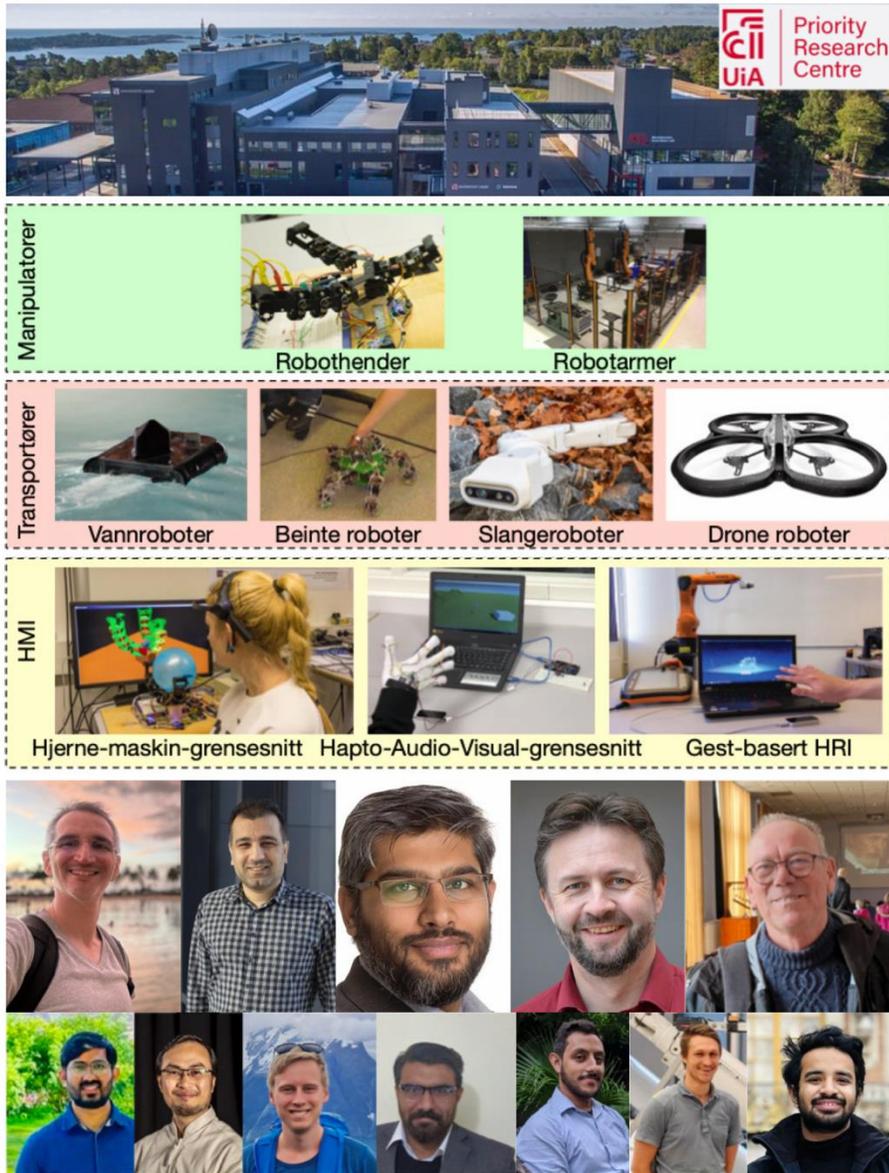


STRUCTURING IMMERSION LEVELS IN THE REALITY-VIRTUALITY CONTINUUM: A MULTI-SENSORY APPROACH

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Introduction



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 - PhD Fellow, Muhammad Hamza Zafar
 - PhD Fellow, Syed Kumayl Raza Moosavi
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Introduction

