NAVAL
POSTGRADUATE
SCHOOL

Enhancing Knowledge Flow with Extended Reality (XR)

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Navy Postgraduate School/NIWC Pacific
HICSS-59 Presentation
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Enhancing Knowledge Flow with XR

Overview

1. 'BLUF'
2. Key Terms
3. Research Motivation, Problem and Purpose
4. Research Question
5. Research Gaps and Hypotheses
6. Research Design, Method, and Materials
7. Data Analysis and Statistical Tests
8. Experimental Results and Summary of Key Findings
9. Research Contributions, Conclusions and Recommendations

1. Bottom Line Up Front (BLUF)

U.S. Navy bridge team perceptions of Extended Reality (XR) training effectiveness were <u>not significantly different</u> than those of the physical bridge mockup.

Software-defined XR can provide the cues needed for experiential learning.

= Availability *= Affordability* *= Readiness*

"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."

(Herbert Simon, 1996)

2. Key Terms

1. Extended Reality (XR). Any combination of Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), Augmented Virtuality (AV), Information Technology (IT) presenting audio & video via Head Mounted Displays (HMDs).
2. Knowledge Flow. Organizational Management term addressing people, processes, technology, and organizational design in movement of knowledge (e.g., individuals, groups, organizations: points in space or time).
3. Synthetic Experience. Use of computer simulation to enable embodied practice of skills in critical life or death operations requiring high levels of repeatable human performance.

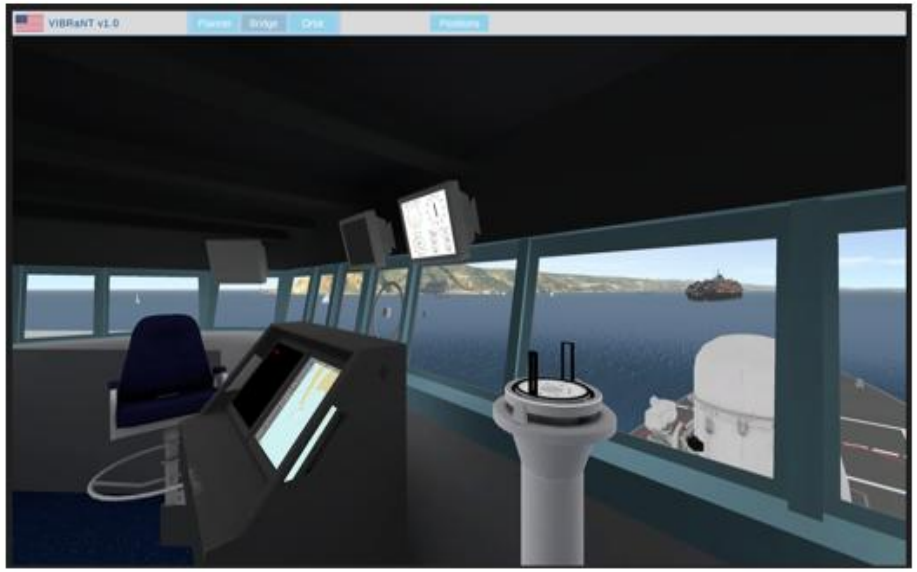
3. Research Motivation, Problem, and Purpose

1. In dangerous or contested operations, such as piloting ships at sea, human performance (speed of command, operating complex machinery, shiphandling, etc.), can make the difference between life and death.
2. To properly train and mitigate risk in complex maritime operations, knowledge must 'flow' from qualified experts who have it, to the performers who need it using limited, expensive, hard to access physical mockups.
3. <u>Recent advancements and falling costs of XR offer new possibilities to facilitate knowledge flow and build tacit expertise in both individuals and teams</u>. These trends greatly expand and enhance organizational opportunity to effectively distribute expertise for competitive advantage.

4. Research Question

To what extent can knowledge flow in bridge training be facilitated by an informational XR trainer compared to a physical mockup trainer?

Physical Mockup Trainer

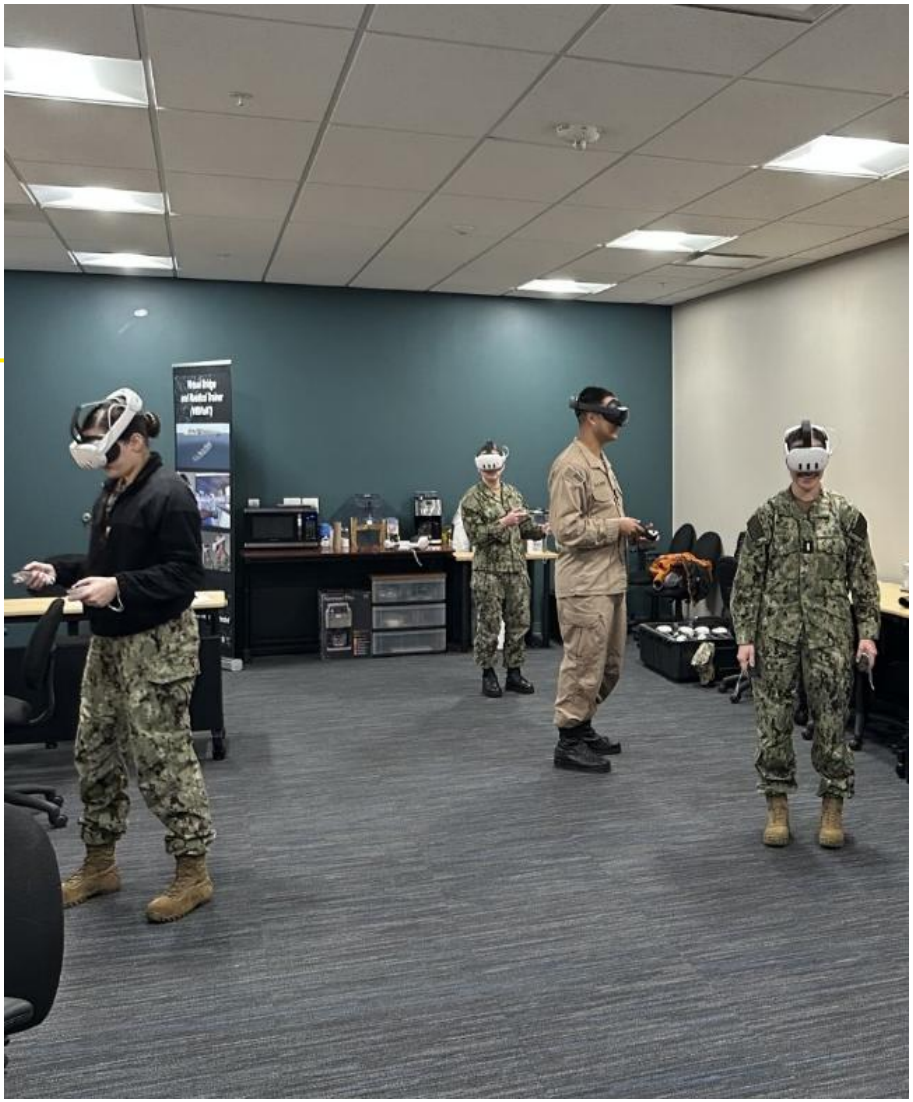


Informational XR Trainer

Physical Mockup Trainer

Informational XR Trainer

Physical Mockup Trainer



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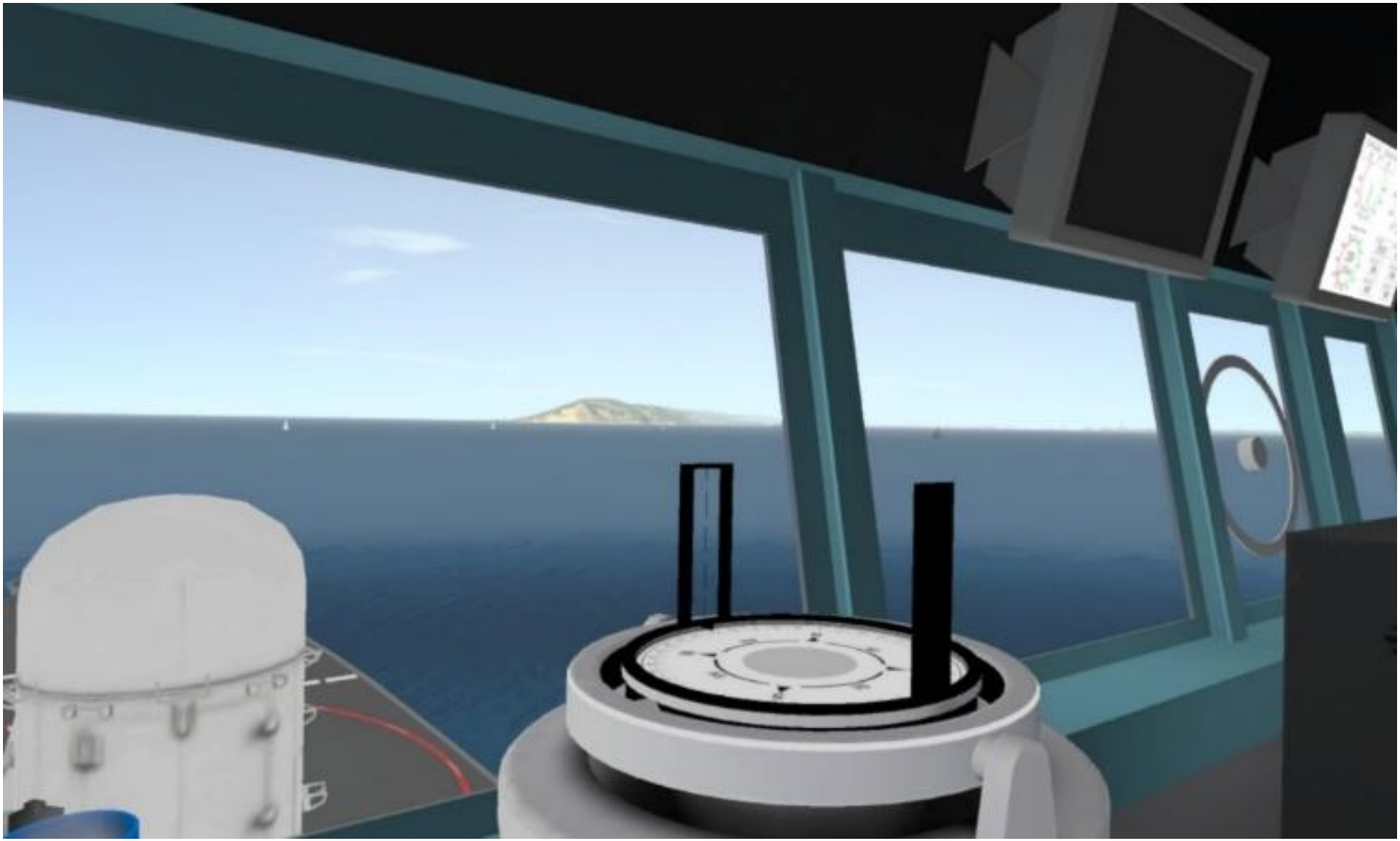


“Inside” the Informational XR Trainer Virtual Environment

5a. Research Gaps

1. Prior research focus was on VR of individuals, NOT bridge teams.

2. VR equipment previously studied was NOT generic “low-cost COTS,” comprehensive VR systems were purpose built for maritime training.

3. Previous studies of XR were NOT performed in the context of Knowledge Flow Theory within the context of bridge team training.

4. Flow of Tacit Knowledge in bridge team training via “XR Synthetic Experience” has NOT been previously investigated.

5b. Research Hypotheses

H_1 - Knowledge Flow facilitated via XR **WILL** (for mapped skills and tasks) be greater than or equal to the facilitation provided via a Mockup Trainer.

H_2 – Extraneous Cognitive Load produced by XR **WILL** (for mapped skills and tasks) be less than or equal to the extraneous cognitive load of the Mockup.

H_3 – Facilitation of critical Situational Awareness (SA) skills via XR **WILL** be greater than or equal to the SA skills facilitation via a Mockup Trainer.

