Northeastern University

Towards an Intelligent Augmented Reality Tutoring System for Precision Manufacturing

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CESAR
COGNITIVE EMBODIED SOCIAL AGENTS RESEARCH

SAIL
Symbiotic & Augmented Intelligence Laboratory

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Introduction

Problem: high demand for skilled workers in advanced manufacturing

Challenges: Current work force aging

Lack of skilled replacements

Our Goal : Combine AR and ITS approaches to train the next generation

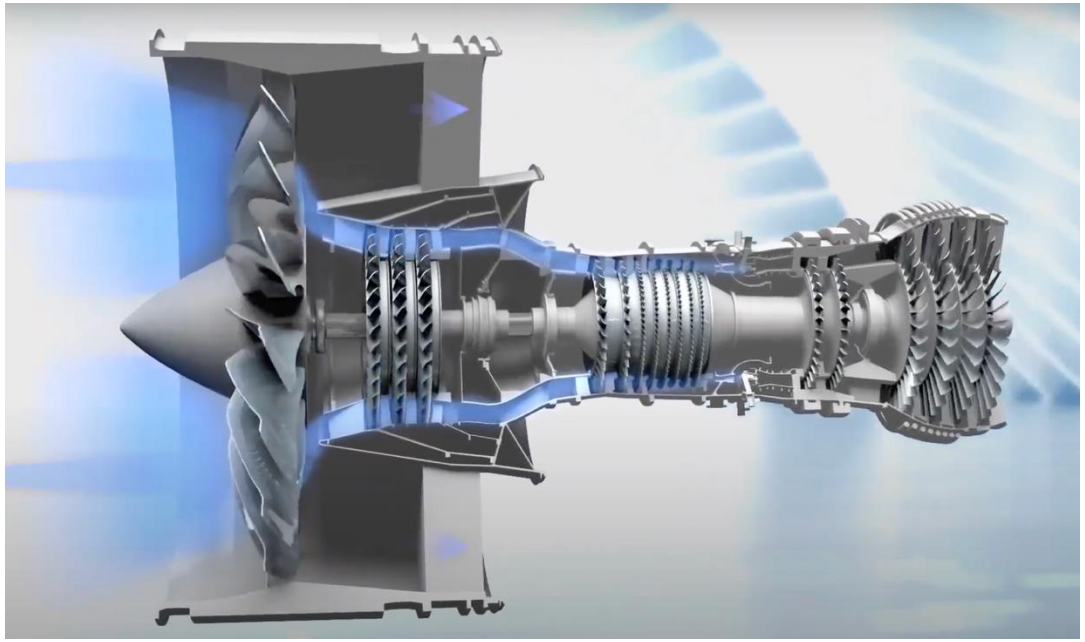
This work: An initial step towards achieving that goal

- Explored an intelligent tutoring approach using a Wizard of Oz experiment

Task Domain:
Precision Inspection in Advanced Manufacturing

Characteristics:

- Comprehend complex technical drawings
  - To determine measurements
- Complex psychomotor skills
  - Measurements require precise physical manipulations
- Highly consequential decision making
  - Faulty parts can lead to aircrafts crashing



Research Questions

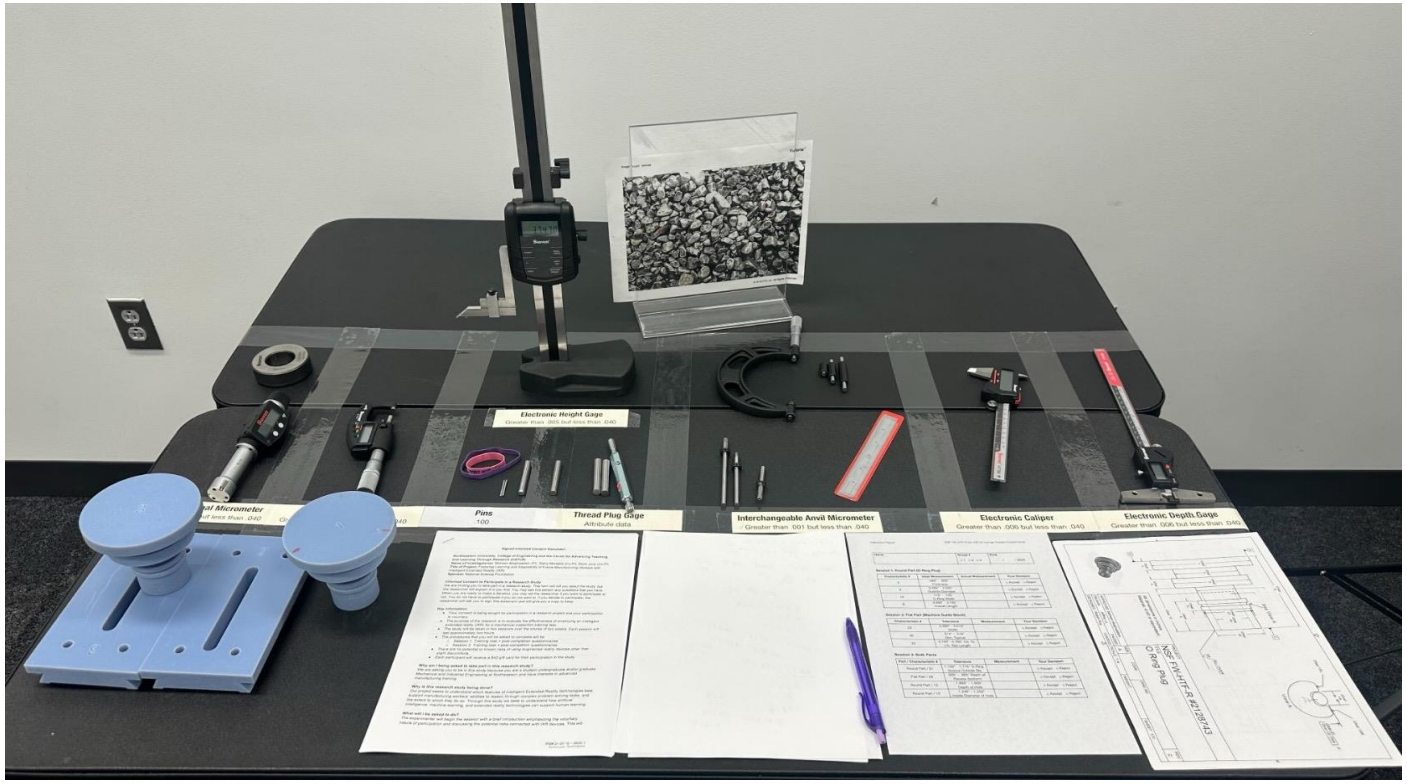
***RQ1*: What is the most effective form of **scaffolding/intervention**?**

