

Embodying Knowledge Flow: The Collision of Synthetic Experience and the Real World

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Abstract

A case study is proposed to address the problem of knowledge friction encountered when attempting to acquire and transfer 1st person, spatial-temporal or experiential knowledge, e.g., operating heavy machinery, ship-handling, warfighting, etc. This research will be conducted in order to evaluate and characterize the use of low cost, Commercial-Off-The-Shelf (COTS) Extended Reality (XR) Head Mounted Display (HMD) facilitation of United States Navy (USN) bridge team training needs. Based in the theories of knowledge flow and embodied cognition, it addresses a gap in literature for employment of COTS XR systems to enhance the facilitation of knowledge flow of expertise typically gained through experience. This study will specifically evaluate XR facilitation of knowledge flow to improve expertise in bridge watch team shiphandling in complex harbor situations. A statistical analysis of an XR bridge training system will be made in comparison to a traditional USN physical bridge mockup simulator. The goal of this research is to determine the extent to which an 'information only' training process (XR) can aid human performance in shiphandling and bridge recourse management.

Keywords: Knowledge Flow, Embodied Cognition, Extended Reality, Synthetic Experience, Shiphandling

1. Introduction

Nothing is more real than death. Since its beginning, humanity has struggled to address death: to cope with its meaning through art and religion, to defend against it with medicine and the military, and most importantly, how to avoid it by advancing its knowledge in every domain of life. As human knowledge has expanded, human welfare and longevity has also increased, yet risks abound. In the domain of military affairs, avoiding death and the destruction of increasingly expensive equipment remains paramount, but how is this to be done when weapons systems have become ever more complex with increased lethality and range? In today's environment, weapon systems such as a Guided Missile Destroyer (Figure 1) have become so intricate that peacetime navigation, let alone combat operations, have become deadly with notable collisions having

taken place in 2017. All of this places ever higher demands on human performance and the knowledge needed to prevent the negative consequences of human failure.



Figure 1. USS Fitzgerald after a deadly collision with MV ACX Crystal. (USN, 2017)

How are we to ensure those placed in harm's way are ready to perform, particularly when tasks at hand require real world experience in matters of life and death? While Mockup simulations, e.g., Link's 'Blue Box', have been in service since the 1920's (Bailenson, 2019) and remain in use today for training USN bridge crews, these systems are expensive, have limited availability, and require trainees to travel to the simulator location. Mockup simulators also suffer from the need to remain generic emulations of otherwise uniquely configured systems in order to accommodate a wide range crews in need of training. Even with these limitations, mockup trainers persist as the primary method to facilitate transfer of 'experiential knowledge', but is there a better way?

2. Research Goals

At the heart of this study, the problem is that loss of life and property can result when human performance fails, particularly in military, contested, or other high-reliability operations where knowledge flows needed for training encounter friction:

1. Traditional Computer Based Training is insufficient
2. On-the-Job Training (OJT) can be unavailable or too dangerous
3. Mockup Trainers are very expensive to operate, limited in availability, and require personnel to travel to specific and limited locations

This is a problem because personnel, equipment, and mission success are placed at risk when dangerous, contested, or high-reliability operations must be performed without the benefit of prior knowledge.

The purpose of this study is to evaluate and characterize XR facilitation of knowledge flows required for high-reliability operations of shiphandling, specifically U.S. Navy (USN) Guided Missile Destroyers. Characterizing XR's ability to build expertise in USN shiphandling will add to general understanding of XR's capacity to enhance knowledge flow and improve human performance. To this end, the research seeks to evaluate and characterize XR knowledge flow facilitation in comparison to physical mockup training and benchmark 'experiential knowledge flow' provided via an information only processes. This leads to the overarching research question: "To what extent can knowledge flow in bridge training be facilitated by an informational based XR Trainer as compared to a physical Mockup Trainer?"

In Figure 2 below, XR Trainer participants use Head Mounted Displays (HMDs) to perceive a virtual bridge environment, complete with avatar enabled social interaction, marine environmental effects, full audio replication of the bridge environment, all of the information related displays, e.g., RADAR, Voyage Management System, etc., and Helm and Lee Helm controls while viewing the external world outside the bridge windows in the same way they would aboard a real ship. In addition, the XR participant, unlike a movie goer, has full agency in what they choose to look at, from where they want to make their observation, and can 'use' binoculars to magnify distant objects very similar to the way it's done in the real world.



Figure 2. XR Bridge Trainer versus USN Mockup

In the Mockup trainer, participants are provided similar affordances, but have the added advantage of physical touch, seating surfaces, proprioception of walking and or colliding with other bridge watch standers. To address this overarching research question, four hypotheses will be tested.