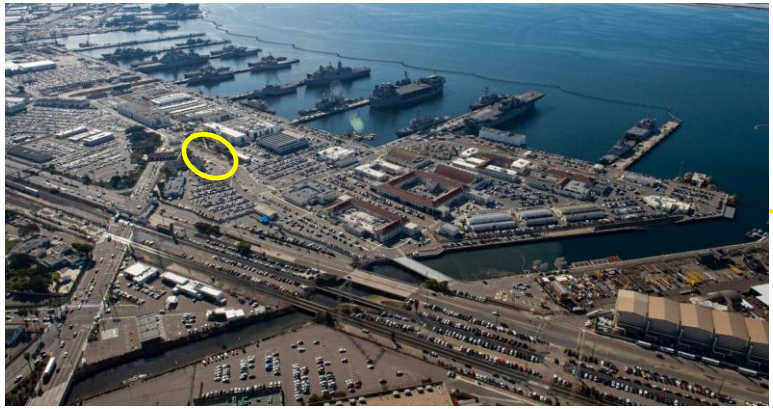
H_4 – Performance in the Mockup **WILL**, when preceded by XR training sessions, be greater than or equal to knowledge flow facilitation in the Mockup when NOT preceded by XR. (No NEGATIVE training from XR)

6a. Research Design, Method and Materials

Within-Subjects, Non-Randomized, Convenience Sampling

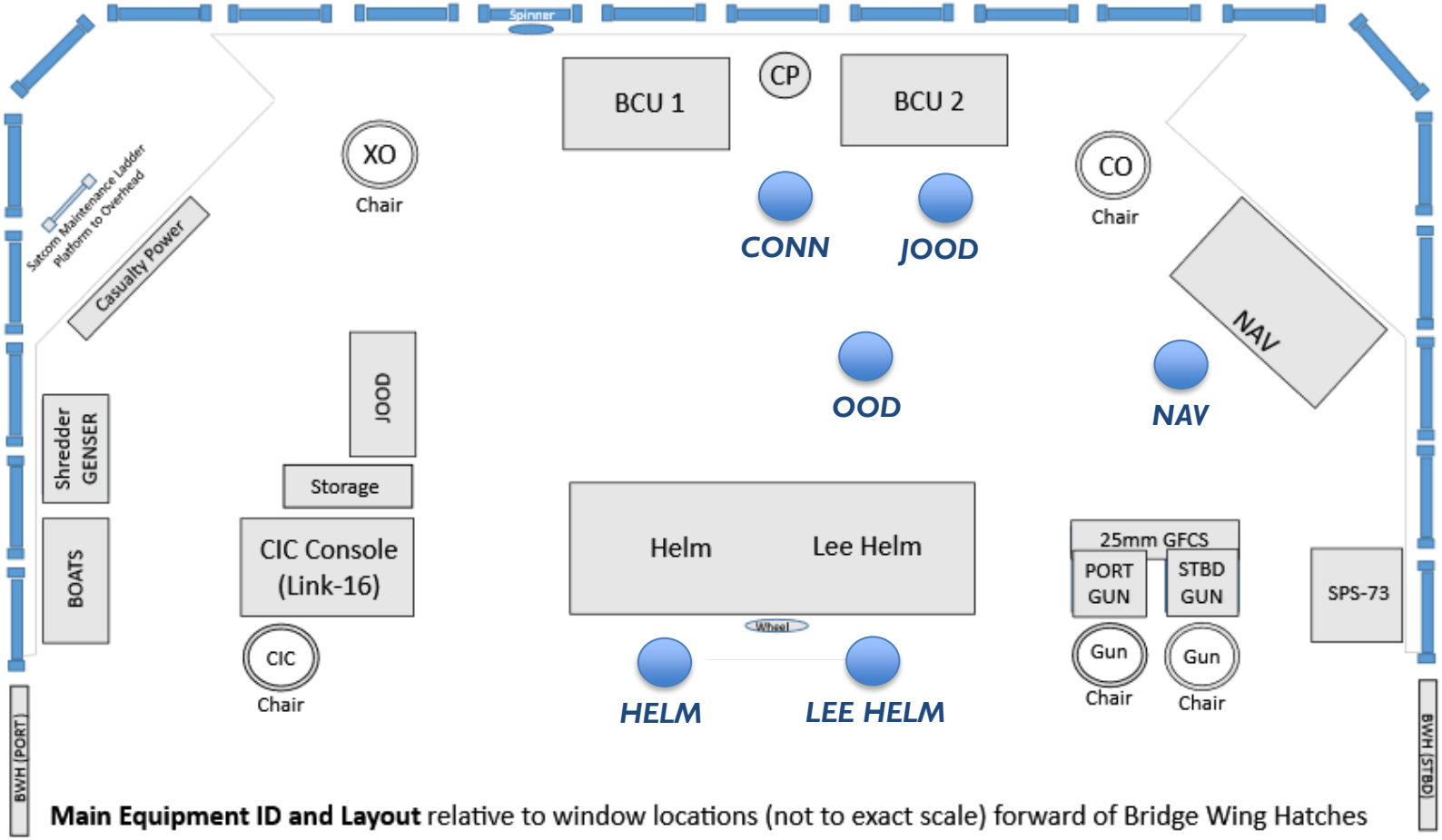
1. Subjects include purposive sample of junior to mid-grade U.S. Naval Officers, Enlisted bridge crew, and Bridge Instructors.
2. Convenience sample; bridge teams scheduled for Mockup training also performed XR training, in a counterbalanced design.
3. After each training event (Mockup and XR) bridge team and instructor participants completed surveys: NASA Task Load Index, System Usability Scale, Bridge Watch Stander Self-Assessment (Watch Team, OOD Officer Of the Deck, or Instructor) Exit Interview Questionnaire.

6b. Research Design, Method and Materials



1. Data was collected (Mockup and XR conditions) at the Mariner Skills Training Center Pacific (MSTCPAC) at 32nd Street Naval Station San Diego.
2. Data collected under Naval Information Warfare Center IRB Protocol, with dissertation work deemed “Data Only” analysis – as per IAIR agreement, having a separate express NPS IRB determination was not required.
3. Data collection performed in March – April 2025, each XR session ~ 1 hour.
4. Data collection leveraged MSTCPAC training schedule, 28 total sessions.

6c. Research Design, Method and Materials



Main Equipment ID and Layout relative to window locations (not to exact scale) forward of Bridge Wing Hatches

6d. Research Design, Method and Materials

MSTCPAC Mockup (NSST)

MSTCPAC Classroom (XR)

Experiment conducted at Mariner Skills Training Center Pacific (MSTCPAC)
32nd Street Naval Station San Diego CA

6e. Research Design, Method and Materials

(Independent and Dependent Variables)

	Independent Variable = Treatment Type		Dependent Variables = Survey Responses
	Mockup (Treatment A)	XR (Treatment B)	
1.	Mockup (Control Condition)	XR (Experimental Condition)	NASA Task Load Index Survey
2.	Mockup (Control Condition)	XR (Experimental Condition)	System Usability Scale Survey
3.	Mockup (Control Condition)	XR (Experimental Condition)	Bridge Watch Team Assessment Survey
4.	Mockup (Control Condition)	XR (Experimental Condition)	OOD Self-Assessment Survey
5.	Mockup (Control Condition)	XR (Experimental Condition)	Instructor Assessment Survey *

Sample size assuming a statistical value of alpha=0.05 and a power of (1-β)=0.80

N=27 was determined as sufficient sample size; N=28 bridge teams participated, 158 individuals provided survey responses.

Approximately 18,000 survey data points collected and statistically analyzed.

* 6/7 Instructors sampled, overlapping multiple Bridge Team / OOD participants sampled.

7a. Data Analysis

(Dependent Variables = Survey Responses)

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7b. Data Analysis

(Dependent Variables = Survey Responses)

NASA-TLX Subscale	NASA-TLX Subscale Question (Full Text)
Mental Demand (Q1)	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the mission easy or demanding, simple or complex, exacting or forgiving?
Physical Demand (Q2)	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand (Q3)	How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?
Performance (Q4)	How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?
Effort (Q5)	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration (Q6)	How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

7c. Data Analysis

NASA-TLX Survey - Dependent Variable Responses

Survey 1, Participant 16-079

Independent Variable		Dependent Variable		
NASA-TLX Survey		NASA-TLX Question Responses, Likert 1-10		
Mockup (Treatment A)	XR (Treatment B)	NASA-TLX Question	NSST	XR
NSST (Control Condition)	XR (Experimental Condition	Mental Demand	4	5
NSST (Control Condition)	XR (Experimental Condition	Physical Demand	5	4
NSST (Control Condition)	XR (Experimental Condition	Temporal Demand	7	7
NSST (Control Condition)	XR (Experimental Condition	Performance	3	4
NSST (Control Condition)	XR (Experimental Condition	Effort	2	2
NSST (Control Condition)	XR (Experimental Condition	Frustration	4	5

Each survey has a different number of questions, e.g., NASA-TLX has 6 questions.

Each question has Likert Scale response values, e.g., NASA-TLX “Mental Demand” 1 to 10

Response values (Dependent Variables) are statistically compared for each condition.

7d. Data Analysis

5 Surveys Instruments and 1 Exit Interview

Survey Description Summary			
Survey Number	**Survey Title**	**Number of Questions**	**Response Type**
1	NASA-TLX	6	Likert 1-10
2	System Usability Scale	10	Likert 1-5
3	Bridge Watch Stander Self-Assessment	28	Likert 1-7
4	Officer of the Deck (OOD) Self-Assessment	29	Likert 1-7
5	Instructor Assessment	31	Likert 1-7
6	Exit Interview	3	Free Text

7e. Data Analysis

(Dependent Variable Statistical Tests / Survey Analysis)

Survey Response Statistical Tests	*Dependent Variable Analyses*	
	Test Purpose	*Survey Analyzed*
Statistical Moments	Data Description	1,2,3,4,5
Distributional Fit Analysis	Data Description	1,2,3,4,5
Shapiro Wilk, D'Agostino-Pearson (Normality)	Para or Non-Para Tests	1,2,3,4,5
Kendall's W (Inter-Rater Reliability)	Respondent Concordance	1,3,4,5
Guttman's Lambda (Internal Consistency)	Systemic Stability	1,2,3,4,5
Hotelling's T^2 (Multivariate Analyses)	Pooled Comparison	1,2, part 3,4,5
Wilcoxon Signed-Rank Test (Bivariate Analyses)	Item Comparison	1,2,3,4,5
Cohen's *d* (Effect Size)	Difference Magnitude	1,2,3,4,5
Bonferroni Correction (WSRT Assessment)	Pooled Comparison Test	1,2,3,4,5
Mann-Whitney Test (Order Effects Comparison)	Order Impact - Control	1,2,3,4,5
Principal Component Analysis with Varimax Rotation	Factor Analysis	1,2,3,4,5
Statistical Power Analysis (Corner Case Analysis)	Sample/Test Assessment	1,2,3,4,5

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Principal Component Analysis with Varimax Rotation	Factor Analysis	1,2,3,4,5
Statistical Power Analysis (Corner Case Analysis)	Sample/Test Assessment	1,2,3,4,5

8a. Experimental Results and Summary of Key Findings (NASA-TLX Comparison)

Subgroup	**Hotelling's T^2 (omnibus)**	**Wilcoxon Significant Subscales ($p < 0.05$)**	**Cohen's *d* (effect size)**	**Bonferroni Correction**
All Participants (N=129)	T^2 = 68.75 F = 11.01 p < **0.001*****	Q4 p < **0.001***** Q6 p = **0.005****	Q4 *d* = 0.81 Q6 *d* = 0.37	Q4 High, All others within CI
OOD (n=26)	T^2 = 17.64 F = 2.35 p = 0.070	Q4 p = **0.010****	Q4 *d* = 0.83	All within CI
JOOD (n=25)	T^2 = 35.74 F = 4.72 p = **0.004****	Q4 p = **0.001*****	Q4 *d* = 1.21	Q4 High, All others within CI
CONN (n=26)	T^2 = 20.60 F = 2.75 p = **0.041****	Q4 p = **0.043**** Q5 p = **0.034****	Q4 *d* = 0.63 Q5 *d* = 0.62	All within CI
NAV (n=16)	T^2 = 29.17 F = 3.24 p = 0.050	Q4 p = **0.036****	Q4 *d* = 0.79	All within CI
HELM/LEE HELM (n=26)	T^2=13.68 F = 1.82 P = 0.145	Q4 p = **0.010****	Q4 *d* = 0.75	All within CI

Q4 measured Self-Assessed "Perceived Performance"

8b. Experimental Results and Summary of Key Findings (SUS Comparison)

Subgroup	Hotelling's T^2 (omnibus)	Wilcoxon Significant Items ($p < .05$)	Cohen's *d* (effect size)	Bonferroni Correction
All Participants (N=130)	T^2 = 76.59 F = 7.12 p < **0.001*** **	Q1, Q2, Q3, Q5, Q6, Q8, Q9, Q10	Q1 *d* = 0.68 Q2 *d* = 0.50 Q5 *d* = 0.52 Q9 *d* = 0.70	Q1,Q9 "High" All others within CI
OOD (N=26)	T^2 = 22.47 F = 1.44 p = 0.249	Q1, Q5, Q9	Q1 *d* = 0.72 Q5 *d* = 0.70 Q9 *d* = 0.72	All within CI
JOOD (N=25)	T^2 = 58.83 F = 3.68 p = **0.012** **	Q3, Q9	Q3 *d* = 0.80 Q9 *d* = 0.66	All within CI
CONN (N=26)	T^2 = 18.92 F = 1.21 p = 0.353	Q7, Q8, Q9	Q7 *d* = 0.42 Q8 *d* = 0.38 Q9 *d* = 0.50	All within CI
NAV (N=16)	T^2 = 25.68 F = 1.03 p = 0.511	Q1, Q6, Q9	Q9 *d* = 1.23 Q6 *d* = 0.87 Q1 *d* = 0.81	All within CI
HELM/LEE HELM (N=27)	T^2 = 70.26 F = 4.59 p = **0.003** **	Q1, Q2, Q5, Q9	Q2 *d* = 1.09 Q1 *d* = 0.79 Q5 *d* = 0.68 Q9 *d* = 0.77	All within CI

Q1 measured "Use frequency," Q9 measured "Use confidence."

