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Use of Microworld Simulator for HRA Data Collection

January 2021

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Changing the World's Energy Future

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1. Background

Efforts to Collect HRA Data to Date

- A lack of data has been identified as one of the challenges in human reliability analysis (HRA).
- Most of the current studies are concentrating on collecting the data from full-scope studies using full-scope simulator and actual operator.
  - U.S.NRC (SACADA) / KAERI (HuREX)
    - *SACADA: Scenario, Authoring, Characterization, and Debriefing Application*
    - *HuREX: Human Reliability data EXtraction*
  - Good to collect high fidelity data in lieu of actual historical measurements

Challenges to Perform Full-Scope Studies

- Difficult to get actual operators for continuously collecting a variety of data due to the high cost
- Utilities' cooperation and data release are relatively limited to few organizations.

1. Background

▶ INL's Approach to HRA Data Collection

- To collect HRA data through the Simplified Human Error Experimental Program (SHEEP)
  - To use simplified simulators and students as a complement – not a replacement – for full-scope studies.
  - To provide the data to support full-scope data collection studies such as HuREX and SACADA

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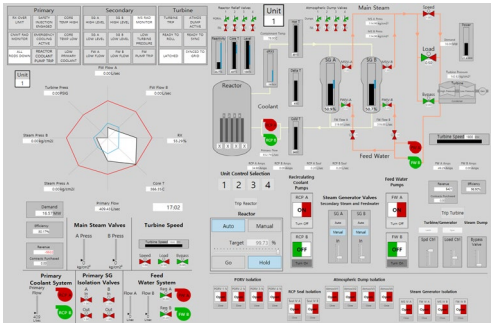
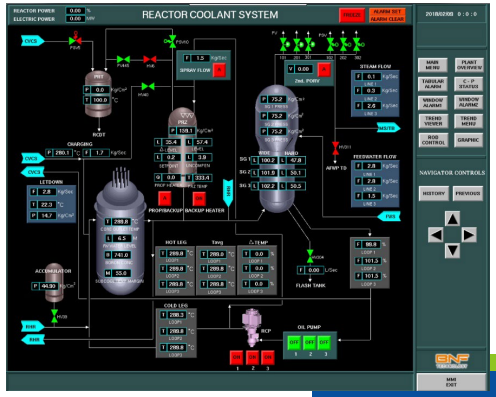


<Rancor Microworld>

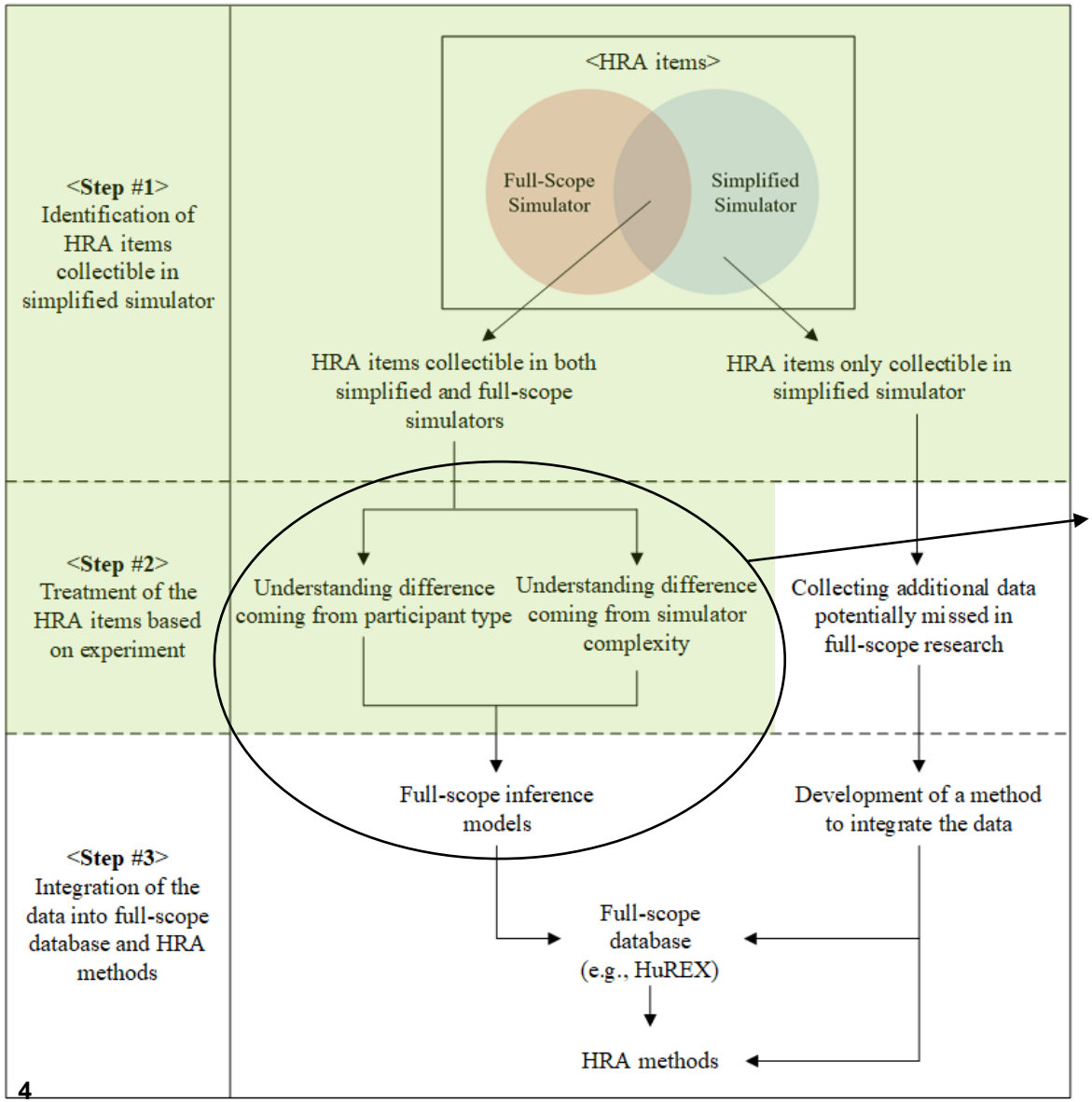
<Chosun University>

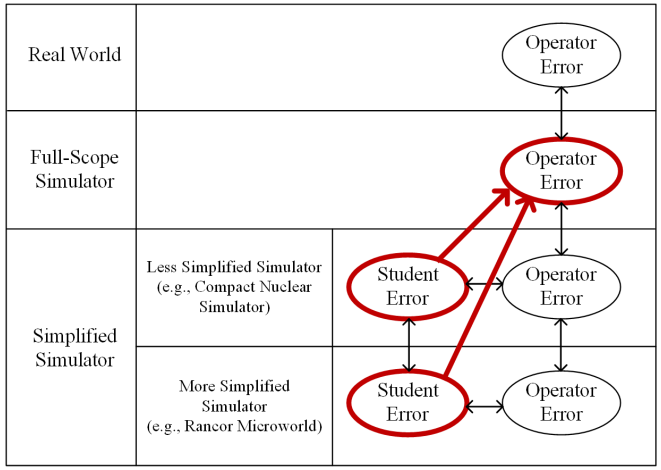
Collecting and analyzing data from simplified simulators, students and operators

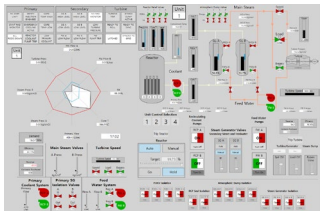


<Compact Nuclear Simulator (CNS)>

2. SHEEP Framework







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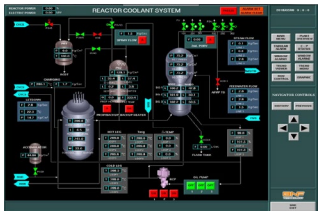


<Compact Nuclear Simulator (CNS)>

3. Step #1 of the SHEEP Framework

- **HRA Items Collectible in Both Simplified and Full-Scope Simulators**
  - Rancor vs. Full-scope (i.e., HuREX HRA data items)

Cognitive Activity	HRA Items Collectible in a Full-Scope Simulator (HuREX)	Collectability Using the Rancor Microworld
Information Gathering and Reporting (IG)	IG-alarm	Collectible
	IG-indicator	Collectible
	IG-synthesis	Uncollectible
	IG-value	Collectible
	IG-comparison	Collectible
	IG-graph	Uncollectible
	IG-abnormality	Uncollectible
	IG-trend	Collectible
Response Planning and Instruction (RP)	RP-entry	Collectible
	RP-procedure	Collectible
	RP-step	Collectible
	RP-information	Uncollectible
	RP-manipulation	Uncollectible
	RP-notification	Uncollectible
Situation Interpreting (SI)	SI-diagnosis	Uncollectible
	SI-identification	Uncollectible
	SI-prediction	Uncollectible
Execution (EX)	EX-discrete	Collectible
	EX-continuous	Collectible
	EX-dynamic	Collectible
	EX-notification	Uncollectible
Other (OT)	OT-manipulation	Collectible

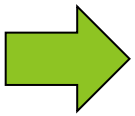
3. Step #1 of the SHEEP Framework

▶HRA Items Only Collectible in Simplified Simulators

- Rancor vs. Generic HRA data items
  - A catalog of generic HRA data items collected from documents issued from the perspective of HRA practitioners and human factors engineers.
  - 88 HRA data items depending on seven categories, i.e., 1) environment, 2) human-machine interface, 3) organization, 4) procedure, 5) task, 6) evaluation criteria or success criteria, 7) performance context

Category	Subcategory	Data Item	Representatively Measurable Instance
HSI	Ergonomics	The existence of barriers	- Failsafe designs - Administrative control - Physical guards or stops - Logical/mechanical interlocks
		The existence of buffers	- Redundant structures or processes - Features to accept time delays - Design for reversible, confirmatory, or staged actions
		The provision of memory aids	- Memory aid from human-machine interface
	Panel design	The conformity of standards, conventions, and nomenclature	- Consistent use of measurement units, information coding, or device configuration - Standard nomenclature defined from NPP administrative procedures
		The availability of indications (clarity of cues/indicators)	- Not specified from existing references
		The availability of controls (devices)	- Not specified from existing references
	Status indication	The existence of wrong or inadequate information	- Not specified from existing references
		The appropriateness of task feedbacks	- Clear, prompt, or precise feedback information
		The provision of clear decision criteria	- Clear decision criteria from the human-machine interface Ambiguous decision criteria in a procedure

※ Park, J., et al.: A guideline to collect HRA data in the simulator of nuclear power plants. KAERI/TR-5206/2013 (2013)



Customizing interfaces or relevant design factors in the simplified simulator is much simpler compared to a full-scope simulator.