3. Background and Related Work

3.1. Knowledge Flow

In the domain of Knowledge Management (KM), conveyance of knowledge from those 'who know' to those 'who do not know' remains a central concern. Michael Polanyi's famous description of mercurial nature of tacit knowledge, that "one can know more than one can tell" (Polanyi, 1967) remains central and is clearly relevant to problem of flowing experiential knowledge in the ship-handling case described above. In the 1990's, Nonaka and Takeuchi expanded KM's conceptions of knowledge conveyance as a "spiral" process of externalizing what experts know tacitly into information objects (explicit knowledge) to be digitized, stored, and made available after experts retired or otherwise left their organizations (Nonaka, 1995).

More recently, Nissen expanded and greatly enhanced Nonaka and Takeuchi's concept of the "knowledge spiral" to his conception of the Multidimensional Model of Knowledge Flow shown in Figure 3.

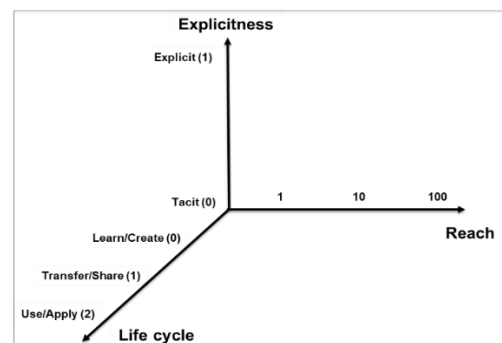


Figure 3. Multidimensional knowledge flow visualization model (Nissen, 2002)

Nissen postulates knowledge flow as the movement of knowledge from 'those who have it' to 'those who need it'. In this, an individual's expertise is first made 'explicit' through a willful act of 'externalizing it' into an information medium, allowing it to then 'flow' along three axes, 1) Explicitness, 2) Reach, and 3) Life Cycle (Nissen, 2002). "Explicitness" refers to the degree of externalization of knowledge, from that which is held by the 'knower' tacitly, (or implicitly, where 'implicit' is operationalized as that which is known and can be easily articulated, but has not yet been made explicit), to that which is represented in an information medium explicitly to be transported to a receiver. "Reach" refers to the degree of socialization, e.g., number of receivers; individual(s), group(s), organization(s), and "Life Cycle" refers to the stage of knowledge flow, e.g.,

creating, sharing, applying, etc. Vectors can be placed onto the model to visualize knowledge flow relational dynamics of direction, speed, and power of a specific flow being described (Nissen, 2014).

Implicit in this model is the idea that flows of knowledge require supplementary flows of information, (and in turn data and signals) where the kind of information required depends on the knowledge needed to accomplish the task. In the case of our ship maneuvering example, the knowledge needed can be said to be ‘experiential’ or ‘performative’, where an individual possessing this expertise or ‘tacit knowledge’ is able to recognize dangerous situations and react appropriately in a timely manner. But how can this knowledge best be externalized in order to ‘flow’ from ‘those who have it’ to ‘those that need it’?

Nobel Prize Laureate Daniel Kahneman (2002 – Economics) summarized the problem of acquiring ship maneuvering knowledge as being a difficulty in recognizing feedback cues “...because of the long delay between actions and their noticeable outcomes. Whether professionals (Harbor Pilots) have a chance to develop intuitive expertise depends essentially on the quality and speed of feedback, as well as on sufficient opportunity to practice” (Kahneman, 2011).

Kahneman’s writing on recognition and feedback referred to fellow Nobel Laureate Herbert Simon’s (1978 - Economics) theories of expertise where, in Simon’s words, “...a major component of expertise is the ability to recognize a very large number of specific relevant cues when they are present in any situation, and then to retrieve from memory information about what to do when those particular cues are noticed.” Additionally, Simon stated “The decision maker of experience has at his disposal a checklist of things (cues, conscious and subconscious) to watch out for before finally accepting a decision...One of the ways we can acquire a checklist of things to ‘watch out for’ is to learn how the world really works and adapt ourselves accordingly” (Simon, 1996).

Given the above, it would appear the flow of explicit knowledge encoded in the information of a book, a video, or even being told by a harbor pilot ‘how to drive the ship’ would be an insufficient means to externalize and flow this kind of knowledge. To better understand the kind of friction encountered in the particular case of maneuvering a ship in tight quarters (or any case where acquiring spatial-temporal performance skills is needed) we can turn to the conception of knowledge friction.