***RQ2*: What technology or **Intelligence** is needed to realize the intelligent AR system?**

Task

Task procedure:

1. Locate the characteristic to measure
2. Select appropriate gauge
3. Prepare the gauge
4. Measure the characteristic
5. Report the measurement
6. Record reject/accept decision



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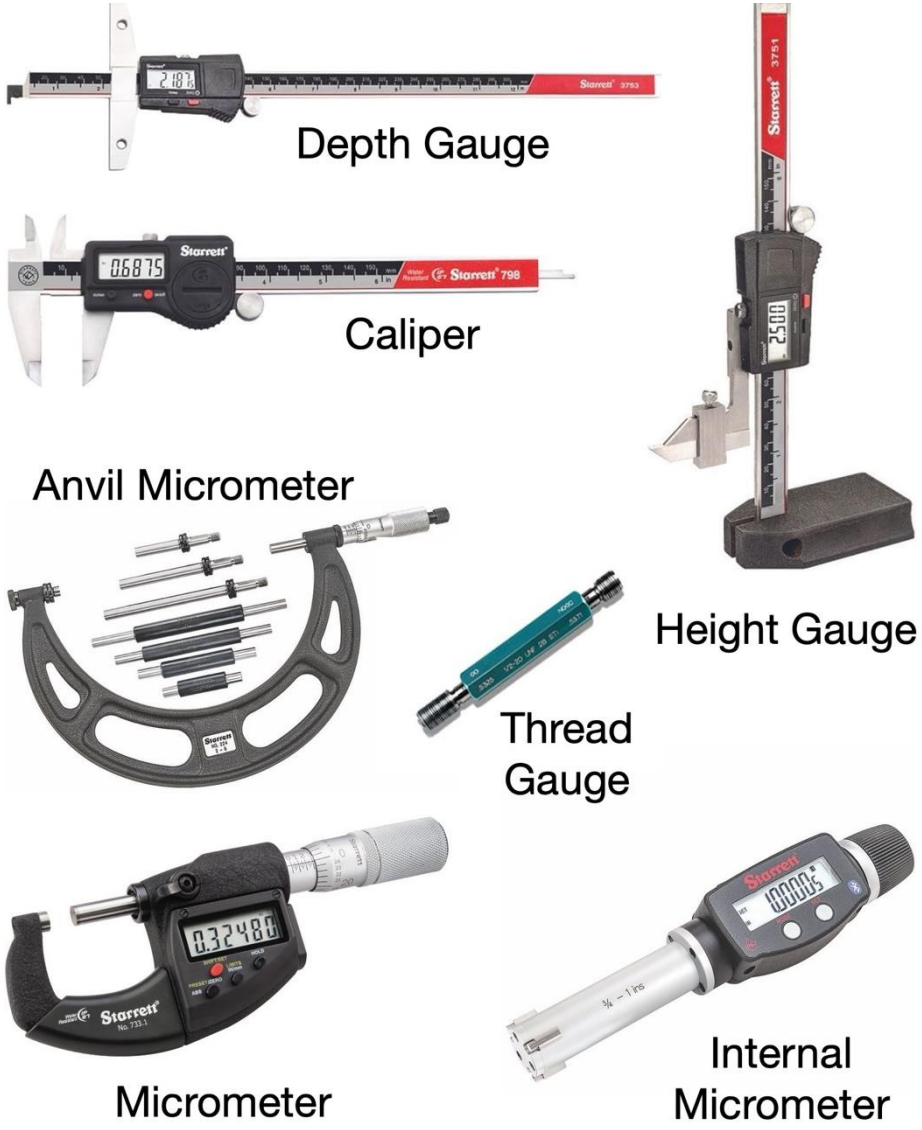

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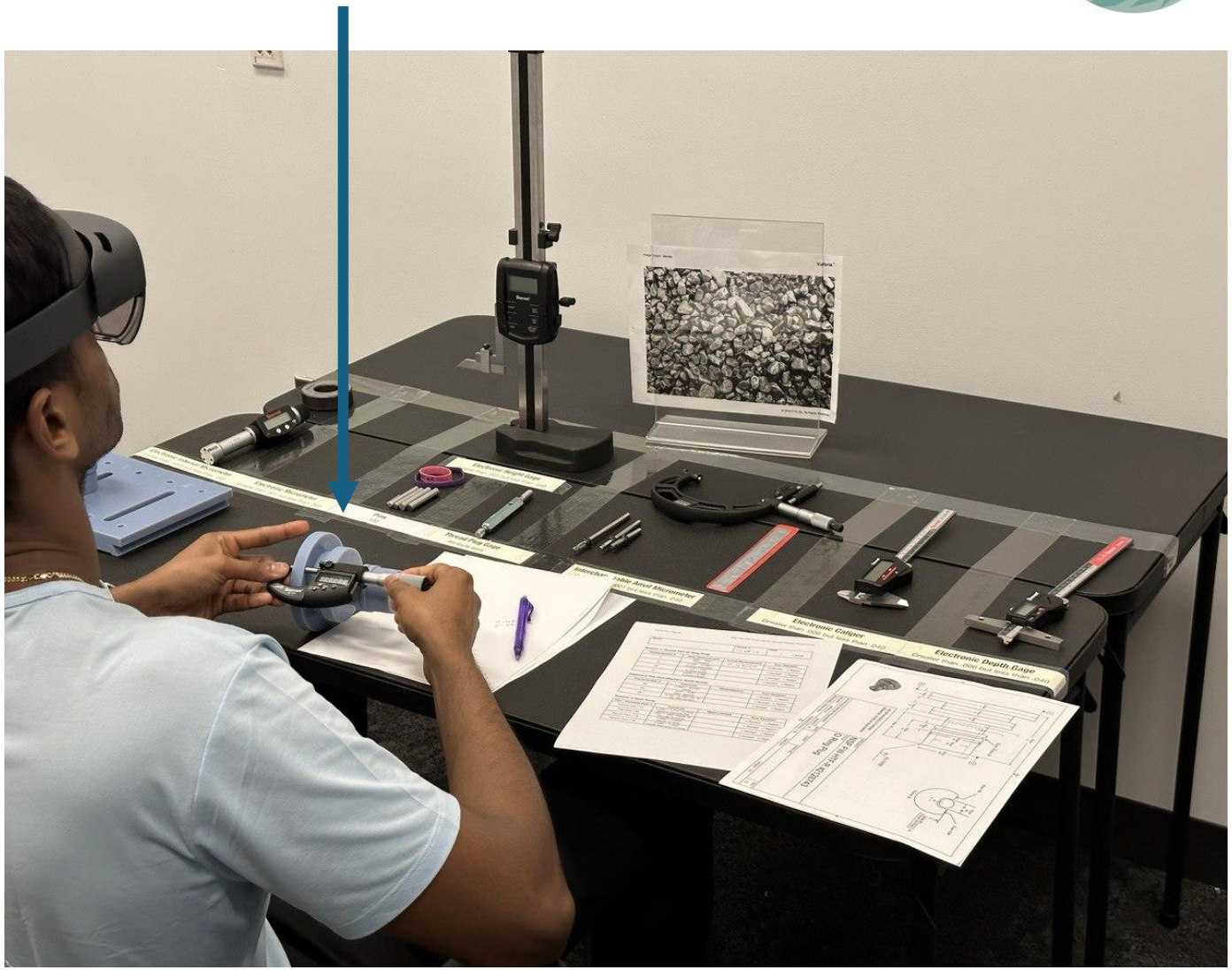