8c. Experimental Results and Summary of Key Findings (BSW SA Comparison)

BWS Subgroup	Sample	Hotelling's T^2 (Omnibus)	WSRT: Qs w/Significant Differences ($p < 0.05$**)	Cohen's *d* (Effect Size)	Bonferroni Correction
All Participants	N=36	T^2 = 105.41 F = 1.51 p = 0.232 (24Qs)	Q1,Q2,Q3,Q4,Q5,Q7,Q8,Q9,Q12,Q14,Q15,Q16,Q17,Q18,Q19,Q21,Q22,Q23,Q24,Q25,Q26,Q27,Q28,Q29	"*d*" Range: (0.34-1.03) Large: Q3,Q4,Q14,Q18,Q19,Q21,Q22 Q23,Q26,Q28	All within CI
OOD	n=24	T^2 = 47.13 F = 2.05 p = 0.114 (12Qs)	Q3,Q4,Q9,Q14,Q18,Q21,Q22,Q28	"d" Range: (0.06-1.15) Large:Q3,Q4,Q9,Q18,Q21 Q22	All within CI
JOOD	n=21	T^2 = 70.09 F = 3.19 p = **0.039**** (11Qs)	Q1,Q3,Q4,Q6,Q7,Q12,14,Q16,Q17,Q18,Q19,Q21,Q22,Q23,Q25,Q26,Q28,Q29	"d" Range: (0.21-2.23) Large:Q1,Q3 Q4,Q6,Q12,Q14,Q16,Q17 Q18,Q19,Q21 Q22,Q23,Q25 Q26	All within CI

8d. Experimental Results and Summary of Key Findings (BSW SA Comparison)

BWS Subgroup	Sample	Hotelling's T^2 (Omnibus)	WSRT: Qs w/Significant Differences ($p < 0.05$**)	Cohen's *d* (Effect Size)	Bonferroni Correction
CONN	n=22	T^2 = 52.59 F = 2.09 p = 0.126 (12Qs)	Q2,Q3,Q4,Q8,Q14, Q21,Q22,Q23,Q26, Q28,Q29	"*d*" Range: (0.57-1.41) Large:Q2-Q5, Q14,Q21,Q22 Q26,Q28	All within CI
NAV	n=16	T^2 = 16.10 F = 1.79 p = 0.199 (6Qs)	Q1,Q2,Q3,Q18, Q19,Q20,Q21,Q22, Q23,Q24,Q26,Q27, Q28, Q29	"*d*" Range: (0.48-2.40) Large:Q2-Q4,Q14,Q18 Q19,Q20,Q22 Q26-Q29	All within CI
HELM / LEE HELM	n=24	T^2 = 47.25 F = 2.05 p = 0.113 (12Qs)	Q11,Q23,Q26,Q27, Q28	"d" Range: (0.06-1.42) Large:Q23, Q27,Q28	All within CI

8e. Experimental Results and Summary of Key Findings (OOD SA Comparison)

BWS Subgroup	Sample	Hotelling's T^2 (Omnibus)	WSRT: Qs w/ Significant Differences ($p<0.05$)	Cohen's *d* (Effect Size)	Bonferroni Correction
OOD	n = 23	T^2 = 927.07 F = 8.87 p < 0.01 (19Qs)	Q1, Q5, Q6, Q10, Q16, Q19, Q21, Q22, Q23, Q24, Q26, Q28	d Range: (-0.03–1.54)	None survive (α=0.0018) All within CI

8f. Experimental Results and Summary of Key Findings (INST Assessment Comparison)

Subgroup	Sample	Hotelling's T^2 (Omnibus)	WSRT: Qs w/ $p < 0.05$	Cohen's d (Effect Size)	Bonferroni Correction
Instructors	n = 1-9 paired (varies by question)	**Insufficient sample**	Q12, Q17, Q21, Q23, Q24, Q29	Range -1.09 -0.69 (NSST > XR)	All within CI

8g. Experimental Results and Summary of Key Findings (Sentiment Analysis)

Role	Themes	Representative Quote
OOD	Realism, SA	"Felt like standing on the bridge"
JOOD	Instrument limits	"Needed more radar tools"
CONN	Motion cues	"Easy to judge crossings"
NAV	Data limits	"Charts lacked depth"
HELM/LEE HELM	Control response	"Felt natural"
INST	Training value	"Useful for teaching"

8h. Summary of Key Findings

Evidence supports all 4 hypotheses

H_1 - Knowledge Flow facilitated via XR **WILL** (for mapped skills and tasks) be greater than or equal to the facilitation provided via a Mockup Trainer. Largely Supported, further research needed

H_2 – Extraneous Cognitive Load produced by XR **WILL** (for mapped skills and tasks) less than or equal to the extraneous cognitive load of the Mockup**.** Supported for most BWS Tasks

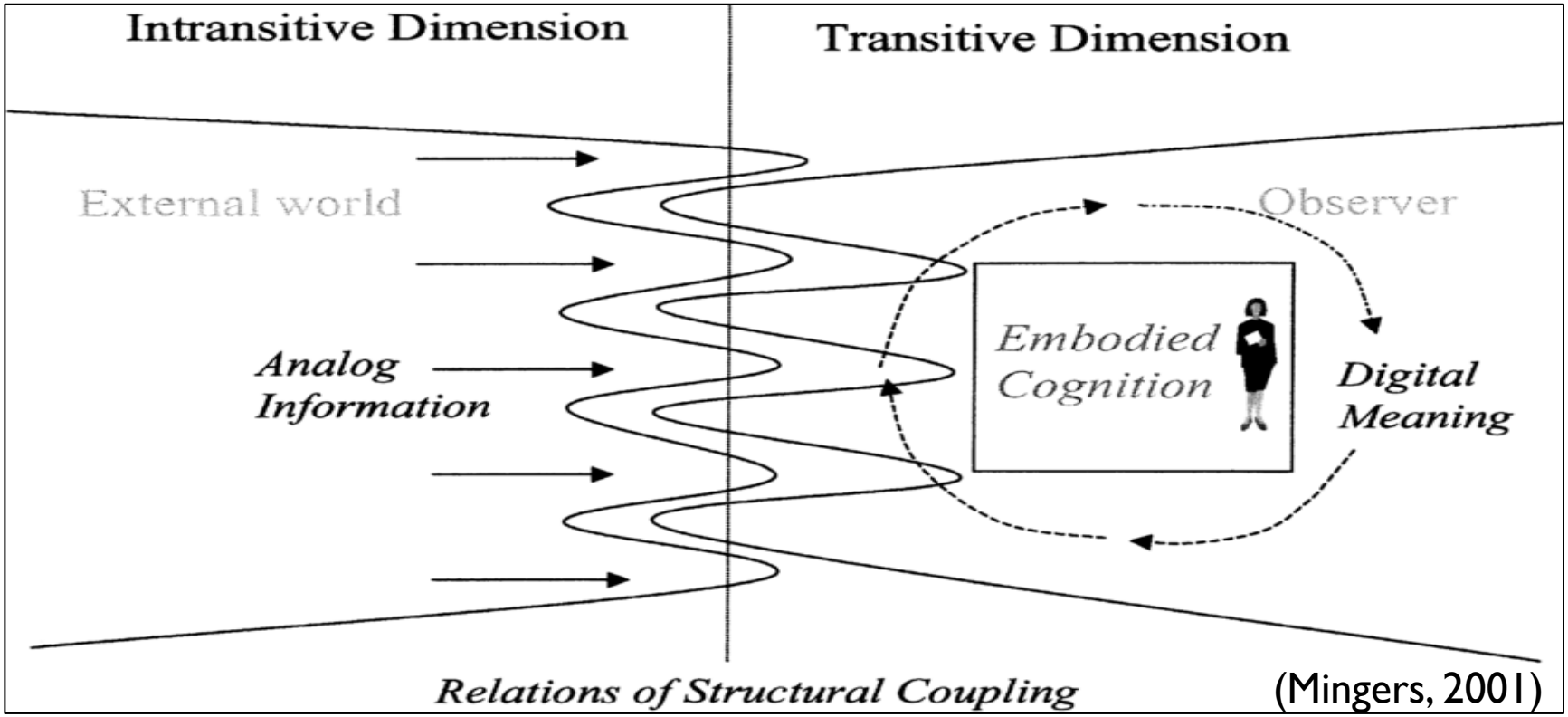
H_3 – Facilitation of critical Situational Awareness (SA) skills via XR **WILL** be greater than or equal to the SA skills facilitation via a Mockup Trainer. Largely Supported, further research needed

H_4 – Performance in the Mockup **WILL**, when preceded by XR training sessions, be greater than or equal to knowledge flow facilitation in the Mockup when NOT preceded by XR. Minor Order Effects, but those found improved perception of mockup performance, further research needed

9a. Research Contributions

1. Theory: Extends Knowledge Flow and Embodied Cognitive Theory by incorporating concepts of XR-presented synthetic experience as an information medium to flow Tacit Knowledge.
2. Method: Adds to the growing body of XR methodologies applied and evaluated for 1st person, team based experiential learning.
3. Practice: Provides the United States Navy an evaluation of XR application to improve the practice of training Navigation, Seamanship, Ship-handling and Bridge Resource Management.

9b. Research Contributions (Theory)

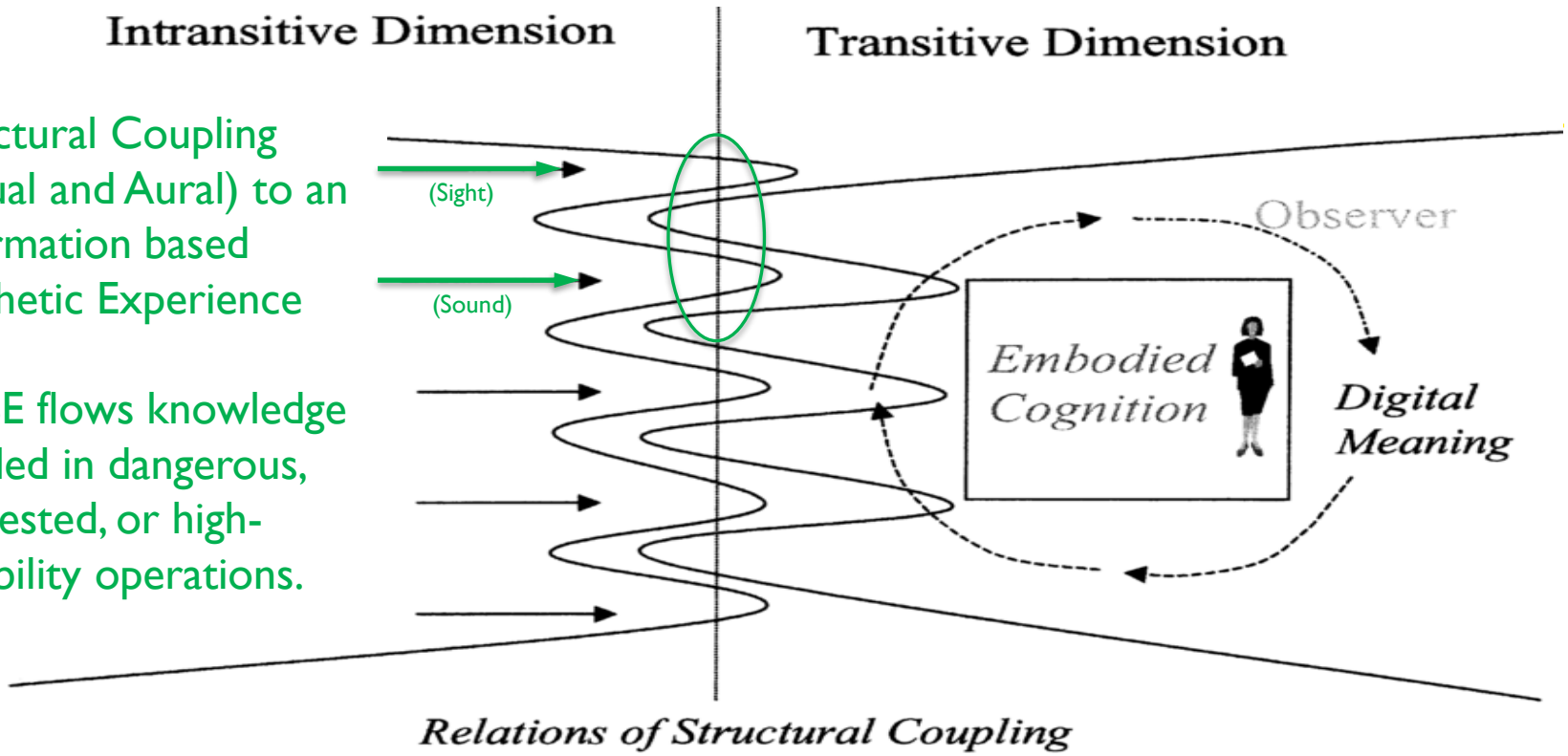


(Mingers, 2001)

Embodied Cognition Theory: a systems approach to human cognitive developed via interaction or "Structural Coupling" of the Observer's mind, brain, and body to the External world.

9c. Research Contributions (Theory)

Structural Coupling (Visual and Aural) to an Information based Synthetic Experience (SE).
An SE flows knowledge needed in dangerous, contested, or high-reliability operations.

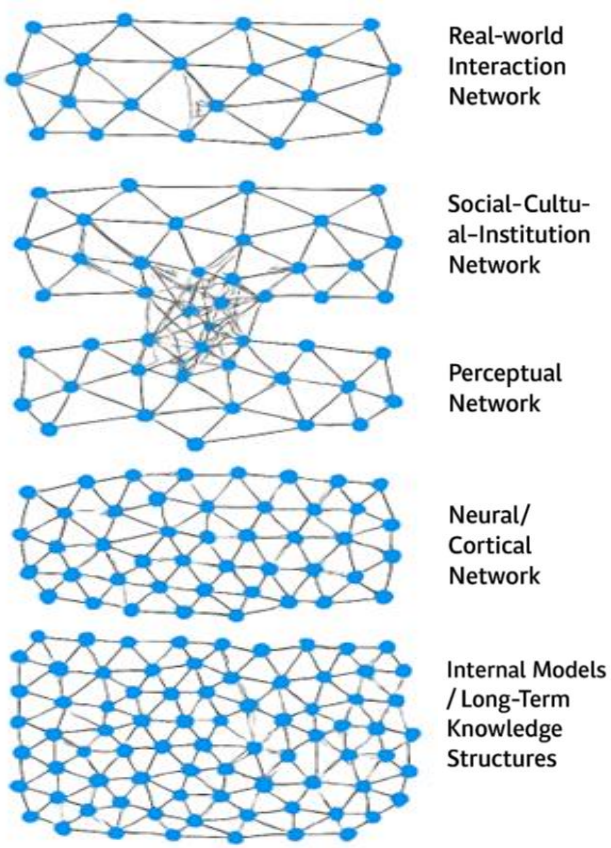


Embodied Cognition via XR: Human cognition developed via an interaction or "Structural Coupling" of the Observer's mind, brain, and body to the SE / 'information only' presentation.