3.2. Knowledge Friction

The concept of knowledge friction, an extension to knowledge flow theory, posits a loss or degradation

or delay in the conveyance of knowledge between the source and the receiver(s) (Shigley, 2021). In this, knowledge friction is not the same as a ‘knowledge barrier’, something blocking the flow between the sending agent and the receiver(s), but rather a delaying or loss of knowledge after it has been collected and imparted by the organizational communicator in the transfer link to the designated recipients; it is the cause of the loss of knowledge between the knowledge transmitter and the knowledge receiver.” The transfer link can be thought of in terms of ‘clarity’, is the knowledge clearly presented to the receiver? This begs the question of how one is clearly articulate experiential knowledge, where clarity of subtle cues is largely held as tacit knowledge by ‘those who know’? The conjecture here is this can be accomplished by removing the need to articulate such tacit knowledge by providing a transit link for a knowledge carrying experience via the information technology of XR. Because XR provides an individual with agency and presence it is relevant to briefly review the theory of embodied cognition.

3.3. Embodying Knowledge Flow

The theory of embodied cognition has gained greater acceptance in the cognitive sciences and postulates human cognition framed as more than ‘brain as computer’ or ‘a brain performing symbolic representational computation’ and expands the theoretical frame to consider the greater whole of an organic and analog system of brain, human body, and the holistic interactions of a person with the environment, both physical and social (Lakoff, 2012; Foglia & Wilson, 2013; Clark, 2023). Additionally, embodied cognition theory hypothesizes knowledge production as an interaction or structural coupling (Maldonado et al., 1988) of the whole body (not just ‘a brain’) with the natural environment through whole body sensory-kinesthetic processes (Alibali & Nathan, 2012; Kanellopoulos et al., 2021; Joyce, 2007) Expanding this idea further, multiple theorists postulate that participation of the body in learning also occurs through social interactivity such as expressions, manners, and emotions (Alexias & Dimitropoulou, 2011).

While the concepts of embodiment in cognition have been argued for years in the disciplines of philosophy of science and philosophy of mind (Varela et al., 2017; Block, 1993; Dennett, 2001; Chalmers, 2019; Clark, 2023) empirical evidence, particularly discoveries made using non-invasive brain monitoring tools of High Resolution Fast Magnetic Resonance Imaging (HR fMRI), continue to support an ever increasing number of embodied cognitivist claims that brain function is indeed ‘structurally coupled’ to the

body and its surroundings. (Barrett, 2020; Prat et al., 2022; Popp et al., 2024; Wu et al., 2023; Magee & Johnston, 1997).

Mingers diagram in Figure 4 (Mingers, 2001) provides a succinct visual representation of embodied cognition showing the individual as informed by, yet also informing the external world through a process of structural coupling.

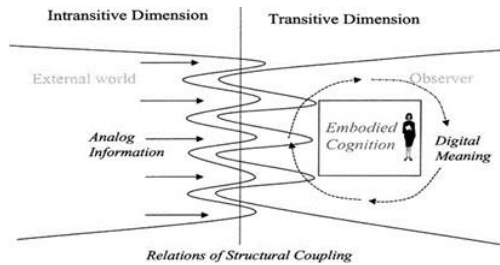


Figure 4. Embodied cognition via the process of structural coupling (Mingers, 2001)

If correct, these tenets of embodied cognition imply knowledge flow is itself an embodied process, particularly when the static presentation of an information object (explicit knowledge, e.g., instructions) is insufficient to convey performance from ‘those who know’ to those ‘who do not know’. From this point of view, the flow of knowledge needed to recognize subtle cues and feedback, Simon’s “checklist of things to watch out for”, is gained not from an ‘information input’, but rather the interaction of the structurally coupled “Intransitive Dimension” of a dynamically changing real world to the “Transitive Dimension” of the body in itself as it adapts processes, to include neural connections, within the individual (Mingers, 2001).

Herein lies our source of knowledge friction; how does one flow experiential knowledge when ‘structural coupling’ to an external world experience is impossible, dangerous, or simply impractical to perform?

As noted, physical mock-up simulations are commonly employed, with limitations, but require great expense of physical infrastructure. Is there an ‘information only’ process available to safely flow Simon’s “checklist of things to watch out for”?

3.4. Synthetic Experience

XR, or spatial computing, refers to the use of HMD technology able to provide a three dimensional (3D) visual and audio Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), or Augmented Virtuality (AV) presentations combined with hand- held haptic controllers and conventional Information Technology (IT), e.g. laptop computers,

network routers, Internet, etc. An umbrella term, XR can include any mix of the aforementioned technologies to provide a user with an embodied sense of agency (Clark, 2023) needed to facilitate a wide variety of learning objectives previously limited to physical mock-up environments (Bailenson, 2018). In the specific case of ship-handling, XR is meant to include not just the HMD and haptic controllers, but also the Scenario Creation and Control Computer used to design and control the training scenario, the Wi-Fi enabled local area network router, server, and Internet backbone technologies comprising the system.