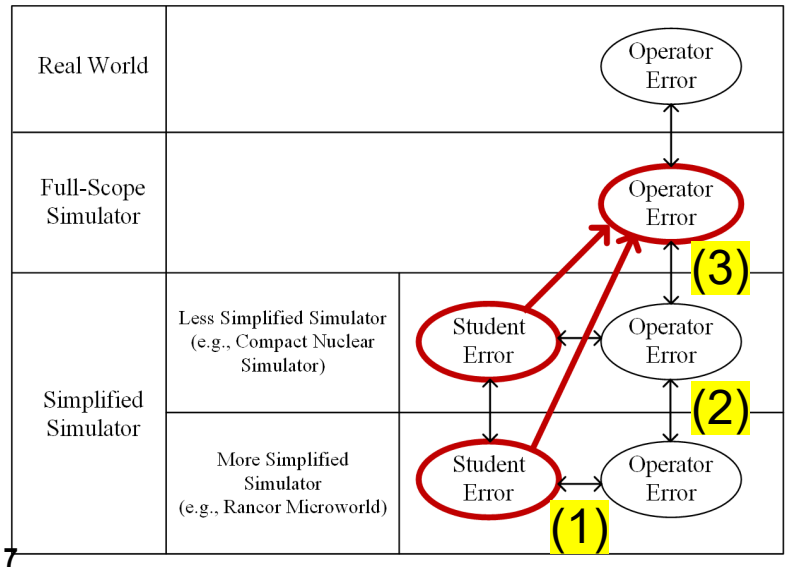
4. Step #2 of the SHEEP Framework

Summary

- HRA items collectible in both simplified and full-scope simulators
  - Data Collection

Simulator	Twenty Students	Twenty Operators
Microworld	Done	Done
CNS	Done	Done

  - Data Analysis
    - To infer full-scope data



The Relationship	Qualitative and Quantitative Data Analysis	
	Human Performance Analysis	HuREX Analysis
Between student and operator groups (1)	Done	Done
Between different types of simplified simulators (2)	Working	Working
Between simplified simulators and full-scope simulators (3)	Not Started	Not Started

4. Step #2 of the SHEEP Framework

Experiment Design

- Two independent variables, i.e., participant type and event class

<The Randomized Factorial Experiment with Rancor Microworld>

Event Class	Participant Type		Scenario
	Actual Operator	Student	
Non-Event			· Fully auto start-up (0% to 100%) · Shutdown (100% to 0%) · Start-up with manual rod control (0% to 100%) · Start-up with manual feedwater flow control (0% to 100%)
Event			· Failure of a reactor coolant pump under full-power operation · Failure of a control rod under full-power operation · Failure of a feedwater pump under full-power operation · Abnormal turbine trip under full-power operation · Steam generator tube rupture with an indicator failure · Loss of feedwater pump

<The Randomized Factorial Experiment with CNS>

Event Class	Participant Type		Scenario
	Actual Operator	Student	
Non-Event			· Fully auto startup (0% to 100%) · Shutdown (100% to 0%)
Event			· Steam generator tube rupture with an indicator failure · Loss of feed-water pump

4. Step #2 of the SHEEP Framework

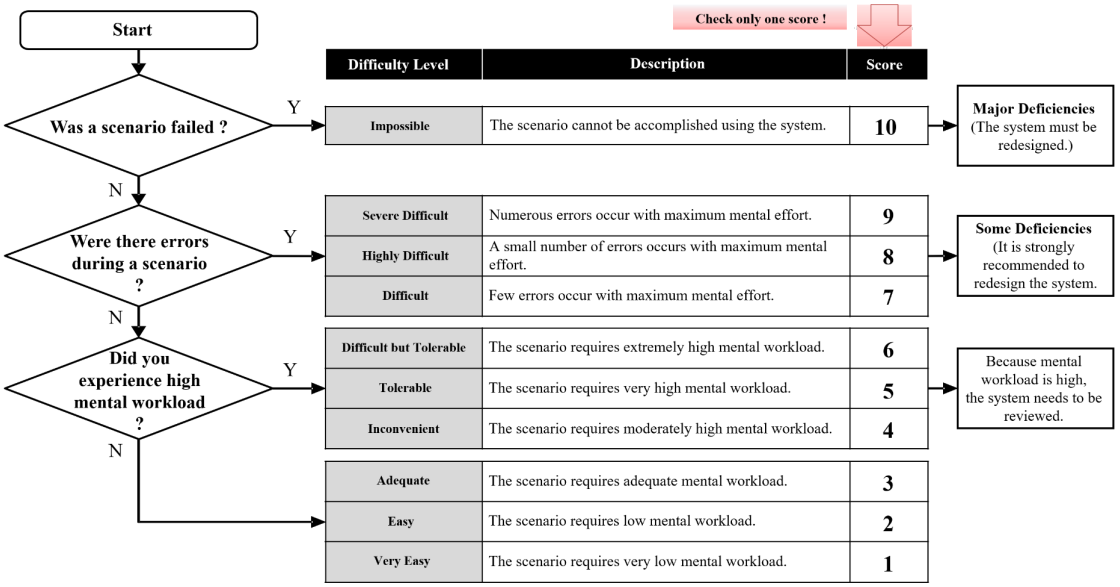
Human Performance

Human Performance Categories	Human Performance Measurements
Workload	Modified Cooper-Harper (MCH)
Situation awareness	Situation Awareness Rating Technique (SART)
Error	Error rate
Time to completion	Average time to complete a step
	Average time to complete an instruction
	Average time to complete a task
Eye movements	Eye fixation count per task
	Eye fixation duration per task
	Blink rate (i.e., blink count per task)
	Heatmap over area of interest (AOI)
Number of manipulations	Number of manipulations per task
	Number of manipulations per scenario completion time

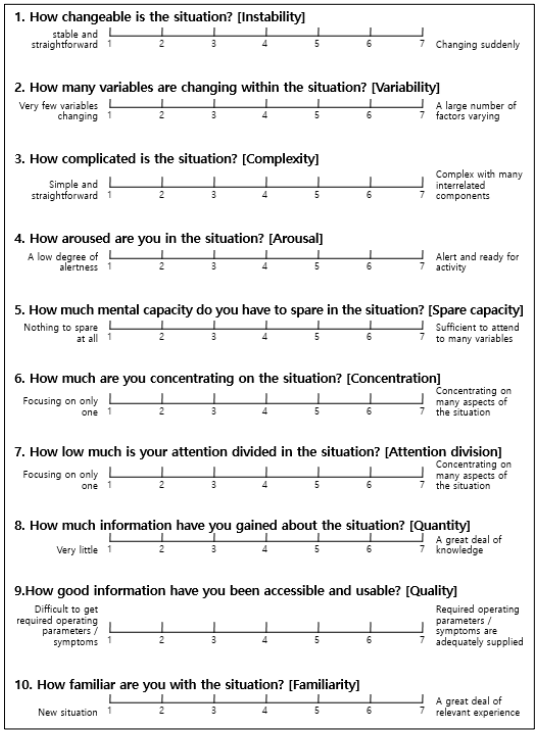
4. Step #2 of the SHEEP Framework

Human Performance (Cont'd)

- **Workload**: MCH Scores
- **Situation Awareness**: SART Scores



Modified Cooper-Harper (MCH)



Situation Awareness Rating Technique (SART)

4. Step #2 of the SHEEP Framework

▶ Human Performance (Cont'd)

- **Error**: Error Rate
  - Error is defined as deviation from expected performances.
  - Same rules used in the HuREX data collection are applied.
  - The HuREX analysts participated in the error analysis.
- **Time to Completion**: Average Time to Complete A Step / An Instruction / A Task
  - Analyzed based on procedures and video records

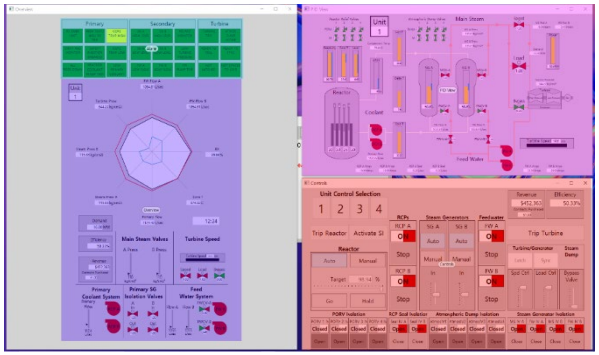
	Scenario	Type of Error	Stu.01	Sum	Stu.02	Sum	Stu.03	Sum	Stu.04	Sum
Non-event	Start-up(#1)	RP-Step(EOC)	2	3		0		1		0
		Ex-Continuous(EOC)					1			
		Ex-Dynamic(EOC)	1							
		RP-Step(EOO)								
	Shutdown(#2)	Ex-Continuous(EOC)		0		0		0		0
		Ex-Dynamic(EOC)								
	Manual Rod during Start_up(#3)	Ex-Dynamic(EOC)	2	2		0		1	1	1
		RP-Step(EOC)					1			
		RP-Step(EOO)								
		RP-Procedure(EOC)								
		OT-Manipulation(EOC)								
		Ex-Continuous(EOO)								
		Ex-Continuous (EOC)								