Mingers' dimensions as network relationships

Mingers' "Intransitive Dimension"

"Transitive Dimension"

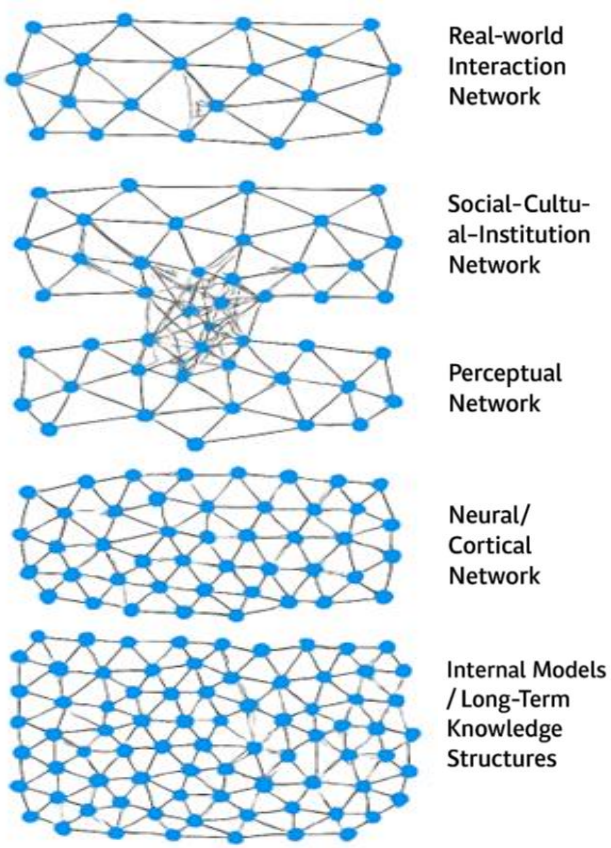


Structural Coupling

Mingers' "Intransitive Dimension"

"Transitive Dimension"

Structural Coupling

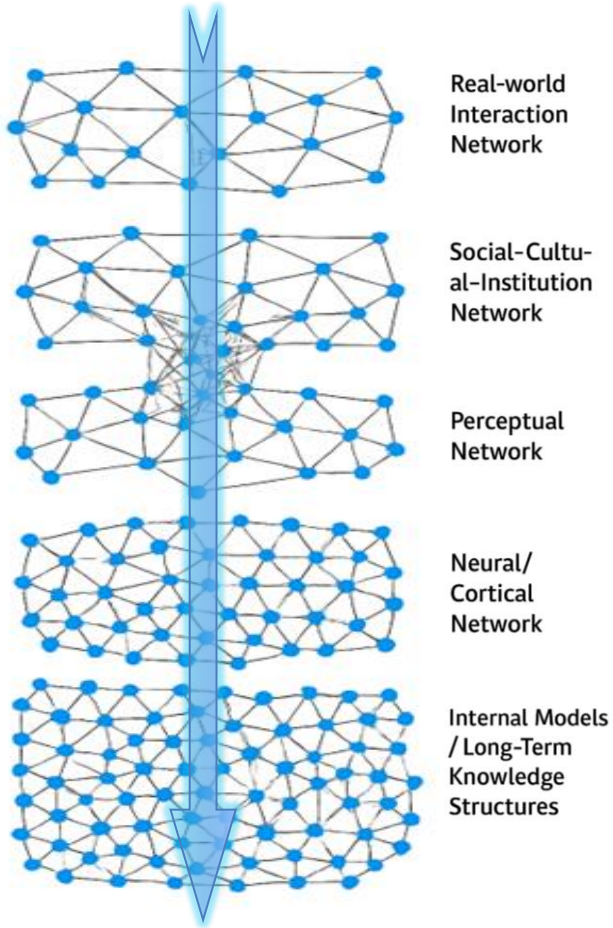


Structural Coupling

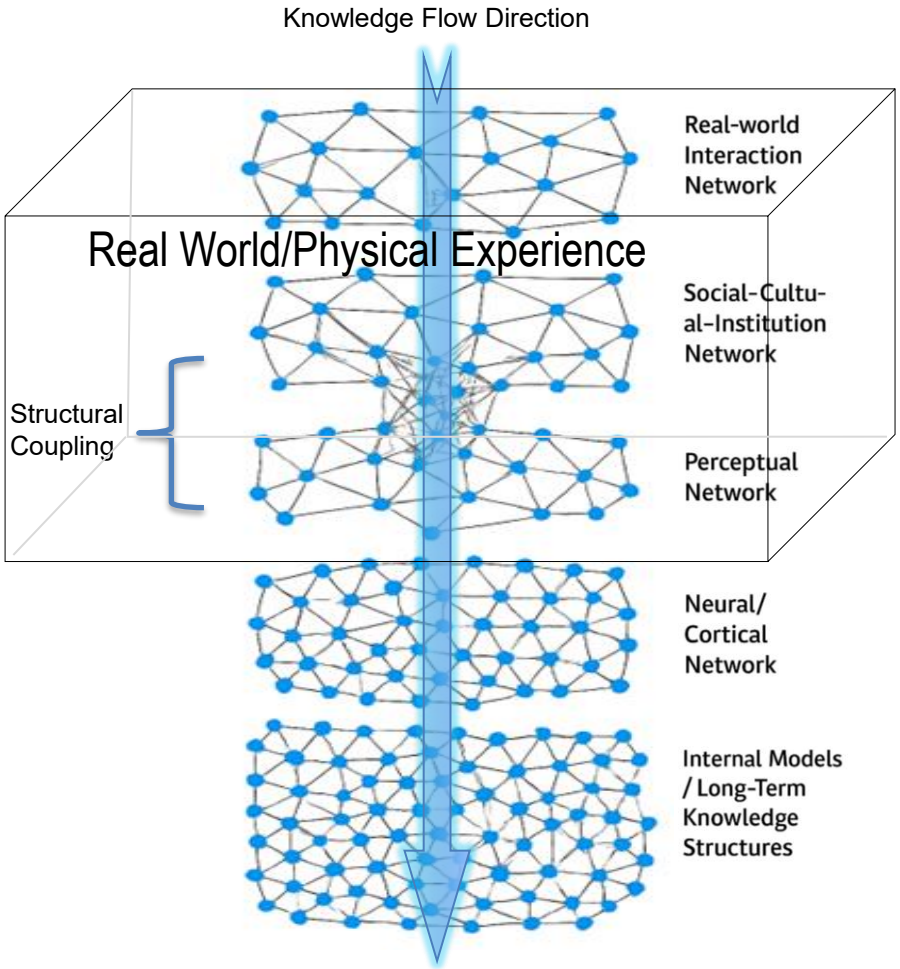
Mingers' "Intransitive Dimension"

"Transitive Dimension"

Structural Coupling



Structural Coupling (Real World)



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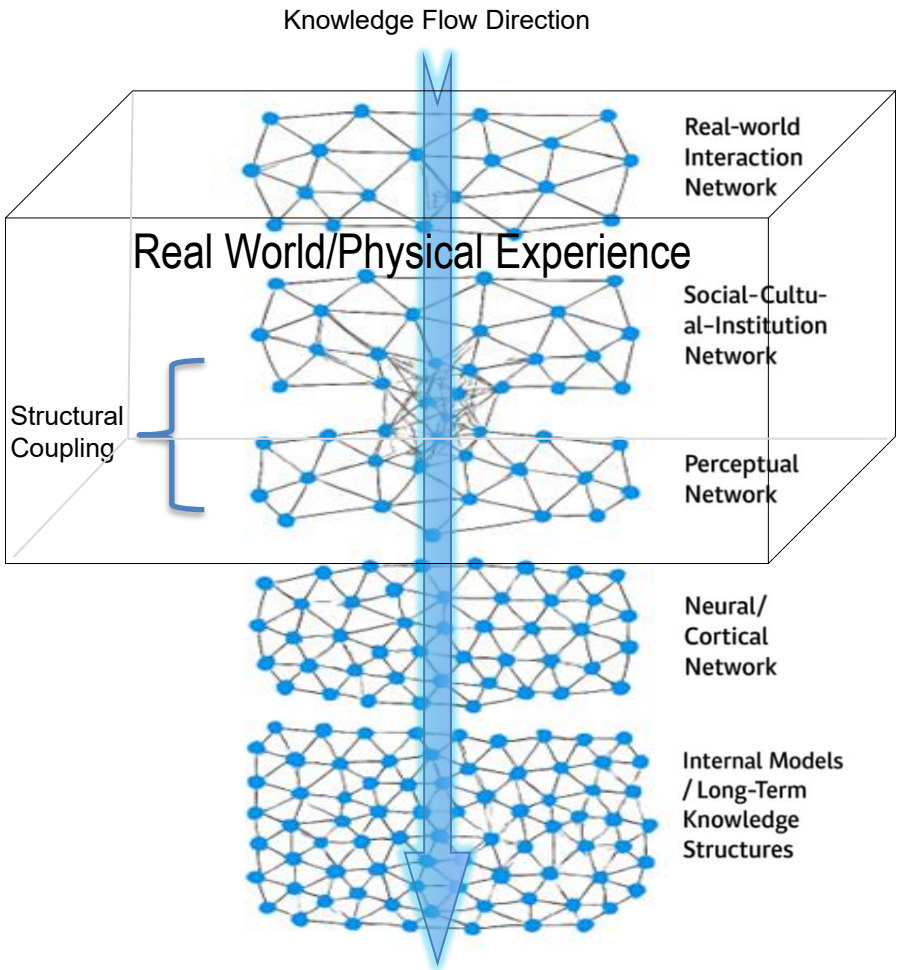
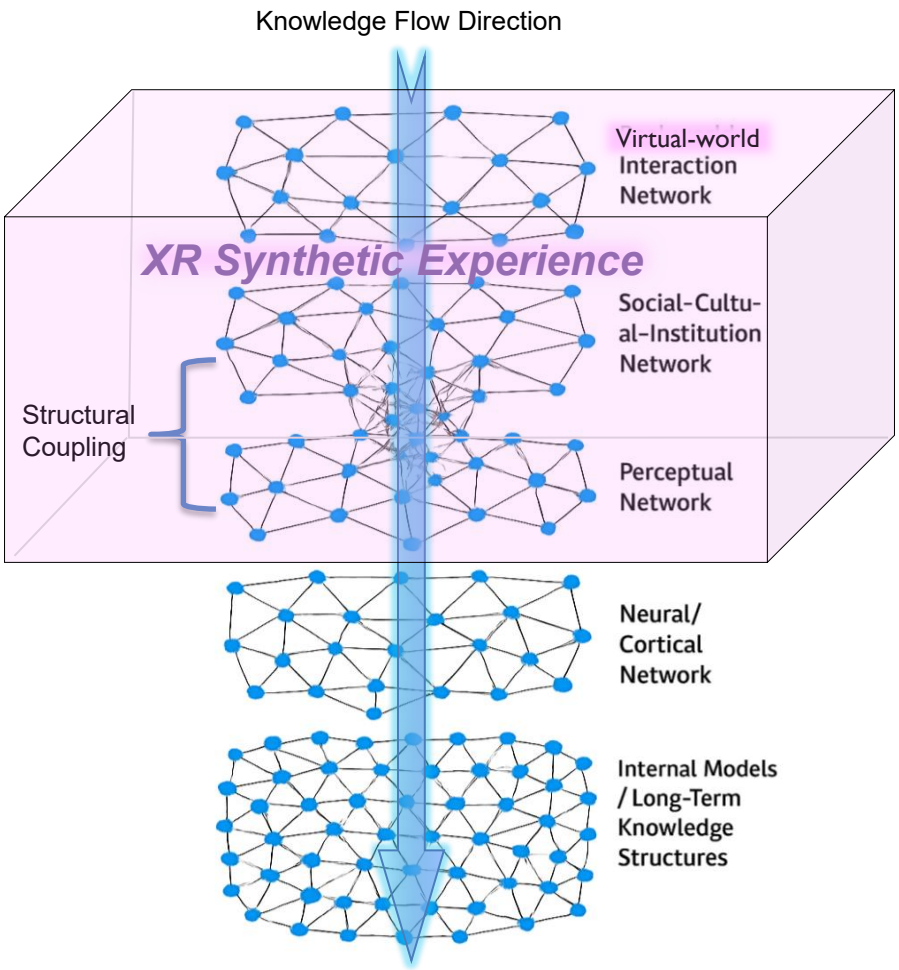
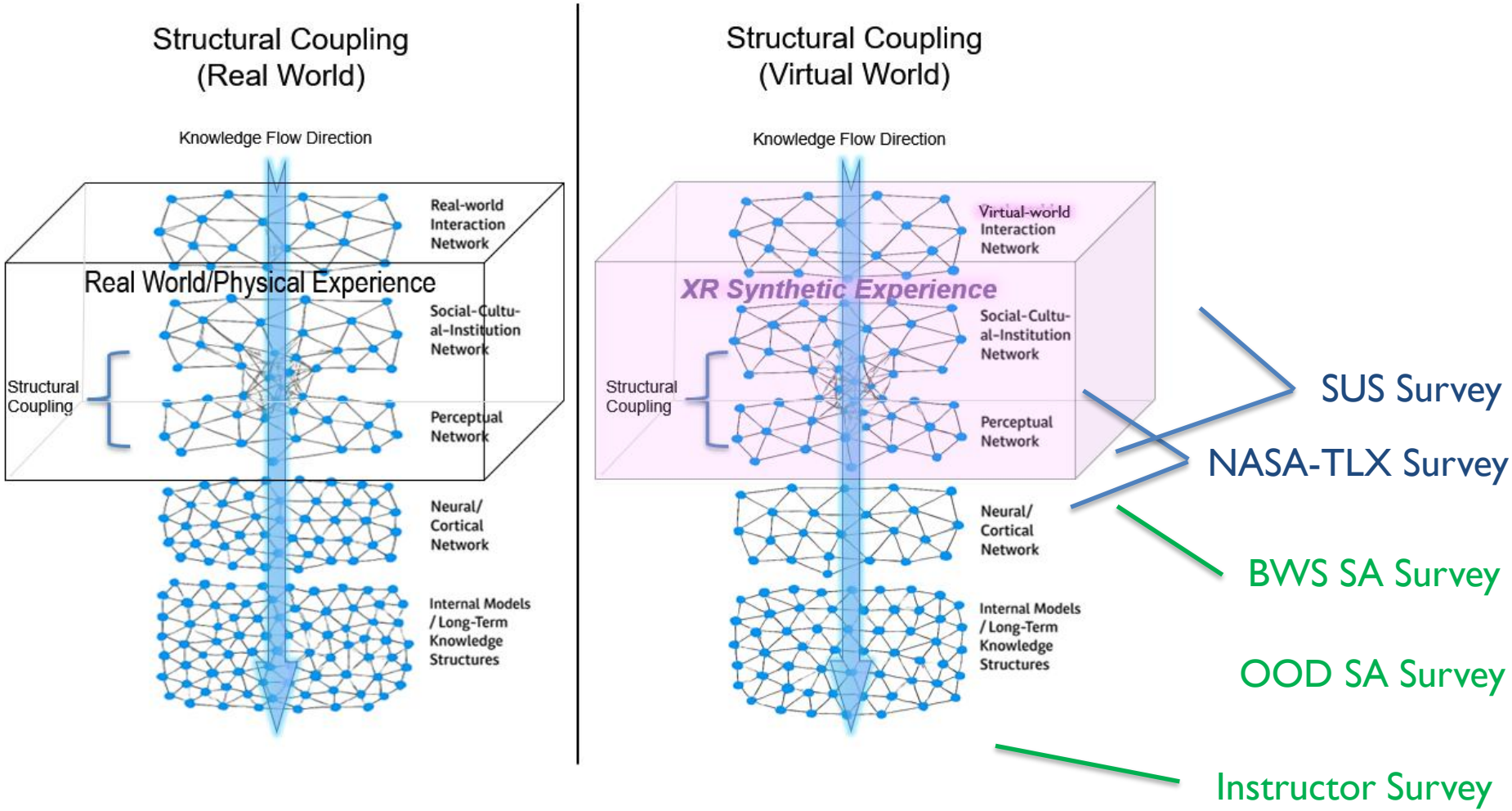