This system of systems builds upon advancements in IT to provide a synthetic experience where aspects of the real world, e.g., sight and sound, are replaced with virtual emulations enabling an information flow of subtle cues and responses to human feedback. As noted earlier, many situations, to include ship-handling, benefit in systems that facilitate knowledge flow in difficult, dangerous, or impossible situations without risk of death or property destruction. By immersing an individual in a virtual emulation, an expert is able to present a synthetic experience akin to what would be expected in dangerous, real world situations thereby enabling critical flows of performative knowledge as the individual interacts and learns from the experience. It is conjectured this kind of interaction, where embodied knowledge flow is facilitated via synthetic experience, that Simon’s checklist of ‘what to look for’ might be acquired. Figure 5 depicts the authors extension of Mingers diagram to account for structural coupling to a synthetic environment via XR.

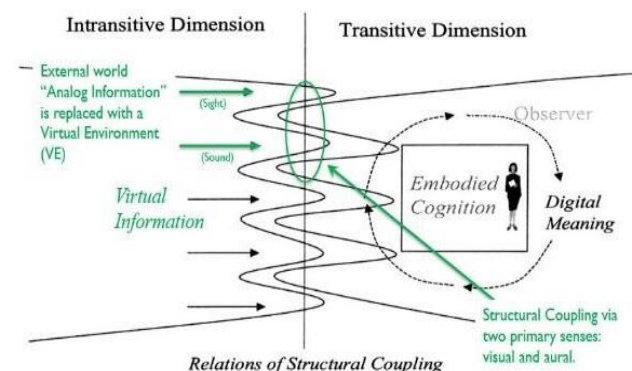


Figure 5. Mingers' depiction of embodied cognition extended for synthetic experience

As conjectured, XR not only facilitates recognition, it shows potential to aid prediction of the best next action as cue recognition is improved. This is particularly important, as Kahneman pointed out, in our ship-handling case where feedback is subtle and delayed.

3.5. Knowledge Explicitness and Synthetic Experience

XR offers a new way to expand knowledge flow in terms of what can be made explicit, or the degree to which tacit knowledge carried in the dense memory structure of an experts embodied experience can be made explicit for the purpose of transferring richer understanding and building tacit knowledge in the novice. In this way, the expert does not need to ‘articulate’ his/her tacit knowledge into language or any other information object, but can (by aiding an XR developer to encode the experiential circumstances needed for understanding into a virtual environment) build tacit knowledge that need not be articulated by the novice. The literature of embodied cognition provides reasoning for how a synthetic experience facilitates this kind of flow by providing levels of immersion and presence near those of actual reality. (Bailenson, 2018; Clark, 2023; Grayling & Rosenberg 2024)

A key tenant of embodied cognition is that of a connectionism, the theory that mental processes are comprised of synaptic connections between neurons where the strength of each connection evolves based on the experience of an individual’s body structurally coupled to its environment (Hebb, 2005). A famous conjecture of Donald Hebb, “Neurons that fire together, wire together”, has been an accepted tenant of neuroscience, proven empirically, and now referred to as Spike-Timing-Dependent-Plasticity or STDP (Gilson et al., 2010). A ramification of STDP is that neuro synaptic network structures of links, nodes, clusters and hubs, form scale invariant architectures in response to their motor-sensory perceptual interaction (structural coupling) to the environment. Hence, a force like ‘gravity’ because it is always and everywhere the same – a least for those of us living on Earth – becomes an invariant representation in the brain. This is relevant in so far as most of human perception is grounded in the ‘invariance’ of that which is perceived, gravity being just one example.

This embodied cognitivist idea human perception as ‘grounded’ in the invariance of bodily experience (Barsalou, 2010) is critical to extension of knowledge flow theory’s axis of ‘explicitness’ to incorporate synthetic experience as means to generate tacit knowledge. What is conjectured is invariances of the virtual environment must match those of the real world. In the case of this specific research, the ship handling characteristics, ocean dynamics of wind, tide, and current, the bridge layout of controls and information displays (to name but a few environmental details) must match, or nearly match those of the actual ship and how it behaves in the real world. When the

XR presentation is created in such a way (invariant matched) then it is possible to extend what is explicit to not just words, numbers, recorded conversations, video captures of procedures and so on, but to information in the form of explicit synthetic experience, see Figure 6