Procedure	Step	Step Num.	Task	Task-Verb	Error	Time	Description
OP-003	3. Primary side coolant injection	Pre-C	Reactor must be provided with adequate coolant to prevent overheating for reactor core. Primary side coolant flow should be maintained at least 127.0 L/sec.			22:24:40	
		3.1	Activate the RCP.			22:24:45	
		3.1.1	·Click RCP A start button.	Perform		22:24:48	
		3.1.2	·Click RCP B start button.	Perform	EOO/R	22:24:50	1. Time: 22:24:50 2. Current State: During the Start-up, RCP B not operation. 3. Action: He didn't click the RCP B start button 4. Result: RCP B not started 5. Description: Recovery by operation knowledge
		3.2	See below to determine if the primary coolant is sufficient.			22:24:50	
		3.2.1	·Low Primary Coolant alarm off confirmation.	Check		22:24:51	
		3.2.2	·Primary Flow indicator is higher than 508.0L / sec	Check		22:24:53	
		3.3	If the above conditions are satisfied, the process moves to step 4.	Move		22:24:55	
	4. Reactivity Control	4.1	To increase Reactivity to 20% using Manual, go to the OP-004 procedure.	Check/Move		22:25:00	

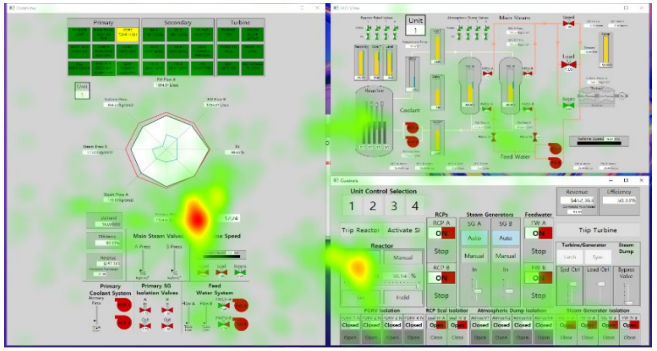
4. Step #2 of the SHEEP Framework

▶ Human Performance (Cont'd)

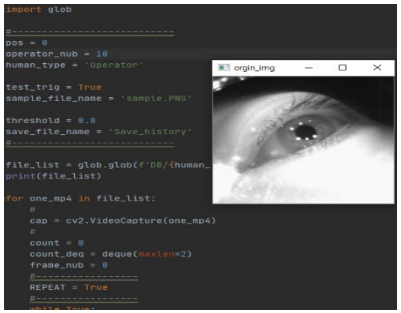
- **<u>Eye Movements</u>**: Eye Fixation Count / Duration Per Task, Blink Rate, Heatmap Over Area of Interests (AOI)
  - Fixation duration and counts, eye blinking, and gaze movement
  - Tobii Pro Glasses 2
  - Four Areas of Interest (AOIs): Alarm, Overview, P&ID, Control Area



<AOIs>



<Heatmap>



<Eye Blinking Rate>

- **<u>Number of Manipulations</u>**: Number of Manipulations per Task / per Scenario Completion Time
  - Estimated from simulator log data

{"EventType":"Simulation", "Tag":"Start", "Time":0, "RX":98.2692294477296, "MW":54.5491744984957}
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{"EventType":"ControlAction", "Tag":"SGSGBin", "Mode":"manual", "Value":"0.461748397052678", "Time":2.0098807, "RX":98.0600762918027, "MW":54.7726059086581}
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4. Step #2 of the SHEEP Framework

- **Participants**
  - Twenty students and twenty operators when using the Rancor Microworld and the CNS respectively
    - Students
      - Undergraduate senior students and master students at the department of nuclear engineering in Chosun University
      - They took courses such as "Introduction to Nuclear Engineering," "Reactor Theory," "Reactor Control", and "Simulator Operation."
    - Operators
      - Licensed operators for Westinghouse type
      - Working at Hanbit Nuclear Site in Korea
- **Training**
  - About more than 3 hours per student and 2 hours per operator
  - Contents
    - Purpose of experiment
    - Simulator systems and its interfaces
    - Scenarios
    - Questionnaires
    - Practicing simulators and Conducting a test scenario

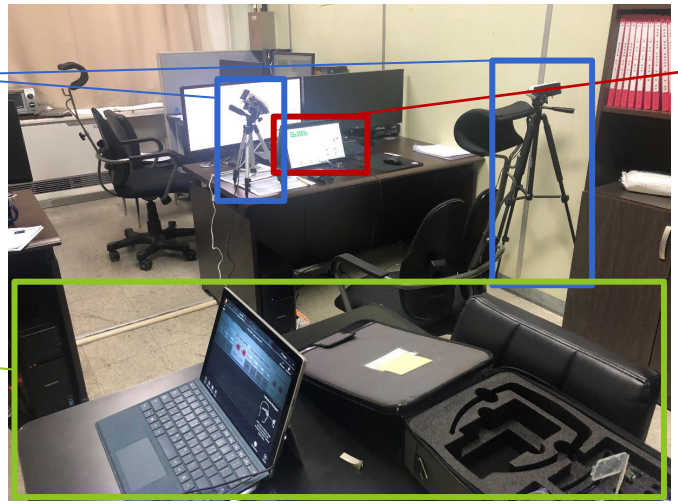
4. Step #2 of the SHEEP Framework

Apparatus

Two cameras

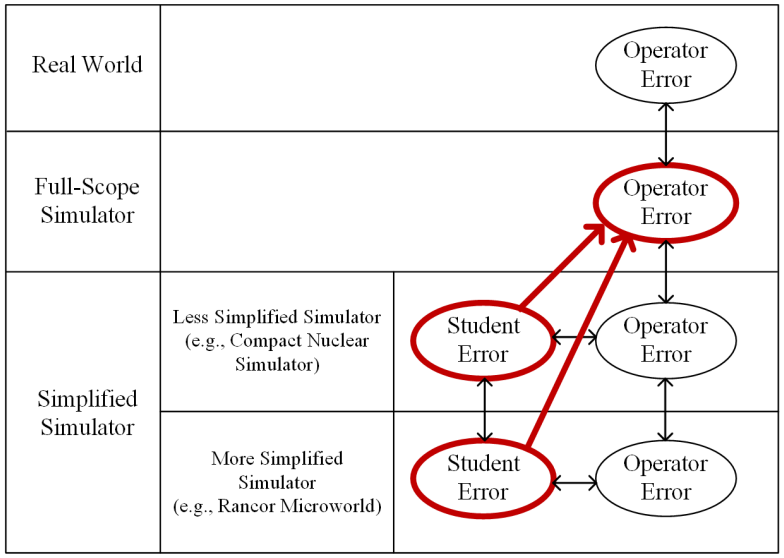
Microworld / CNS on the tablet

Tobii Pro Glasses 2: Eye tracking system



4. Step #2 of the SHEEP Framework

- **Data Analysis**
  - Human performance analysis between student and operator groups
  - HuREX Analysis between student and operator groups



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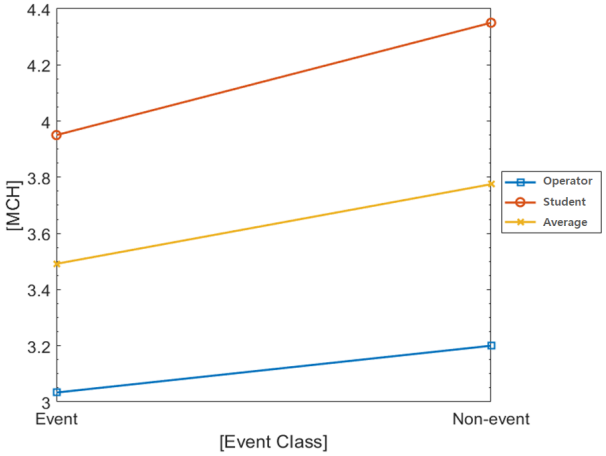
4. Step #2 of the SHEEP Framework

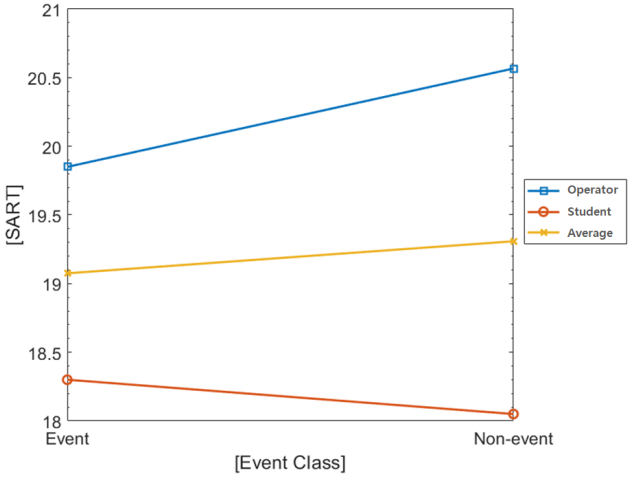
- **Human performance analysis between student and operator groups**
  - ANOVA Test