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Inspection Report — Human Subject Experiments

Name	Group #	Date
	▫ 1 ▫ 2 ▫ 3	/ / 2023

Session 1: Round Part (O-Ring Plug)

Characteristic #	Ideal Measurement	Measurement	Your Decision
2	.480 - .500 Thickness		▫ Accept ▫ Reject
3	2.495 - 2.505 Outside Diameter		▫ Accept ▫ Reject
19	.110 - .120 O-Ring Width		▫ Accept ▫ Reject
6	3.680 - 3.700 Overall Length		▫ Accept ▫ Reject

Session 2: Flat Part (Machine Guide Block)

Characteristic #	Ideal Measurement	Measurement	Your Decision
23	3.990-4.010 Width		▫ Accept ▫ Reject
32	.51401-.51610 Dim. Typical		▫ Accept ▫ Reject
35	3.740-3.760 Ctr. To Ctr. Slot Length		▫ Accept ▫ Reject

Session 3: Both Parts

Part / Characteristic #	Ideal Measurement	Measurement	Your Decision
Round Part / 21	1.700 - 1.715 O-Ring Groove Outside Dia.		▫ Accept ▫ Reject
Flat Part / 26	.055-.065 Depth of Recess (bottom)		▫ Accept ▫ Reject
Round Part / 13	1.893 - 1.900 Depth of Hole		▫ Accept ▫ Reject
Round Part / 15	1.246 - 1.250 Inside Diameter of Hole		▫ Accept ▫ Reject

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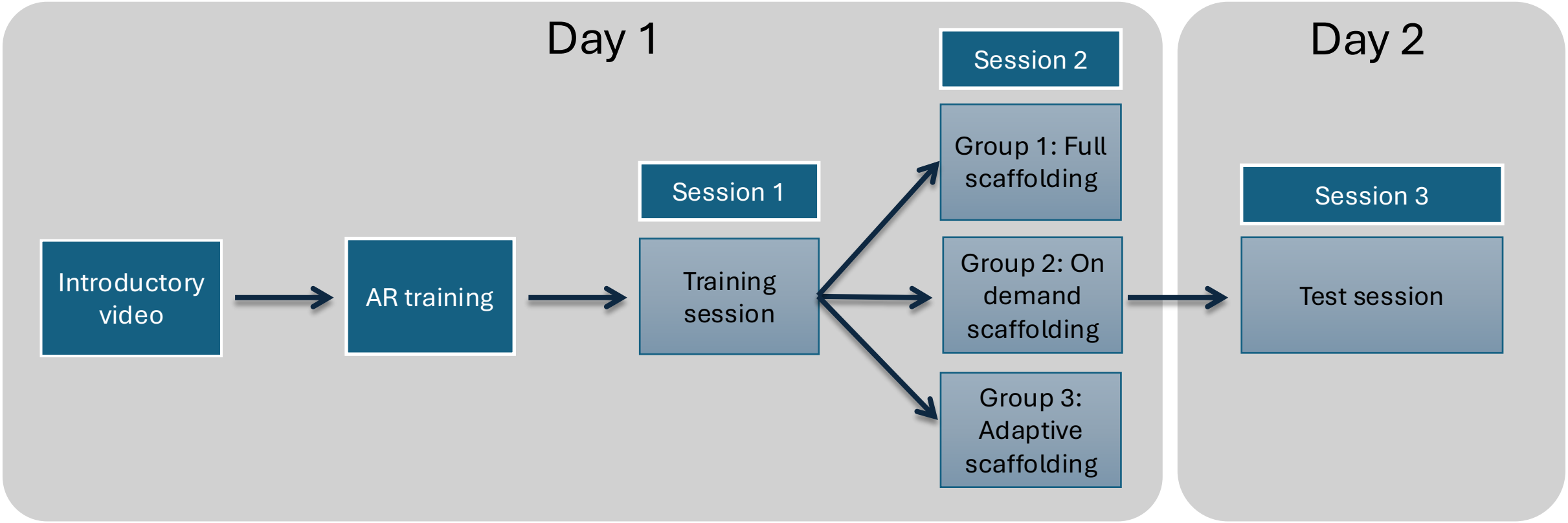
AR System Guides the Trainee

Real-time instructions

- Textual step instructions
- Auditory instructions
- 3D animations demonstrating individual steps

Methods: Experiment design

Study design: between subject study, three conditions, 24 participants (6 female, 18 male)