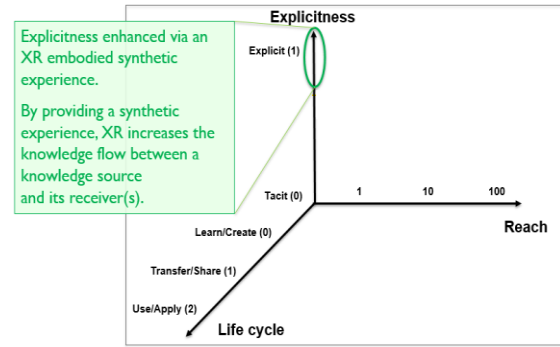


Figure 6. Nissen's model extended to encompass synthetic experience

To test this conjecture, that human performance will improve in the real world as a result of practice in synthetic environments, a statistical analysis is proposed to determine how well XR facilitates experiential knowledge flow in comparison to a physical bridge mockup simulator. Prior research has demonstrated efficacy of using VR synthetic experience to facilitate this kind of knowledge flow, (Grant & Magee, 1998), (Hays & Vincenzi, 2000) but a statistical comparison of an XR facilitated, synthetic experience to that of a ship-handling physical mockup trainer has not been found in current literature.

4. Proposed Study

To perform this study, a low-cost COTS XR training system will be modified to include the addition of USN relevant 3D models (Norfolk and San Diego) and a DDG-51 class guided missile destroyer bridge virtual emulation will be created in VR as noted in Figure 7.

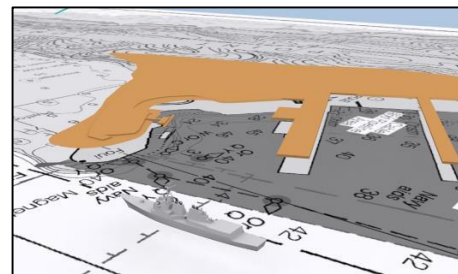


Figure 7. Creating a USN virtual emulation to facilitate synthetic experience (USN, 2024)

Once modified, the XR system will be compared to the USN Navigation, Ship- handling, Seamanship Training (NSST) physical mock-up trainer to evaluate

XR's ability to facilitate experiential learning. The research team, working in cooperation with USN ship-handling Subject Matter Experts (SMEs), will perform the NSST comparisons at the Mariner Skills Training Center Pacific (MSTCPAC) located at 32nd Street Naval Station in San Diego, CA. Researchers hypothesize the visual and auditory presentation provided by the XR platform will facilitate knowledge flow of critical spatial-temporal understanding equal to the legacy platform provided by NSST.

To perform the comparison, a 'counter-balanced within-subjects' experimental design will be employed such that participants will perform the same training scenarios on both training platforms, XR and NSST respectively. Training results will be evaluated based on (1) time to task (reaction time), (2) time to task completion, (completion time after initial recognition), (3) a System Usability Scale (SUS) survey, (4) a NASA Task Load Index (NASA TLS) survey, (5) Instructor Assessment Survey, (6) Instructor Officer of The Deck (OOD) Assessment Survey, (7) Bridge Watch Team Self-Assessment Survey, (8) Eye-Tracking Gaze Rate Data, (9) Eye-Blink Rate Data, and (10) Qualitative oral feedback of the training experience in XR compared to NSST. These metrics will be statistically analyzed to compare facilitation of knowledge flow in support of bridge watch standing between the XR system and the NSST physical bridge mockup system.

4.1. Proposed Method

Performance data taken from training events in both the XR and NSST platforms will be controlled for a consistent set of baseline factors: presented environmental conditions (e.g., winds, tides, currents), ship physics (e.g., rate of turn, speed over ground, engine/rudder state), density of contacts (e.g., air, surface, subsurface), constraining maritime passages, (e.g., San Diego Bay) crisis points, (e.g., engine failure) numbers of other trainees and instructors interacting in the training, (e.g., in XR and NSST), etc. 'Within-Subjects' data will be counterbalanced for statistical comparison of the same scenarios performed in XR versus NSST.

Prior to beginning observations and data collection, an Institutional Review Board (IRB) Protocol approval will be sought to ensure the study is fully compliant to Human Research policies, to include Privacy Act Compliance, (all data will be anonymized) health and safety standards are maintained, (Participants are appropriately screened for and monitored during observations for simulator sickness), and data collection meets all requirements of Informed Consent (Participants receive a full

description of the data being collected and the right to withdraw at anytime from the study without negative repercussions).

The research team will seek to eliminate instrumentation, confirmation, and other bias by closely controlling potential confounding variables, e.g., scenario miss-matches, ship performance miss-match, number of trainees in each group, etc., such that results determined are causally tied to the primary independent variable of the training platform, XR and NSST, respectively. Experimental design, variable operationalization, and resultant data are intended to either support or refute the overarching research hypothesis (H_a): that the XR training platform is equivalent in facilitating knowledge flow of mapped skills and tasks to the control condition null hypothesis of the NSST (H_0).

