutions. For STTS development, external assets were used to build the ocean model, the skybox, and the graphical user interface (GUI). Lastly, it is possible to release final applications for many platforms, operating systems and consoles, with none or very few adaptations needed to the main source code. The final STTS application was built for Windows personal computers but Unity allows easy conversion to Mac OS, Android, iOS, and other operating systems, which might be useful for future iterations of the STTS.

2.   Blender

Blender is a multi-platform, open-source 3D tool for modeling, animations and game development. In spite of being open-source, it can be compared to other proprietary and expensive competitors in terms of creation power. From individual developers to big companies, Blender has a large adoption worldwide, which contributes for collaboration and learning process. The 3D environment for the submarine control room and the periscope model were built using Blender ("About," 2016).

3.   GIMP

GNU Image Manipulation Program (GIMP) is a powerful open-source tool for image manipulation. It was used to create and edit the textures used in the submarine model and the periscope screen mask.

4.   Microsoft Visual Studio

Visual Studio is the integrated development environment (IDE) chosen to code for Unity game engine because it has C# as one of the supported languages. Visual Studio Tools for Unity is a plug-in that allows the visualization of scripts following the same

hierarchy found in Unity. It also provides a Unity console inside Visual Studio, which is a very useful tool for debugging.

C.   MODELS

This section lists and describes the models used to build STTS and the technical approaches to integrate them.

1.   External Environment

a.   *Ocean*

The ocean model used is a part of a project created by an individual developer (Hawkins, 2013). This asset was retrieved from his blog, where is possible to find all the documentation and the files to download. This asset is based on a radial grid created over a plane and the vertices of this grid are visually moved up and down to create the wave effect. For performance purposes, the heavy fast Fourier transform (FFT) calculations for each individual vertex of the grid are done on the GPU and fetched once per frame. Since the data is calculated on the GPU, the vertices are not physically moved. The appearance of movement is created by the height maps generated from the FFT done on the GPU. This asset allows modifying the seas by controlling wind speed, wave period, and amplitude. It uses a light source as reference for realistic sun reflections. The lack of real geometry being moved in the scene grants the model an optimized performance, however it does not allow the use of geometry for physics calculations, such as buoyancy.

To address the issue of lack of buoyancy movements in the vessels, a script was implemented to rotate the submarine and the targets around the original "heads-up" position, using Perlin noise. Originally created to generate naturalistic procedural textures (Perlin, 2002), the Perlin noise was adapted to generate smooth continuously changing movement along both longitudinal (roll) and horizontal (pitch) ships' axes. The Perlin noise was applied over a long amplitude sine wave and adjusted using specific factors for roll and pitch (see Figure 8).

```
 //Noise to simulate waves:
      float noise = Mathf.Sin(Time.realtimeSinceStartup * waveFreq) *
          Mathf.PerlinNoise(Time.realtimeSinceStartup,0f) / waveFreq;

      float noisePitch = noise * waveMagnitude * pitchFactor;
      float noiseRoll =  noise * waveMagnitude * rollFactor;

 //Rotation to simulate waves:
      transform.Rotate(new Vector3(noisePitch, 0, noiseRoll));
```

Figure 8. Perlin Noise Procedural Wave Movements.

b.   *Skybox*

The environmental background was created using a skybox downloaded together with the ocean model (see Figure 9).

Figure 9. Periscope View of the Ocean, Skybox, and Target.

c.   *Earth Curvature*

Due to the curvature of the earth, at great distances the apparent waterline of a ship when viewed through a periscope differs from the actual waterline. Thus, at great ranges, it affects the distance reported by the periscope's stadimeter, and the PO must consider this effect when determining distance. Therefore, the game was designed to reflect this to mitigate the potential for negative training.

To account for this, a simple mathematical model was implemented to simulate the earth's curvature effect (ECE) on distant objects, which appear to be as "deeper" in the water than they are. Figure 10 shows a schematic diagram and the variables involved.
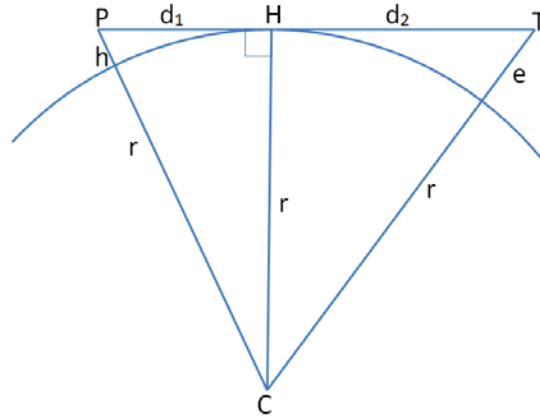
Figure 10. Earth's Curvature Effect.

First, the distance to horizon for the submarine was calculated (d1) based on the periscope height (h). The Pythagorean Theorem was used on the triangle CHP, since the line from the periscope lens to the target (segment P-T) is tangent to the earth on the horizon (point H).

$$(r+h)^2 = r^2 + d_1^2$$
$$r^2 + 2rh + h^2 = r^2 + d_1^2$$
$$d_1 = \sqrt{h(2r+h)}$$
(3)

Considering the Earth radius $r = 6{,}967{,}410$ yards and the mean periscope height $h = 1.0$ yards above the sea level, the virtual horizon is $d1 = 3732$ yards.

To calculate dynamically the ECE (e), the same process was used for the triangle CHT.

$$(r+e)^2 = r^2 + d_2^{\;2}$$
$$r^2 + 2re + e^2 = r^2 + d_2^{\;2}$$
$$d_2^{\;2} = 2re + e^2 \qquad (4)$$

Once e^2 is significantly smaller then $2re$ the simplified formula for e is:

$$e = \frac{d_2^{\;2}}{2r} \qquad (5)$$

Also considering:

$$d_2 = Range - 3732 \qquad (6)$$

Substituting (7) on (6), we have the final formula for ECE given by Equation (8):

$$e = \frac{(Range - 3732)^2}{2r} \qquad (7)$$

This effect is applied to the simulation (if the range is greater than 3732 yards) by subtracting e from the "y" coordinate of the targets, once per frame, causing them to be deeper in the water plane proportional to the distance to the submarine.

2.   Ships

The 3D models of frigate type 22 (Brazilian Navy Class Greenhalgh) were kindly provided from Brazilian Navy Modeling and Simulation Office. Originally developed in Autodesk 3DS Max, the model used an .fpx extension. The model can be directly imported into Unity, which removed the need for additional processing. A comparison of the model and a picture of the actual frigate is shown in Figure 11.

Figure 11. Frigate Greenhalgh (Type 22) Model Loaded in Unity (above) and
Real Picture (below). Source: Área Militar (2011).

3.   Submarine

The only visible part of the submarine in the STTS is the control room's interior. Requirements for a detailed model of the control room did not emerge from the task analysis so it is presented as a rough approximation. The main factor for including a 3D environment for the control room was the need to simulate the rotation of the periscope while it goes up or down (steps 1.1.2.3.3.4 and 1.1.2.3.1.4 on the task analysis). The 3D model was considered important to help the participants to position themselves spatially when rotating the periscope during ascent and descent. In this scene, it is possible to see the three metallic tubes, which compose the periscope: two lateral hydraulic pistons and, in the center, the periscope itself. Simple cubes were used to represent the walls forming the forward compartment. A cylinder represents the submarine's hull. Three fully functional indicators are positioned on the walls and include a wall clock on the right, a digital depth indicator showing the keel depth in meters, and a "bubble" indicator, showing the hull inclination on the left side (necessary to accomplish step 1.1.2.3.1.1 on the task analysis). To provide information required to complete the simulated GODEX

task, three stopwatches are displayed on the bottom of the viewport. This mimics the stopwatches used, in a real GODEX mission to maintain LIs. Figure 12 illustrates the interior view.

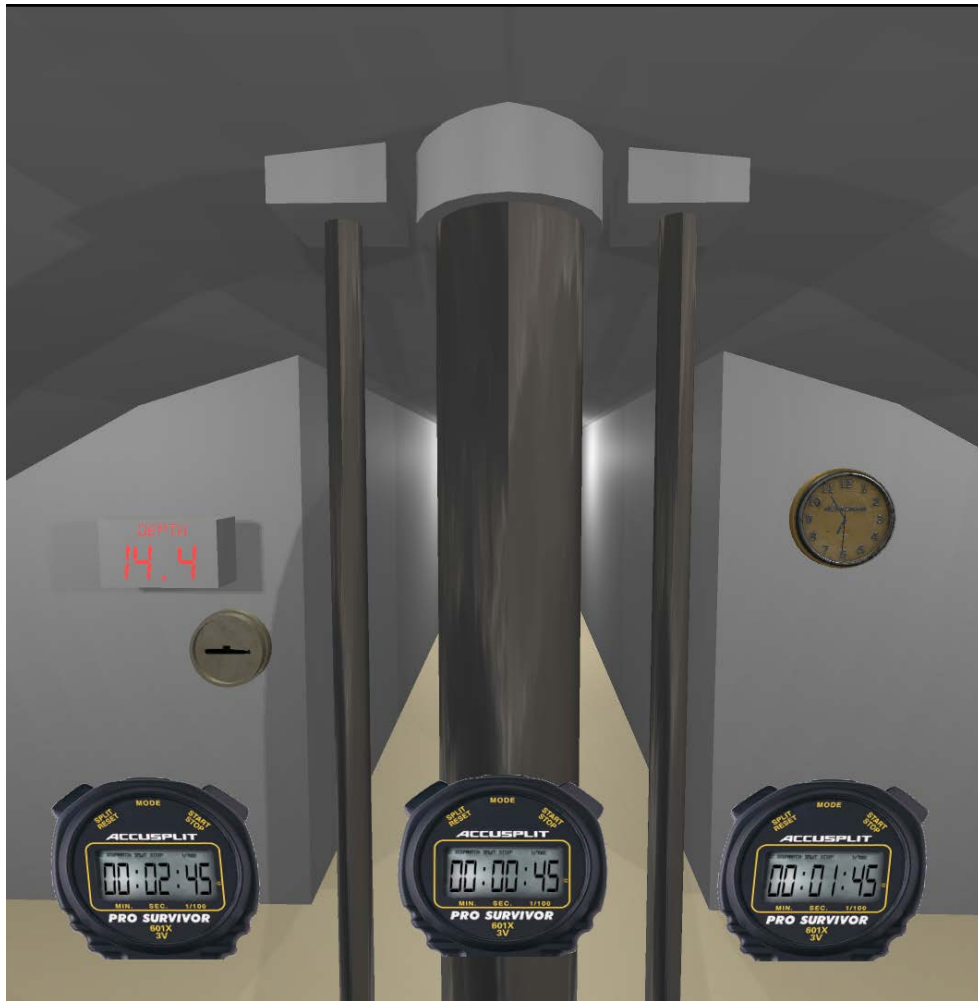Figure 12. Control Room Simulated in STTS.

The inside and outside of the submarine are two distinct game objects in the scene, as shown in Figure 13. The only connection between the two are the movements applied to the physical periscope that holds the cameras on the outside submarine and the representation of the periscope inside submarine. Figure 13 shows how the objects are connected in Unity.
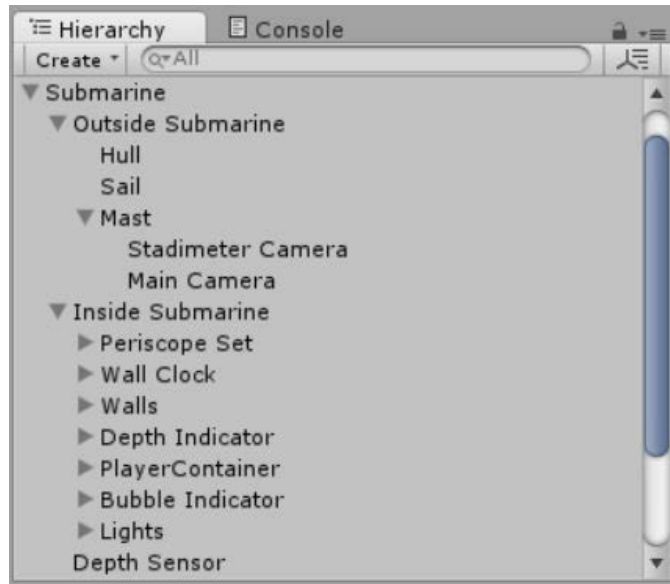
Figure 13. Unity Game Objects Hierarchy Showing Two Distinct Game Objects
for Interior and Exterior Submarine Models.