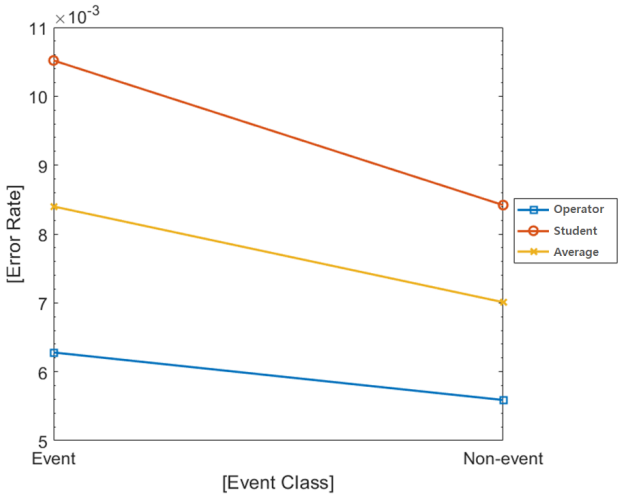
Human Performance Characteristic	Human Performance Measurement	Independent Variable (p-value)		
		Participant Type	Event Class	Participant Type * Event Class
Workload	MCH	**0.001****	0.350	0.700
Situation Awareness	SART	**0.027***	0.798	0.597
Error	Error rate	**0.046***	0.430	0.686
Time to Completion	Average time to complete a step	0.801	**0.000****	**0.002****
	Average time to complete an instruction	**0.047***	**0.000****	**0.000****
	Average time to complete a task	0.148	**0.000****	**0.000****
Eye Movements	Eye fixation count per task	0.706	**0.000****	**0.016***
	Eye fixation duration per task	0.787	**0.000****	**0.005****
	Blink rate	**0.008****	0.595	0.863
Number of Manipulations	Number of manipulations per task	0.727	**0.000****	0.053
	Number of manipulations per scenario completion time	0.222	**0.001****	0.139

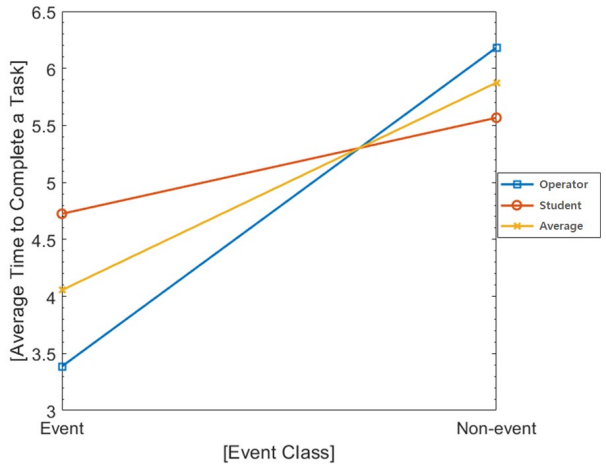
4. Step #2 of the SHEEP Framework

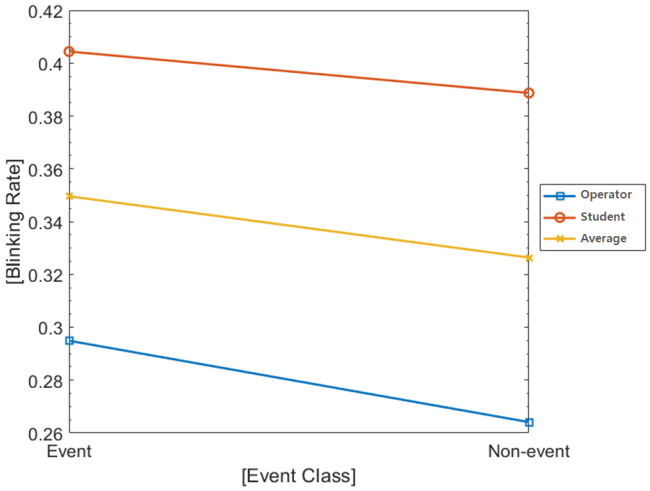
- **Human performance analysis between student and operator groups**
  - Comparison of Human Performance Measures

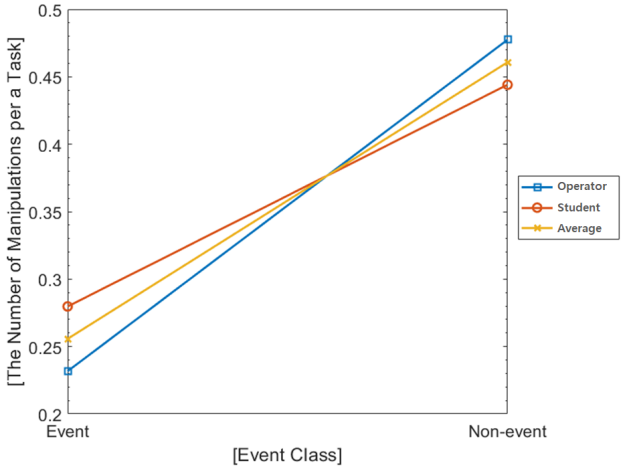












4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Correlation Analysis

***: 95% confidence level and r > 0.3**

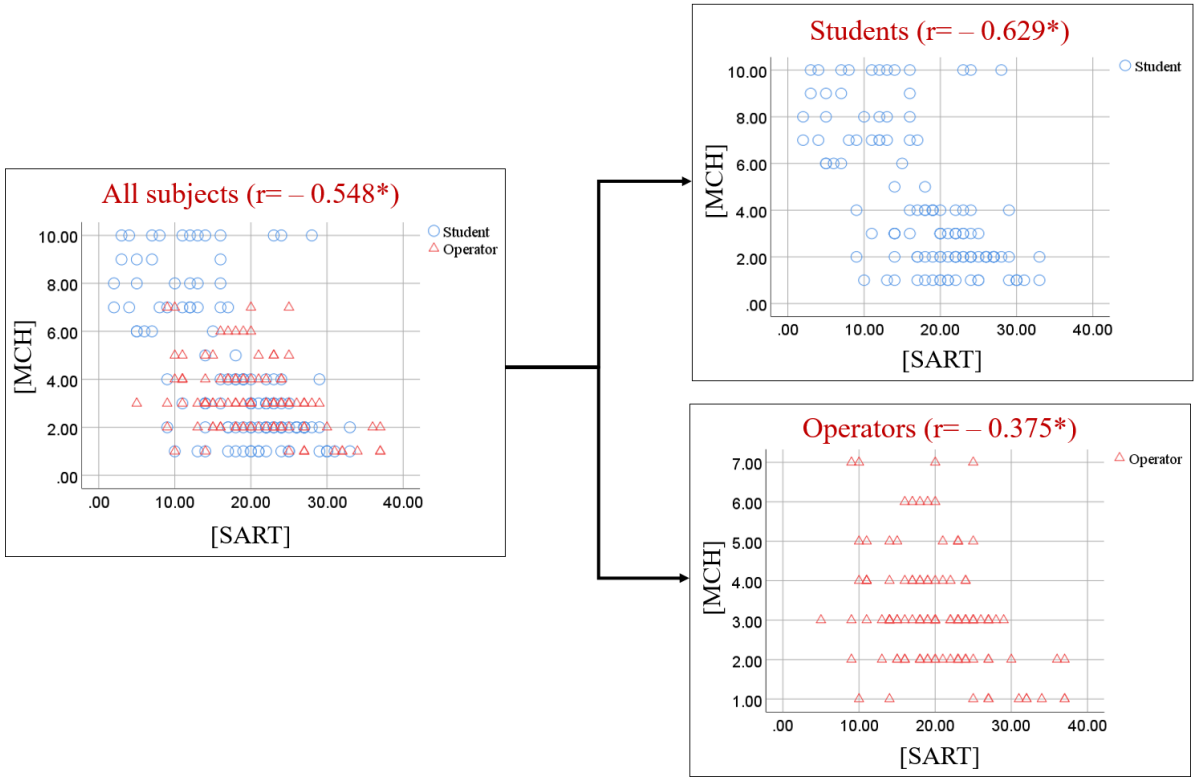
<All participants>	MCH	SART	Error rate	Time to completion per task	Eye fixation count per task	Blink rate	Number of manipulations per task
MCH	1						
SART	**-0.548***	1					
Error rate	**0.435***	**-0.247***	1				
Time to completion per task	0.097	-0.069	-0.015	1			
Eye fixation count per task	0.040	-0.009	0.006	**0.743***	1		
Blink rate	0.117	-0.097	0.028	0.134*	-0.158*	1	
Number of manipulations per task	-0.122	0.128*	-0.145*	**0.481***	**0.477***	0.045	1

<Operators>	MCH	SART	Error rate	Time to completion per task	Eye fixation count per task	Blink rate	Number of manipulations per task
MCH	1						
SART	**-0.375***	1					
Error rate	0.168	0.028	1				
Time to completion per task	0.004	0.025	-0.070	1			
Eye fixation count per task	-0.005	0.127	-0.053	**0.780***	1		
Blink rate	0.024	-0.121	-0.109	0.194*	-0.058	1	
Number of manipulations per task	-0.048	0.095	-0.086	**0.605***	**0.571***	-0.010	1

<Students>	MCH	SART	Error rate	Time to completion per task	Eye fixation count per task	Blink rate	Number of manipulations per task
MCH	1						
SART	**-0.629***	1					
Error rate	**0.485***	-0.362*	1				
Time to completion per task	0.171	-0.184*	0.004	1			
Eye fixation count per task	0.096	-0.131	-0.003	**0.606***	1		
Blink rate	0.107	-0.044	0.053	0.053	-0.209*	1	
Number of manipulations per task	-0.190*	0.169	-0.202*	0.274*	**0.486***	0.088	1