4.2. Participants

Participants will include a range of civilian and military personnel, from researchers lacking maritime skills, novice ship-handlers, master mariners, qualified USN Officers Of the Deck (OODs), and senior Surface Warfare Officers (SWOs). Participation will be required across two phases of the study, (1) the design phase, broken into two design 'sprints', and (2) the evaluation phase. Civilian personnel will be recruited from NIWC PAC and the Naval Postgraduate School (NPS). Military personnel will come largely from MSTCPAC, with back-up participants coming from MSTC Atlantic (MSTCLANT) in Norfolk VA and NPS in Monterey CA. If research support is needed from other military commands, e.g. NPS, a request to add these will be submitted to the IRB for approval. All participation will be voluntary, and participants will be informed they can withdraw from the study at any time with no repercussions.

4.3. Human Subjects Sample

It is hypothesized the XR platform will be as effective at facilitating knowledge flow (for those skills and tasks mapped) as the NSST. Given this hypothesis, the expected mean results of XR facilitation will either not differ or be better than the NSST results. Assuming a statistical value of $\alpha=0.05$ and a power of $(1-\beta) = 0.80$, a sample size of $N=27$ participant groups is required for analysis (27 participant groups subjected to both the control and experimental conditions, where each 'group' is a Bridge Watch Team). The target sample is purposive of a typical USN Bridge Team comprising 7 individuals including: 3 junior grade Naval Officers, ranking from O1 to O4, and 4 enlisted watch standers,

e.g., Helm, Lee Helm, Boatswain Mate of the Watch, (BMOW) and 1 Quartermaster of the Watch (QMOW).

The sample is also one of convenience, designed such that the research does NOT overly disrupt the normal routine of ships activities, but leverages personnel attending routinely scheduled NSST training held at MSTCPAC. A potential risk of this approach is the dependence on ship schedules, where any number of real world events may prevent ship participation and thus limit the total sample to below the target of N=27.

A contingency plan is to travel to other trainers, e.g., MSTCLANT, to reach a desired population of N=27. If this too fails, a 'Between-Subjects' design will be utilized to broaden the participation base to include participants from other locations, e.g., NPS. Throughout the evaluation phase, a broad range of statistical tests, to include non-parametric tests (as required) will be utilized to assess if required numbers of participants have provided reliable results from the data obtained.

4.4. Study Pilot Testing

The research team plans to use one bridge team scenario (either San Diego or Norfolk) for pilot testing to ensure desired data can be collected and analyzed according to the planned facilitation effectiveness surveys and eye-tracking metrics. Video and audio recordings are typically captured during NSST training evolutions; the research team will leverage these recordings in both the design phase and during the pilot study to compare time stamps on the instructor screen and note when key events occur in the scenario. These observations will inform when to measure 'reaction time' and 'time to task completion' in order to minimize instrumentation bias and enable a performance comparison based on platform presentation (XR or NSST).

4.5. Study Observations

XR system evaluation and characterization testing will be conducted concurrently with MSTCPAC scheduled NSST training scenarios set in San Diego (or Norfolk) with DDG-51 bridge crews. Observations will be facilitated such that bridge crew trainees will either train first with XR followed by NSST, or begin with NSST training followed by XR. At the conclusion of each observation period, a variety of surveys will be handed out to collect participant responses (Likert scales) to each training experience, XR and NSST. Survey instruments issued will differ depending on the role of the participant; instructors

will fill out a SUS survey and Instructor Assessment Questionnaires. Trainees will fill out the SUS survey, a NASA TLX survey, and a Bridge Team Self-Assessment Questionnaire. A handful of instructors and trainees will also participate in a brief qualitative response feedback session.

During NSST simulator downtime, the research team will review video and audio capture of bridge team interactions and compare them to instructor scenario views to determine key event 'reaction time' and 'task completion time'. NSST 'control scenarios' will bound the development of the XR experimental testing scenarios to ensure as close a match can be made (to NSST) to ensure internal validity of the XR vs NSST comparison. Measurement of reaction time and task completion time will be performed on the self-contained video playback capability provided in the XR system. It is anticipated each XR training session will last approximately 1 hour, with 10 minutes for screening, Privacy Statement, and Informed Consent, 10 minutes to receive initial XR indoctrination, 30 minutes to perform in XR, and 10 minutes to complete response surveys and exit interview(s).

4.6. Study Apparatus

The apparatus, tools, and materials of the experimental phase of this study will consist primarily of IT, specifically the COTS XR system militarized for USN application. Meta Platforms Meta Quest 3 Head Mounted Display, a scenario and controller PC, and a wireless router for bringing up to 12 individuals into the same virtual environment. The Meta Quest 3 headsets will be configured with 512GB of storage, 2 color cameras and 3D spatial audio. A Meta Quest Pro will also be used to collect eye tracking data, but essentially provides the same presentation as the Meta Quest 3.