4.   Periscope Display

Once the periscope is raised the viewport changes to the outside view, simulating
the image perceived by the PO while looking through the periscope eyepieces.

a.   *Periscope Mask*

A peripheral blur is a visual artifact experienced when SOs use periscopes. In
order to simulate this effect, a texture mask was used over the periscope camera in the
STTS. This texture was created by applying consecutive growing transparent circles to a
black background image. This process resulted in a simulated blur observed on the view's
peripheries when looking through the periscope. Figure 14 shows this effect. Masking
was also used to model the horizontal and vertical reticle patterns. The upper digital
display indicates the range when the stadimeter is applied. The lower left display
indicates the true bearing and the lower right display indicates the relative bearing. In this
scenario, the bearing indications are always the same because the submarine course is
fixed as 000° (North).

Figure 14. Outside View with Stadimeter Applied.

b. *Stadimeter*

The stadimeter is a very important instrument onboard a submarine and it is used by SOs when finding the range of contacts. The process of using a stadimeter to determine range consists of employing trigonometric determination of one side of a right triangle, by knowing one angle and the length of the opposite side. By rotating the range control knob in the periscope, an angle (Θ) is applied to one of the lenses creating the lagging effect visualized in Figure 14. The known side of the right triangle is the target's height. This value in feet must be pre-set in the periscope. To have a correct measurement of target's range, the periscope operator must align lower edge of the upper image to the upper edge of the lower image. For this simulation, the upper and lower references are

the rear yardarm (horizontal mast) and the ship's waterline, respectively. Figure 15 and Equation (9) show the triangle and the formula used to calculate the target's range.
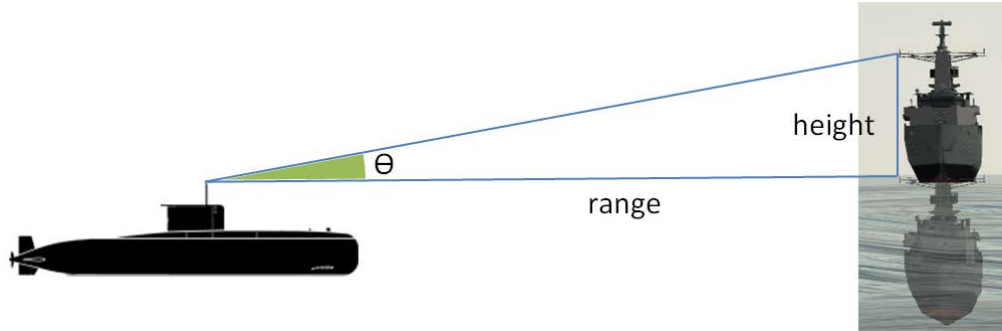

Figure 15. Stadimeter's Operation Principle.

$$Range = \frac{Height}{\tan \theta}$$

(8)

This operation principle was simulated in STTS by the use of two cameras positioned in the exact same place on the top of periscope mast. By rotating the mouse wheel down, a proportional angle up (Θ) is applied to one of the cameras, resulting in the image in this camera being translated down. Every frame, the image captured by this camera is converted into a raw image and the transparency necessary for the desired effect is applied. This treated raw image is projected in a GUI layer, in front of the original camera, and rendered together with the rest of the scene. When angle Θ is close to zero, the stadimeter camera is disabled and there is no overlay to optimize performance.

c. Zoom Levels

The zoom levels simulated in STTS are 1.5x (low zoom) and 6x (high zoom). To implement it in the simulation, the field-of-view (FOV) camera property was adjusted in both main and stadimeter cameras. In low zoom, the cameras are set to 32 degrees FOV and in high zoom they are set to 8 degrees FOV.

d. *Periscope Controls*

Table 3 provides a list of all mouse and keyboard commands used to control the periscope.

Table 3.   Periscope Controls List.

ACTION	MOUSE	KEYBOARD
Rotate left	Left mouse button	Left arrow or "D"
Rotate right	Right mouse button	Right arrow or "A"
Rotate slower	-	+ Shifta
Rotate faster	-	+ Controla
Adjust lens up	-	Up Arrow or "W"
Adjust lens down	-	Down Arrow or "S"
Adjust height up	-	"Q"
Adjust height down	-	"E"
Swap zoom	Middle mouse button	"Z"
Stadimeter increase Ө	Rotate mouse wheel down	-
Stadimeter decrease Ө	Rotate mouse wheel up	-

[a] Keys to be pressed together with regular rotation command.

5.   GUI

The graphical user interface (GUI) is a very important component of this simulation. It was designed to be able to simulate the dynamic actions of a real exercise on board a submarine. Each button pressed corresponds to a command or report made in real life. The sequence of commands and reports is also an important learning objective, so the participant must follow the top down sequence in the simulation or a penalty score would be applied. The buttons' colors are representative of their states, being red for available and green for already pressed buttons (see Figure 16). The "Emergency 40 meters" button is always available. Only mouse clicks and mouse-wheel rotations are used as input methods. To inform the AOB value, the user rotates the mouse-wheel to set the estimated angle and finish the observations by clicking the "Submit" button.

The upper part of the right panel on the GUI is used for display both raw and adjusted score. For participants on the RTF group, the lower part displays a log of

previous messages allowing them to review their actions, while waiting to raise the periscope. For participants on PHF group, this message log is disabled.

Figure 16. Graphical User Interface for RTF Group.

D.   SCENARIO DEVELOPMENT

Based on the LOs, the scenario was designed to facilitate the comprehension of the concepts taught. It was also considered the desired flow, in order to maximize the number of contact observation executed in each trial. Three surface contacts were positioned, such that the participant could have enough time to observe them as they approach, following the PDOT. The participants were informed that the GDR considered for this scenario was 1000 yards. If any contact gets closer than 1200 yards, it is considered a good time to maneuver to SD.

Each run was designed to take between seven minutes to exactly nine minutes and 24 seconds to be completed depending on the moment that the decision to dive is made. The correct timeframe for diving occurred from eight minutes and 36 seconds to nine minutes. If the participant failed to abandon the PD, the run is finished when a contact reaches 900 yards.

E. AUTOMATIC GROUP ASSIGNMENT

The algorithm detailed in Appendix A was used to automatically assign participants to either PHF or RTF group. This approach enabled each experimental group to have equivalent distribution of experience scores. The experience score is based on answers to "YES" or "NO" questions on the demographics survey.

If an experimental group had four more subjects than the other, then the next subject is automatically assigned to the group with fewer subjects. Otherwise, the mean experience score in each group is established. The new mean scores are calculated for each group considering the inclusion of the new participant in that group.

After comparing new and old mean scores the new participant, is added to the group that would generate the smaller difference of experience scores. If the difference between scores is the same regardless of which group the participant is assigned to, the algorithm chooses the group with lower number of participants.

The actual assignment occurs by setting the Boolean variable *hasFeedback* to "true" if RTF is the chosen group or "false" otherwise. A new line is created on the setup file correspondent to the chosen group to include the participant's data. The final mean experience score was 17.35 for PHF group and 17.05 for RTF group, with 17 participants in each.

F. SCORE MANAGEMENT

In order to evaluate performance, each subject received a score for each run in STTS. These scores were calculated by assigning each learning objective a score defined for partial or complete achievement of that part-task. Some tasks were binary: either the subject performed them or not, such as "Chose Correct Contact." For these, subjects either gained or lost points. Other tasks could be performed to varying degrees as competency, such as correctly estimating the range or bearing to a contact. For these, subjects' performance was ranked "Excellent," "Good," "Average" or "Poor," and subjects received or lost points based upon which category their performance fell into. Table 4 shows the tasks and their associated points.

Table 4.   Raw Score Components.

ACTION	SCORE
Choose wrong contact	-100
Choose correct contact	+100
Raise periscope with less than 20 seconds remaining in the Stopwatch	+100
Bearing mark precision:	
Bearing error < 0.1 degrees – EXCELLENT	+200
0.1 degrees < Bearing error < 0.2 degrees – GOOD	+100
0.2 degrees < Bearing error < 0.4 degrees – AVERAGE	+50
Bearing error > 0.4 degrees – POOR	-100
Distance mark precision	
Distance Percentage error < 5% – EXCELLENT	+200
5% < Distance Percentage Error < 10% – GOOD	+100
10% < Distance Percentage Error < 15% – AVERAGE	+50
Distance Percentage Error > 15% – POOR	-100
Lower with stadimeter not zeroed and zoom applied	-200
Lower with stadimeter not zeroed	-100
Lower with zoom applied	-100
Lower without zoom or stadimeter applied	+100
Choose wrong AOB side	-100
AOB estimation precision:	
AOB error < 3 degrees – EXCELLENT	+200
3 degrees < AOB error < 6 degrees – GOOD	+100
6 degrees < AOB Error < 12 degrees – AVERAGE	+50
AOB error > 12 degrees – POOR	-100
Emergency call scoring criteria:	
Emergency Distance > 1600	-400
1600 > Emergency Distance > 1500	-200
1500> Emergency Distance > 1300	-100
1200 > Emergency Distance > 1000	+400
1000 > Emergency Distance > 900	-200
Emergency Distance < 900	-400
Button clicked out of sequence	-100
Stopwatch reached zero	-200
Periscope raised for more than 35 seconds	-100
Contact range reached 1000 yards	-200

After each run, points for each subject's actions were summed to create a raw score, which reflected how well the subject carried out all the given tasks but one. The other task was minimizing the percentage of time that the periscope was up during the trial, known in the submarine community as submarine indiscretion ratio (SIR). It was

continuously calculated by dividing the accumulated time between "Raise Periscope" and "Lower Periscope" actions by the total time in the run. To penalize subjects for a high SIR, an adjusted score was calculated for each run.

The adjusted score was calculated based on the raw score and the SIR. The optimal ratio between precision and speed factors were defined based on preliminary experimental tests with STTS. Without including a penalty, a participant could increase his/her raw score by making more observations, which was tactically incorrect because it increased periscope exposure. Including a penalty for the amount of time the periscope was raised would result in a decreased adjusted score. Experimentation based upon the designer's experience as a submarine officer found that by dividing raw score by SIR cubed was an appropriate penalty. The constant 20 was use to keep the adjusted score in a reasonable range around the raw score. Equation 10 shows the formula for adjusted score calculation.

$$AdjScore = \frac{RawScore}{SIR^3 \times 20}$$

(9)

G.   DATA COLLECTION

All data generated during the training sessions was stored as tables in .csv files. The system generates one file per run for all participants, and stores each observation as a line in the file. In that lines the system records all possible errors committed during the observation as Boolean variables (true if the error existed or false otherwise), numeric precision errors (like bearing error, AOB estimation error, etc.), raw score, SIR, adjusted score and times spent in each action. The primary variables of interest for the experiment are raw score, SIR and adjusted score. The others were recorded in case additional questions needed to be answered during data analysis.

The simulation also generates one file per trial, per participant to store the feedback generated during the run. These files were presented to the PHF group participants in the end of each trial.

V. EXPERIMENT

A. DESIGN OF EXPERIMENT

In order to answer research the research questions, this experiment was designed to determine if different types of feedback (RTF and PHF) affected participants' performance. Exploratory investigations examined if various demographic factors (age, time in service, military affiliation, and gaming experience) affected the efficacy of these types of feedback. Participants were assigned to one of two treatment groups (PHF or RTF) which were balanced by the subjects' experience levels. The factors used to define this experience were asked as "YES" or "NO" questions, as described in section IV.E. Each group performed two runs in the STTS, which varied in the type of feedback: one group received real-time feedback, while the other received post-hoc feedback after completion of the run. After these two runs, each group performed a final run with no feedback delivered. All three runs were scored using an algorithm described in the section IV.F.

B. RECRUITMENT

Following the approved protocol (Appendix B), subjects were recruited by posting copies of the recruitment poster (Appendix C) across campus and by sending a bulk email to all NPS students (Appendix D).

C. PROCEDURE

Subjects were greeted, seated at a comfortable workstation, and were given an informed consent form (Appendix E) to read and sign. After consenting to participate, subjects were randomly assigned a unique identifier to track subjects' system generated data. There was no connection between this number and identifiable information of the subjects.