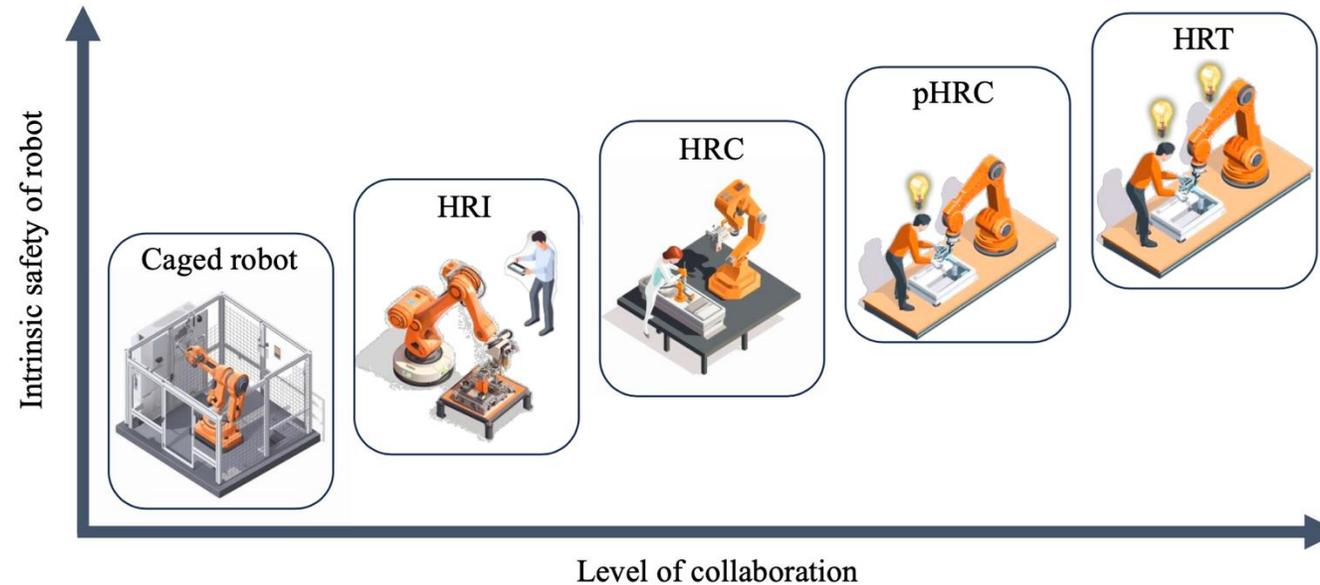


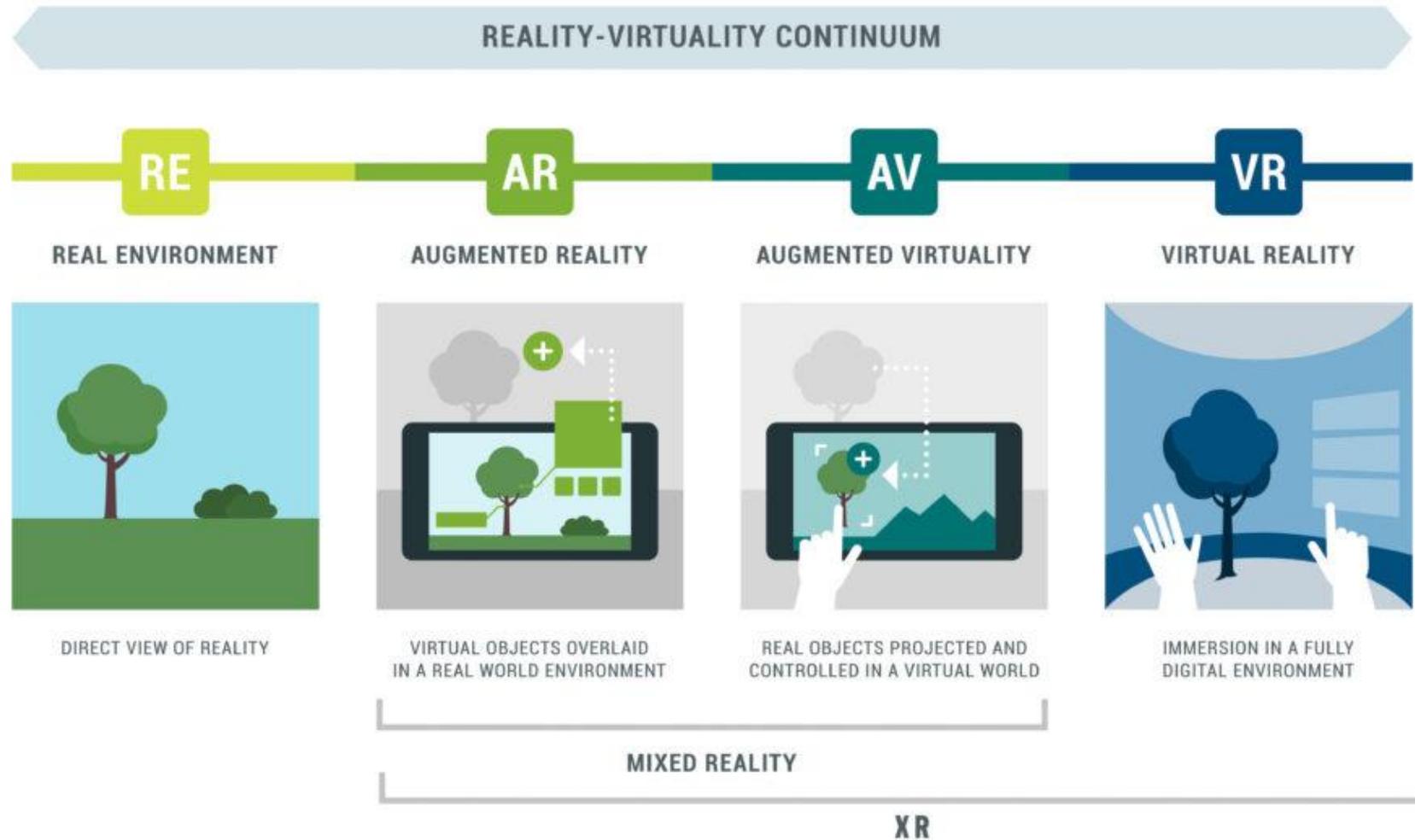
Figure: Transition from caged robots, to human-robot interaction (HRI), to human-robot collaboration (HRC), to physical human-robot collaboration (pHRC), to human-robot teaming (HRT).