In addition, the XR system uses the Control PC to provide instructors the ability to design and configure scenario parameters for training and to control scenario input stimuli during runtime. The instructor based hardware consists of a laptop with specific XR support software, 3D models of San Diego, Norfolk, and the DDG-51 bridge configuration loaded into the system. The Meta Quest 3 headsets communicate to the controller PC via an 'off network' Local Area Network (LAN) using a wireless network router. The specifications of the instructor PC Controller hardware suite are:

- Laptop - HP ZBook Firefly 14 Core i7-1165G7 32GB RAM, 512GB SSD 14IN FHD Win 11 Pro
- NVIDIA Quadro T500 (4GB Graphics)
- Router NETGEAR RAX20 Wi-Fi 6 Router
- 1x HP EliteDesk 800G4 Mini i5-Gen8 8GB

256GB SSD Win 10 Pro

At the start of this study, a Meta Quest 3 will be used. Meta Quest 3 is a full VR headset that blocks out the outside world and presents an entirely computer-generated environment into the participant's visual field. It also has a High Definition 'color-pass-through mode' that allows the operator to 'see' the actual physical environment where the testing is being performed. (This 'pass-through' mode is an important safety feature that allows the participant to quickly and easily 'exit' the virtual environment without needing to remove the HMD.) In addition, the research team will conduct eye tracking analysis using a nearly equivalent HMD from Meta Platforms, the Meta Quest Pro, Figure 8.



Figure 8. Meta Quest Pro HMD (Author)

Meta Quest Pro enables eye tracking via onboard cameras, is completely passive, has no impact on user experience, allows full color 'pass-through', and will present scenarios with nearly identical levels of visual fidelity as the Meta Quest 3. The subjects selected will for eye tracking will be OOD's, who will be notified and sign a release form for collecting their gaze vector data. All gaze vector data will be anonymized such that the only identification made will be to a particular watch standing position, e.g., OOD Subject Nr. 1. Meta Quest 3's and Meta Quest Pro's will be used in accordance to manufacturer's specifications and fact sheets.

Unity 3D VR enabling software will provide the environment to support simulated sea navigation environment. This will include: (1) simulation of current, wind, and other environmental factors, (2) simulation of own-ship hydrodynamic forces, including engine and rudder dynamics, (3) simulation of other ships, including tugs, logistics ships for underway replenishment, and other private, commercial, and military ships in the nearby environment, (4) models of common ports, to include San Diego and Norfolk port approaches, (5) a DDG-51 class bridge configuration to include it's control systems, control interfaces, space layout, and audio environment, and (6) DDG-51 class ship-handling and maneuvering feedback displays, e.g., Multi-Function Control

Repeater (MFCR) response.

5. Discussion

The implication for research and practice of this study are manifold. The evaluation and characterization of XR to support knowledge flow as described in this case offer the potential to aid other researchers seeking to either apply XR to their unique needs, or to further scholarship on how tacit knowledge can be transferred without need of either the sender or the receiver having to articulate or make 'explicit' knowledge in question as the 'flow' is a result of a 'knowledge carrying experience' made explicit, not the knowledge itself. Additionally, because XR platforms are becoming more and more affordable, are small, software based, and portable they (1) have a tremendous potential to scale beyond fixed site training facilities, (2) allow teams to practice from dispersed and remote locations, at odd hours, in a single, multi-user 'virtual' environment, (3) can be easily customized to represent unique environmental configurations, (4) can aid 'cue recognition' based on specific and unique visual and sound environments, (5) enable over-the-air software up-dates to provide different internal (e.g., bridge) and external (e.g., ports) models for mission rehearsal at costs far lower than a physical simulator etc. Given this, evaluating and characterizing XR for proper application is more urgent than ever.

This particular case offers the Navy potential to better understand how XR technology enhances knowledge flow, not just for bridge crews, but also Navy Instructors, Researchers, and Program Managers in providing a use case to assess a novel, mobile, highly scalable XR capability designed specifically for USN use. XR and the virtual environments they provide offers new ways to flow knowledge virtually through shared synthetic experience in a limitless number of situations, from simple to extremely complex.

Additionally, study participants will be able to share their expertise with researchers and provide their feedback as potential users of a system that will benefit the Navy, not just the 'bottom line.' Participation in system effectiveness evaluations will aid in quantifying the benefits (and limitations) of these technologies to ensure end users truly benefit from technology being developed.

This study will not only evaluate potentials of XR to aid OOD's in bridge watch standing, it will also add to scientific knowledge by objectively demonstrating the utility of XR to enhance knowledge flow in dangerous, life and death situations requiring spatial-temporal skills and judgement.