Once assigned a number, participants took a computer-based survey to collect demographic data, which was subsequently used to assign the participant to one of the experimental groups. This was done in order to ensure that the two groups were balanced

in terms of number of participants and mean experience score (detailed explanation on the process used can be found in the section IV.E). Once assigned to a group, the experimenter read this text describing the scenario to the subject:

> You are the CO of a submarine located in a patrol zone, where the transit of an enemy task force is expected. There is a leakage in the main circulation pipe connector. Your engineers need low pressure in the pipes so they can fix the leakage. You also cannot use propulsion because the cooling system for the main shaft is secured, due to the leakage. Propulsion can be used only in emergency case, for diving. You as the CO, decide to stay at PD as long as you can, diving only in case of imminent danger. The submarine starts at PD, with all the masts lowered; speed zero and heading north (Course 000°). When the scenario starts, you have already detected and tracked three contacts. They are classified as frigates of the Greenhalgh class (Type 22). Contact 1 is the frigate on bearing 010°, Range 6000 yards. Contact 2 has bearing 350°, range 6500 yards. Contact 3 is straight on your bow, bearing 000°, range 5500 yards.

Figure 17 illustrates the initial state for the described scenario.
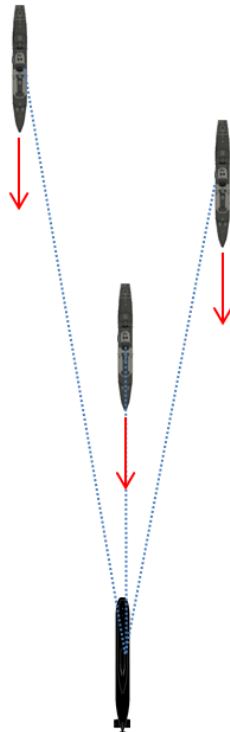
Submarine and ships representations not to scale.

Figure 17. Scenario Initial Situation.

Subjects then watched a training video that explained details of the study and how to operate the STTS. Since there were differences in the STTS for the different conditions, each group received a different video, which was specific for their condition. The complete transcripts of both videos are in the Appendix F.

After watching the video tutorials, participants were given five minutes to familiarize themselves on a basic control version of the STTS. After these five minutes of familiarization, participants were redirected to the main application, and asked to execute three trials of the GODEX scenario. Participants in the PHF group had three minutes after the first and second runs to read the feedback generated for each run, which was presented to the participant on the screen as text file. Participants in RTF group received feedback during their first two trials. Neither group received feedback during the third trial so that the third runs were comparable between groups.

After completing the main exercise, the participants completed a post task survey (see Appendix G).

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VI. EXPERIMENT RESULTS

A. SUBJECTS SCREENING

A total of 40 participants volunteered and were enrolled in the experiment. In the early stages of the experiment, a software bug causing the participants on the PHF group to have improper scores was detected. The bug was promptly fixed; however, data generated for five participants could not be included in the final analysis. One participant used improper tactics to achieve an artificially high score and these data were excluded from the analysis. The next chapter discusses this case in detail. In total, 34 valid cases were analyzed for this investigation. The median age for the participants was 32, while the median time of military service for those in the military was 10 years. Demographics for the all subjects are shown in Figure 18.

Demographic information was used to place each subject into one or the other treatment group (RTF or PHF) in a manner described in section IV.E in order to maintain an equivalent level of experience in each group. The demographics for each group are shown in Figure 19 and Figure 20.
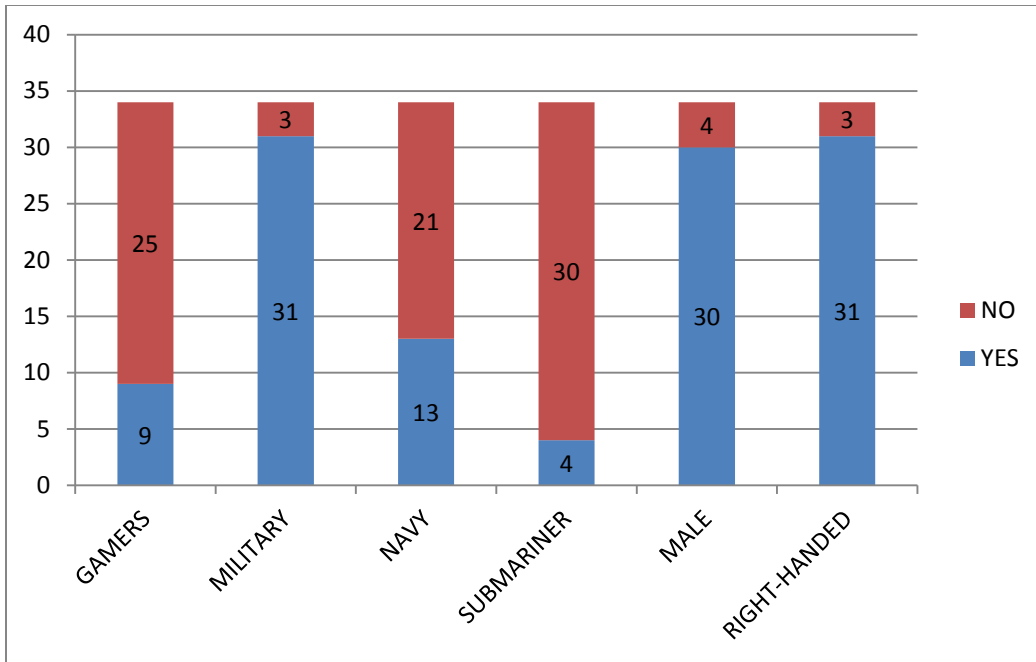
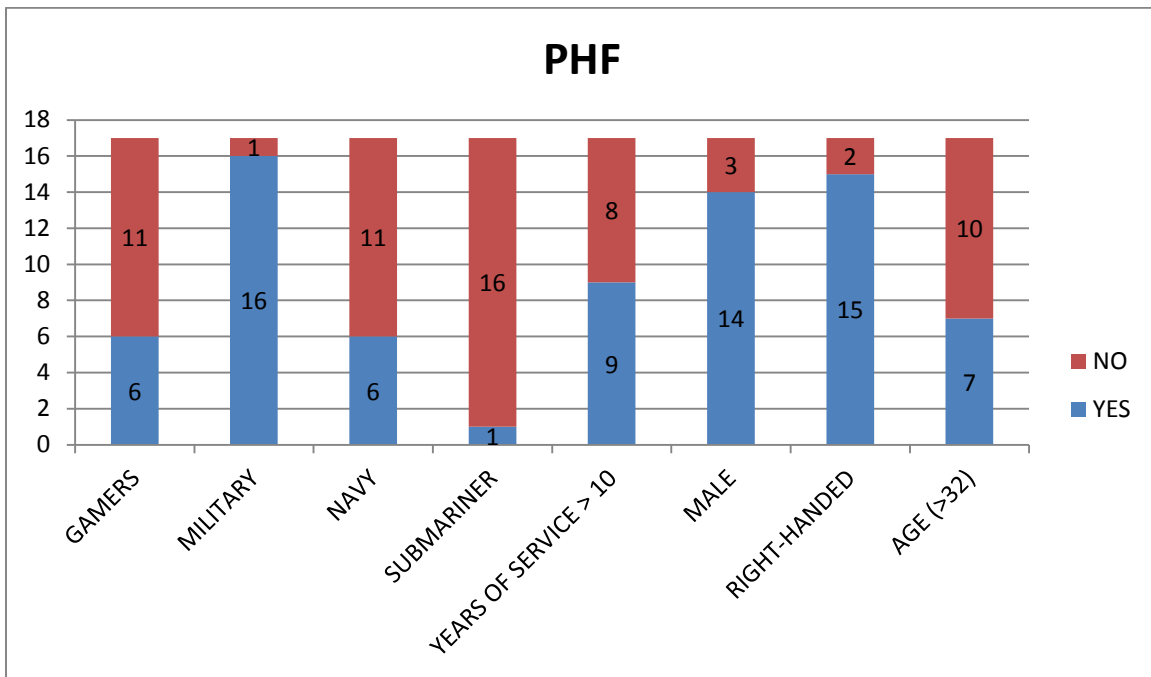Figure 18. Participant Demographics.

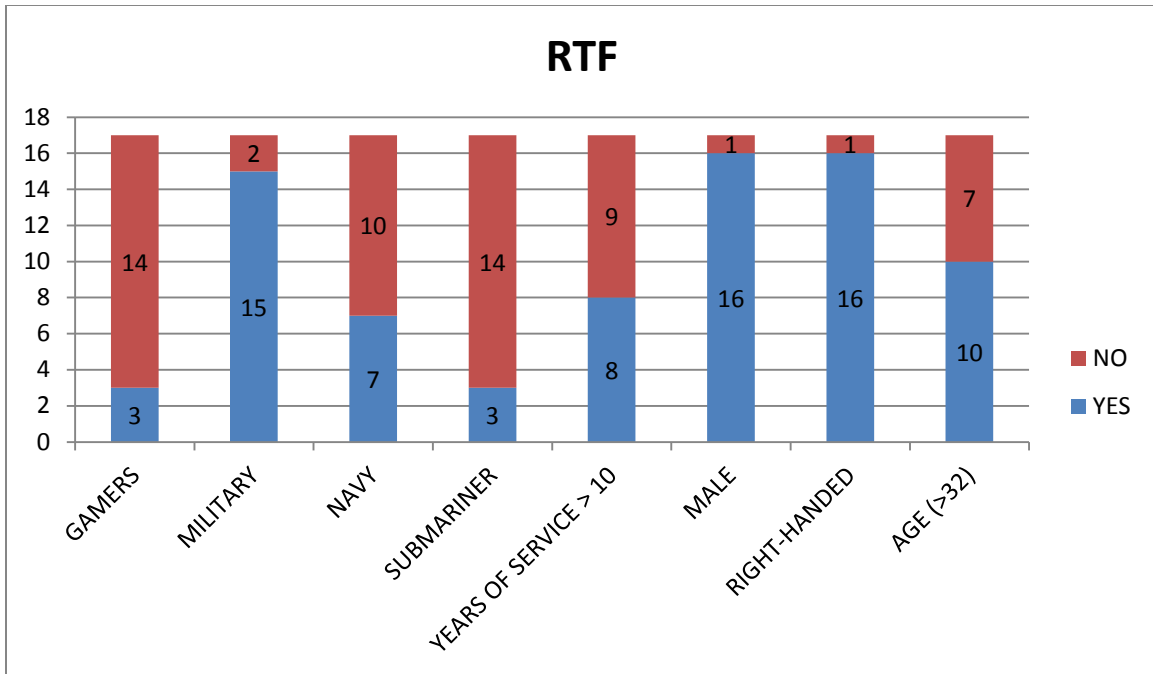Figure 19. Demographic Factors: PHF Group.

Figure 20. Demographic Factors: RTF Group.

B.   STATISTICAL ANALYSIS

JMP (Version 12.0.1; SAS Institute, 2015) was used to conduct all statistical analysis for this study.

For the statistical analysis of the results, three different response variables were used:

- Observation Time: the mean time that the participant spent with the periscope raised for all observations in a trial.

- Raw Score: the total of points accumulated during one trial. The raw score calculation consists of all correct and incorrect actions rights and wrongs committed by the participant during the trial.

- Adjusted Score: this response variable represents overall performance combines both speed and precision factors. Figure 21 illustrates a surface plot with participants' mean adjusted scores, mean raw scores and mean observation times.
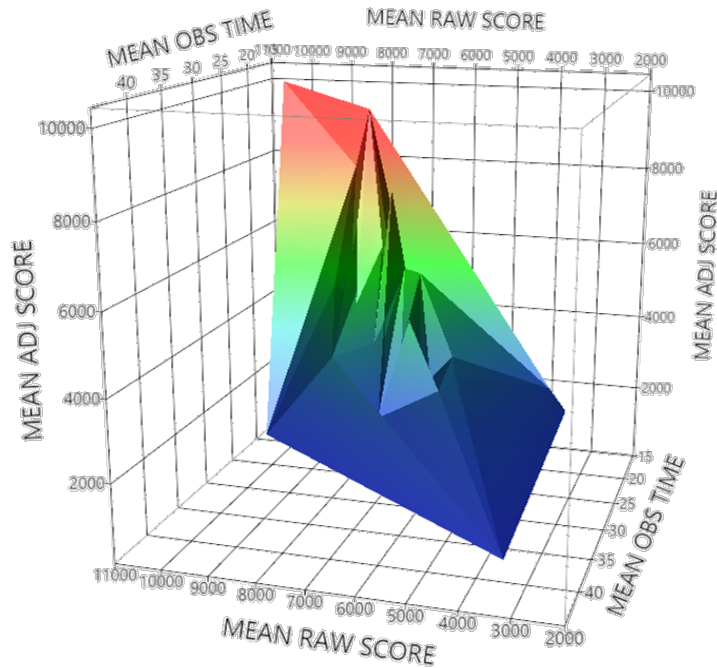
Figure 21. Surface Plot of the Three Response Variables.