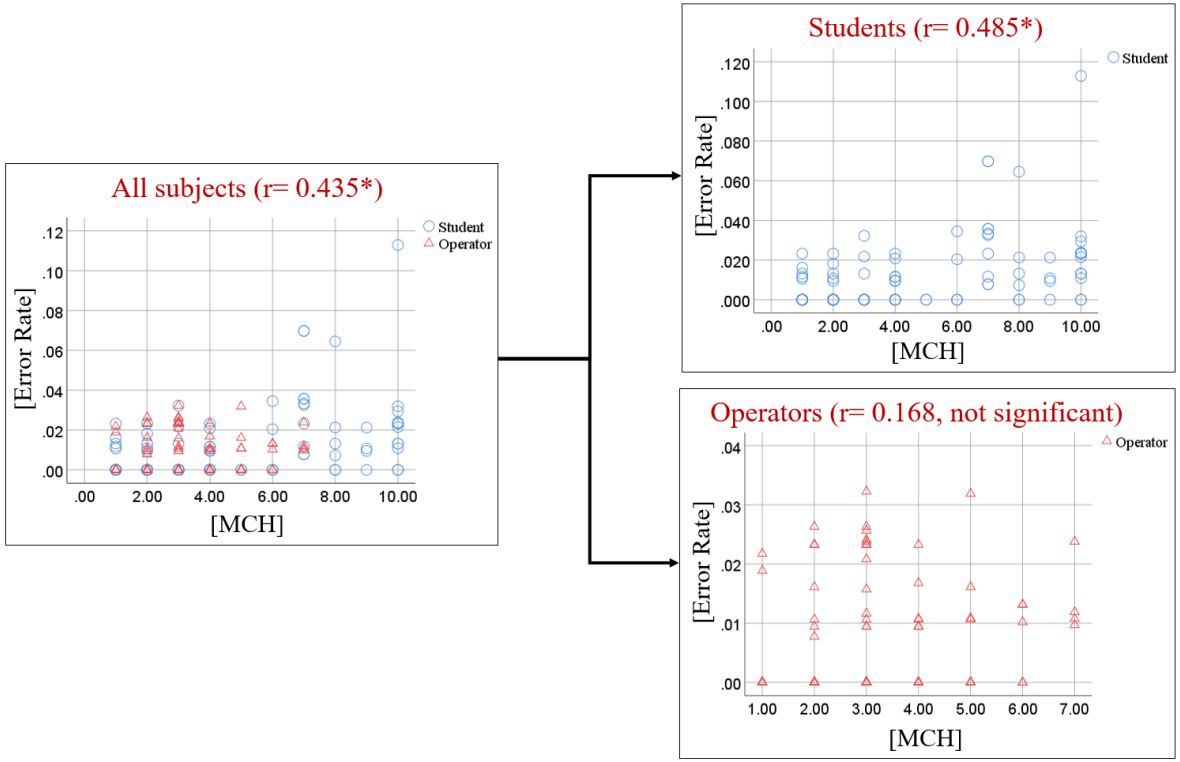
4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - MCH-SART
    - Both participant types show significant negative linear correlations for MCH and SART, meaning that situation awareness generally decreases with increased workloads.
    - The student group presenting a stronger correlation than the operator group.



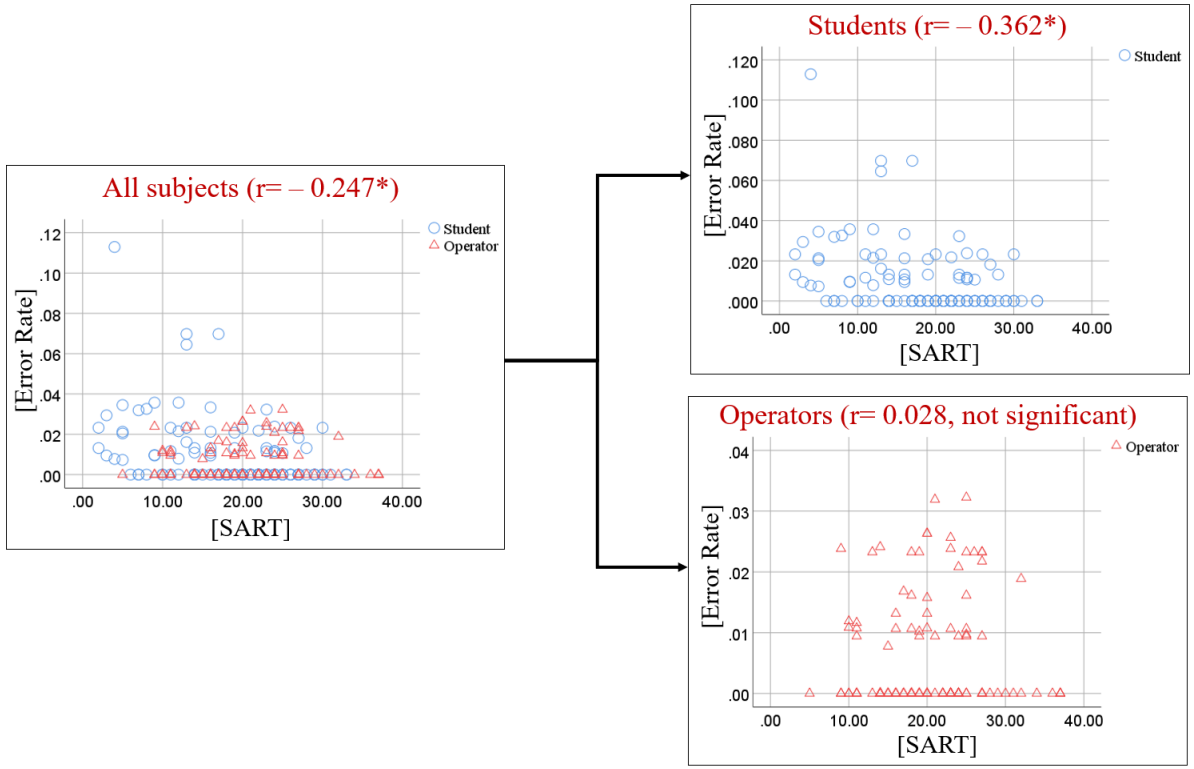
4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Error Rate - MCH
    - Both participant types show moderately positive linear correlations for error rates and workloads.
    - However, when separated, only the students show a positive correlation for error rates and MCH scores, whereas no statistically significant correlations exist for the operators' error rates and MCH scores.



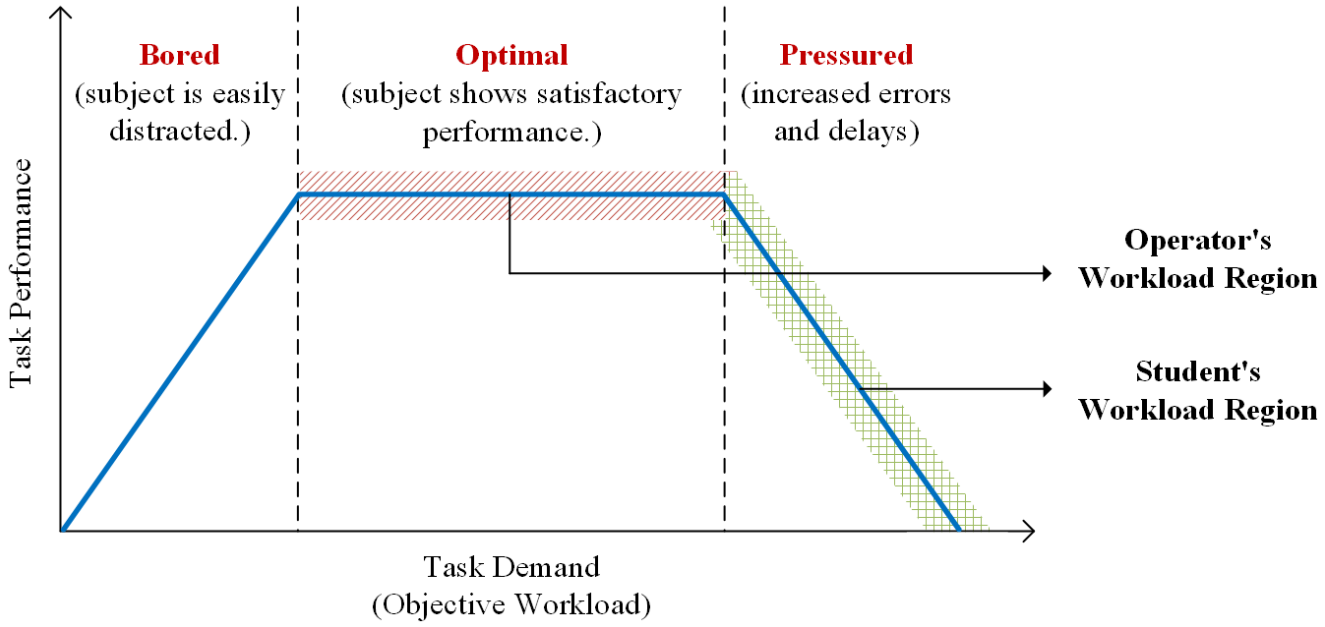
4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Error Rate - SART
    - Both participant types show small negative linear correlations in regard to error rates and SART scores.
    - However, when separated, only the students show a moderate linear correlation for error rates and SART values, whereas no statistically significant correlation exists for the operators' error rates and SART values.



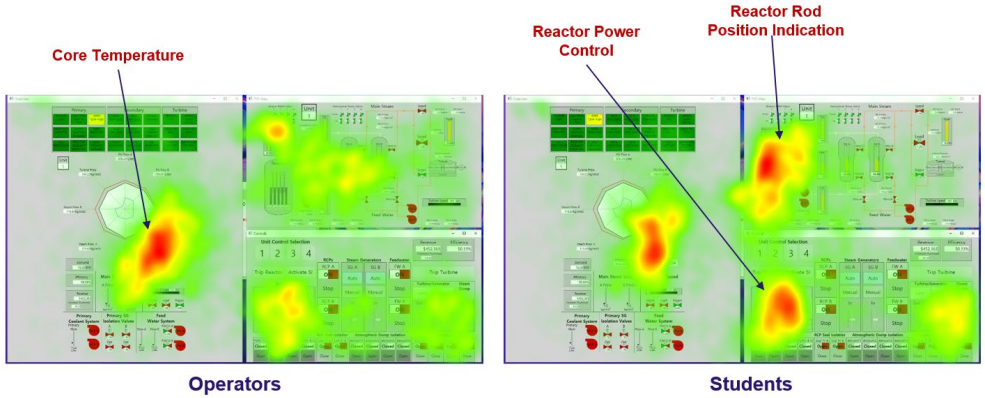
4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Insight #1
    - The operators perform better than students in terms of workload, situation awareness, and error in the result of ANOVA test.
    - The correlations were found between human performance characteristics, including workload and situation awareness, error rate and workload, and error rate and situation awareness.
    - The error rate for students correlates with their workload and situation awareness, whereas the error rate for operators does not.