[1,2]

[1] **Muhammad Hamza Zafar, Even Falkenberg Langås, and Filippo Sanfilippo.** “Exploring the synergies between collaborative robotics, digital twins, augmentation, and industry 5.0 for smart manufacturing: A state-of-the-art review”. In: *Robotics and Computer-Integrated Manufacturing* 89 (2024), p. 102769.

[2] **Even Falkenberg Langås, Muhammad Hamza Zafar, and Filippo Sanfilippo.** “Exploring the synergy of human-robot teaming, digital twins, and machine learning in industry 5.0: A step towards sustainable manufacturing”. In: *Journal of Intelligent Manufacturing* (2025), pp. 1–24.

Introduction



Introduction

Table 1. Multi-Sensory Extension of the Reality–Virtuality Continuum

RV Parti- tion	Vision	Audio	Touch	Smell	Taste
RE	Natural vision	Environmental sounds	Physical touch	Natural scents	Natural taste
AR	Digital overlays	3D spatial audio	Wearable haptics	Scent augment.	Limited taste augment.
AV	Blended objects	Virtual audio	Tactile feedback	Simulated scents	Basic taste sim.
VR	Synthetic visuals	360° audio	Force feedback	Digital scents	Synthetic taste



Introduction



Beyond the Classroom:
Virtual Reality, Augmented
Reality and Haptics for
Enhanced Surgical
Training and Education
(ImmersiveSurgicalEdu),
<https://immersivesurgical.edu.eu/>



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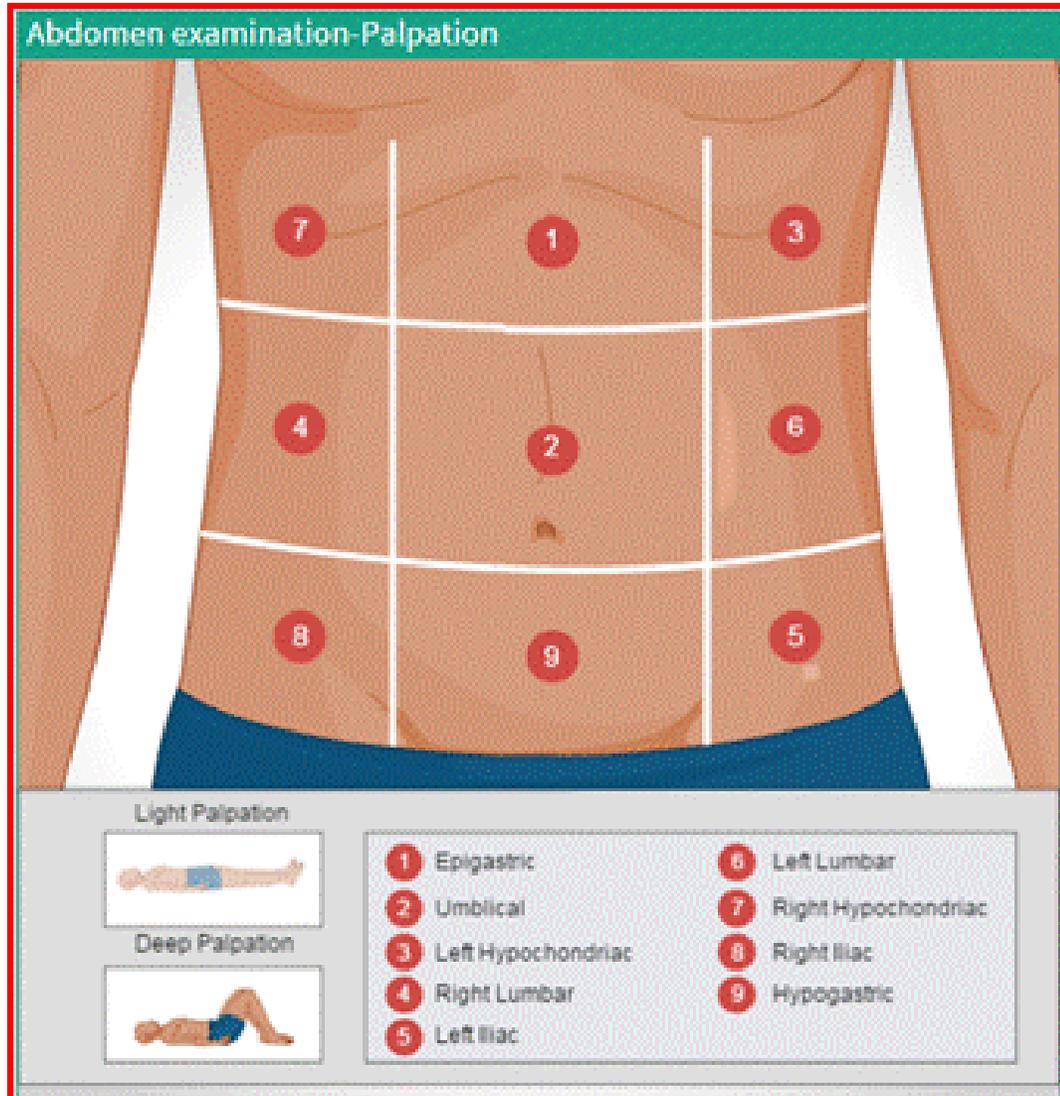