The variables analyzed as influence factor for the response variables are:

- Group (Categorical - PHF or RTF)

- Gamer (Categorical - YES or NO);

- Military (Categorical - YES or NO);

- Navy (Categorical - YES or NO);

- Submariner (Categorical - YES or NO);

- Years of Service (YOS) (Categorical - YES or NO)

- Gender (Categorical - MALE or FEMALE)

- Preferred hand for writing (Categorical - RIGHT or LEFT)

- Trial (Interval - 1, 2, or 3)

1.   Research Question 1

Research question 1 was "Can a game-based, part-task periscope simulation that incorporates the appropriate cues to train identified knowledge, skills, and abilities be developed to supplement periscope operator training?" Paired-samples *t*-tests were used to verify the improvements on adjusted scores achieved by the 34 participants throughout the three trials of the experiment. Results indicated that performance improved significantly for each trial. See Table 5 and Figure 22. Detailed results can be found in Appendix H.

Table 5.   Paired-Samples *t*-Test Results for Participants' Adjusted Scores.

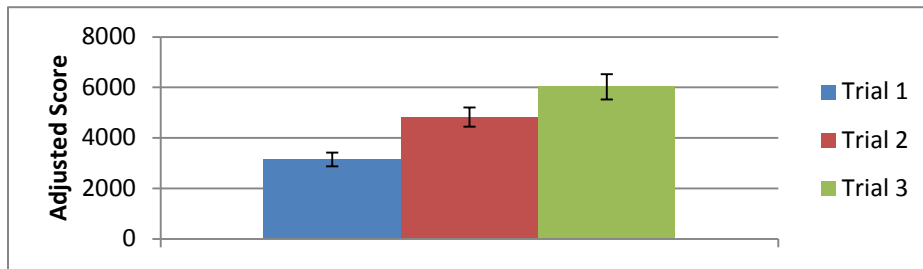|	*M*	*SD*	*t*	Sig. (2-tailed)
Trial 1	3146.36	1553.38	6.99	$< .0001$
Trial 2	4826.28	2215.14		
Trial 1	3146.36	1553.38	7.48	$< .0001$
Trial 3	6024.04	2943.65		
Trial 2	4826.28	2215.14	4.00	.0003
Trial 3	6024.04	2943.65		

Figure 22. Adjusted Scores by Trial.

2.   Research Question 2

Research question 2 was "Do differences in trainee performance exist when exposed to different feedback types over the course of multiple sessions?" Paired-samples *t*-tests were used to analyze adjusted scores improvements for each condition (RTF and PHF). Results indicated that performance improved significantly for each trial for RTF and PHF (see Figure 23). Table 6 (PHF) and Table 7 (RTF) show the results for adjusted score for each group. Detailed results are shown in Appendix I.

Table 6.   Paired-Samples *t*-Test Results for Participants' Adjusted Scores in the PHF Group.

	M	*SD*	*t*	Sig. (2-tailed)
Trial 1	2798.60	1441.74	6.89	< .0001
Trial 2	4899.35	2062.07		
Trial 1	2798.60	1441.74	7.14	< .0001
Trial 3	6178.79	2496.86		
Trial 2	4899.35	2062.07	3.48	.003
Trial 3	6178.79	2496.86		

Table 7.   Paired-Samples *t*-Test Results for Participants' Adjusted Scores in the RTF Group.

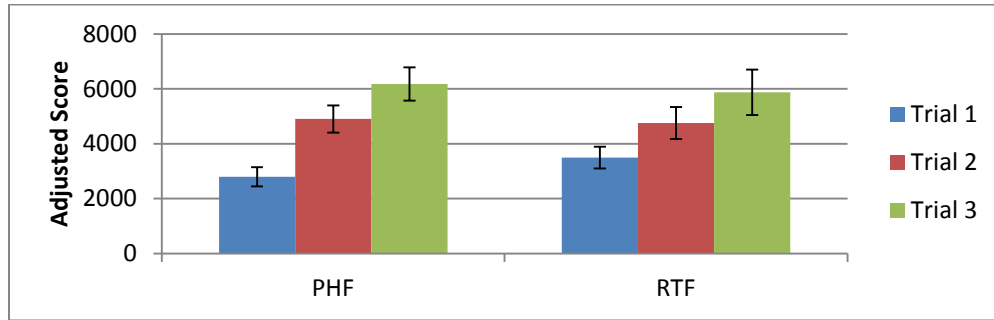|	*M*	*SD*	*t*	Sig. (2-tailed)
Trial 1	3494.11	1625.17	3.59	.002
Trial 2	4753.20	2420.10		
Trial 1	3494.11	1625.17	3.98	.001
Trial 3	5869.29	3403.90		
Trial 2	4753.20	2420.10	2.31	.034
Trial 3	5869.29	3403.90		

Figure 23. Adjusted Scores by Trial, by Group.

3.   Exploratory Investigation of Research Question 2

Based upon the observation of the results presented above, an exploratory analysis was conducted to determine if differences existed between groups across trials. When comparing performance achieved by participants in each group for each trial, a significant difference in adjusted scores between PHF group ($M = 2586.17$, $SD = 1182.75$)

and RTF group ($M = 3494.11$, $SD = 1625.17$), $t(29.20) = 1.84$, $p = 0.0378$ were observed for trial one (see Figure 24). Significant differences between PHF and RTF were not observed for trials two and three.
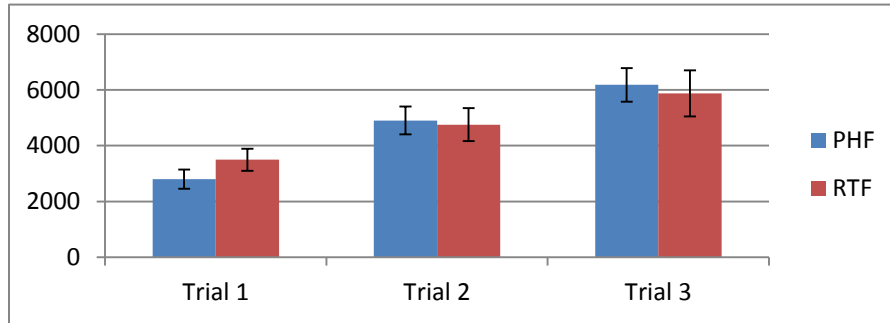

Figure 24. Adjusted Scores Compared between Groups per Trial.

In order to visually observe raw score (related to the precision of observations) and observation time (related to participants' speed), these variables were plotted on the graph shown in Figure 25. Mean raw score (Y-axis) is compared to observation time (X-axis) and four quadrants were constructed around the medians—7125 points and 25.64 seconds, respectively. Quadrant I shows the lowest possible adjusted scores (high observation times and low raw scores). Data points in quadrant II represent short observation times and low raw scores, while quadrant III shows long observation times and high raw scores. The best performance is shown in quadrant IV and represents participants with short observation times and high raw scores.
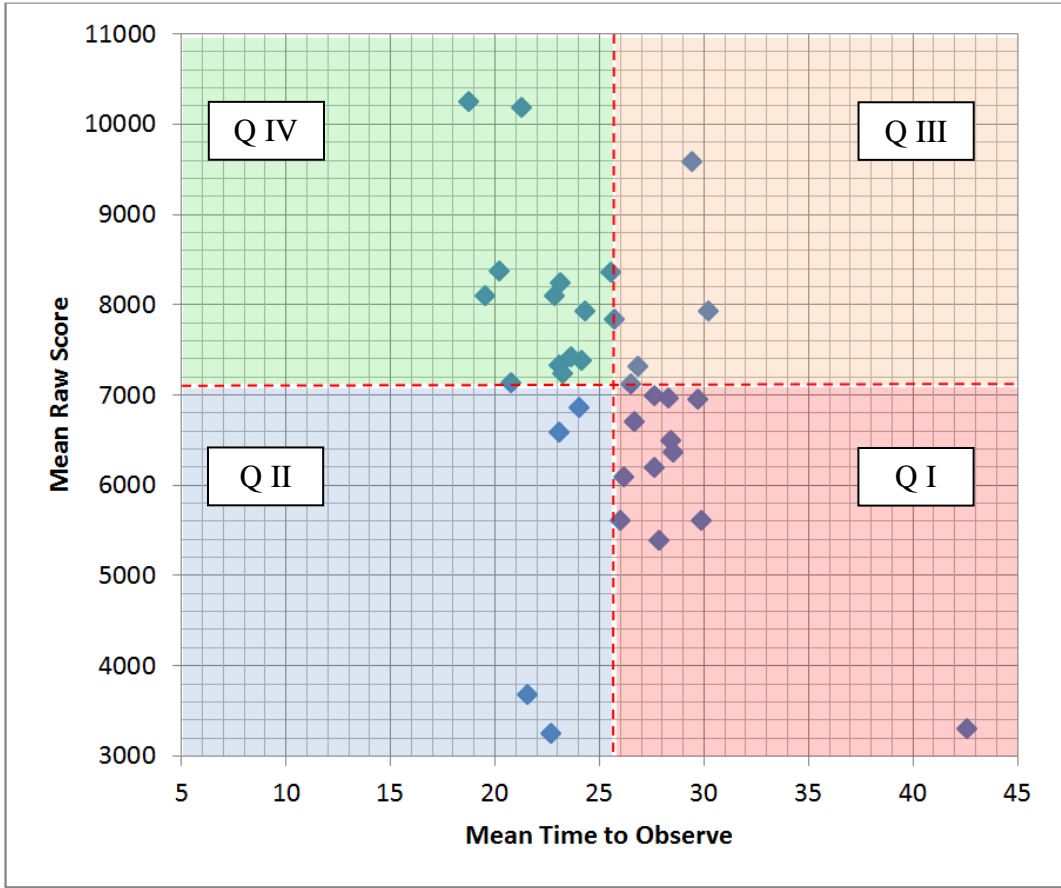
Figure 25. Subjects Distributed on Quadrants Based on Mean Results for the
Three Trials.

By observing participants' evolutions through the quadrants trial by trial, it is
possible to observe that there was a general movement from Q-I to Q-IV, confirming the
conclusion that performance incrementally improved through each trial (see Table 8).

Table 8.   Quadrant Distribution across Trials.

QUADRANT	TRIAL 1	TRIAL 2	TRIAL 3
Q I	17	11	7
Q II	3	5	7
Q III	10	7	3
Q IV	4	11	17

4.   Research Question 3

Research question 3 was "What, if any, differences exist between real-time feedback (RTF) and post-hoc feedback (PHF) on final trainee performance?" The experiment was designed to allow the comparison between treatment groups. Both PHF and RTF subjects received their specific feedback for the first and second trials. The third trial for both groups was the same, with no feedback provided, and thus provides a more equivalent representation of the performance of each group. Therefore, the third trial was used for all further analysis involving comparisons between groups.

A *t*-test was used to compare the adjusted score achieved for each group and revealed that there was not enough evidence to reject the null hypothesis $H3_0$. There was no significant difference between the adjusted scores achieved from participants in PHF group (*M* = 6178.79, *SD*=2496.89) and RTF group (*M* = 5896.29, *SD* = 3403.90), *t*(29.35) = -0.3023, *p* = 0.7646 (see Figure 26).