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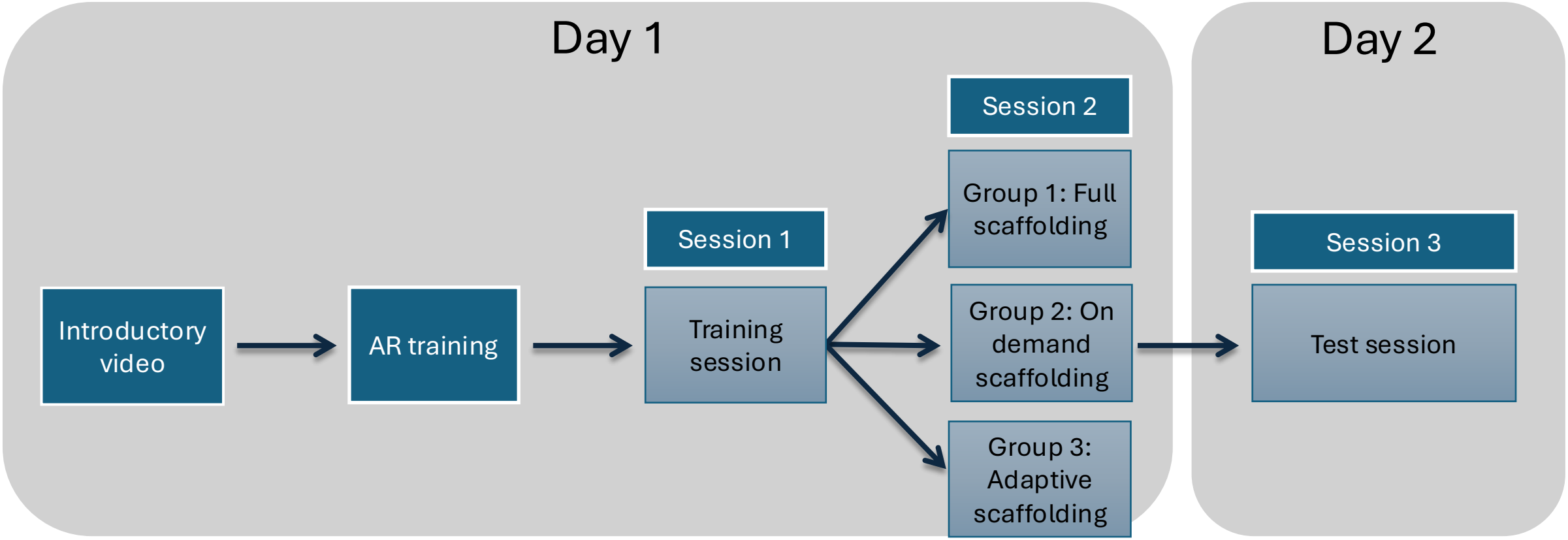


Hypothesis:

The **adaptive** scaffolding condition will result in a significantly **greater performance increase**

Methods: WoZ Design

Adaptive scaffolding condition is semi-automated

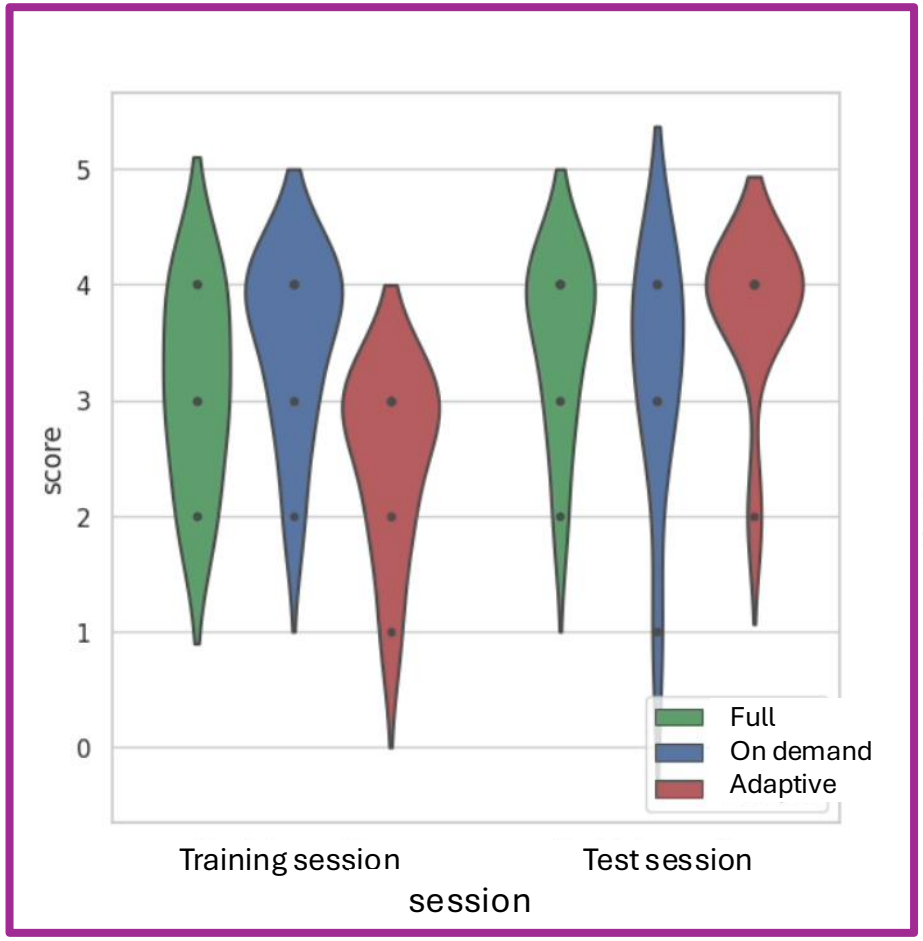
- Researcher behind the curtain
  - Observes trainees
  - Identifies incorrectly performed steps
- Automated script determines intervention
  - Provides **audio** message based on identified step