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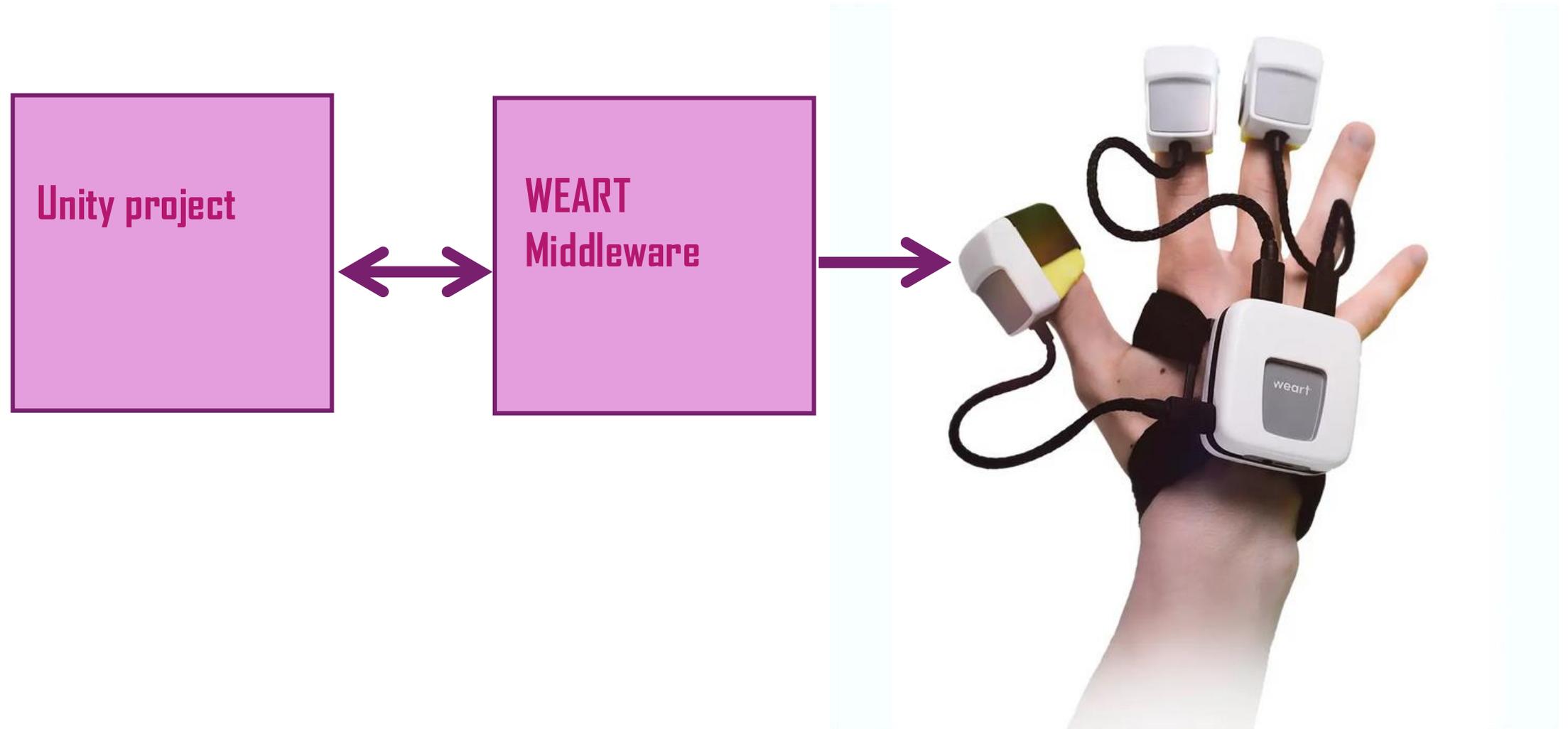
Introduction