Oneway Analysis of ADJ SCORE RUN3 By GROUP

Quantiles

Level	Minimum	10%	25%	Median	75%	90%	Maximum
PHF	3212.387	3516.48	4353.645	5554.447	7720.583	10039.78	13093.44
RTF	1744.809	1998.616	3001.262	4703.991	9072.266	11248.7	12510.28

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
PHF	17	6178.79	2496.86	605.58	4895.0	7462.6
RTF	17	5869.29	3403.90	825.57	4119.2	7619.4

t Test

RTF-PHF

Assuming unequal variances

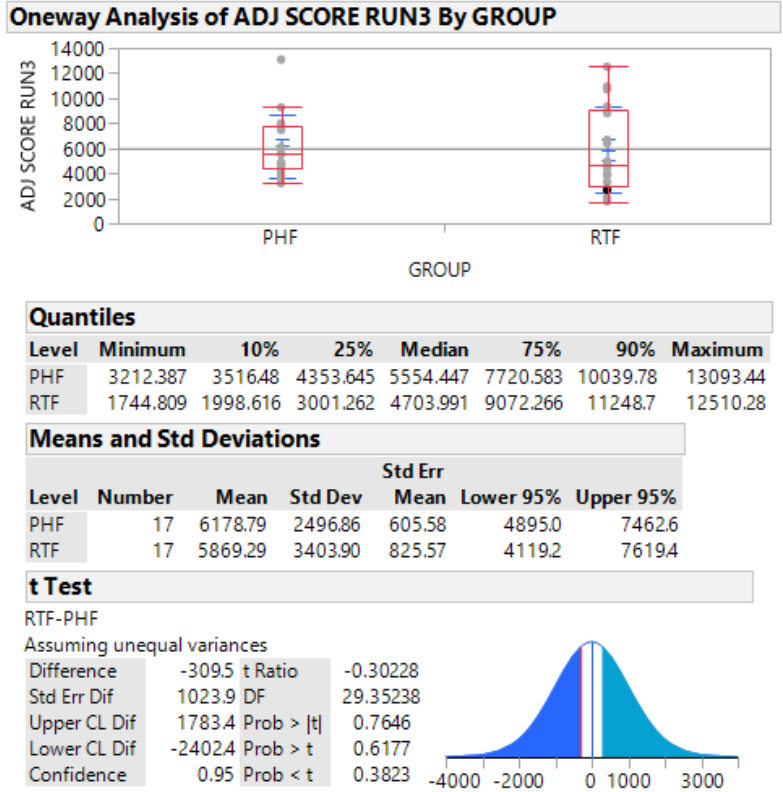|			
Difference	-309.5	t Ratio	-0.30228
Std Err Dif	1023.9	DF	29.35238
Upper CL Dif	1783.4	Prob > |t|	0.7646
Lower CL Dif	-2402.4	Prob > t	0.6177
Confidence	0.95	Prob < t	0.3823

Figure 26. Adjusted Scores on Trial 3 Compared between Groups.

5.   Exploratory Investigation on Research Question 3

As no significant performance differences were observed for trial three, additional analysis were conducted to potentially observe effects of other contributing factors.

To determine the effects of demographic factors on adjusted score achieved in trial 3, a linear regression fit was performed across all 34 participants. The factors *military*, *submariner*, *gender*, and *handedness* were not considered in the analysis across groups due to their small representation in this dataset. None of the factors was statistically significant to the model for the PHF group. On the RTF group, the factors *age* ($p = 0.005$), *gamer* ($p = 0.02$), and the combination *navy * YOS* ($p = 0.013$) were included as significant for the regression model, $F(6,10) = 4.42$, $p = 0.019$, $R^2 = .073$ with an adjusted $R^2 = .561$. Figure 27 details the elements of this analysis.
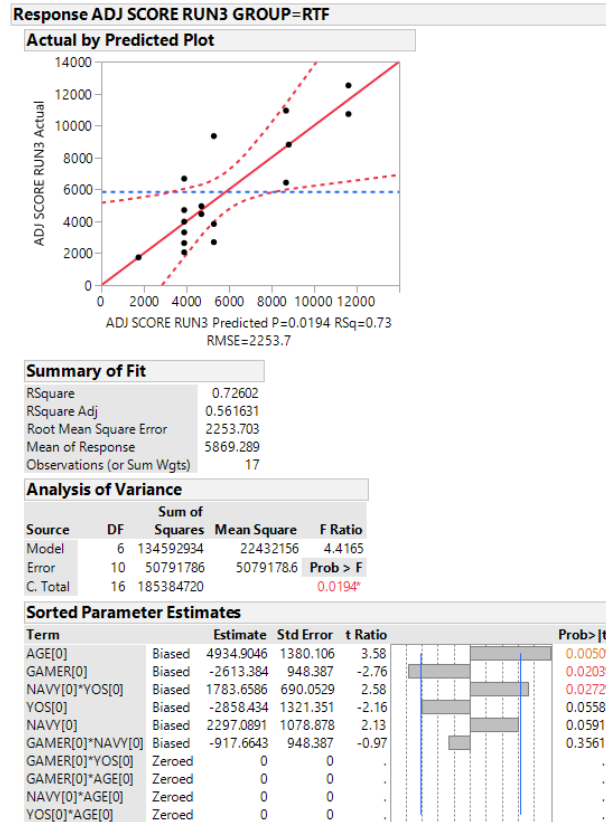
Figure 27. Effects of Demographic Factors on Adjusted Scores.

An additional two-tailed *t*-tests comparing both response variables (raw scores and observation times) by the factors (gaming experience and age) was performed to determine if age and gamer experience contributed to the results above. Results showed statistically significant difference of raw scores between *gamers* (M = 9066.67, SD = 292.97) and *non-gamers*, $t(14.94)$ = 2.41, p = 0.029 (see Figure 27). Statistically significant difference were also found for observation times for *non-gamers* (M = 26.01, SD = 4.89) and *gamers* (M = 21.53, SD = 2.17), $t(7.37)$ = -2.47, p = 0.041; and for age group *32 years or less* (M = 22.54, SD = 3.28) and age group *above 32 years* (M = 27.10, SD = 4.95), $t(14.98)$ = 2.28, p = 0.037 (see Figures 28 and 29).
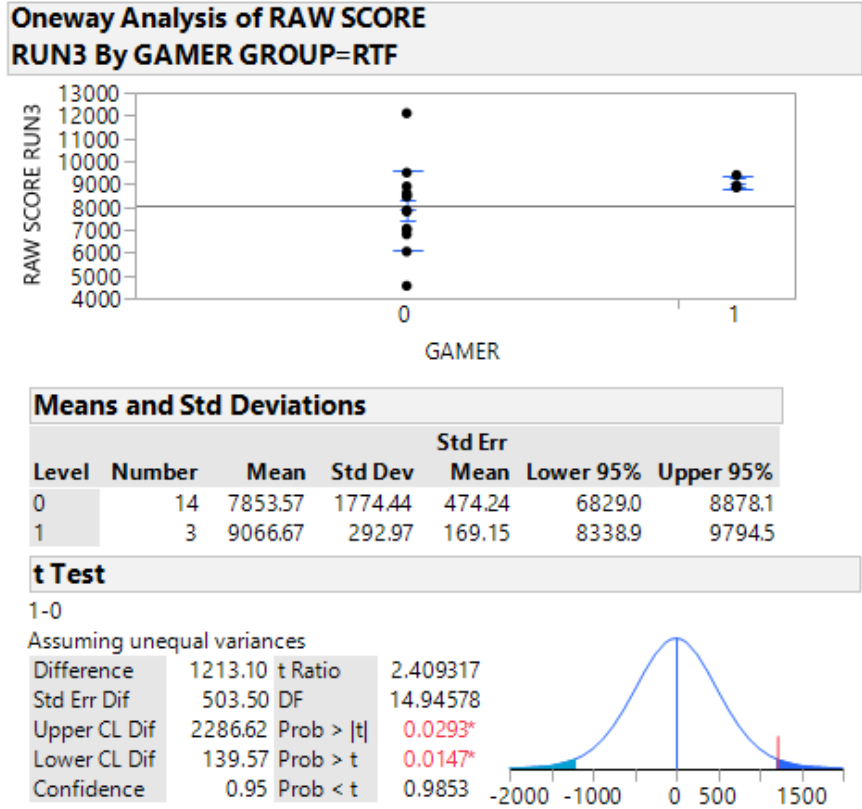
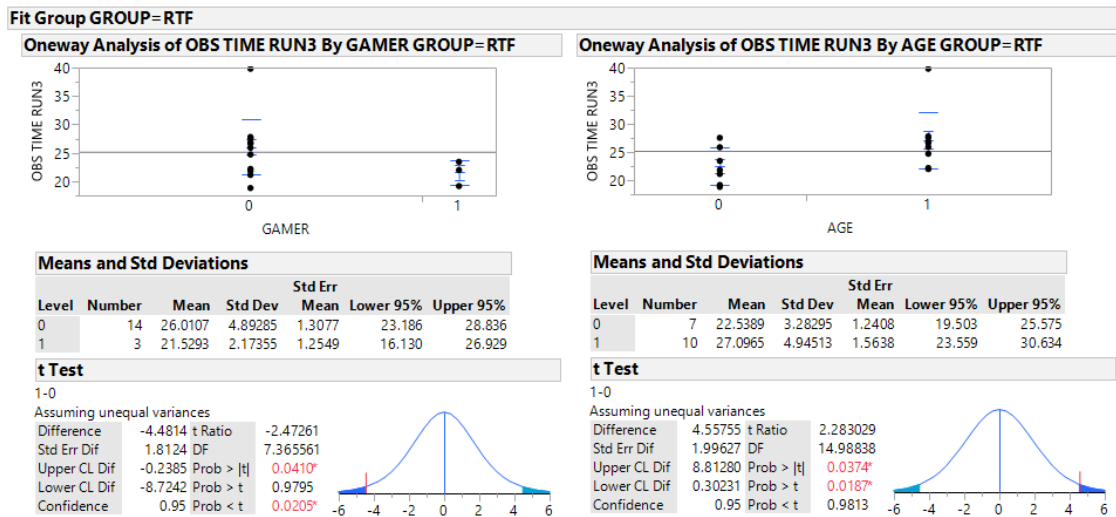Figure 28. Statistically Significant Difference on Raw Scores for Gamers.

Figure 29. Statistically Significant Difference on Observation Times for Both
Gamers and Participants <=32 Years Old.

VII. DISCUSSION

The overarching goal of this thesis was to develop a prototypical training tool for submarine officers and to determine if use of the tool could improve performance. Following an ISD process, RQ1 was answered by the analysis, design, development, and implementation of the STTS. Further, the results of paired t-tests comparing performance scores across the three trials demonstrate that users of the system did experience a learning effect on the simulated GODEX task. These results should be considered in context of the conditions of the experiment and that performance gains shown here may not guarantee improved performance on an actual GODEX mission.

The performance increase for each group during the experiment (RQ2) was assessed by paired t-tests comparing adjusted scores for each trial. The significant increase of adjusted scores for both groups taken with the exploratory analysis which showed significant difference of performance between groups only on trial one (RTF > PHF), can be attributed to the total lack of feedback received by the PHF group during the first trial. Participants receiving RTF higher performance scores in trial one are likely due to the feedback they received during that trial. These results support the notion that RTF can be used, at least initially, to improve performance under conditions similar to those used in this study.

To determine whether different types of feedback would affect the performance of participants (RQ3), the mean scores obtained by participants in each group were compared. There was no statistically significant difference for the third trial (trial used to make comparisons across groups).

The simple comparison of mean adjusted scores for RQ3 was taken to be non-conclusive. An exploratory analysis provided a deeper understanding about the effect of demographic factors on adjusted scores. Participants who received RTF and had no-gaming background had a significant decrement in their performance compared to gamers. Further analysis showed that there was a significant increase on observation time (negatively affecting the adjusted score). Additionally, gamers exposed to RTF, were

more precise in their observations thus achieving better raw scores. The age factor affected the observation time, indicating that participants older than 32 who were provided with RTF had longer observation times, indicating that this type of feedback can be distracting. These results suggest that age, experience, and behavioral factors should be considered when deciding the feedback type that training participants should receive when developing a system for training. Further, using the background and age of participants, an intelligent tutoring system should be able to deliver only the necessary amount of information, in the correct moment during training events.