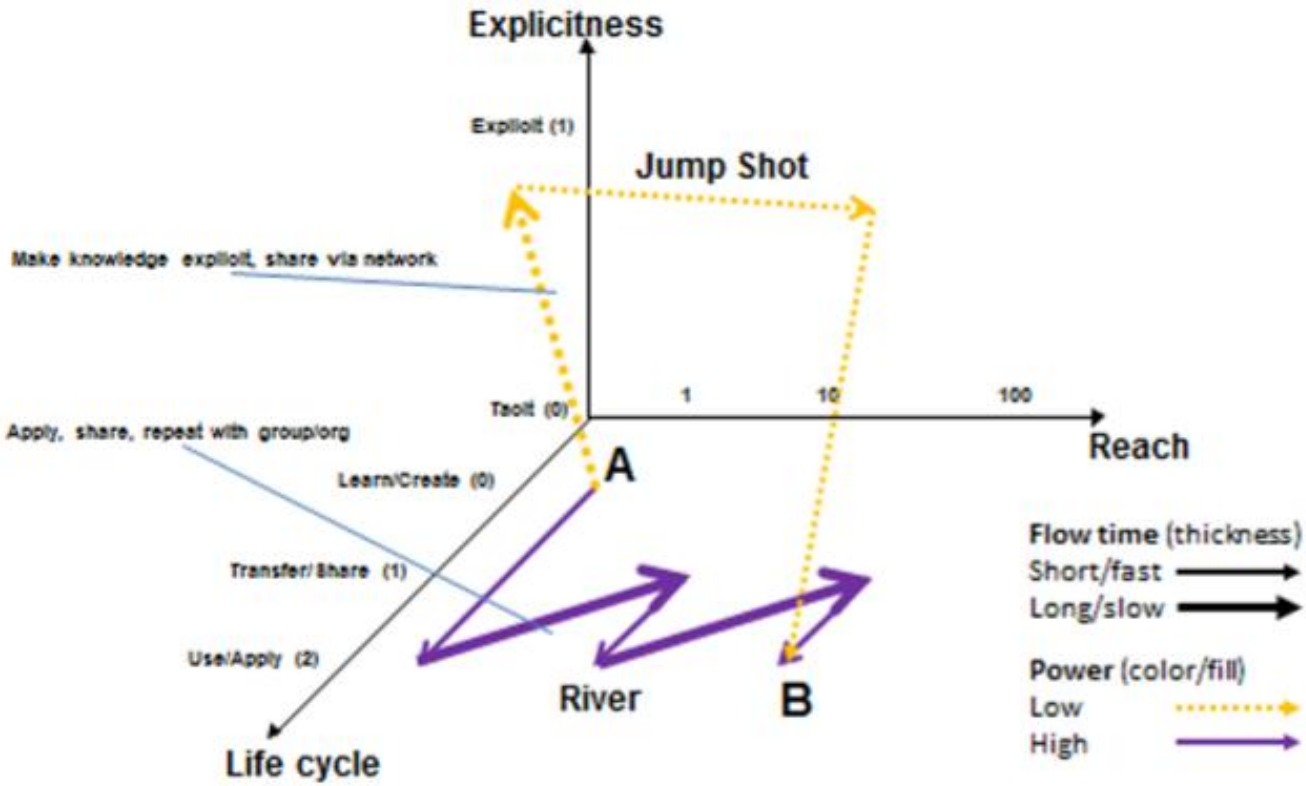
Structural Coupling (Virtual World)



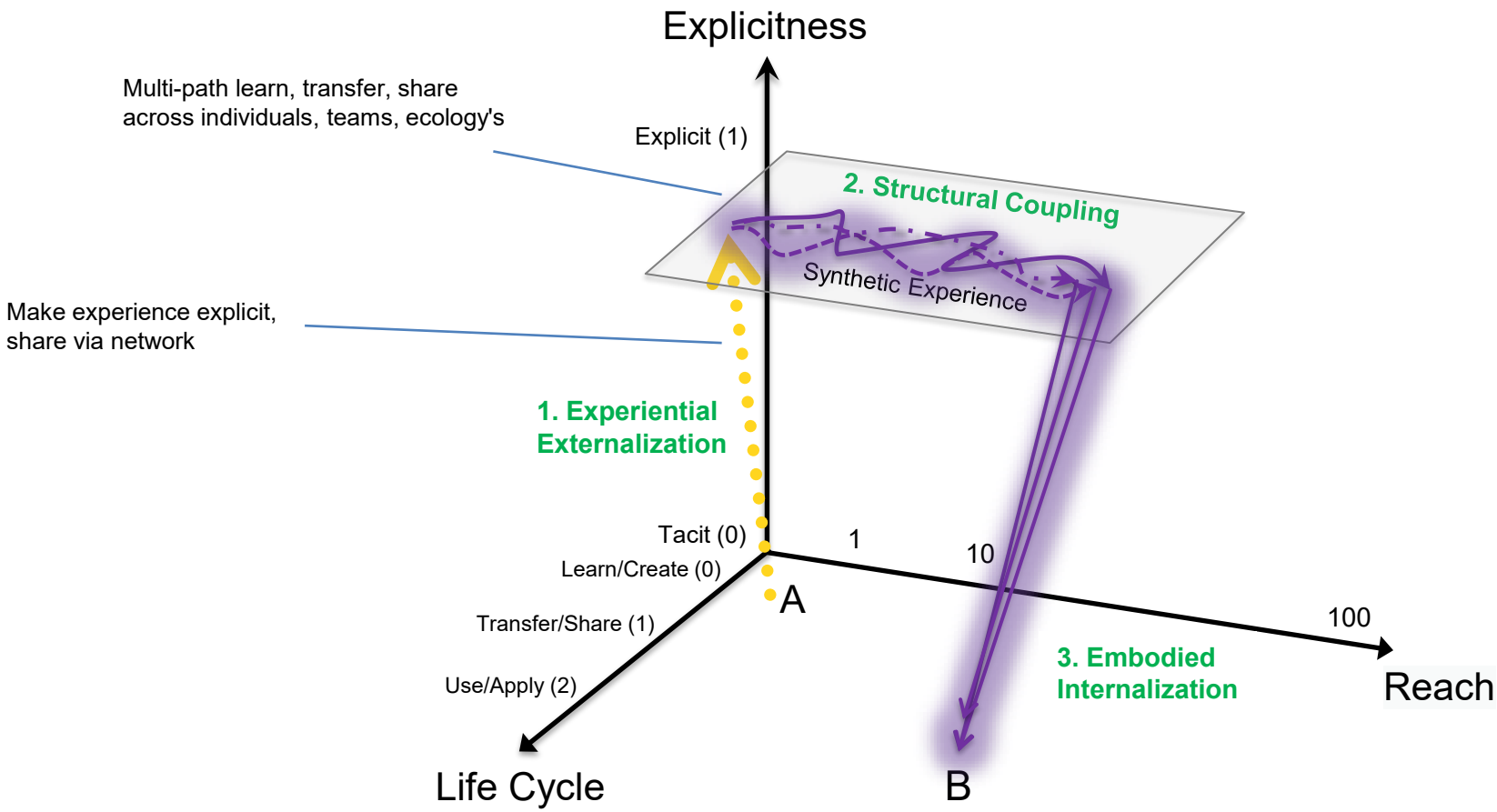


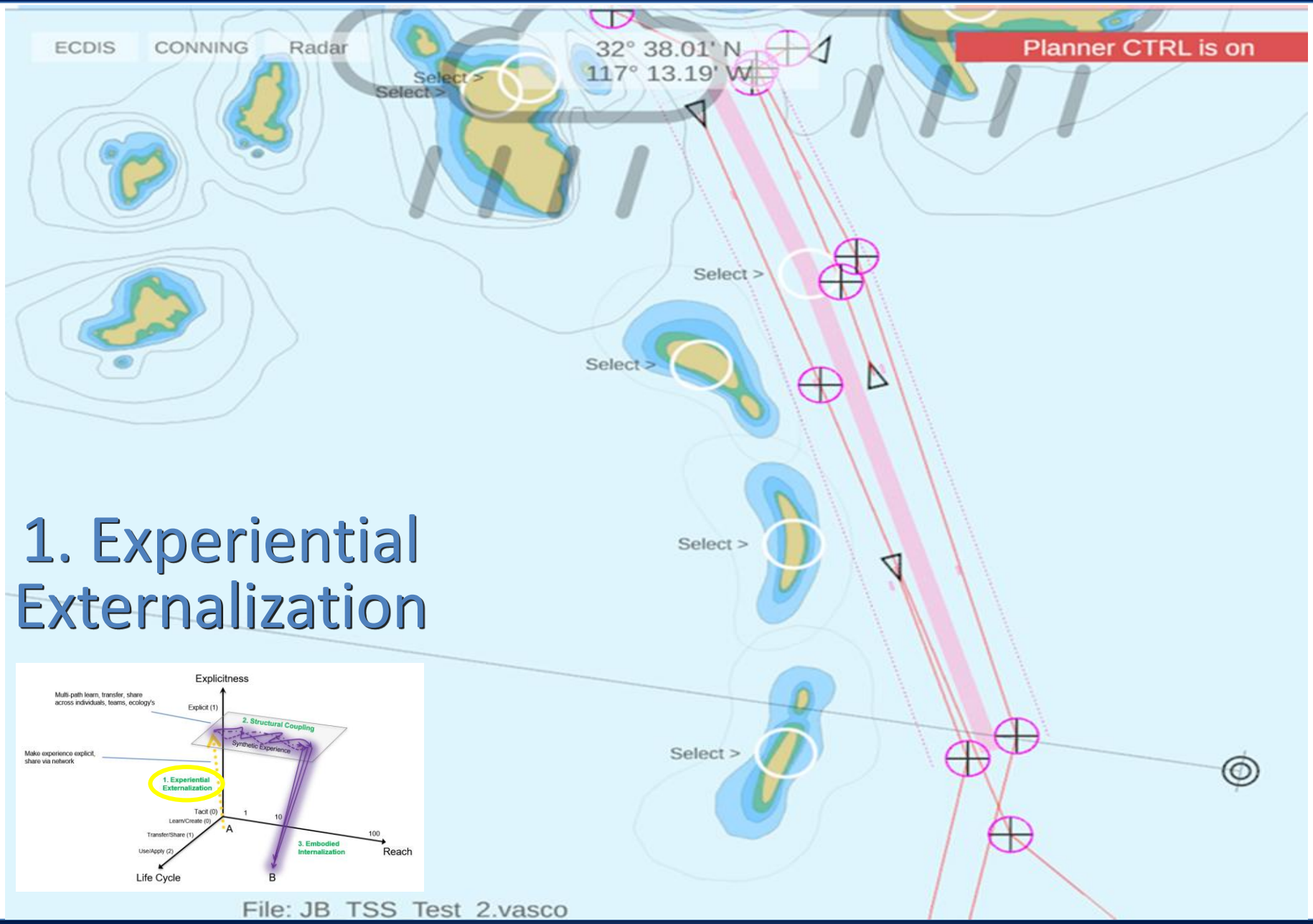
Social / Team Tacit Knowledge Transfer Facilitation in physical and informational domains