4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Insight #2
    - The operators are more likely to concentrate on major parameters necessary to the context of a given scenario as well as monitor overall interface.
    - The students may continually seek out options in the control window, as well as changes implemented due to a particular manipulation.



4. Step #2 of the SHEEP Framework

- **HuREX analysis between student and operator groups**
  - Comparison of errors from the HuREX and SHEEP studies

Cognitive Activity	Task Type	HUREX Study			SHEEP Study (Using the Rancor Microworld)					
					Student			Operator		
		Opportunity	EOO	EOC	Opportunity	EOO	EOC	Opportunity	EOO	EOC
Information Gathering and Reporting	IG-alarm	1,387	-	1	701	-	-	714	-	-
	IG-indicator	9,572	-	19	1,370	-	6	1,417	-	-
	IG-synthesis	598	-	2	-	-	-	-	-	-
	IG-value	334	-	-	146	-	-	144	-	-
	IG-comparison	6,930	-	1	1,056	-	-	1,082	-	-
	IG-graph	256	-	-	-	-	-	-	-	-
	IG-abnormality	1,594	-	-	-	-	-	-	-	-
	IG-trend	2,121	-	4	317	-	-	310	-	-
Response Planning and Instruction	RP-entry	624 (analog)	2 (analog)	-	1,650	-	-	1,653	-	-
	RP-procedure	253 (analog)	1 (analog)	-	132	-	6	135	-	3
	RP-step	71 (analog)	4 (analog)	-	993	2	7	982	9	6
	RP-information	8,840	22	9	-	-	-	-	-	-
	RP-manipulation	1,967	24	10	-	-	-	-	-	-
	RP-notification	387	18	-	-	-	-	-	-	-
Situation Interpreting	SI-diagnosis	12	-	-	-	-	-	-	-	-
	SI-identification	197	-	1	-	-	-	-	-	-
	SI-prediction	4	-	-	-	-	-	-	-	-
Execution	EX-discrete	2,762	34	3	1,342	2	-	1,323	2	-
	EX-continuous	87	4	-	556	-	23	565	5	12
	EX-dynamic	556	20	9	44	-	22	43	-	15
	EX-notification	366	7	-	-	-	-	-	-	-
Other	OT-manipulation	-	-	-	-	-	10	-	-	2
Total		38,918	136	59	8,307	4	74	8,368	16	38

4. Step #2 of the SHEEP Framework

- **HuREX analysis between student and operator groups**
  - Comparison of HEPs from the HuREX and SHEEP studies

Cognitive Activity	Task Type	HUREX Study		SHEEP Study (Using the Rancor Microworld)			
		HEP (EOO)	HEP (EOC)	HEP (EOO) - Student	HEP (EOC) - Student	HEP (EOO) - Operator	HEP (EOC) - Operator
Information Gathering and Reporting	IG-alarm	-	3.610e-4	-	-	-	-
	IG-indicator	-	9.940e-4	-	4.380e-03	-	-
	IG-synthesis	-	1.680e-3	-	-	-	-
	IG-value	-	-	-	-	-	-
	IG-comparison	-	7.220e-5	-	-	-	-
	IG-graph	-	-	-	-	-	-
	IG-abnormality	-	-	-	-	-	-
	IG-trend	-	9.450e-4	-	-	-	-
Response Planning and Instruction	RP-entry	3.205e-3 (analog)	-	-	-	-	-
	RP-procedure	3.953e-3 (analog)	-	-	4.545e-02	-	2.222e-02
	RP-step	5.634e-2 (analog)	-	2.014e-03	7.049e-03	9.165e-03	6.110e-03
	RP-information	2.490e-3	5.110e-4	-	-	-	-
	RP-manipulation	1.230e-2	2.590e-3	-	-	-	-
	RP-notification	4.650e-2	-	-	-	-	-
Situation Interpreting	SI-diagnosis	-	-	-	-	-	-
	SI-identification	-	2.550e-3	-	-	-	-
	SI-prediction	-	-	-	-	-	-
Execution	EX-discrete	1.230e-2	5.500e-4	1.490e-03	-	1.512e-03	-
	EX-continuous	4.600e-2	-	-	4.137e-02	8.850e-03	2.124e-02
	EX-dynamic	3.660e-2	8.540e-3	-	5.000e-01	-	3.488e-01
	EX-notification	1.910e-2	-	-	-	-	-
Other	OT-manipulation	-	-	-	-	-	-

4. Step #2 of the SHEEP Framework

- **HuREX analysis between student and operator groups**
  - Insight #1
    - Comparison of the number of EOOs and EOCs
      - Rancor Data: EOOs (st: 4 / op: 16) < EOCs (st:74 / op: 38)
      - HuREX Data: EOOs (136) > EOCs (59)
    - Most of EOCs observed in the experiment correspond to “Rule Violations”.
    - Transitioning from a full-scope simulator to a simplified one may result in a larger number of violations than omissions.

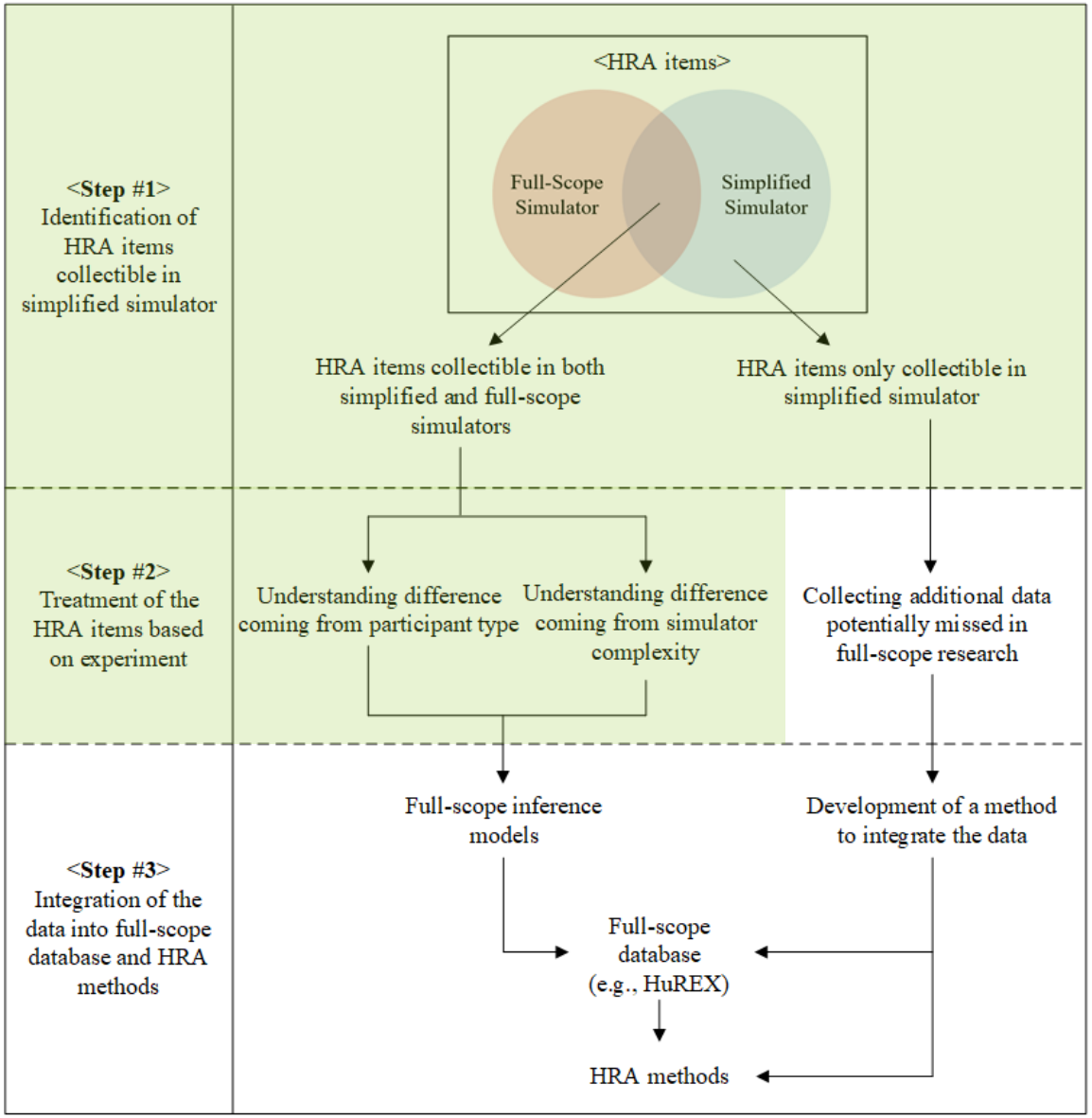
Error Class	Potential Errors
Qualitative Errors	• Action incorrectly performed • Too much of action • Too little of action • Action repeated • Task execution incomplete
Selection Errors	• Right action on wrong object • Wrong action on right object • Wrong action on wrong object • Task executed too early • Task executed too late
Sequence Errors	• Incorrect sequence • Action in wrong direction • Misalignment/orientation error
Extraneous Acts	• Rule violations
Instructional Interaction Errors	• Information not obtained/transmitted • Wrong information obtained/transmitted • Information misread or misinterpreted

4. Step #2 of the SHEEP Framework

- **HuREX analysis between student and operator groups**
  - Insight #2
    - The reasons why there are differences between the HuREX and the SHEEP data may be different depending on each task type.
    - Representatively, differences in procedure-related task types such as RP-entry, RP-procedure and RR-step highly depend on the difference on procedure contents.
    - For example, procedures for Rancor Microworld include more instructions for RP-step (i.e., transferring to another step in a procedure) than actual full-scope procedures.
    - Accordingly, the number of errors and opportunities for RP-step in the SHEEP data are higher than those in the HuREX data.
    - Thus, these kinds of qualitative and quantitative differences on each task type need to be further investigated when developing full-scope inference models in Step #3 of the SHEEP framework.