6. Conclusion

This study seeks to both evaluate and characterize XR technology as applied to the real world problem of safe operation of USN destroyer. In this, it could prove that XR is NOT the answer, or only a partial answer to how the Navy employs emergent XR capabilities for knowledge flow purposes. The intent is to review collected responses and thoroughly explore the data found – beyond hypothesized results – and characterize findings for potential future research. This study is currently scheduled to begin observations in the fall of 2024 with data analysis and study results expected by the summer of 2025. It is the hope of the research team to publish and report findings at the HICSS-2026 conference.

References

- Alexias, G., & Dimitropoulou, E. (2011). The body as a tool: Professional classical ballet dancers' embodiment. *Research in Dance Education*, 12(2), 87-104.
- Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the learning sciences*, 21(2), 247-286.
- Bailenson, J. (2019). *Experience on Demand: What Virtual Reality is, How it Works, and What it Can Do*. W.W. Norton & Company.
- Barrett, L. F. (2020). *Seven and a half lessons about the brain*. Houghton Mifflin.
- Block, N. (1993). Consciousness Explained. In: JSTOR.
- Chalmers, D. (2019). Extended cognition and extended consciousness. *Andy Clark and his critics*, 9-20.
- Clark, A. (2023). *The experience machine: how our minds predict and shape reality*. Pantheon.
- Dennett, D. (2001). Are we explaining consciousness yet? *Cognition*, 79(1-2), 221-237.
- Foglia, L., & Wilson, R. A. (2013). Embodied cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, 4(3), 319-325.
- Gilson, M., Burkitt, A., & van Hemmen, J. L. (2010). STDP in recurrent neuronal networks. *Frontiers in computational neuroscience*, 4, 23.
- Grant, S. C., & Magee, L. E. (1998). Contributions of proprioception to navigation in virtual environments. *Human Factors*, 40(3), 489-497.
- Hebb, D. O. (2005). *The organization of behavior: A neuropsychological theory*. Psychology press.
- Hays, R. T., & Vincenzi, D. A. (2000). Fleet assessments of a virtual reality training system. *Military Psychology*, 12(3), 161-186.
- Joyce, R. A. (2007). Embodied subjectivity: gender, femininity, masculinity, sexuality. *A companion to social archaeology*, 82-95.
- Kahneman, D. (2011). *Thinking, Fast and Slow*. Random House.
- Kanellopoulos, A., Koutsouba, M., & Giossos, Y. (2021). Proposition for the introduction of the concept telemathesis in videoconferencing in distance education. *European Journal of Open, Distance and E-Learning*, 23(2), 83-98.
- Lakoff, G. (2012). Explaining embodied cognition results. *Topics in cognitive science*, 4(4), 773-785.
- Magee, J. C., & Johnston, D. (1997). A synaptically controlled, associative signal for Hebbian plasticity in hippocampal neurons. *Science*, 275(5297), 209-213.
- Maldonado, P. E., Maturana, H., & Varela, F. J. (1988). Frontal and lateral visual system in birds: Frontal and lateral gaze. *Brain, Behavior and Evolution*, 32(1), 57-62.
- Mingers, J. (2001). Embodying information systems: the contribution of phenomenology. *Information and Organization*, 11(2), 103-128.
- Nissen, M. E. (2002). An extended model of knowledge-flow dynamics. *Communications of the Association for Information Systems*, 8(1), 18.
- Nissen, M. E. (2006). *Harnessing knowledge dynamics: Principled organizational knowing & learning* IGI Global.
- Nissen, M. E. (2014). *Harnessing Dynamic Knowledge Principles in the Technology-Driven World*. IGI Global.
- Nonaka, I. T., H. (1995). *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. Oxford University Press.
- Polanyi, M. (1967). *The Tacit Dimension*. University of Chicago Press.
- Popp, J. L., Thiele, J. A., Faskowitz, J., Seguin, C., Sporns, O., & Hilger, K. (2024). Structural-functional brain network coupling predicts human cognitive ability. *NeuroImage*, 290, 120563.
- Prat, O., Petrucco, L., Štíh, V., & Portugues, R. (2022). Comparing the representation of a simple visual stimulus across the cerebellar network. *bioRxiv*, 2022.2009.2012.507660.
- Shigley, P. (2021). *Conceptualizing Knowledge Friction* Naval Postgraduate School
- Simon, H. A. (1996). *Models of my Life*. MIT Press.
- Varela, F. J., Thompson, E., & Rosch, E. (2017). *The embodied mind, revised edition: Cognitive science and human experience*. MIT press.
- Wu, J., He, Y., Liang, S., Liu, Z., Huang, J., Liu, W., Tao, J., Chen, L., Chan, C. C., & Lee, T. M. (2023). Effects of computerized cognitive training on structure-function coupling and topology of multiple brain networks in people with mild cognitive impairment: a randomized controlled trial. *Alzheimer's Research & Therapy*, 15(1), 158.