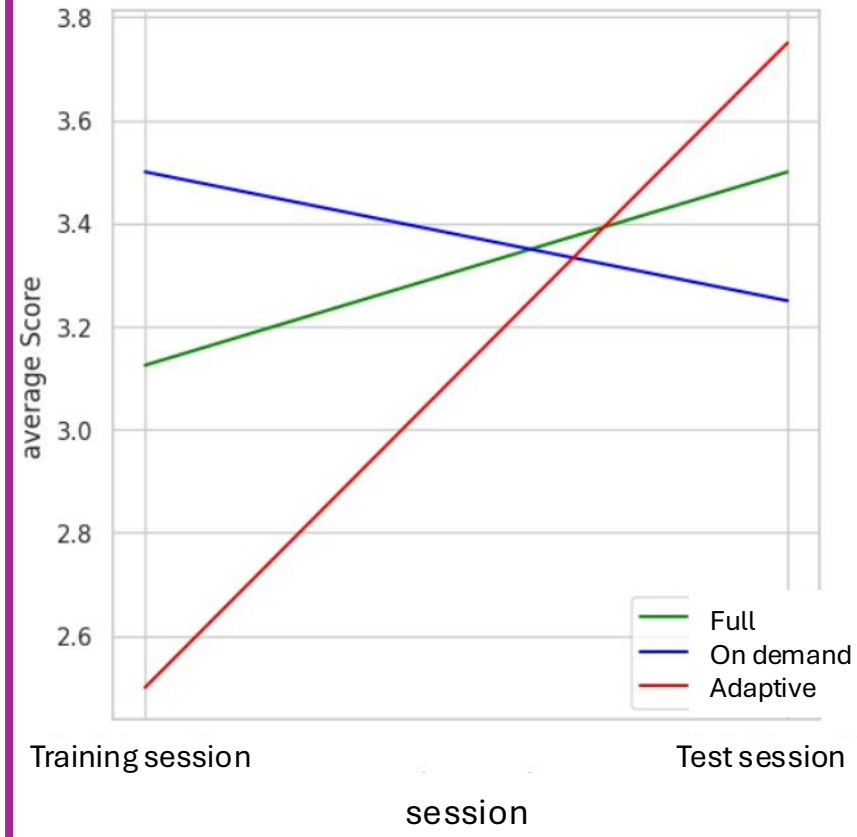
Example:

Researcher detected mistake: wrong gauge is picked up

Automated Message: “You have chosen the wrong gauge. You need to pick up a gauge with higher precision. For more guidance, please refer to step 1”

Analysis


score
5
4
3
2
1
0
Full
On demand
Adaptive
Training session
Test session
session


average Score
3.8
3.6
3.4
3.2
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2.8
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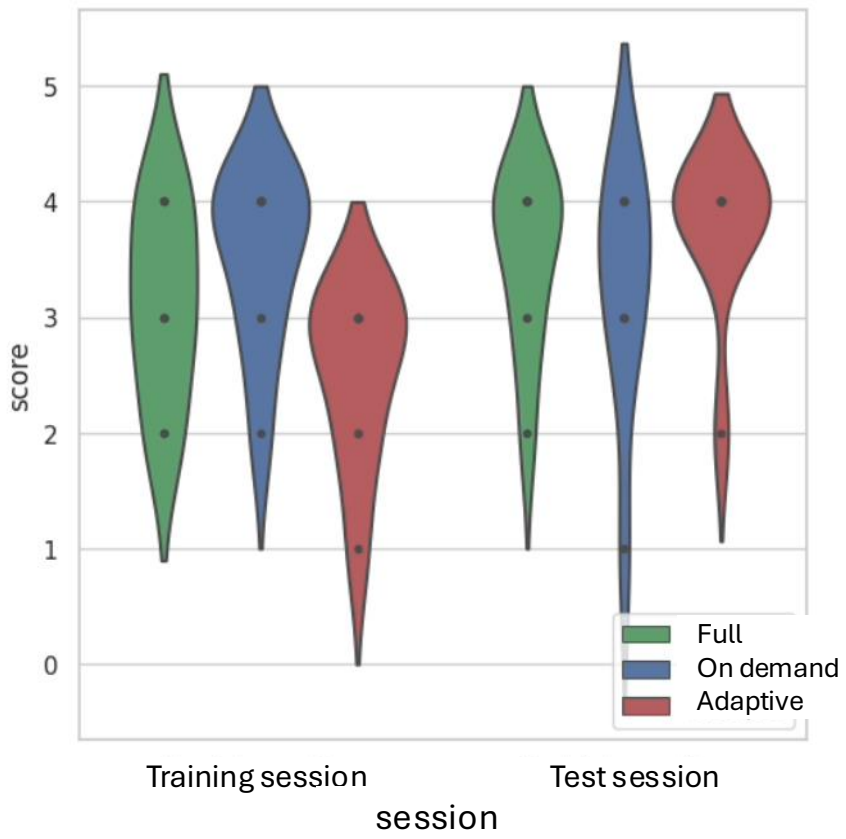
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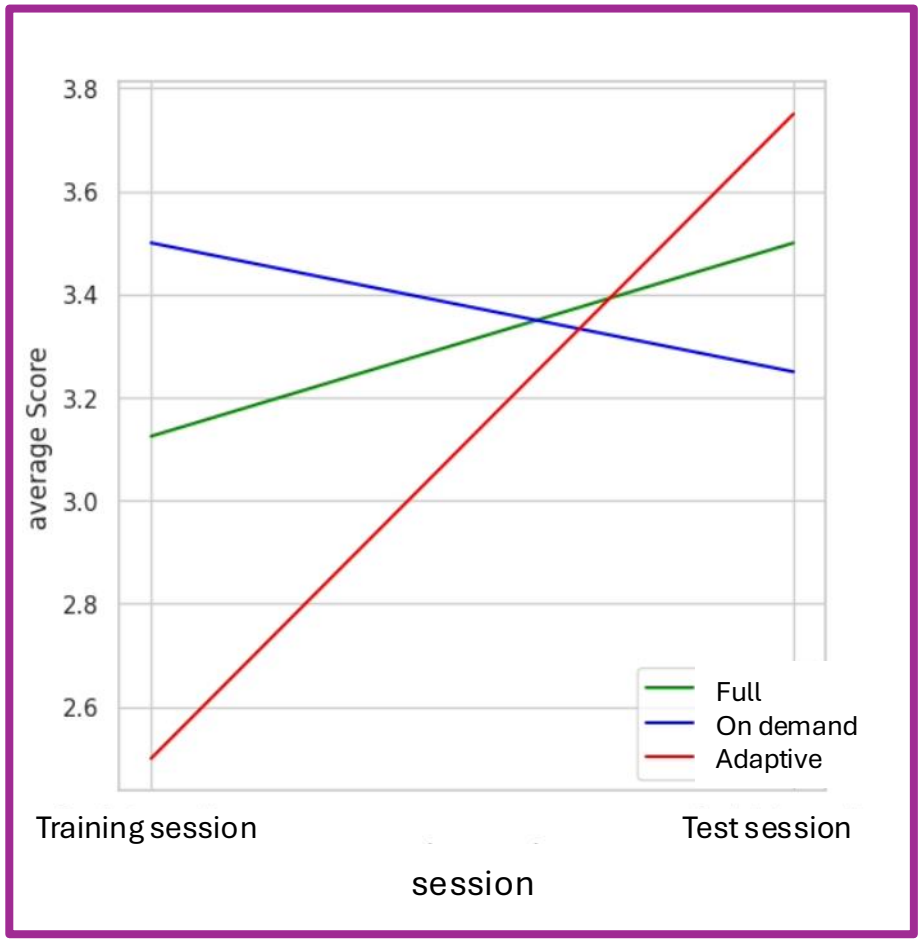
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Analysis