Cognitive Activity	Task Type	HUREX Study			SHEEP Study (Using the Rancor Microworld)					
					Student			Operator		
		Opportunity	EOO	EOC	Opportunity	EOO	EOC	Opportunity	EOO	EOC
Response Planning and Instruction	RP-entry	624 (analog)	2 (analog)	-	1,650	-	-	1,653	-	-
	RP-procedure	253 (analog)	1 (analog)	-	132	-	6	135	-	3
	RP-step	71 (analog)	4 (analog)	-	993	2	7	982	9	6

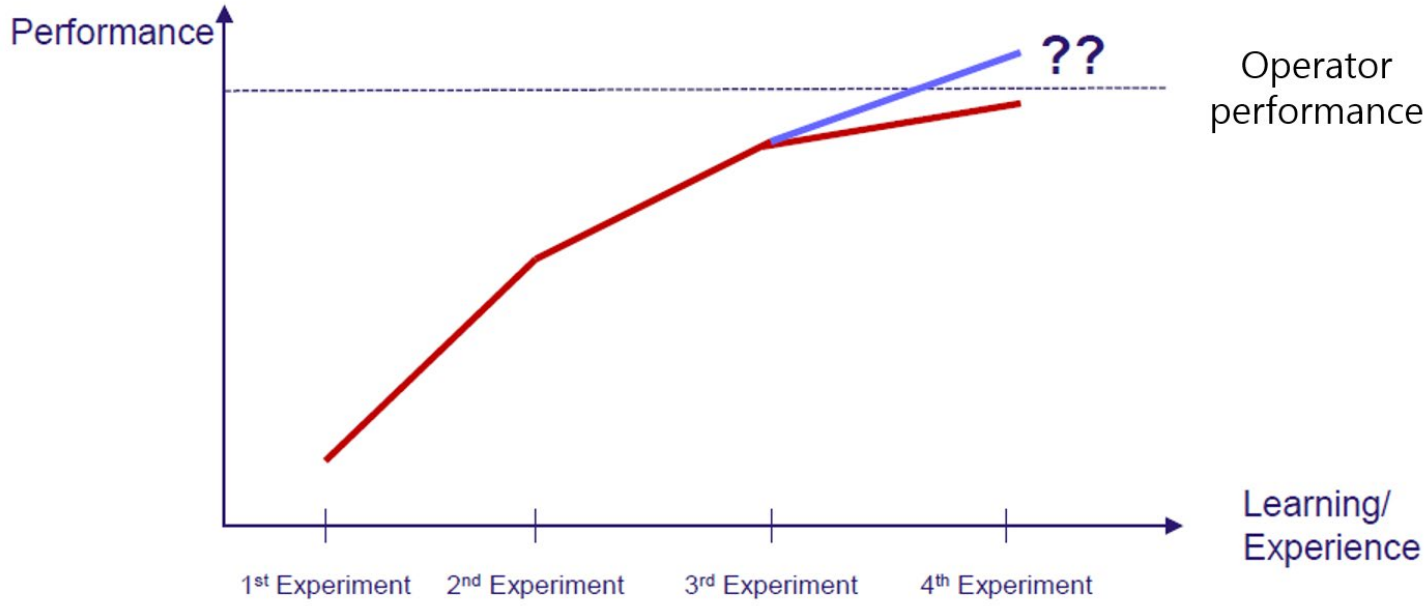
5. Future Works



5. Future Works

Perform Additional Experiment Using the Rancor Microworld

- To investigate students' learning effects and performance trends over a certain longitudinal period when using the Rancor Microworld, then compare the results with the operator performance results from this study
- This trend could be used to understand the gap between trained student performance and operator performance, then identify how much training or education is required in order to use students for collecting HRA data, and whether we can collect HRA data from students.



5. Future Works

Keep Working on the Data Analysis

The Relationship	Qualitative and Quantitative Data Analysis	
	Human Performance Analysis	HuREX Analysis
Between student and operator groups (1)	**Done**	**Done**
Between different types of simplified simulators (2)	**Working**	**Working**
Between simplified simulators and full-scope simulators (3)	**Not Started**	**Not Started**

Develop Full-scope Inference Models

- TAsk COMplexity (TACOM) [53-56] method as a bridge to connect the simplified simulator data to the full-scope framework
  - The TACOM method is a tool to represent the effect of task complexity on human performance in an objective manner.
  - By quantifying TACOM scores of tasks, the feasibility of performance data integration on the HuREX framework will be investigated in the future.

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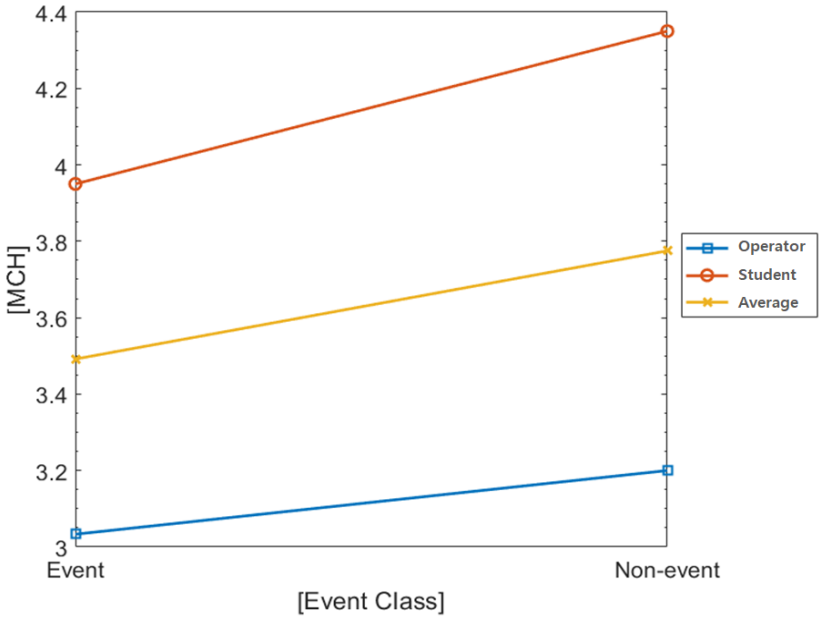
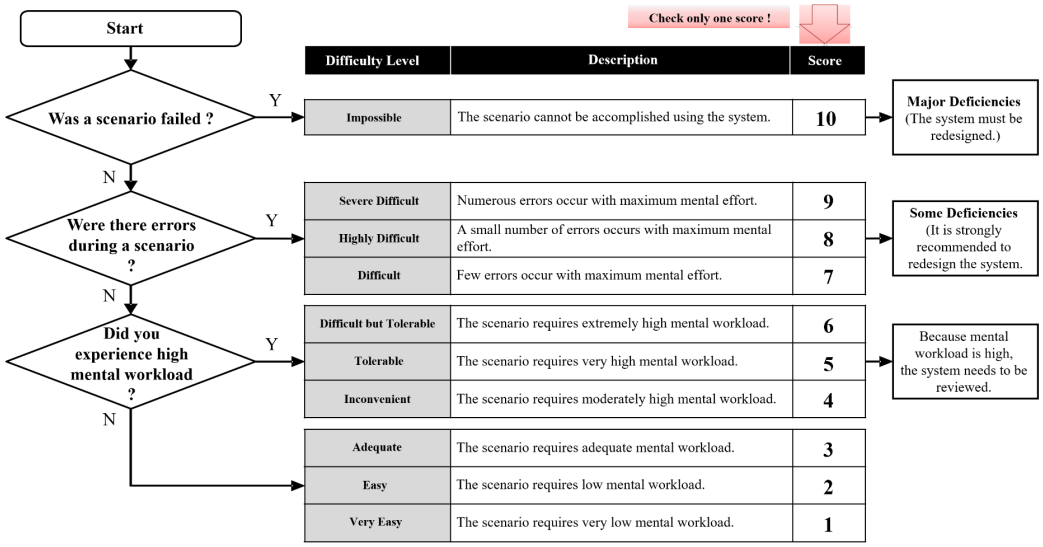
4. Step #2 of the SHEEP Framework

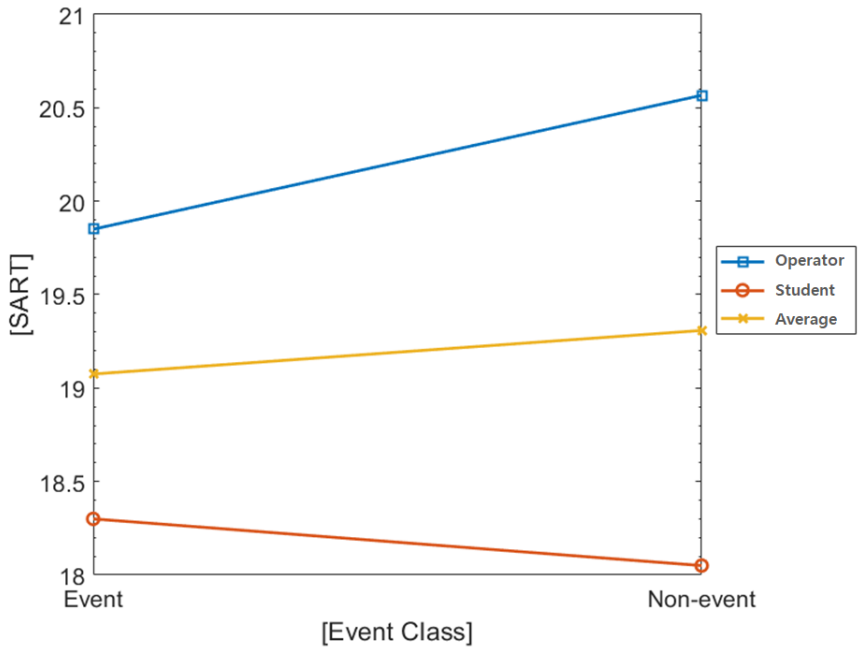
- **Human performance analysis between student and operator groups**
  - Workload (MCH)
    - The MCH scores showed a significant difference for participant type.
    - The student group had, on average, higher MCH scores than the operator group: 4.150 vs. 3.117, respectively.
    - The student group's average workload approximately corresponded to the "inconvenient" level of difficulty (indicating a moderately high mental workload), whereas the operator group's average workload was close to the "adequate" difficulty level (indicating an adequate mental workload).