Palpation examination overview

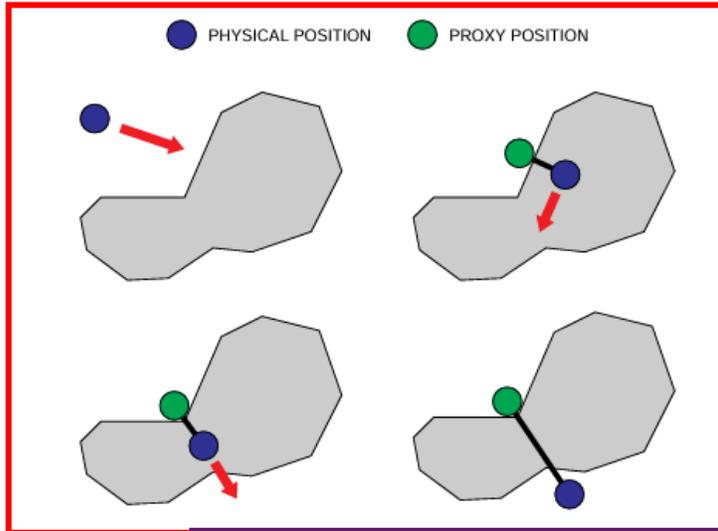


Methodology

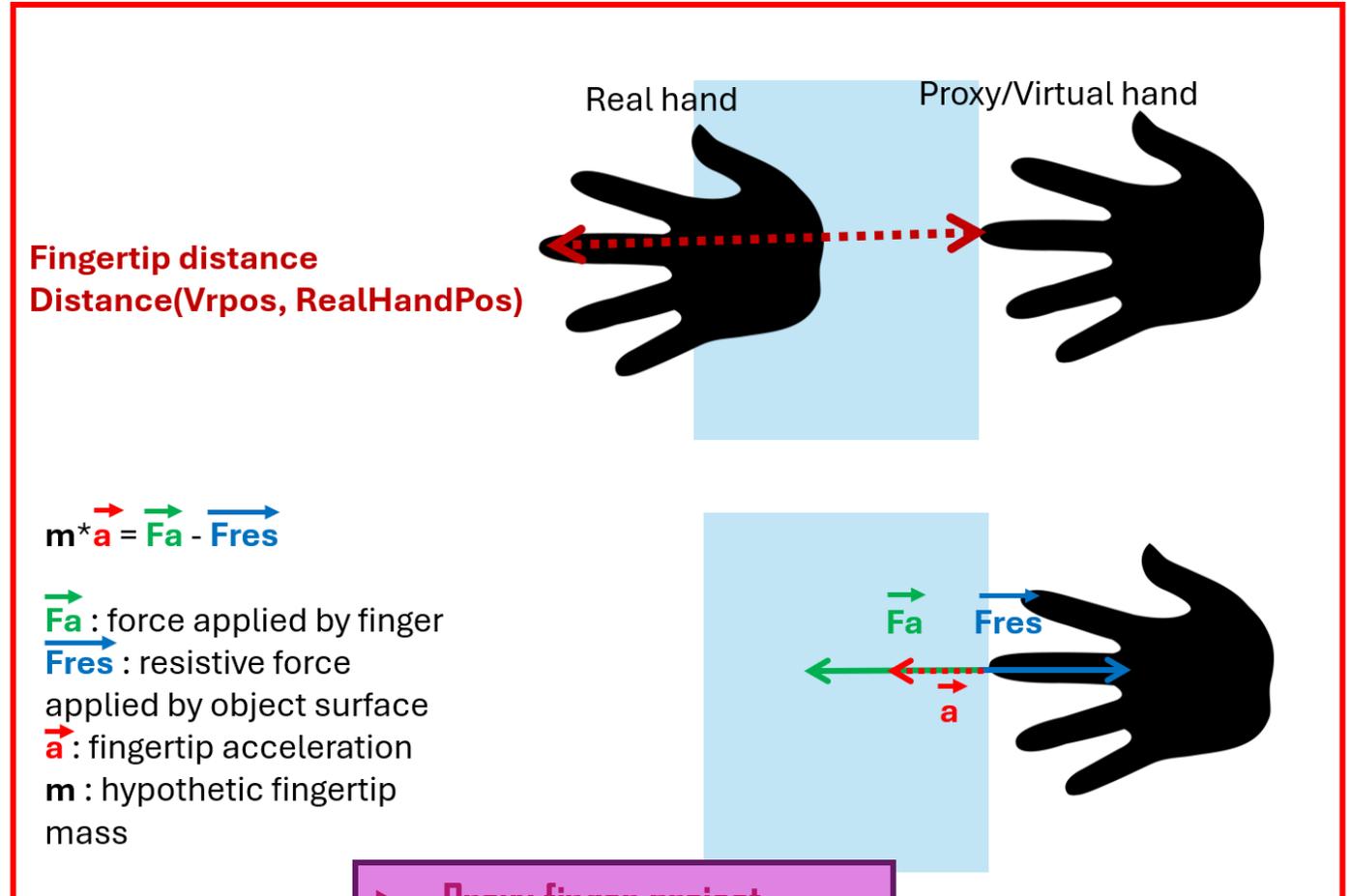


Methodology

Proxy finger method



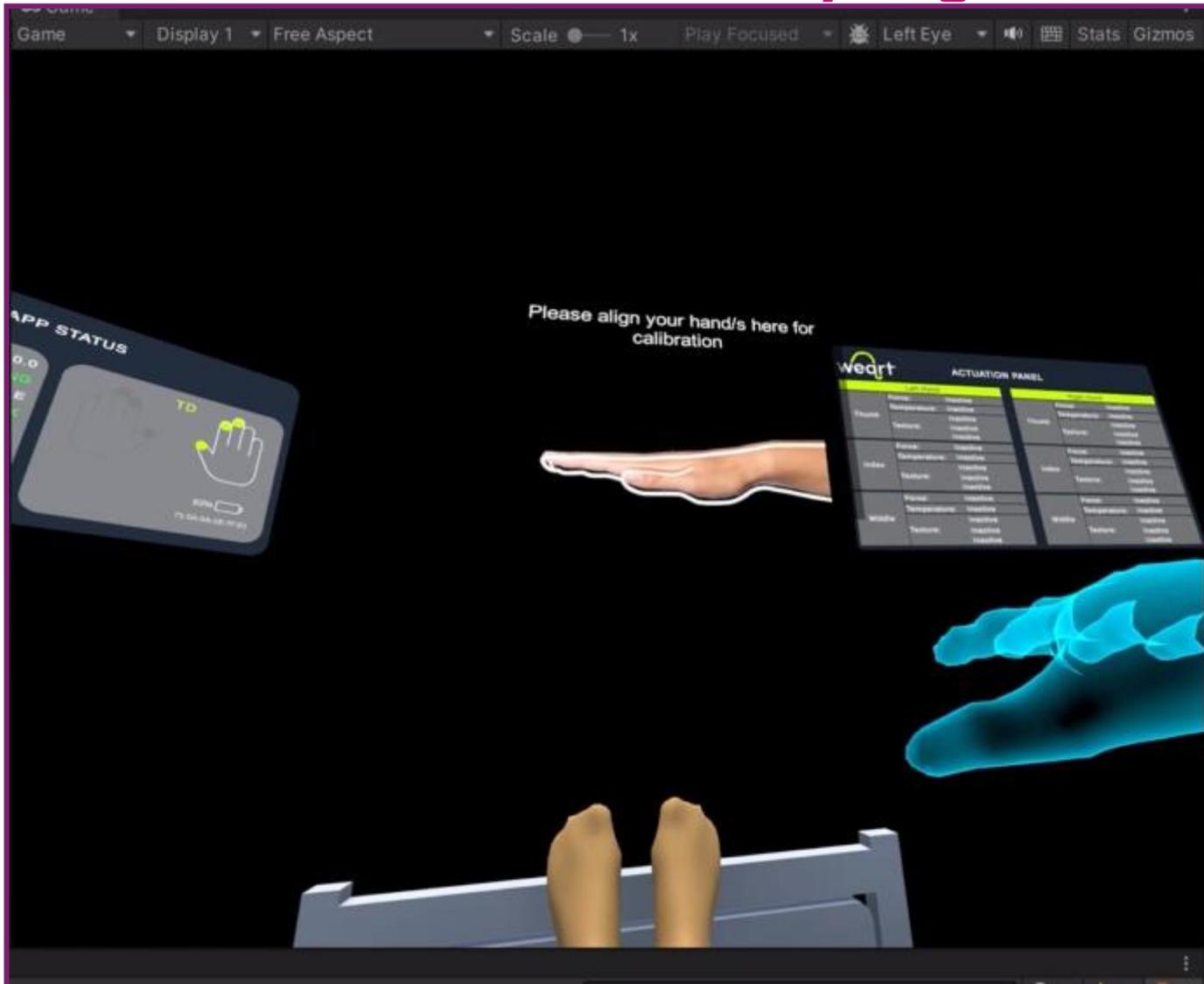