Model: logistic mixed effect model

Predictor variables:

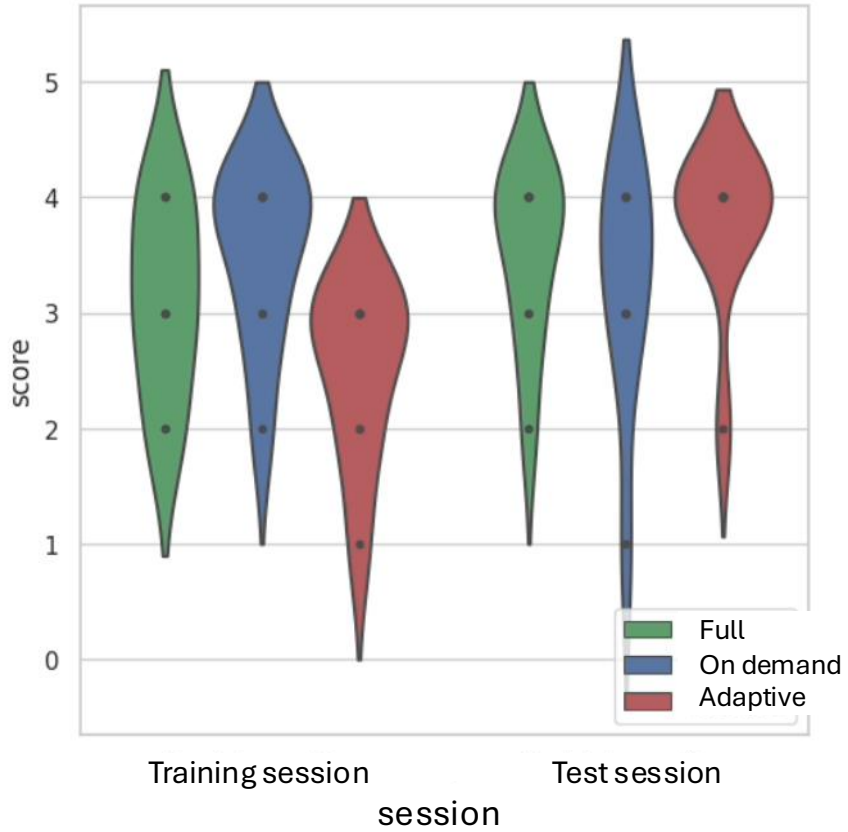
- Session: s1 (training session), s3 (test session)
- Condition: g1 (full scaffolding), g2 (on-demand scaffolding), g3 (adaptive scaffolding)
- Session and Condition interaction (s_i, g_j)

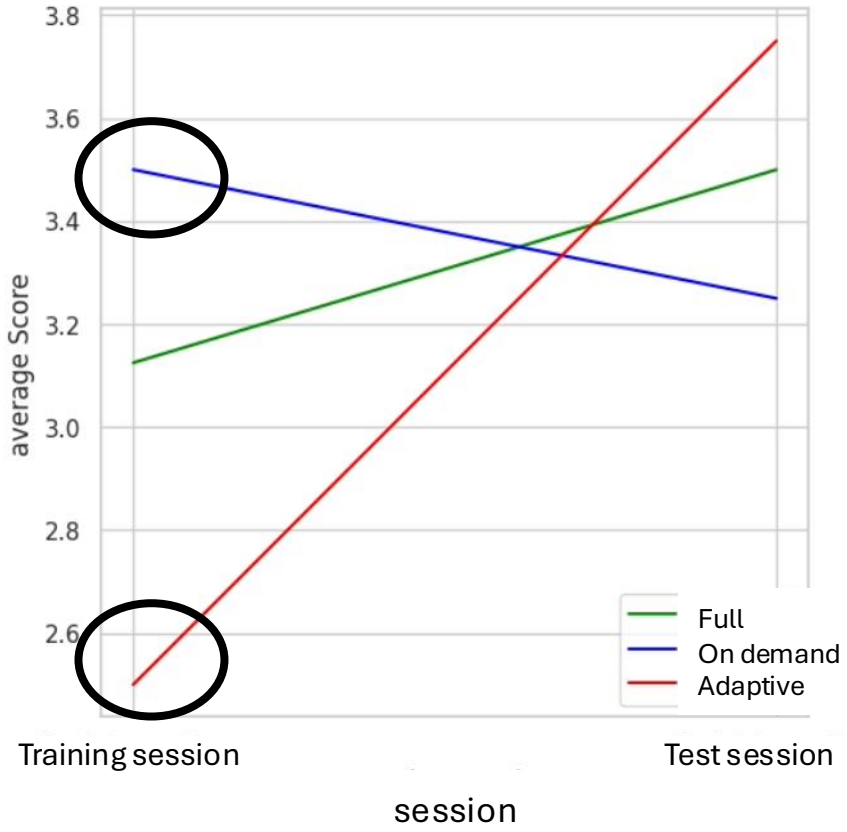
Independent variable:

- performance score (i.e., the number of correct answers on the inspection report)

Results

The difference between the on demand and adaptive group scores in session 1	Change of scores from session 1 to session 3, comparing the on demand adaptive group
$b_3 = -1.55, SE = 0.76, p_{\text{value}} < 0.05$	$b_5 = 2.8211, SE = 1.1085, p_{\text{value}} < 0.05$