9d. Research Contributions (Theory)



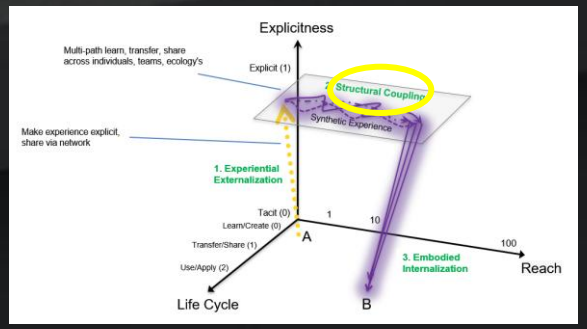
9e. Research Contributions (Theory)



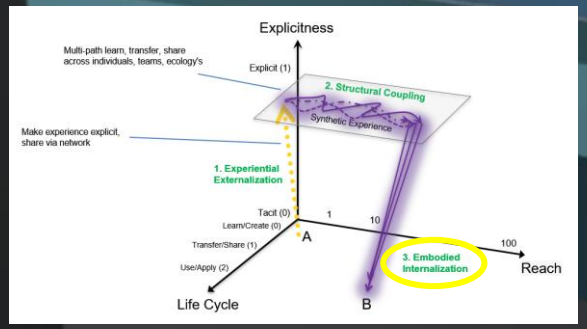


1. Experiential Externalization

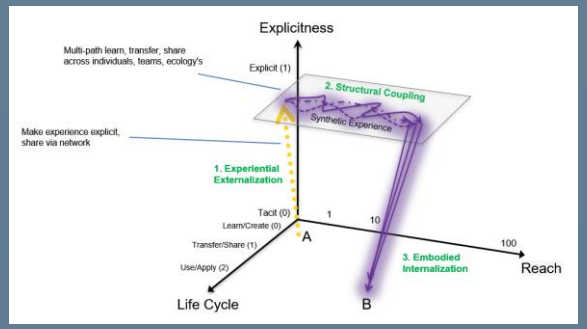
2. Structural Coupling



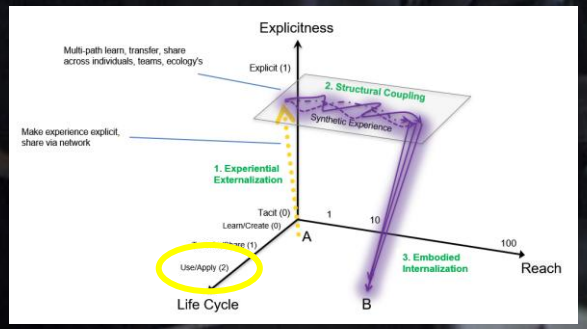
3. Embodied Internalization



3. Embodied Internalization (Panmodal)



Use/Apply


Explicitness
Multi-path learn, transfer, share across individuals, teams, ecology's
Explicit (1)
2. Structural Coupling
Synthetic Experience
Make experience explicit, share via network
1. Experiential Externalization
Tacit (0)
Learn/Create (0)
Use/Apply (2)
Life Cycle
A
B
1
10
100
Reach
3. Embodied Internalization

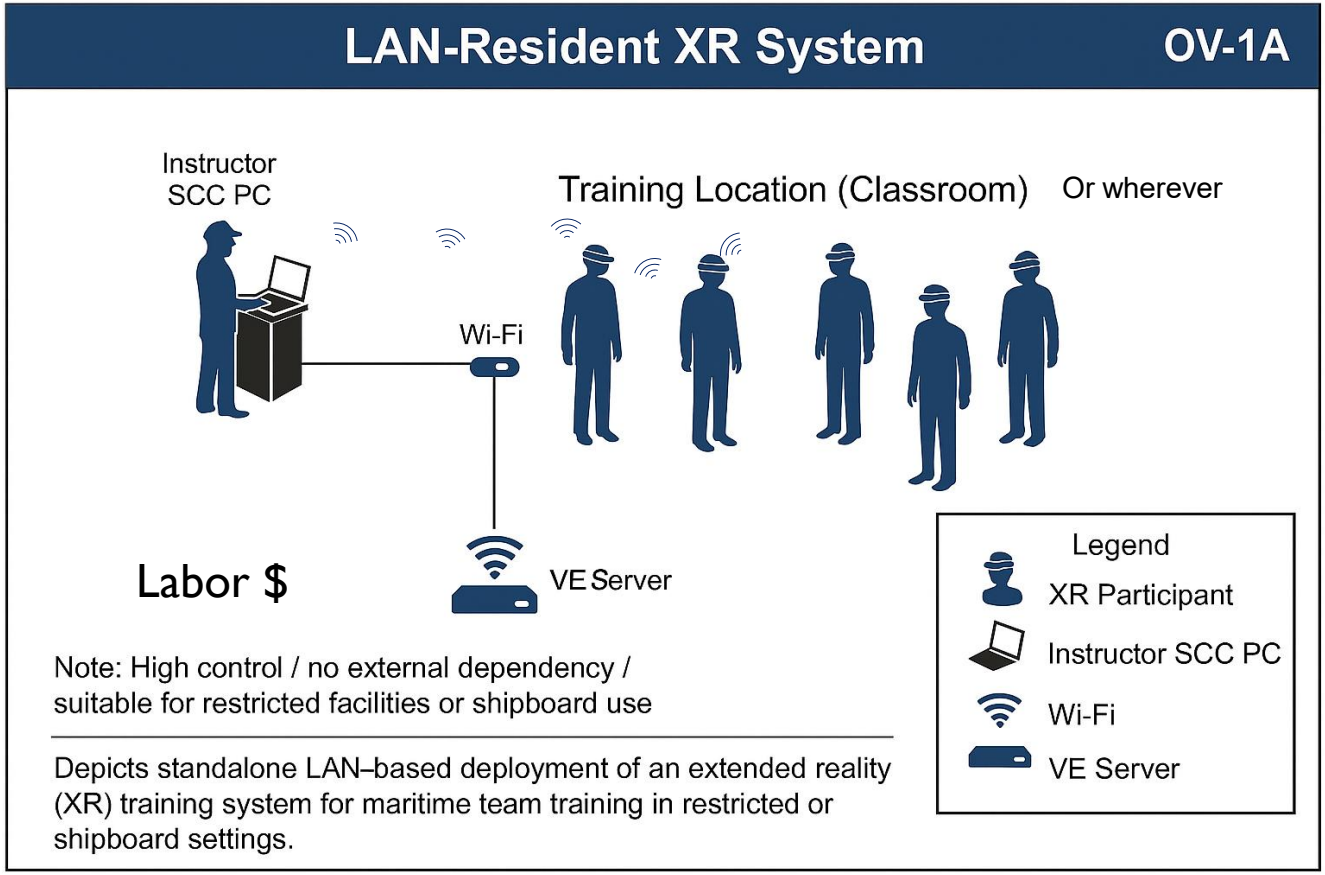
9f. Research Contributions (Method)

Category	Description	Contribution Type	Example/Application
Design	Within-subjects, counterbalanced quasi-experimental design comparing XR prototype system and the NSST physical mock-up under matched maritime scenarios.	Experimental Rigor / Control of Individual Differences	Controls for participant variability and explicitly examined order/sequence effects across XR and physical training conditions.
Measurement Framework	Integrated battery of NASA-TLX (workload), System Usability Scale (SUS), self-assessment surveys, instructor assessments and text analysis metrics.	Multi-Instrument Evaluation / Triangulation	Provides multi-dimensional view of user experience, workload, and perceived team performance—rarely combined in prior XR training studies.

9g. Research Contributions (Method)

Category	Description	Contribution Type	Example/Application
Analytic Approach	Applied multiple non-parametric tests (e.g., Wilcoxon Signed-Rank with Bonferroni correction) to detect condition differences and manage multiple comparisons.	Statistical Rigor / Transparency	Ensures robustness of inferential results while controlling for family-wise error rate.
Team Context	Evaluation embedded in distributed cognition and tacit knowledge transfer framework, with expert and novice roles replicated from actual bridge watch teams.	Ecological Validity / Contextual Realism	Extends XR evaluation from individual tasks to team-based cognitive processes, increasing ecological validity and generalizability to other needed spatial-temporal skill sets.
Implementation Practice	Practical alignment of XR and NSST scenarios (e.g., Underway Replenishment, Channel Transit) with instructor calibration and scenario realism.	Method Transferability	Offers reproducible configuration and procedural guidance for future XR team-training evaluations in safety-critical environments.

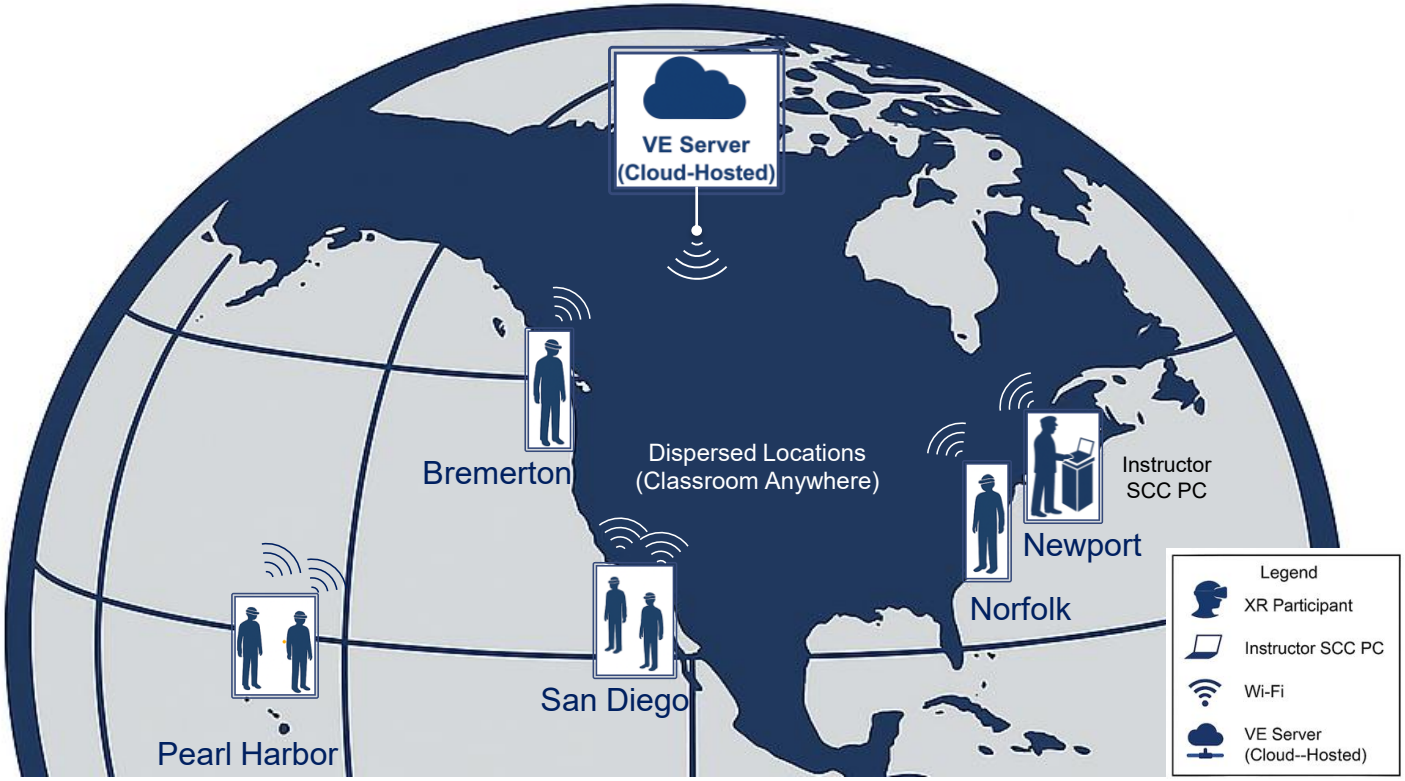
9h. Research Contributions (Practice)