► Proxy finger method from state of art



► Proxy finger project implementation diagram

Methodology

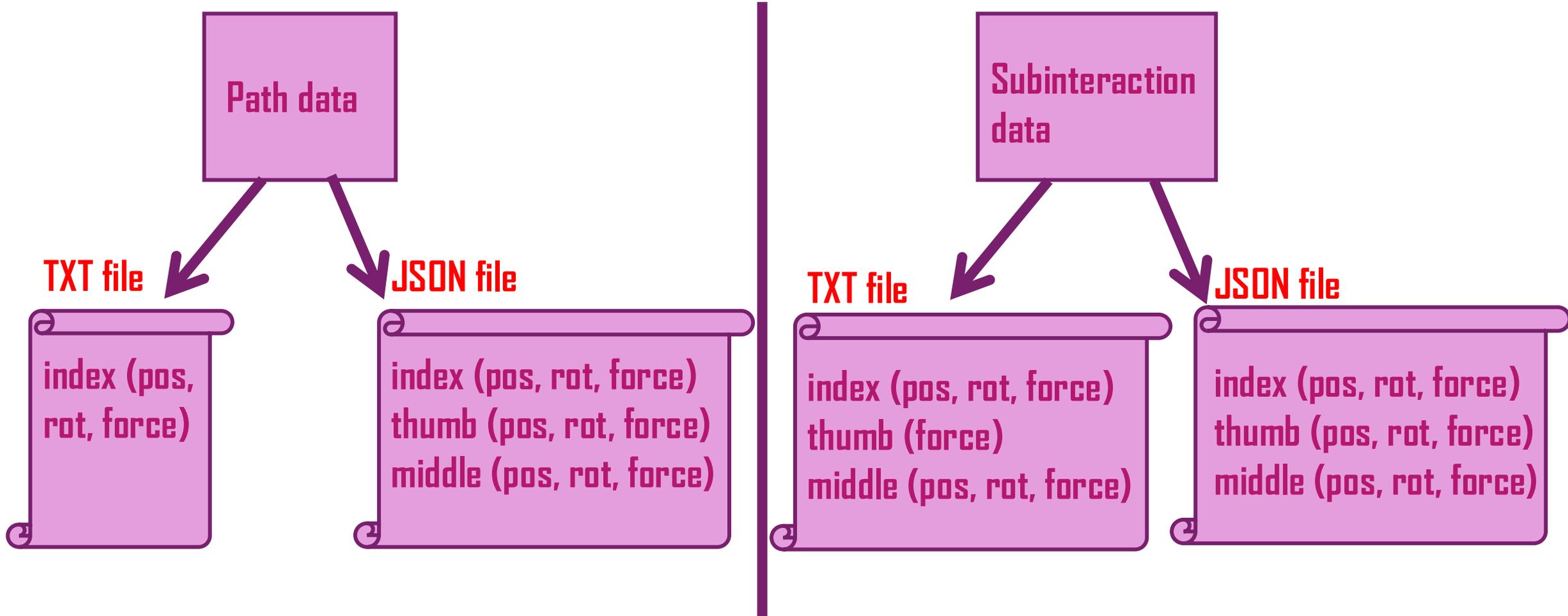
Proxy finger method



▶ Video showing in game proxy finger and finger press