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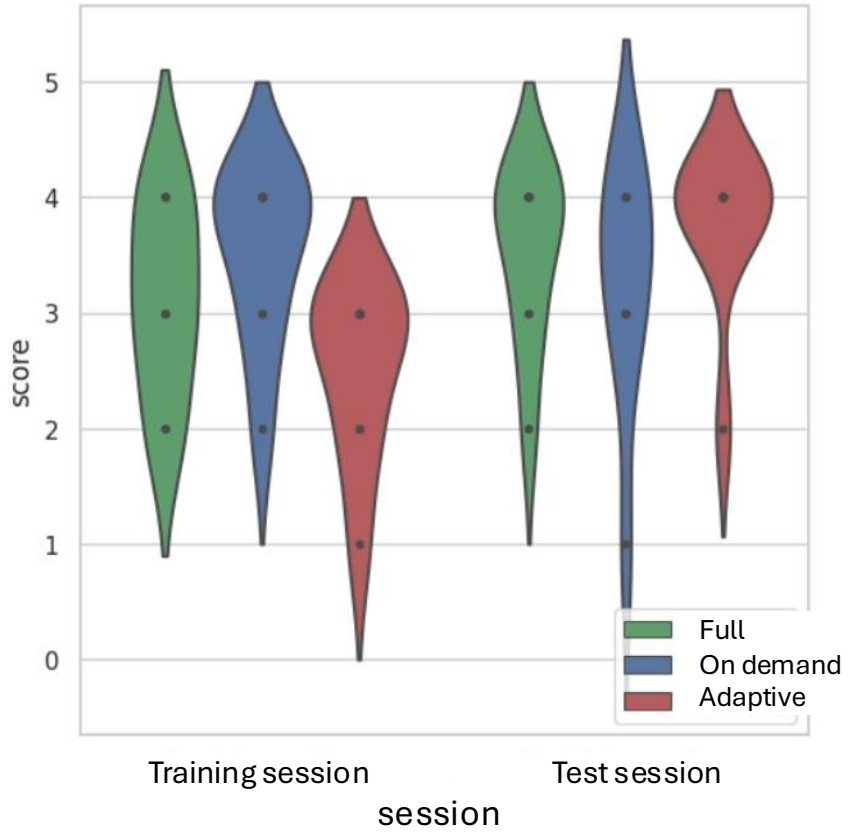

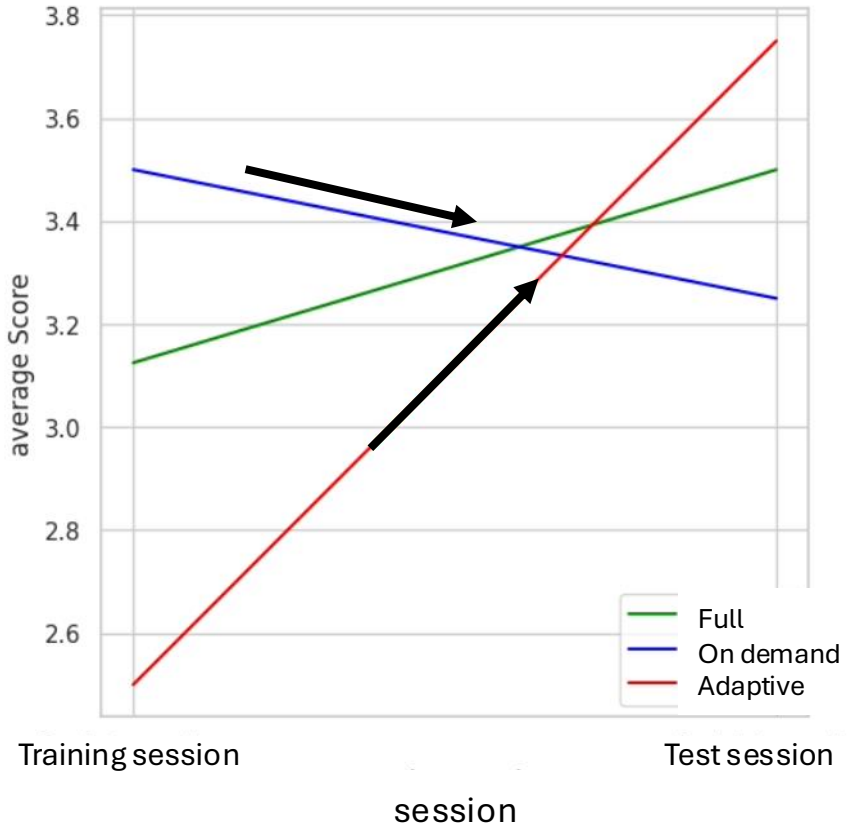

Challenges in Automating ITS: Vision

- Gauge selection
  - Wrong gauge (tolerance/fit)
- Gauge preparation
  - Calibration/zeroing out/wipe cleaning
- Measurement
  - Positioning the part and gauge/repeating the measurement/reading the gauge

→

Mistakes often involve precise hand movements
Hard to detect

→

Advanced vision system

Challenges in Automating ITS: Tailoring

Subjects responses to WoZ feedback and its effectiveness

- Timing
  - Instant interventions
  - Slow interventions
- Content
  - Affirmative feedback

→ modes of intervention, individual differences →

Adaptive and personalized ITS

Questionnaire Results

- High level of satisfaction in the proposed system
  - “The live demonstration of how to use the equipment was really helpful.”
  - “I am very positive towards the use of AR for training and industrial working purposes as I believe it can avoid the missing of tasks which were supposed to be done and can also make the entire process more intuitive and hands-on rather than just reading some text in a training manual.”
- Adaptive scaffolding enhances performance but lowers confidence
- Importance of individual preferences in intervention timing and content

Conclusions

- Participants in the Adaptive scaffolding performed better
- Realizing a fully automated system will require:
  - Individual differences need to be taken into account
  - Need for an advanced vision system

Questions

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Analysis cont.