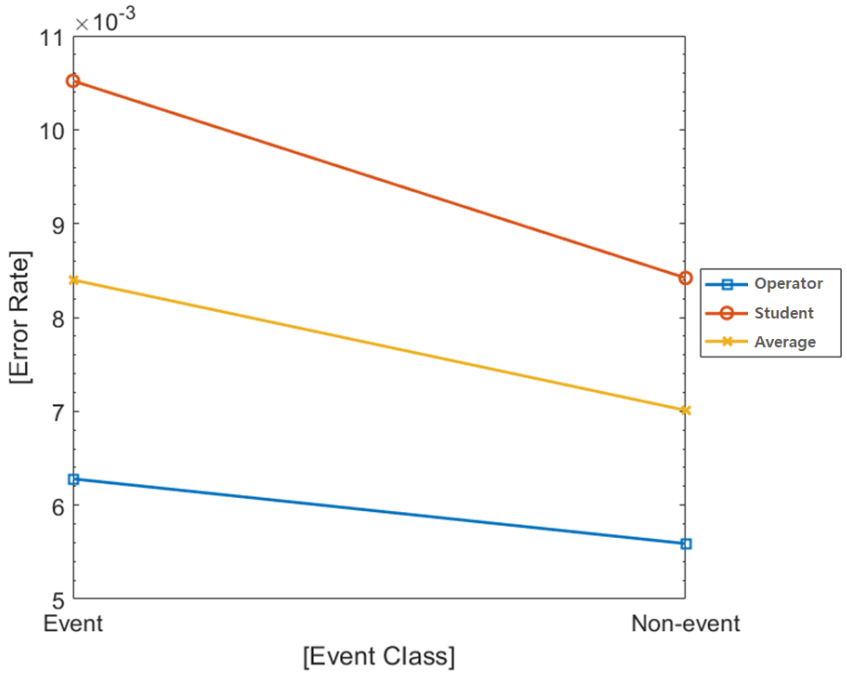
4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Situation Awareness (SART)
    - The SART scores only showed a statistical difference for participant type.
    - The operator group reported higher values than the student group: 20.208 vs. 18.175, respectively.
    - A higher SART score indicates better situation awareness.



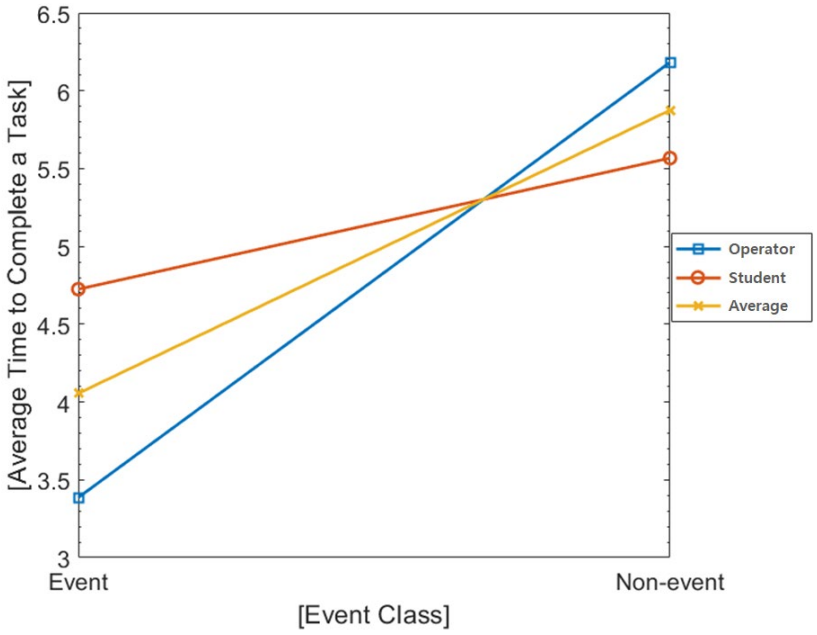
4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Error (Error rate)
    - The error rate statistically differed for participant type but not event class.
    - The error rate for the student group was 1.5 times higher than for the operator group: 9.0e-3 vs. 6.0e-3, respectively.
    - The operator group had better performance (i.e., lower error rates) than the student group, regardless of event class.



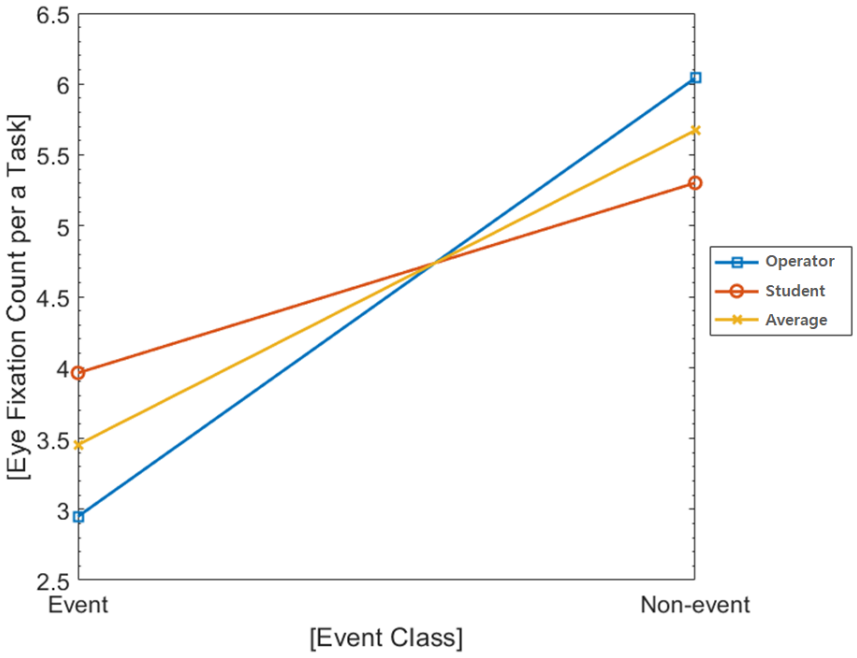
4. Step #2 of the SHEEP Framework

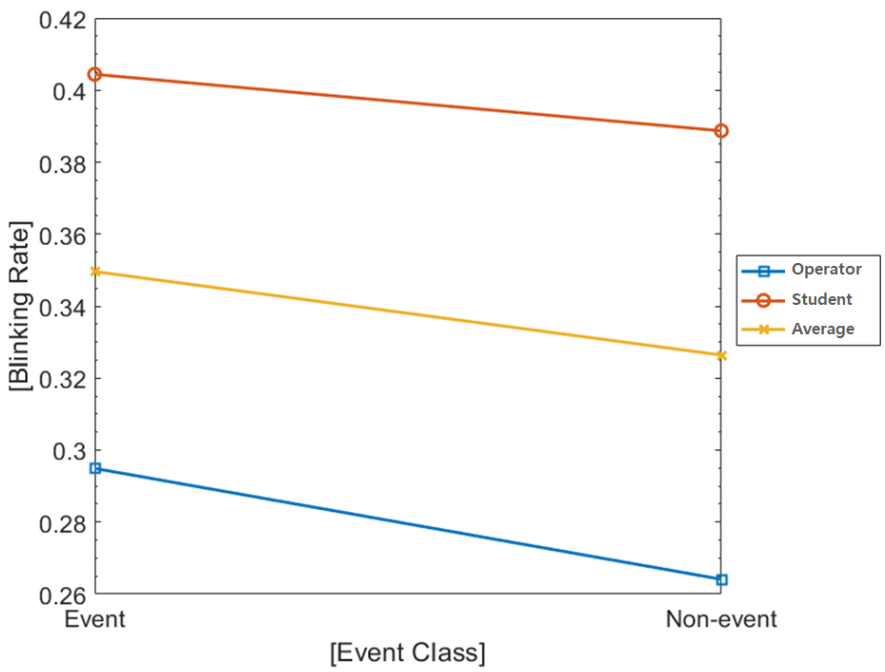
- **Human performance analysis between student and operator groups**
  - Time to Completion (Average time to complete a task)
    - Showed significant differences for event class, though there was no statistical difference for participant type.
    - The event scenarios had lower average times than non-event scenarios: 4.055 vs. 5.875 seconds, respectively.
    - The interaction between participant type and event class is statistically significant.



4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Eye Movements (Eye fixation count per a task; blinking rate)
    - The eye fixation count per task revealed statistically significant differences for event class but not participant type, while the blink rate only showed a significant difference with respect to participant type.





4. Step #2 of the SHEEP Framework

- **Human performance analysis between student and operator groups**
  - Number of Manipulations (The number of manipulations per a task)
    - The number of manipulations per a task showed significant differences for event class, though there was no statistical difference for participant type.
    - Comparing number of manipulations per task shows the non-event scenario group performed more manipulations per task than the event scenario group: 0.461 vs. 0.256, respectively.
    - The non-event scenarios require more manipulations than event scenarios, regardless of participant type.