Methodology

Data recording



Methodology

Student evaluation : overview

Complete
validation method

Score list:

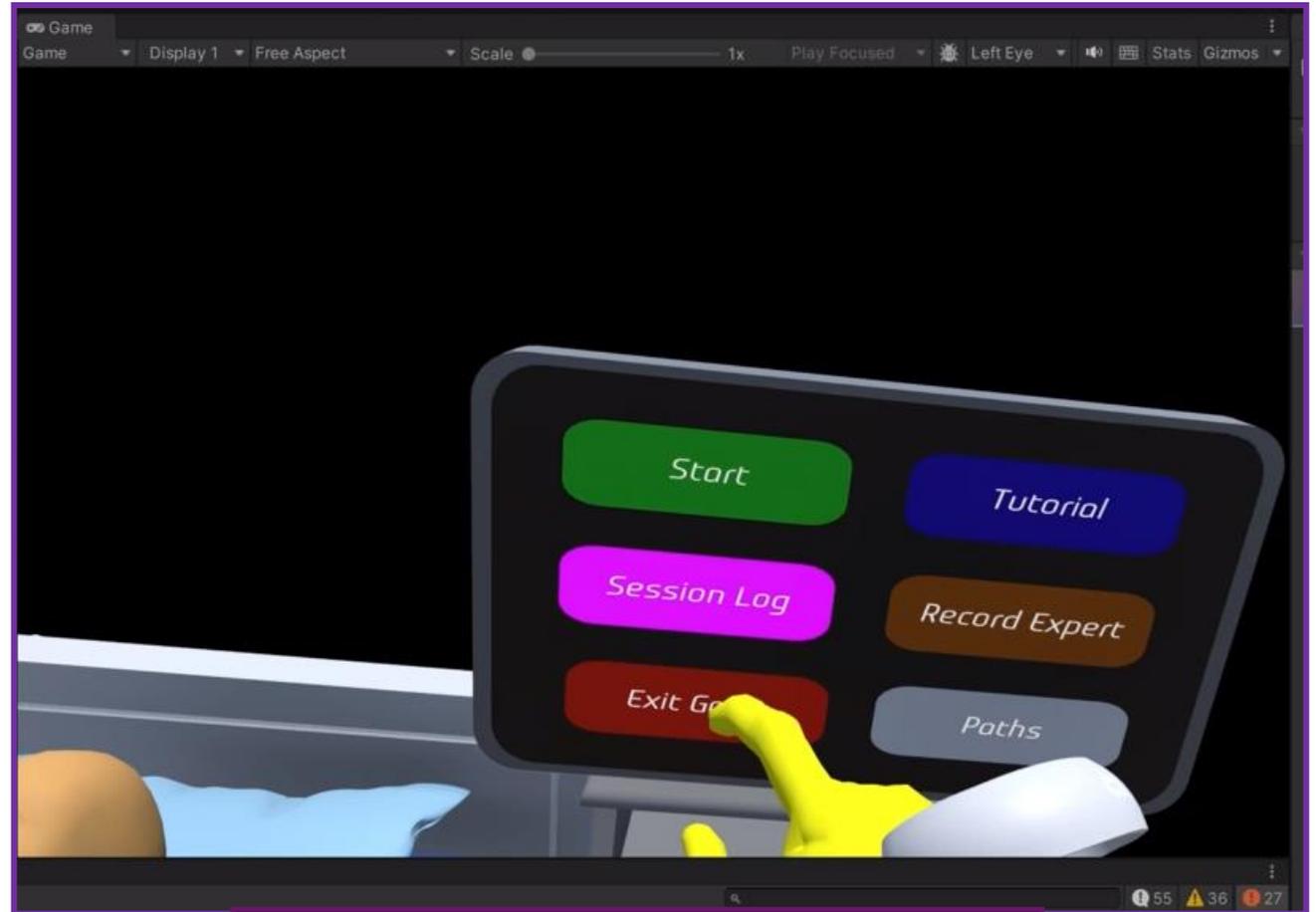
Force value (index, thumb, middle)