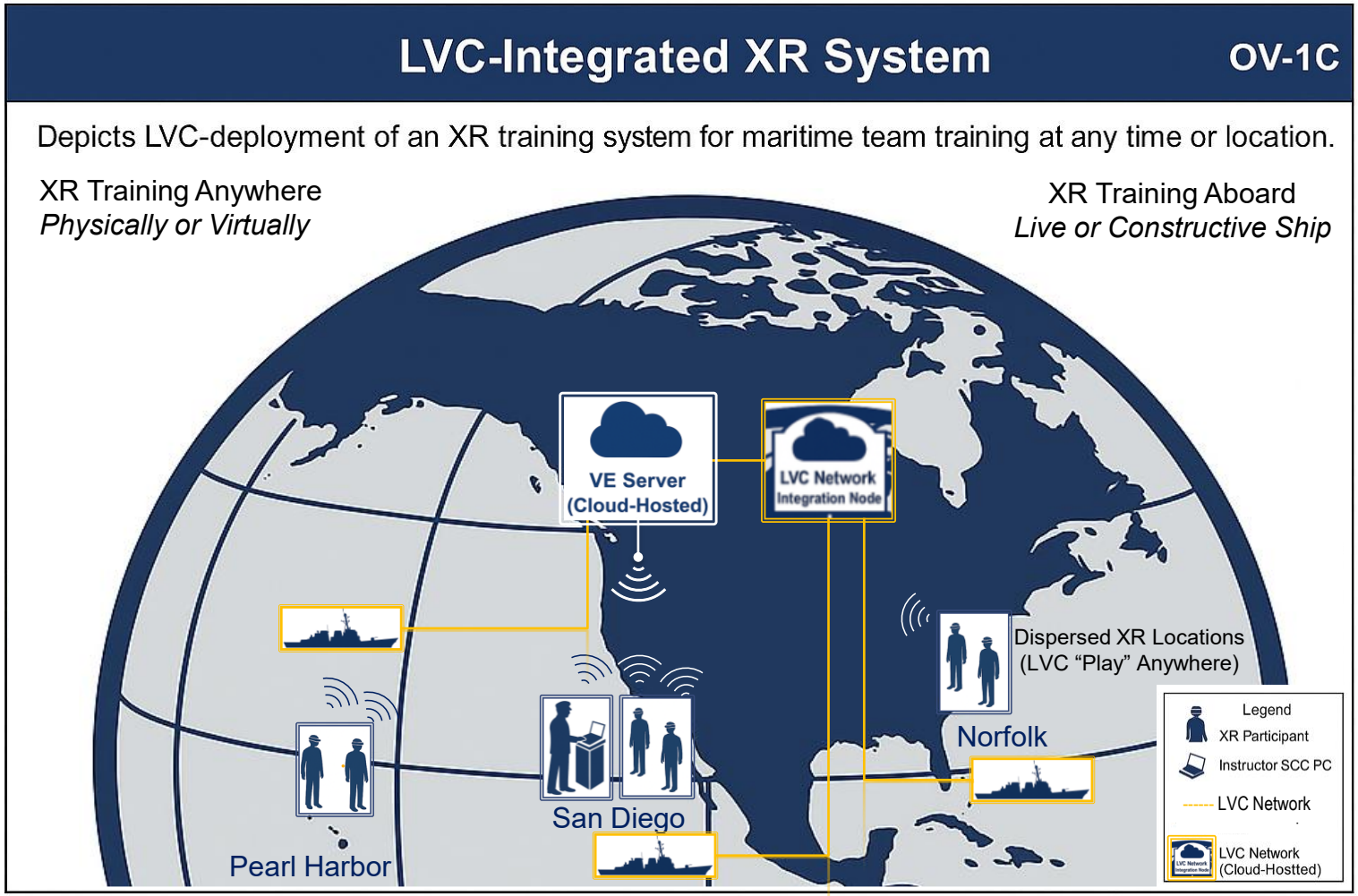
9i. Research Contributions (Practice)

Cloud-Enabled XR System OV-1B

Depicts cloud-deployment of an XR training system for maritime team training at any time or location.



9j. Research Contributions (Practice)



9k. Conclusions

1. U.S. Navy bridge team perceptions of XR training were *not significantly different* than those of the physical bridge mockup.

So What??????????????

2. *XR vastly increases facilitation of Tacit Knowledge Flow:*

A. Expert Reach / Training Availability is *Virtually Unlimited*. Speeds the window from training to engagement.

B. Scenarios presented via XR are *Virtually Unlimited*. Any bridge, any ship, any maritime environment, any set of weather conditions.

C. *Highly Affordable*.

D. *Highly Portable*.

Questions & Recommendations

(Synthetic Experience of a USN Guided Missile Destroyer entering San Diego Bay)

Acknowledgements

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- ONR Technical Solutions Team: Dr. Jessica Jones, Mr. Jason Payne, Mr. John Coffey

U.S. Navy Officers and Sailors – Participants

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- Mariner Skills Training Center Pacific Mr. Eric Stailey – Executive Director

Michele, Audrey, and Ellie – my foundation who's love and unwavering support made it possible.

Back-up Slides:

The following slides are for back-up to address questions and provide additional context.

7c. Research Design, Method and Materials (continued)

Within-Subjects Quasi-Experimental Design (Mockup vs XR) *

$$Yitc = \mu + \alpha i + \beta t + \gamma c + \varepsilon itc$$

Yitc	Observed result for participant "i" at time "t" in condition "c"
μ	Grand mean (overall baseline)
αi	Participant/team effect (controls for individual differences)
βt	Time/order effect (XR-first vs NSST-first)
γc	Treatment effect (difference between XR and NSST)
εitc	Residual error (unexplained variance)

* Research design framework taken from Cook, Campbell, & Shadish 2002

7d. Research Design, Method and Materials (continued)

1) Each participant experiences both conditions → controls for αi (individual differences).
2) Counterbalanced order → mitigates βt (learning/fatigue).
3) WSRT tests γc (treatment effect) at bivariate level; Hotelling's T^2 multivariate level.
4) Bonferroni correction → protects statistical conclusion validity.
5) PCA → validates construct coherence (Y structure).

History / Maturation	Counterbalancing, identical scenarios
Testing / Triangulated Instrumentation	Standardized TLX, SUS, Maritime Knowledge: BWS SA, OOD SA, INST Assessment, and TA
Selection	Within-subject pairing (same participants)
Statistical Error	Bonferroni correction, effect sizes, WSRT

* Research design framework taken from Cook, Campbell, & Shadish 2002

Knowledge Flow Defined:

- Knowledge is operationalized as "know how", it enables direct action.
- In Knowledge Management, such know how can exist in three forms, 'Tacit', 'Implicit', or 'Explicit' where 'explicitness' refers to knowledge which has been informed in a medium as information.
  - Knowledge Flow chiefly concerns the movement of explicit knowledge from "…how, when, and where it exists to how, when, and where it is needed." (Nissen, 2014)

In this conception, knowledge flows begin as expertise of 'those who know', either as tacit or implicit knowledge, which is

1) made explicit as information
2) conveyed to 'those who do not know'
3) informed as "know how" in the minds of the receiver

.

Knowledge Friction Defined:

- Knowledge Friction, as defined by Nissen (2019) and extended by Shigley (2021);

"The 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."

XR represents a novel transfer link compared to a physical Mock-up simulation, impacting explicitness, reach, and power.

Literature Review: Philosophical Lens

In classical philosophy, 'knowledge' is conceptualized along three categorical terms / types:

- Episteme - Propositional, Symbolic / Linguistic, Abstract.
- Empeiria – Acquaintance, Direct Experience, Familiarity.
- Techne – Skill, True Art, Technique. (Benefit to who or what the skill is being used for.)

These philosophical conceptualizations remain largely intact, updated as "Knowledge that", "Acquaintance", and "Knowledge How" respectively. (Russell, Ryle, Quine, Peirce, etc.)

Literature Review: Philosophical Lens

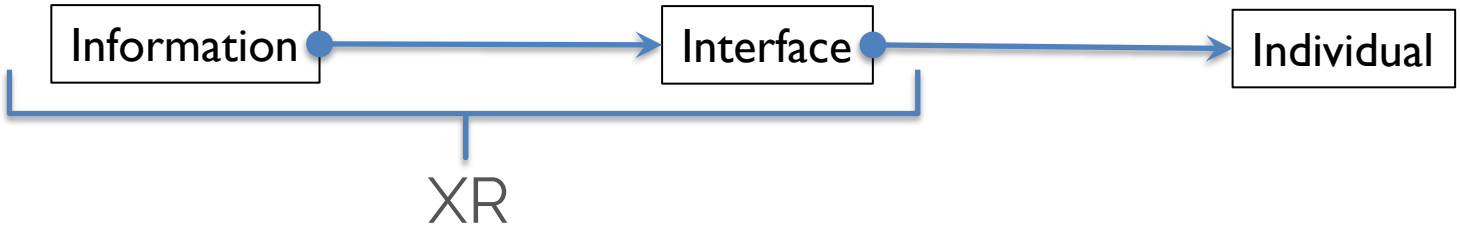
- Episteme - Propositional, Symbolic / Linguistic, Abstract.

- Empeiria – Acquaintance, Direct Experience, Familiarity.
- Techne – Skill, True Art, Technique. (Benefit to who or what the skill is being used for.)

This research addresses knowledge gap in creating and applying, 'Virtual-World Empeiria' to develop 'Real-World Techne'

Literature Review: Information Science

"Information Science is that discipline that investigates…the means of processing information for optimum accessibility and usability. It is concerned with the body of knowledge relating to the origination, collection, organization, storage, retrieval, interpretation, transmission, and utilization of information."



From "Information Science: What is it?" (Borko, 1968)

High Reliability Organization

1. Sensitivity to Operations *(i.e., Heightened awareness of the state of relevant systems and processes.)*
2. Preoccupation with Failure *(i.e., To view near misses as opportunities to improve, rather than proof of success.)*
3. Reluctance to Simplify *(i.e., The acceptance that work is complex, with the potential to fail in new and unexpected ways.)*
4. Practicing Resilience *(i.e., To prioritize emergency training for many unlikely, but possible, system failures.)*
5. Deference to Expertise *(i.e., To value insights from staff with the most pertinent safety knowledge over those with greater seniority.)*

9A. Literature Review

Embodied Cognition Theory / with references

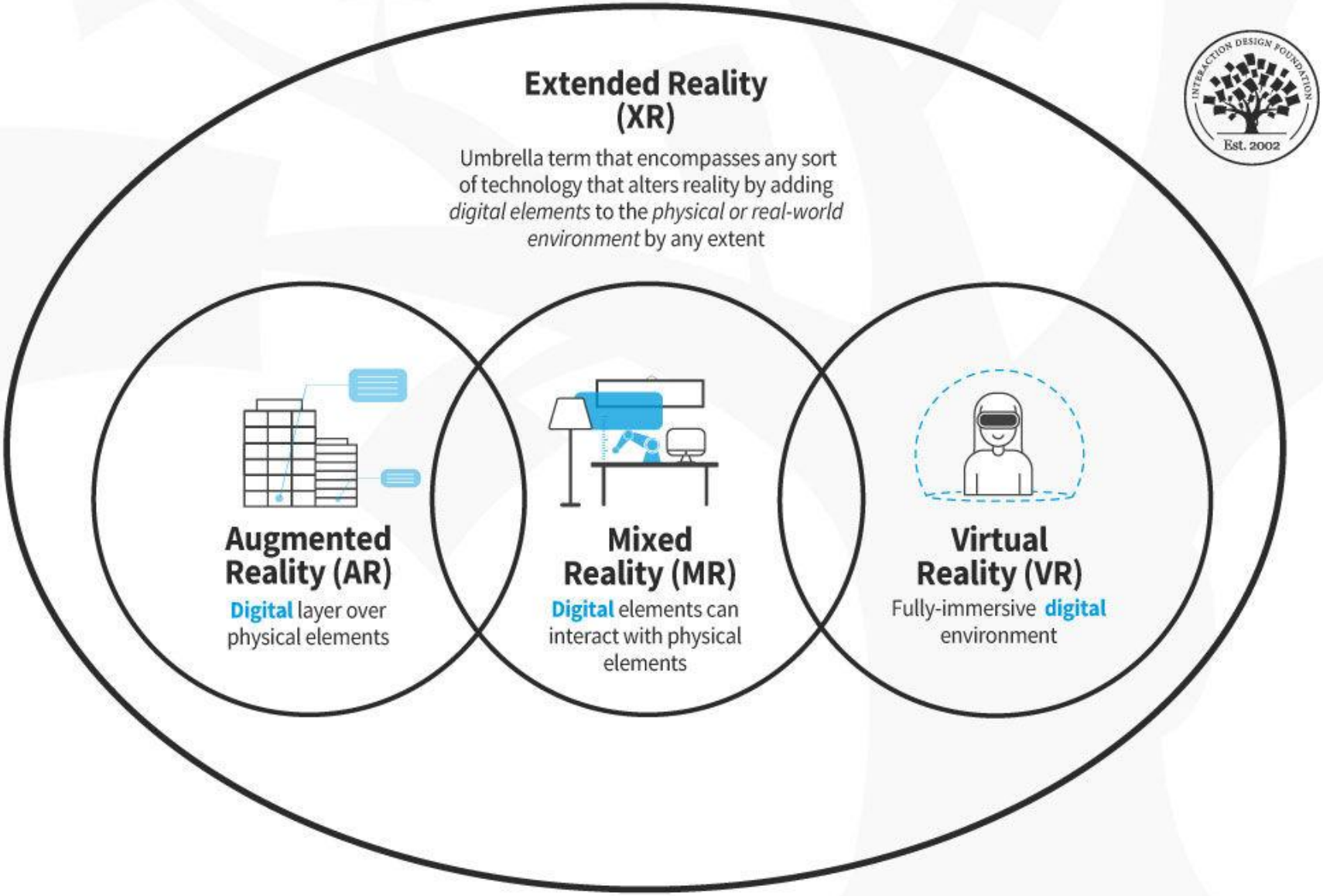
Theory of Embodied Cognition (Lakoff, 2012; Wilson & Foglia, 2016) knowledge is acquired via the interaction or *structural coupling*, (Maturana & Varela, 1988) of the body with the natural environment through sensory-kinetic processes (Alibali & Nathan, 2012; Iraklioti, Pantidos, & Birbili, 2017; Kokkinidou, 2017)

Participation of the body in learning also occurs through social interactivity such as expressions, manners, and emotions. (Kokkinidou, 2017; Alexias, 2011).

1. Human Body as primary cognitive agent. (NOT just within the brain.)
2. Human cognition as connectionist. (NOT based on 'brain as computer'.)
3. Knowledge as a result of structural coupling of the body, memory, and environment.