As noted in section VI.A., one subject employed an approach to maximize the STTS score that was not consistent with the instructions of the game. After trial 1, the subject decided to ignore the lateral targets and focus solely on the center contact. The decision to not observe the other contacts allowed the observation time for each become negative. These actions resulted in the subject being able to make fewer observations. This resulted in a better SIR and a much higher adjusted score. The raw score was not highly impacted because the scoring rules were defined so these actions would result in only the loss of points one time for each contact that has its look interval exceeded. As stated above, data from this trial were not included in the final analysis due to the fact that the participant deliberately disobeyed the rules as they applied to submariners in order to maximize the adjusted score.

Game developers, especially serious game developers, must thoughtfully create rules and scoring approaches. If subverting the game's intent to better achieve the goal does not incur a penalty from the rules, users are likely to discover and exploit potential loopholes. Game designers need to be very careful that their games do not contain such "cheats," since it can lead to negative training, and they must constantly tune play to ensure only correct real-world behaviors result in acceptable scores in the game or simulator.

VIII. CONCLUSION AND FUTURE WORK

A. CONCLUSION

The prototype developed for this thesis is an initial prototype that can be the basis for future training systems for the BNSS. Additionally, the results presented here demonstrate the value of automated feedback to performance. Of equal importance, when designing adaptive or intelligent training systems, understanding demographics of the training audience should be considered when determining the type of feedback to employ. Knowing the differences in efficacy of feedback type for different populations will aid in the appropriate selection feedback for the desired training.

Clearly, affordable part-task training solutions that incorporate automated feedback such as the STTS can be rapidly developed by following a sound ISD process. Future instructional systems designers can benefit from the results and conclusions of this thesis. Further, the development of the STTS was supported by the extensive features available in the Unity community, the use of external assets and the range of support, which can be found online, for beginners and experts alike, resulted in a steep learning curve. This resulted in a complete simulation, fully functional for the purpose of this thesis, in only few months. This accomplishment demonstrates that the rapid innovation of systems is now firmly in the realm of the possible. Ultimately, this may mean that the approach to designing, validating and acquiring new training systems and programs may need to be modified in order to take advantage of these advances.

B. FUTURE WORK

In order to be validated as a training tool, the STTS and concepts explored here will require modifications and additional transfer of training research. The ability to tailor feedback, by the system, instructor and/or trainee could provide improved training results and these areas should be isolated and explored in a controlled environment. It is important to note that for this study, RTF was provided as pop-up text messages that were viewable for three seconds on the main screen of the simulation for each action taken. Future research using the STTS or other game-based simulations should consider

investigating the impact of the number of messages on performance during time constrained tasks. Additionally, a worthy exercise would be an investigation of how pausing the simulation and providing longer periods of instructions. Finally, the influence of feedback modality on performance and retention should be investigated.

The system developed for this thesis is a prototype and a starting point for developing a real tactical training tool. The considerations made to keep the STTS an UNCLASS system limited the scope of what can be trained by a real submarine officer by this system. Future work to adjust this base architecture to a complete tactical trainer include:

- Incorporation of realistic buoyancy effects with a different sea model and realistic physics, to allow for the adjustment of varied conditions of sea-states and weather.

- The implementation of voice recognition in order to make the simulator more closely model the SO's actions as well as optimize the usability of the GUI solution developed for this thesis.

- The incorporation of excluded TTPs and other types of observations for the GODEX mission which would need to be included if implementing a classified version for use in controlled environments.

- The implementation of an intelligent tutoring system, capable of adapting to the type and amount of feedback, based on trainee's performance, previous experience, and age.

- A usability study using a sample from the population from the intended users of the simulation.

- Additionally, this simulation could be adjusted for use with tablets, smartphones, and other display technologies in order to increase portability and take advantage of built in gyroscopes and accelerometers for control the periscope.

APPENDIX A. GROUP ASSIGNMENT ALGORITHM

1. Assign 0 or 1 to each of the 5 variables on the equation's right side based on the answers given on the Demographics Survey (0 if "NO", 1 if "YES");

$$experienceScore = (gamer \times 15) + (military \times 5) + (navy \times 10) + (sub \times 20) + (yos \times 5)$$

2. Read from files the experiences of subjects in each group;
3. If difference of number of subjects is more than three, then assign the subject to the group with fewer subjects and go to step 7;
4. Average the experience in each group (m and n are the number of subjects in the control and treatment groups, respectively);

$$oldMeanControl = \frac{\sum_{i=1}^{m} experience(i)}{m}$$

$$oldMeanTreat = \frac{\sum_{i=1}^{n} experience(i)}{n}$$

5. Find the new means for each group considering that the subject was assigned to that group;

$$newMeanControl = \frac{\sum_{i=1}^{m} experience(i) + experienceScore}{m+1}$$

$$newMeanTreat = \frac{\sum_{i=1}^{n} experience(i) + experienceScore}{n+1}$$

6. Assign the subject to the group that will generate a smaller difference between means;
If

$(|oldMeanControl - newMeanTreat| < |oldMeanTreat - newMeanControl|)$, then

assign the subject to the treatment group;

If $(|oldMeanControl - newMeanTreat| > |oldMeanTreat - newMeanControl|)$, then

assign the subject to the control group;

If $(|oldMeanControl - newMeanTreat| = |oldMeanTreat - newMeanControl|)$, then

assign the subject to the group with fewer subjects;

7. Write a new line in the correspondent file with subject number and his/her experienceScore;
8. Setup the simulation to present feedback accordingly to the group chosen.

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APPENDIX B. NPS IRB PROTOCOL APPROVAL

Naval Postgraduate School
Human Research Protection Program

From: President, Naval Postgraduate School (NPS)
To: LT Lee Sciarini, USN
       Mr. Perry McDowell, Modeling, Virtual Environments and
       Simulation Institute (MOVES)
       LT Rodrigo da Silva Vieira, USN
Via: Vice Chairman, Institutional Review Board (IRB)

SUBJ: GAME-BASED PERISCOPE SIMULATOR FOR SUBMARINE OFFICERS
       TACTICAL TRAINING

Encl: (1) Approved IRB Initial Review Protocol

1. The NPS IRB is pleased to inform you that the NPS President
has approved your initial review protocol (NPS IRB#
NPS.2016.0051-IR-EP7-A). The approved IRB Protocol is found in
enclosure (1). Completion of the CITI Research Ethics Training
has been confirmed.

2. This approval expires on 30 June 2016. If additional time
is required to complete the research, a continuing review report
must be approved by the IRB and NPS President prior to the
expiration of approval. At expiration all research (subject
recruitment, data collection, analysis of data containing PII)
must cease.

3. You are required to obtain documented consent as outlined in
the approval protocol.

4. You are required to report to the IRB any unanticipated
problems or serious adverse events to the NPS IRB within 24
hours of the occurrence.

5. Any proposed changes in IRB approved research must be
reviewed and approved by the NPS IRB and NPS President prior to
implementation except where necessary to eliminate apparent
immediate hazards to research participants and subjects.

6. As the Principal Investigator (PI) it is your responsibility
to ensure that the research and the actions of all project
personnel involved in conducting this study will conform with
the IRB approved protocol and IRB requirements/policies.

Subj: GAME-BASED PERISCOPE SIMULATOR FOR SUBMARINE OFFICERS
        TACTICAL TRAINING

7.   At completion of the research, no later than expiration of
approval, the PI will close the protocol by submitting an End of
Experiment Report.

K. J. Euske

Digitally signed by K. J. Euske
DN: cn=K. J. Euske, o=NPS,
ou=GSBPP,
email=kjeuske@nps.edu, c=US
Date: 2016.04.04 15:06:30 -07'00'

Kenneth J. Euske, PhD
Vice Chair
Institutional Review Board

Ronald A. Route
Vice Admiral, U.S. Navy (Ret.)
President, Naval Postgraduate School

Date: 4/6/16

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APPENDIX D. RECRUITMENT SCRIPT

"Game-based Periscope Simulator for Submarine Officers Tactical Training"

Good Morning,

Curious about We are conducting an experiment as part of a research study to increase our understanding in how feedback can impact the overall performance during training.

As a participant, you will use the "Submarine Tactical Training Simulation" which was developed to support the experiment.

We recognize how busy you are. Your participation will support the effort of a thesis student, and we appreciate your willingness to assist in this study.

If you decide to participate, you will act as a Submarine's Commanding Officer and your goal will be to keep the submarine safely in the periscope depth while surface contacts approach in collision route.

All participants will be provided detailed instructions on the use of the simulation and the simulated task you will be asked to perform.

The experiment will take from 1 to 1.5 hours.

Risks associated with this study are minimal. Participation is voluntary. The point of contact for risk questions or concerns is the Principal Investigator, Dr. Lee Sciarini (*lwsciari@nps.edu*). Prospective subjects may contact NPS IRB Vice - Chair, Dr. Ken Euske (831-656-2860 - *kjeuske@nps.edu*) regarding rights as a participant.

All the data collected will be kept confidential. Each participant will be assigned a number code to help ensure that personal identifiers are not revealed during the analysis and write up of findings.

There is no compensation for participating in this study. However, your participation will be a valuable addition to our research and findings could lead to greater understanding of feedback as tools for training and education systems.

If you are willing to participate please suggest a day and time that suits you and I'll do my best to be available. If you have any questions please do not hesitate to ask.

The experiment poster is attached.

Thanks!

Rodrigo da Silva Vieira
Lieutenant Commander
Brazilian Navy Submarine Officer
MOVES Department

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APPENDIX E. INFORMED CONSENT FORM

Naval Postgraduate School
Consent to Participate in Research

Introduction. You are invited to participate in a research study entitled "Game-based Periscope Simulator for Submarine Officers Tactical Training". The purpose of the research is to analyze the impact of different types of feedbacks over the performance of a subject in a military training context.

Procedures. 30 – 40 NPS students, faculty or staff (military or not) will complete an operative task as a submarine Captain. The objective of the task is the maintaining the safety of the submarine and crew while staying in the periscope depth as surface warships approach. Stopwatches will display intercept times for approaching ships (time remaining for the next observation of that contact). You will prioritize observations by remaining time to intercept and execute the "Go deep" command (dive) when the closest contact reaches a critical point. You will be asked to complete this task three times, with 8-10 minutes expected for each trial. You also will be asked to complete a demographic survey, and a post-task survey. The duration of your participation will be approximately 1-1.5 hours. The simulation used and procedures described are new and are only related to the research and serve no purpose other than this research endeavor.

Location. The study will take place *at NPS, Watkins 212a.*

Cost. There is no cost to participate in this research study.

Voluntary Nature of the Study. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw. The alternative to participating in the research is to not participate in the research.

Potential Risks and Discomforts. We anticipate no to very minimal discomfort. Participants will sit in an air-conditioned room on a comfortable chair for about 1-1.5 hours while they complete the computerized tasks and answer the surveys. Breach of confidentiality is a risk.

Anticipated Benefits. If this study proves that one type of feedback is significantly better than the other, future training and education simulations can benefit from this knowledge and the methods of training intervention can be optimized. You may gain insight into basic submarine operations and if you are a submariner you can benefit from this basic training prototype.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. In accordance with NPS data storage instruction, data will only be kept on approved NPS Systems. Hard copies of informed consent forms will be kept in a locked container behind a locked door. To protect against disclosure of any information all participants will be assigned a random identification number and will only be identified on surveys by that number. All the scores gained by the subject while operating the simulation will only be associated with that random number as well. All demographic data will be kept secure in a password protected computer.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Lee Sciarini at 831-656-7675 or *lwsciari@nps.edu*. Questions about your rights as a research subject or any other concerns may be addressed to the Naval Postgraduate School IRB Vice - Chair, Dr. Ken Euske, 831-656-2860, *kjeuske@nps.edu*.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

_____   _____

Participant's Signature   Date

_____   _____

Researcher's Signature   Date

APPENDIX F. VIDEO TUTORIAL SCRIPTS

VIDEO TUTORIAL SCRIPT
REAL-TIME FEEDBACK GROUP

Welcome to the SUBMARINE TACTICAL TRAINING SYSTEM, and thank you for applying to this experiment. This is the MAIN SCREEN. In the LEFT PANEL you will see INTERIOR OF THE SUBMARINE, if the periscope is DOWN or the OCEANIC ENVIRONMENT outside the submarine, if the periscope is UP. The CENTER PANEL is called INPUT PANEL and it will be used to control the periscope, give orders and provide information about the observations. The RIGHT PANEL is called the FEEDBACK PANEL and it will be used to show the SCORES and a log of the feedback received before.