The logit of getting the score right for group 1 session 1

The logit of getting the score right for group 3 in session 1

$$Logit(probablity\ of\ getting\ the\ answer\ right) =$$

$$\boldsymbol{b_{0,g2,s1}} + b_{0,p_i} + b_1.s_3 + b_2.g_1 + b_3.g_3 + b_4.s_3.g_1 + b_5.s_3.g_3$$

The logit of getting the answer right for group 2, session 1

the random effect of participants

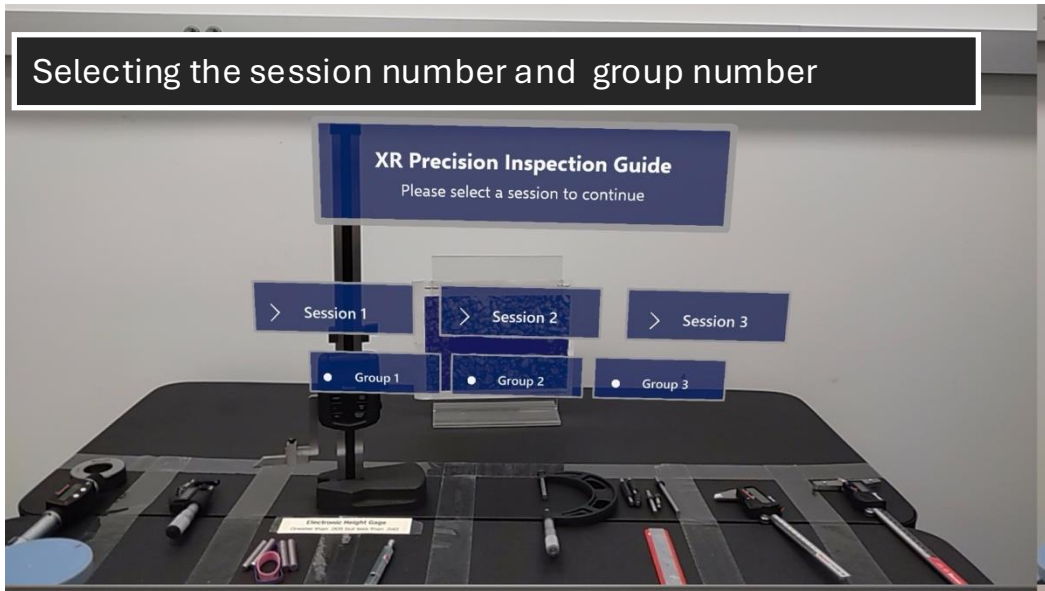
The logit of getting the score right for group 2 session 3

The logit of getting the score right in session 3 group 1

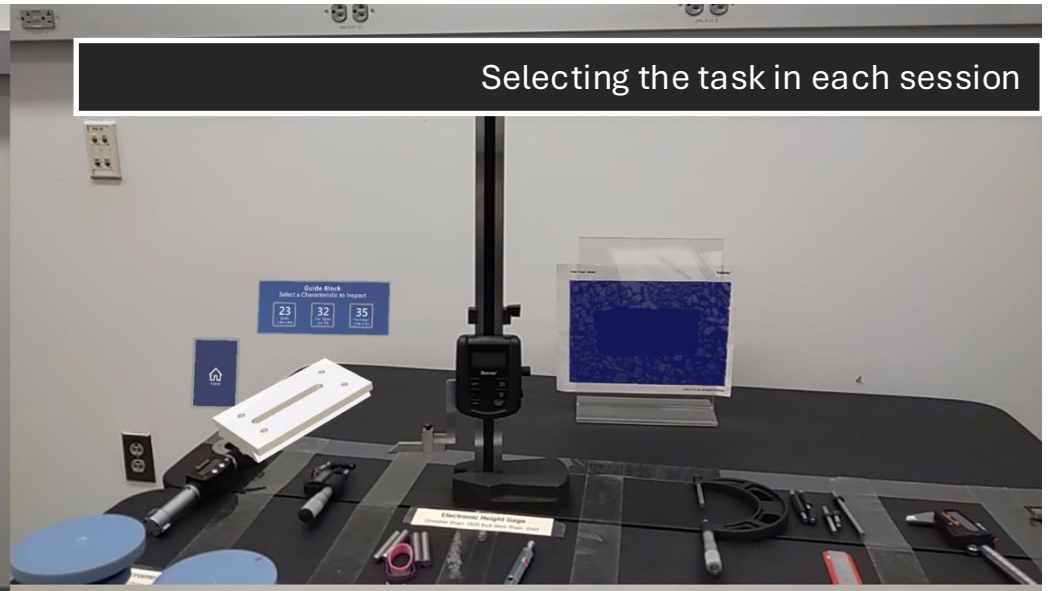
The logit of getting the score right in session 3 for group 3

AR app interface

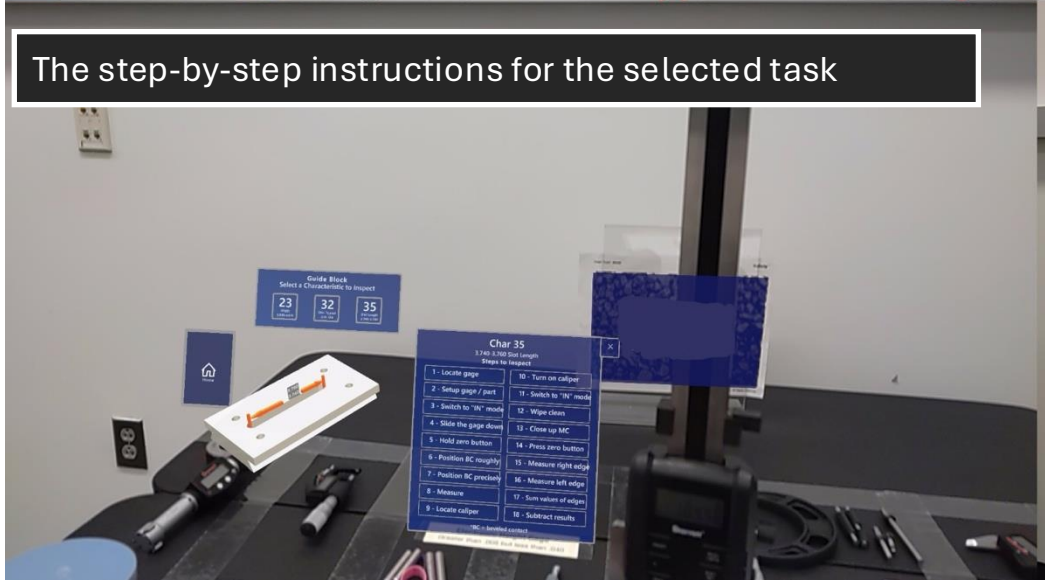
Selecting the session number and group number



Selecting the task in each session



The step-by-step instructions for the selected task



Textual/audio/animated instructions for each step of the task