Institutional Review Board (IRB) Requirements

- Study requires data collection from human subjects, is considered "Human Subjects Research"
- NPS Student will conduct data collection under the umbrella of NIWC Pacific VIBRaNT IRB Protocol Submission.
- NIWC Pacific to serve as IRB of Record for dissertation data collection activities.
- NPS Student must complete CITI training, submit certification letter to NPS IRB after submission has been provided and approved by NIWC Pacific IRB.
- NIWC Pacific / NPS IRB coordination via Bryan Hudgens and Dr. Mollie McGuire and Kara Sorensen (NIWC IRB Chair)


Extended Reality (XR)
Umbrella term that encompasses any sort of technology that alters reality by adding *digital elements* to the *physical or real-world environment* by any extent
Augmented Reality (AR)
Digital layer over physical elements
Mixed Reality (MR)
Digital elements can interact with physical elements
Virtual Reality (VR)
Fully-immersive digital environment
INTERACTION DESIGN FOUNDATION
Est. 2002

9B. Knowledge Flow Theory (Cont)

Nissen Flow Model with sample flow vectors across 3 axes, Explicitness, Reach, and Life Cycle.

"…a dynamic model that can be used to classify and visualize a diversity of knowledge-flow patterns through the enterprise."

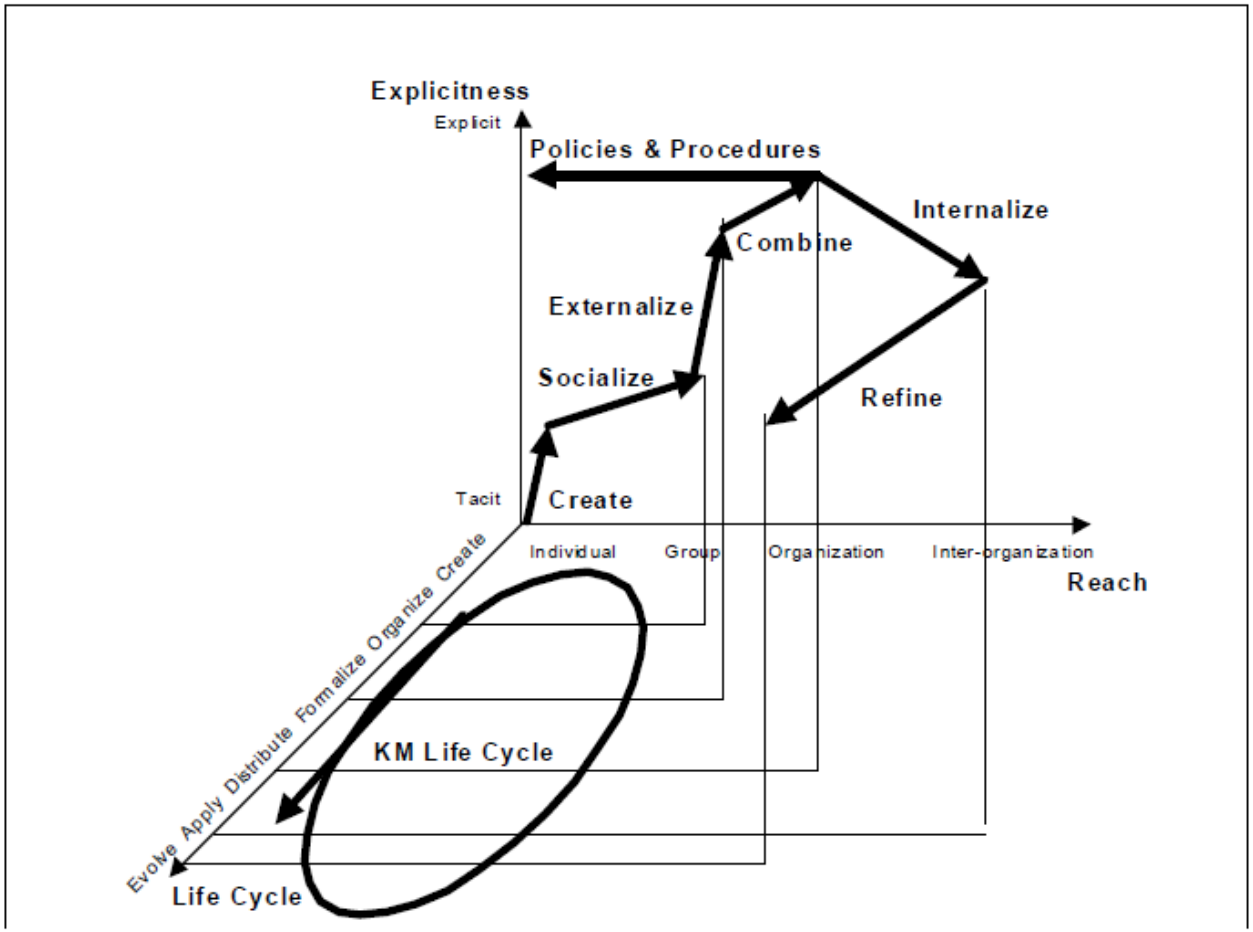


Figure 5. Extended Model with Knowledge Flows

(Nissen, 2002)

9A. Literature Review – 2 Key Theories

Embodied Cognition Theory

Theory of Embodied Cognition poses knowledge as acquired via the interaction or *structural coupling* of the not just the brain, but the whole body with the natural environment through sensory-kinetic processes.

Participation of the body in learning through social interactivity with others is also critical, e.g., expressions, manners, and emotions.

1. Human Body as primary cognitive agent. (NOT just within the brain.)
2. Human cognition as connectionist. (NOT based on 'brain as computer'.)
3. Knowledge as a result of structural coupling of the body, memory, and environment.

(Clark, 2023; Lakoff, 2012; Wilson & Foglia, 2016; Maturana & Varela, 1988)

9B. Literature Review

Knowledge Flow Theory

Knowledge Flow is a term from Knowledge Management based on theory beginning with the Tacit Dimension (Polanyi, 1967), the Knowledge Spiral (Nonaka & Takeuchi, 1995) leading to Nissen's 5-Degree Theory of Knowledge Flow which addresses the movement of knowledge from its source to destination along three axes, 1) Level of Explicitness, 2) Reach, and 3) Life Cycle (Nissen, 2002; Nissen, 2014).

- **Explicitness:** degree of externalization of knowledge, from that which is held by the 'knower' tacitly, to that which is represented in an information medium.
- **Reach:** degree of socialization, e.g., individual, group, or organization.
- **Life Cycle:** stage of knowledge flow, creating, sharing, applying, etc.
- **Flow Vector:** Graphical representation of knowledge flow magnitude (e.g., thick vector = slow movement) and direction (e.g., from 'source' to 'destination(s)').

7i. Research Design, Method and Materials (continued)

System Usability Scale (SUS) Survey Questions

SUS Statement	Full SUS Question/Statement
Q1 (Frequent Use)	I think that I would like to use this system frequently.
Q2 (Complexity)	I found the system unnecessarily complex. (R)
Q3 (Easy to Use)	I thought the system was easy to use.
Q4 (Need Support)	I think that I would need the support of a technical person to be able to use this system. (R)
Q5 (Well Integrated)	I found the various functions in this system were well integrated.
Q6 (Inconsistency)	I thought there was too much inconsistency in this system. (R)
Q7 (Learn Quickly)	I would imagine that most people would learn to use this system very quickly.
Q8 (Cumbersome)	I found the system very cumbersome to use. (R)
Q9 (Confidence)	I felt very confident using the system.
Q10 (Learning Needed)	I needed to learn a lot of things before I could get going with this system. (R)

7j. Research Design, Method and Materials (continued)

Bridge Watch Stander (BWS) Self-Assessment Questions 1-10

Self-Assessment Statement	Full Question/Statement
Q1 (Reaction Time)	I was able to react in sufficient time to commands given.
Q2 (Decision Time) (R)	I could not make decisions with sufficient time for the action to be carried out.
Q3 (Mission Success) (R)	I was not able to accomplish the scenario's mission.
Q4 (Comm CIC)	I was able to consistently communicate with CIC.
Q5 (Comm CCS) (R)	I could not effectively exercise communication procedures with CCS.
Q6 (Bridge to Bridge)	I was able to communicate with other vessels via Bridge to Bridge radio when needed.
Q7 (Focus) (R)	I could not focus on the correct area of interest for the situation at hand.
Q8 (Rules of Road)	I was able to correctly apply Rules of the Road.
Q9 (OOD Backup) (R)	I was not able to provide forceful OOD backup.
Q10 (Notify OOD)	I was able to notify the OOD of potential violations of Rules of the Road.

7k. Research Design, Method and Materials (continued)

BWS Self-Assessment Questions 11-20

Self-Assessment Statement	Full Question/Statement
Q11 (Collision Avoidance)	I was able to identify and point out potential collision / near miss situations.
Q12 (Perceive Danger) (R)	I was not able to perceive potential dangers.
Q13 (Team Commands)	My Bridge Team used standard commands to effectively conn the ship.
Q14 (Set & Drift) (R)	My Bridge Team did not perceive set and drift conditions to conn the ship.
Q15 (Situational Foresight)	My Bridge Team foresaw situational dynamics needed to conn the ship.
Q16 (COLREGS) (R)	My Bridge Team was not able to operate our ship in accordance with COLREGS.
Q17 (System Ease)	It was easy for me to use the training system.
Q18 (VMS Trouble) (R)	I had trouble interacting with the simulated VMS.
Q19 (RADAR Ease)	I could easily interact with the simulated RADAR.
Q20 (Helm Trouble) (R)	I had trouble interacting with the simulated Helm / Lee Helm controls.

7l. Research Design, Method and Materials (continued)

BWS Self-Assessment Questions 21-29

Self-Assessment Statement	Full Question/Statement
Q21 (Team Interaction)	It was easy to interact with my fellow Bridge Team members during the training scenario.
Q22 (System Interference) (R)	The training system interfered with learning of the content in the scenario.
Q23 (Skills Development) (R)	The training system will not help refine my seamanship / ship-handling skills.
Q24 (Immersion)	After the training began, I forgot about the training system and was immersed in the scenario.
Q25 (Bridge Realism) (R)	The training system was not a good representation of a ship's bridge environment.
Q26 (Team Cohesion)	Using this training system helps build Bridge Team cohesion.
Q27 (COLREGS Practice) (R)	The training system does not provide a sufficient way to practice proper execution of COLREGS.
Q28 (Motion Set & Drift) (R)	The training system did not give the motion sense needed in assessing Set & Drift.
Q29 (Motion Advance & Transfer)	The training system gave the motion sense needed in assessing Advance & Transfer.

7m. Research Design, Method and Materials (continued)

OOD Self-Assessment Questions 1-10

OOD Self-Assessment Statement	Full Question/Statement
Q1 (Timing of directions) (R)	The OOD vocalized directions with sufficient time for watch standers to respond.
Q2 (Vocal volume)	The OOD vocalized directions with sufficient volume for watch standers to hear and understand.
Q3 (Command clarity) (R)	Watch standers did not need to ask for repeated commands due to understanding directions given by the OOD.
Q4 (Command confirmation)	The OOD consistently confirmed commands from watch standers.
Q5 (Ongoing observation)	The OOD continued to make observations even as up-dated orders were being issued.
Q6 (Problem solving) (R)	When problems emerged, the OOD issued new orders that generated appropriate outcomes.
Q7 (Focus of attention)	The OOD focused on the correct area of interest for the situation at hand.
Q8 (OOD confidence)	The OOD projects confidence.
Q9 (Directing JOOD)	The OOD directed the JOOD appropriately.
Q10 (Monitoring CONN) (R)	The OOD monitored the CONN appropriately.

7n. Research Design, Method and Materials (continued)

OOD Self-Assessment Questions 11-20

OOD Self-Assessment Statement	Full Question/Statement
Q11 (Standard commands)	The OOD ensured the Helm and Lee Helm / Conning Officer used standard commands.
Q12 (CO standing orders) (R)	The OOD adhered to the COs standing orders.
Q13 (VMS navigation use) (R)	The OOD employed bridge VMS system appropriately for navigation.
Q14 (RADAR contact mgmt)	The OOD employed bridge RADAR system for contact management and relative vectors.
Q15 (Comms discipline)	The OOD managed the level of communication so that only appropriate watch standers conversed when needed.
Q16 (CIC communication)	The OOD communicated with CIC about their requirements consistently.
Q17 (CCS casualty comms)	The OOD communicated casualty reports with CCS in a timely manner.
Q18 (CO communication)	The OOD communicated with CO in terms that a mariner would find useful.
Q19 (Contact reports) (R)	The OOD followed the CO's procedures for communicating Contact Reports.
Q20 (Bridge-to-Bridge comms)	The OOD ensured communication with other vessels via Bridge to Bridge radio when needed.

7o. Research Design, Method and Materials (continued)

OOD Self-Assessment Questions 21-28

OOD Self-Assessment Statement	Full Question/Statement
Q21 (Team empowerment)	Bridge team members were empowered to question / provide feedback to the OOD.
Q22 (Team cohesion) (R)	The OOD and his/her bridge team worked well together.
Q23 (Rules of Road) (R)	The OOD followed the Rules of the Road.
Q24 (Ship-handling skill) (R)	The OOD demonstrated knowledge of effective ship-handling.
Q25 (Helm/Lee Helm mgmt) (R)	The OOD properly managed Helm/Lee Helm ship-handling operations.
Q26 (COLREGS Rule 2)	The OOD operated in accordance with COLREGS Rule 2.
Q27 (Mission accomplishment) (R)	The OOD accomplished the scenario's mission.
Q28 (Platform interference) (R)	The training platform did not interfere with the OOD's ability to execute the mission.