One observation consists of this sequence:

1. CHOOSE the contact to observe;
2. RAISE the periscope;
3. Take the contact's BEARING;
4. Take the contact's DISTANCE;
5. LOWER the periscope;
6. Inform the contact's ANGLE OF BOW;
1. CHOOSE the contact to observe

Click on one of these buttons to choose the contact to observe. These three buttons correspond to the three contacts outside. Contact 1 is the Frigate on your right side, Contact 2 is the Frigate on your left side, and Contact 3 is the one on your bow. In order to select the most dangerous contact, you will use these 3 stopwatches. As if it happens to the buttons, these three stopwatches also correspond to the contacts outside. To select the correct contact, you will observe the stopwatches and click on the button that corresponds to the Stopwatch with the least remaining time (in this case, the contact number 3). The remaining time in the stopwatch indicates the maximum time to observe the contact.

> ➤ ATTENTION: Always choose the contact that has the LEAST remaining time. If you choose the wrong contact to observe, you will have to first finish the observation of the wrong contact and in the next observation, choose the correct contact to observe. If you see a negative sign in one of the stopwatches, it means that you have to choose this one for the next observation.

2. RAISE the periscope

After selecting the contact, you will have some amount of time in the correspondent stopwatch. Try to RAISE THE PERISCOPE only when this remaining time is close to ZERO. This procedure will allow you to have a better SCORE ADJUSTED. The SCORE ADJUSTED is calculated based on the main SCORE and the amount of exposition time, which means the accumulated total time that the periscope was up. The longer you can stay with the periscope down, the better your ADJUSTED SCORE will be. You can advance the time by clicking the numbers from 2 to 9 in the main keypad. While holding the key number 2, the time will advance 2X faster. While holding the key number 3 the time will advance 3x faster, and so on. When you release the key, the time will return to normal speed. Use this feature wisely: it is highly recommended that you use the spare time to study the feedback received before.

➢ Click on this button to RAISE THE PERISCOPE. Less than 20 seconds is considered a good timing.

This is the OUTSIDE VIEW. This is what you see when looking through the periscope. Here you can read the bearing, the true angle to where the periscope is pointing. Here you can read the distance. When the stadimeter is off the distance shown is 16000. When the stadimeter is on, the distance will be displayed here. Later I will explain how to take the contact's distance. Now let's understand how to manipulate the periscope.

➢ To rotate the periscope to the RIGHT use the RIGHT MOUSE BUTTON.
➢ To rotate it to the LEFT, use the LEFT MOUSE BUTTON.
➢ To make the rotation FASTER, press the SHIFT button together with the mouse.
➢ To make the rotation SLOWER, use the CONTROL button.
➢ To swap between high and low ZOOM, press the MIDDLE MOUSE BUTTON.

3. Take the contact's BEARING

Now you are able to take the contact's BEARING.

➢ Align the vertical line in the middle of the periscope screen to the center of the contact.
➢ Click on the BEARING MARK button.

4. Take the contact's DISTANCE

To take the contact's distance:

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➤ Rotate down the MOUSE WHEEL until the horizontal rear mast is aligned to the ship's WATER LINE.
➤ Be sure that the ZOOM is applied (by clicking the MIDLE MOUSE BUTTON).
➤ Click on the DISTANCE MARK button.

5. LOWER the periscope

Before LOWERING the periscope:

➤ TURN OFF the stadimeter by rotating the MOUSE WHEEL UP;
➤ Return the ZOOM to LOW by clicking the MIDLE MOUSE BUTTON.

6. Inform the contact's ANGLE OF BOW

The "Angle of Bow" is the angle from where the contact can look to your submarine. This angle starts from his bow, to the left or to the right. So, to inform the AOB, you first need to inform the side (PORT or STARBOARD) and then the value of the Angle. In this example, the contact can see you from his RIGHT so the side is STARBOARD. This side is also the side of the ship which you can see. The value of the angle is around 40°. So the complete AOB is STBD40. This is the image on the periscope. In this example, the contact can see you from his LEFT so the side is PORT. The value of the angle is around 70°. So the complete AOB is STBD70. This is how you will see it in the simulation. It does not matter in which side of your bow the contact is. Pay attention only to the side of the ship that you can see.

To set the AoB value:

➤ First choose the side (STDB or PORT) and then, rotate the mouse wheel DOWN to increase or UP to decrease. Click in the SUBMIT button to apply this value.
➤ Now you can start a new observation by choosing again the contact with least remaining time in the stopwatch.

You will repeat this whole process until one of the contacts gets so close that will force you to dive, to avoid collision. This distance is called GO DEEP RANGE. In this scenario, it is calculated as 1000 yards. If a contact is 1200 yards or less, you are allowed to dive. If it gets closer than 1000 yards, you have to dive immediately.

Congratulations! You have finished the tutorial. Now you are ready to the experiment. GOOD LUCK!

Welcome to the SUBMARINE TACTICAL TRAINING SYSTEM, and thank you for applying to this experiment. This is the MAIN SCREEN. In the LEFT PANEL you will see INTERIOR OF THE SUBMARINE, if the periscope is DOWN or the OCEANIC ENVIRONMENT outside the submarine, if the periscope is UP. The CENTER PANEL is called INPUT PANEL and it will be used to control the periscope, give orders and provide information about the observations. The RIGHT PANEL is called the FEEDBACK PANEL and it will be used to show the scores.

One observation consists of this sequence:

1. CHOOSE the contact to observe;
2. RAISE the periscope;
3. Take the contact's BEARING;
4. Take the contact's DISTANCE;
5. LOWER the periscope;
6. Inform the contact's ANGLE OF BOW;

1. CHOOSE the contact to observe

Click on one of these buttons to choose the contact to observe. These three buttons correspond to the three contacts outside. Contact 1 is the Frigate on your right side, Contact 2 is the Frigate on your left side, and Contact 3 is the one on your bow. In order to select the most dangerous contact, you will use these 3 stopwatches. As if it happens to the buttons, these three stopwatches also correspond to the contacts outside. To select the correct contact, you will observe the stopwatches and click on the button that corresponds to the Stopwatch with the least remaining time (in this case, the contact number 3). The remaining time in the stopwatch indicates the maximum time to observe the contact.

➢ ATTENTION: Always choose the contact that has the LEAST remaining time. If you choose the wrong contact to observe, you will have to first finish the observation of the wrong contact and in the next observation, choose the correct contact to observe. If you see a negative sign in one of the stopwatches, it means that you have to choose this one for the next observation.

2. RAISE the periscope

After selecting the contact, you will have some amount of time in the correspondent stopwatch. Try to RAISE THE PERISCOPE only when this remaining time is close to

ZERO. This procedure will allow you to have a better SCORE ADJUSTED. The SCORE ADJUSTED is calculated based on the main SCORE and the amount of exposition time, which means the accumulated total time that the periscope was up. The longer you can stay with the periscope down, the better your ADJUSTED SCORE will be. You can advance the time by clicking the numbers from 2 to 9 in the main keypad. While holding the key number 2, the time will advance 2X faster. While holding the key number 3 the time will advance 3x faster, and so on. When you release the key, the time will return to normal speed.

➢ Click on this button to RAISE THE PERISCOPE. Less than 20 seconds is considered a good timing.

This is the OUTSIDE VIEW. This is what you see when looking through the periscope. Here you can read the bearing, the true angle to where the periscope is pointing. Here you can read the distance. When the stadimeter is off the distance shown is 16000. When the stadimeter is on, the distance will be displayed here. Later I will explain how to take the contact's distance. Now let's understand how to manipulate the periscope.

➢ To rotate the periscope to the RIGHT use the RIGHT MOUSE BUTTON.
➢ To rotate it to the LEFT, use the LEFT MOUSE BUTTON.
➢ To make the rotation FASTER, press the SHIFT button together with the mouse.
➢ To make the rotation SLOWER, use the CONTROL button.
➢ To swap between high and low ZOOM, press the MIDDLE MOUSE BUTTON.

3. Take the contact's BEARING

Now you are able to take the contact's BEARING.

➢ Align the vertical line in the middle of the periscope screen to the center of the contact.
➢ Click on the BEARING MARK button.

4. Take the contact's DISTANCE

To take the contact's distance:

➢ Rotate down the MOUSE WHEEL until the horizontal rear mast is aligned to the ship's WATER LINE.
➢ Be sure that the ZOOM is applied (by clicking the MIDLE MOUSE BUTTON).

➥ Click on the DISTANCE MARK button.

5. LOWER the periscope

Before LOWERING the periscope:

➥ TURN OFF the stadimeter by rotating the MOUSE WHEEL UP;
➥ Return the ZOOM to LOW by clicking the MIDLE MOUSE BUTTON.

6. Inform the contact's ANGLE OF BOW

The "Angle of Bow" is the angle from where the contact can look to your submarine. This angle starts from his bow, to the left or to the right. So, to inform the AOB, you first need to inform the side (PORT or STARBOARD) and then the value of the Angle. In this example, the contact can see you from his RIGHT so the side is STARBOARD. This side is also the side of the ship which you can see. The value of the angle is around 40°. So the complete AOB is STBD40. This is the image on the periscope. In this example, the contact can see you from his LEFT so the side is PORT. The value of the angle is around 70°. So the complete AOB is STBD70. This is how you will see it in the simulation. It does not matter in which side of your bow the contact is. Pay attention only to the side of the ship that you can see.

To set the AoB value:

➥ First choose the side (STDB or PORT) and then, rotate the mouse wheel DOWN to increase or UP to decrease. Click in the SUBMIT button to apply this value.
➥ Now you can start a new observation by choosing again the contact with least remaining time in the stopwatch.

You will repeat this whole process until one of the contacts gets so close that will force you to dive, to avoid collision. This distance is called GO DEEP RANGE. In this scenario, it is calculated as 1000 yards. If a contact is 1200 yards or less, you are allowed to dive. If it gets closer than 1000 yards, you have to dive immediately.

Congratulations! You have finished the tutorial. Now you are ready to the experiment. GOOD LUCK!

APPENDIX G. POST-TASK SURVEY

GODEX Task
Post Task Survey

Subject number: Date:

1. During the task, what was your strategy to avoid "losing the stopwatch" of a contact?
    a. I had no specific strategy.
    b. I waited until the last moment to observe a contact to avoid "Exposition Penalty".
    c. I waited until the last moment, taking into consideration the stopwatch of the next contact to observe.
    d. I observed the contacts as soon as I finished the previous one.
    e. Other

    _____

    _____

    _____

2. Do you think that your performance improved during the course of the experiment? Please comment.

    _____

    _____

    _____

3. If you are (or was) a submariner, how do you compare this simulation to other that you have saw during your career. Please comment.
    a. Significantly Worse   _____
    b. Worse   _____
    c. Similar   _____
    d. Better   _____
    e. Significantly Better   _____
    f.   _____

4. If you received feedback during the runs, please rank the type of feedback from **least useful**(1) to **most useful**(5):
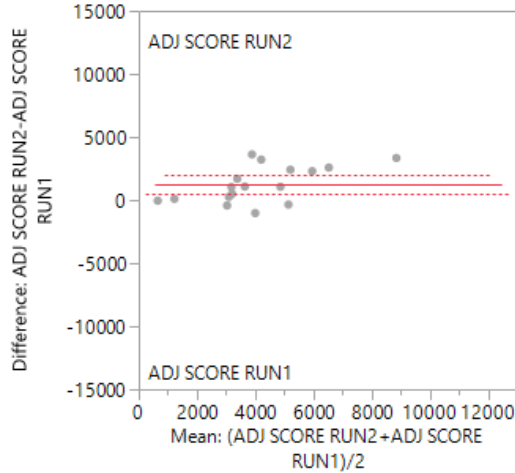   a. Auditory: 1   2   3   4   5
    b. Text (Pop-up Messages): 1   2   3   4   5
    c. Text (Message Log):   1   2   3   4   5
    d. Color (Pop-up Messages): 1   2   3   4   5
    e. Scores: 1   2   3   4   5

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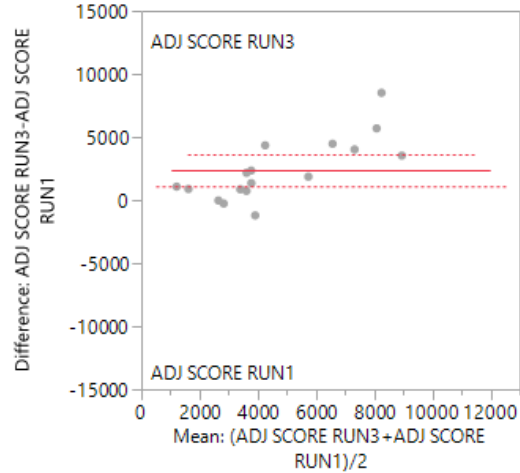
APPENDIX H. DETAILED STATISTICAL RESULTS

Matched Pairs GROUP=RTF
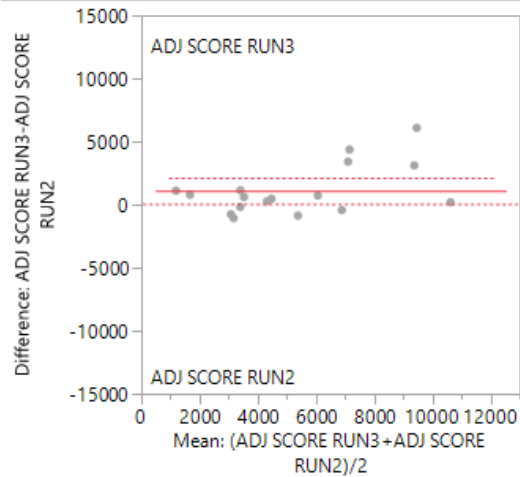
Difference: ADJ SCORE RUN2-ADJ SCORE RUN1

ADJ SCORE RUN2	4753.2	t-Ratio	3.587511
ADJ SCORE RUN1	3494.11	DF	16
Mean Difference	1259.09	Prob > |t|	0.0025*
Std Error	350.965	Prob > t	0.0012*
Upper 95%	2003.1	Prob < t	0.9988
Lower 95%	515.078		
N	17		
Correlation	0.81413		

Difference: ADJ SCORE RUN3-ADJ SCORE RUN1

ADJ SCORE RUN3	5869.29	t-Ratio	3.982161
ADJ SCORE RUN1	3494.11	DF	16
Mean Difference	2375.18	Prob > |t|	0.0011*
Std Error	596.455	Prob > t	0.0005*
Upper 95%	3639.61	Prob < t	0.9995
Lower 95%	1110.75		
N	17		
Correlation	0.73933		

Difference: ADJ SCORE RUN3-ADJ SCORE RUN2

ADJ SCORE RUN3	5869.29	t-Ratio	2.312486
ADJ SCORE RUN2	4753.2	DF	16
Mean Difference	1116.09	Prob > |t|	0.0344*
Std Error	482.636	Prob > t	0.0172*
Upper 95%	2139.23	Prob < t	0.9828
Lower 95%	92.9465		
N	17		
Correlation	0.81839		

Matched Pairs GROUP=PHF

Difference: ADJ SCORE RUN2-ADJ SCORE RUN1
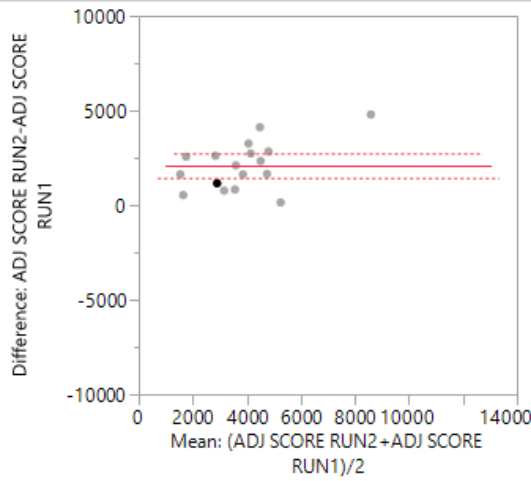
ADJ SCORE RUN2	4899.35	t-Ratio	6.885527
ADJ SCORE RUN1	2798.6	DF	16
Mean Difference	2100.75	Prob > |t|	<.0001*
Std Error	305.097	Prob > t	<.0001*
Upper 95%	2747.53	Prob < t	1.0000
Lower 95%	1453.97		
N	17		
Correlation	0.79858		

Difference: ADJ SCORE RUN3-ADJ SCORE RUN1
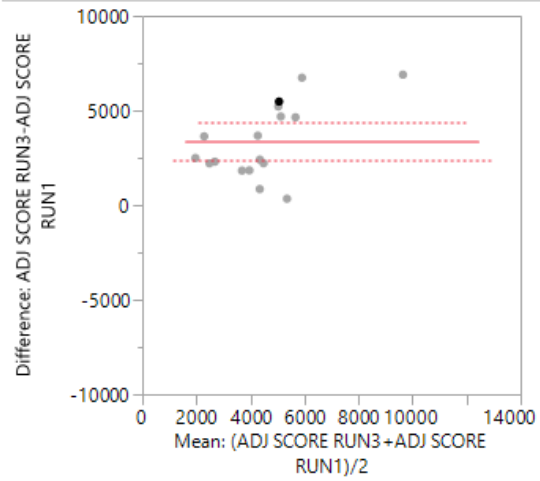
ADJ SCORE RUN3	6178.79	t-Ratio	7.143197
ADJ SCORE RUN1	2798.6	DF	16
Mean Difference	3380.18	Prob > |t|	<.0001*
Std Error	473.203	Prob > t	<.0001*
Upper 95%	4383.33	Prob < t	1.0000
Lower 95%	2377.04		
N	17		
Correlation	0.6259		

Difference: ADJ SCORE RUN3-ADJ SCORE RUN2
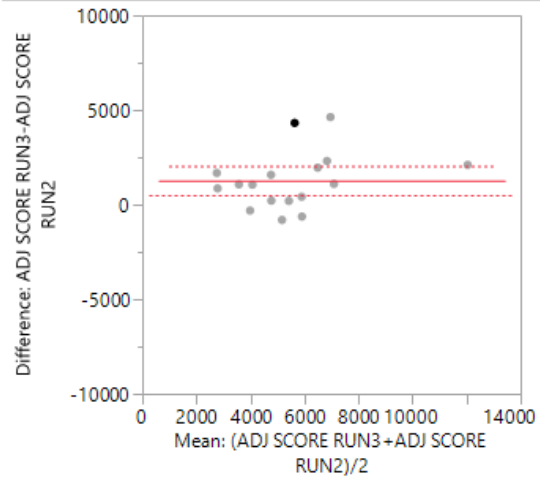
ADJ SCORE RUN3	6178.79	t-Ratio	3.479882
ADJ SCORE RUN2	4899.35	DF	16
Mean Difference	1279.43	Prob > |t|	0.0031*
Std Error	367.666	Prob > t	0.0015*
Upper 95%	2058.85	Prob < t	0.9985
Lower 95%	500.017		
N	17		
Correlation	0.79519		

LIST OF REFERENCES

About. (2016). Retrieved from http://www.blender.org/about

Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review*, *94*, 129–210.

Área Militar. (2011). Fragata Classe Greenhalgh (tipo Type 22) [Website]. Retrieved from http://www.areamilitar.net/directorio/NAV.aspx?NN=26

Astwood, R., Van Buskirk, W., Cornejo, J. & Dalton, J. (2008). The impact of different feedback types on decision-making in simulation based training environments. Proceedings of the 52nd Annual Meeting of the Human Factors and Ergonomics Society, New York, NY.

Bastos, R. S. (2014). *Development of a web-based periscope simulator for submarine officer training* (Master's thesis). Retrieved from Calhoun: http://calhoun.nps.edu/handle/10945/43873

Branson, R.K., Rayner, G.T., Cox, J.L., Furman, J.P., King, F.J., Hannum, W.H. (1975). Interservice procedures for instructional systems development. (Vols. 1-5) TRADOC Pam 350-30, NAVEDTRA 106A. Ft. Monroe, VA: U.S. Army Training and Doctrine Command.

Buff, W. L., & Campbell, G. E. (2002). What to do or what not to do?: Identifying the content of effective feedback. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *46*, 2074–2078. http://doi.org/10.1177/154193120204602517

Cohen, V. B. (1985). A reexamination of feedback in computer-based instruction: Implications for instructional design. *Educational Technology*, *25*(1), 33–37.

Deane, D. H., Hammond, K. R., & Summers, D. A. (1972). Acquisition and application of knowledge in complex inference tasks. *Journal of Experimental Psychology*, *92*(1), 20–26. Retrieved from http://dx.doi.org/10.1037/h0032162

Ferguson, J. H. (2014). C*anadian submariners in Europe, 1915–1917. In Through a Canadian periscope: The story of the Canadian submarine service* (2nd Edition), pp. 96–96. Toronto, Canada: Dundurn Group.

Gist, M. E., & Mitchell, T. R. (1992). Self-Efficacy: A theoretical analysis of its determinants and malleability. *Academy of Management Review*, *17*, 183–211.

Hammond, K. R. (1971). Computer Graphics as an Aid to Learning. *Science*, *172*(3986), 903–908. American Association for the Advancement of Science. Retrieved from http://science.sciencemag.org/content/172/3986/903

Hawkins, J. (2013, February 24). Ocean surface effects in Unity [Blog post]. Perth, WA: *ScrawBlog*. Retrieved from https://scrawkblog.com/2013/02/24/ocean-renderer-for-unity

Ilgen, D.R., Fisher, C.D., & Taylor, M.T. (1979). Consequences of individual feedback on behavior in organizations. *Journal of Applied Psychology*, *64*, 349–371.

Kluger, A.N. & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin*, *119*, 254–284.

Kozlowski, S.W.J., Toney, R.J., Mullins, M.E., Weissbein, D.A., Brown, K.G. & Bell, B.S. (2001). Developing adaptability: A theory for the design of integrated-embedded training systems. In E. Salas (Ed.), *Advances in human performance and cognitive engineering research* (pp. 59–123). Amsterdam: JAI/Elsevier Science.

Landsberg, C. R., Van Buskirk, W. L., & Astwood, R. S. (2010). Does feedback type matter? Investigating the effectiveness of feedback content on performance outcomes. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *54*(27), 2304–2308. Retrieved from http://pro.sagepub.com/content/54/27/2304

Mack, S. (2003). Perisher: Submarine command training in the Royal Navy. *Undersea Warfare*, Spring. Retrieved from http://www.public.navy.mil/subfor/underseawarfaremagazine/Issues/Archives/issue_18/perisher.htm

Michael, D. R., & Chen, S. L. (2005). *Serious games: Games that educate, train, and inform*. Independence, KY: Cengage Learning PTR..

NATO. (2002). *Multinational submarine and antisubmarine exercise manual* (MXP-1D, Vol. 1). Washington, DC: Author.

Perisher: The British Submarine Commanders Qualifying Course. (2007, October 27). Retrieved from http://forums.ubi.com/showthread.php/650328-PERISHER-The-British-Submarine-Commanders-Qualifying-Course-Forums

Perlin, K. (2002, July). Improving noise. In *ACM Transactions on Graphics (TOG)*, *21*(3), 681–682.

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science*, *18*(2), 119–144. Retrieved from http://link.springer.com/10.1007/BF00117714

SAS Institute. (2015), JMP (Version 12.0) [Computer software], Cary, NC. Retrieved from http://www.jmp.com/en_us/offers/free-trial.html

Smither, J.W., Wohlers, A.J., & London, M. (1995). A field study of reactions to normative versus individualized upward feedback. *Group Organization Management*, *20*, 61–89.

Summers, D. A., Taliaferro, J. D., & Fletcher, D. J. (1970). Judgment policy and interpersonal learning. *Behavioral Science*, *15*(6), 514–521. Retrieved from http://doi.wiley.com/10.1002/bs.3830150605

Todd, F. J., & Hammond, K. R. (1965). Differential feedback in two multiple-cue probability learning tasks. *Behavioral Science*, *10*(4), 429–435. Retrieved from http://doi.wiley.com/10.1002/bs.3830100406

Unity. (n.d.). Retrieved June 16, 2016, from http://unity3d.com/unity

White, D. S. H. (1993, October). The submarine command course. *The Naval Review*, *81*(4), 362–365. Retrieved from http://www.naval-review.com/issues/1990s/1993-4.pdf

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