Force time (index)

Position (index, middle)

Rotation (index, middle)

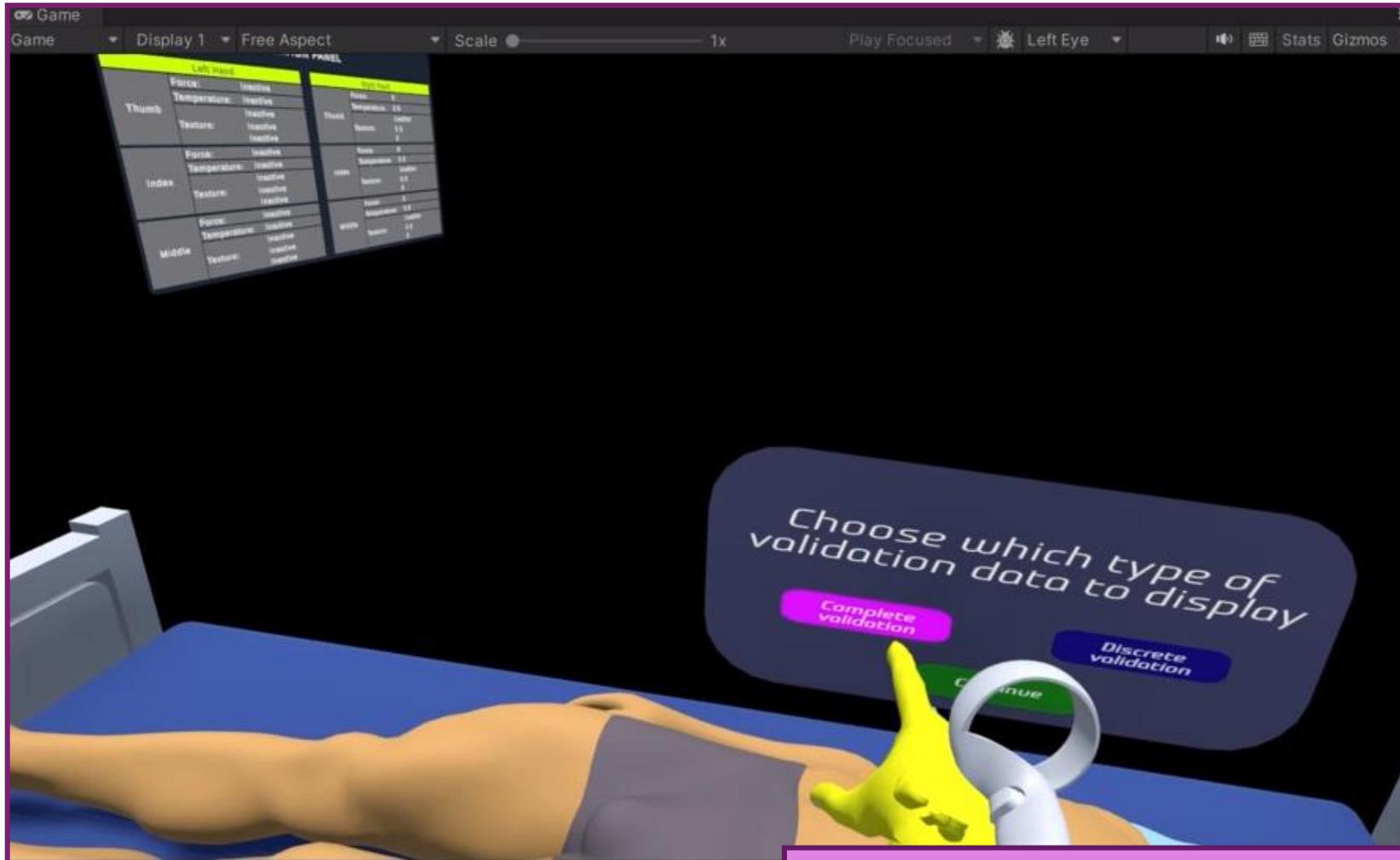
global (mean all scores)



▶ In game canvas for tuning exam difficulty

Methodology

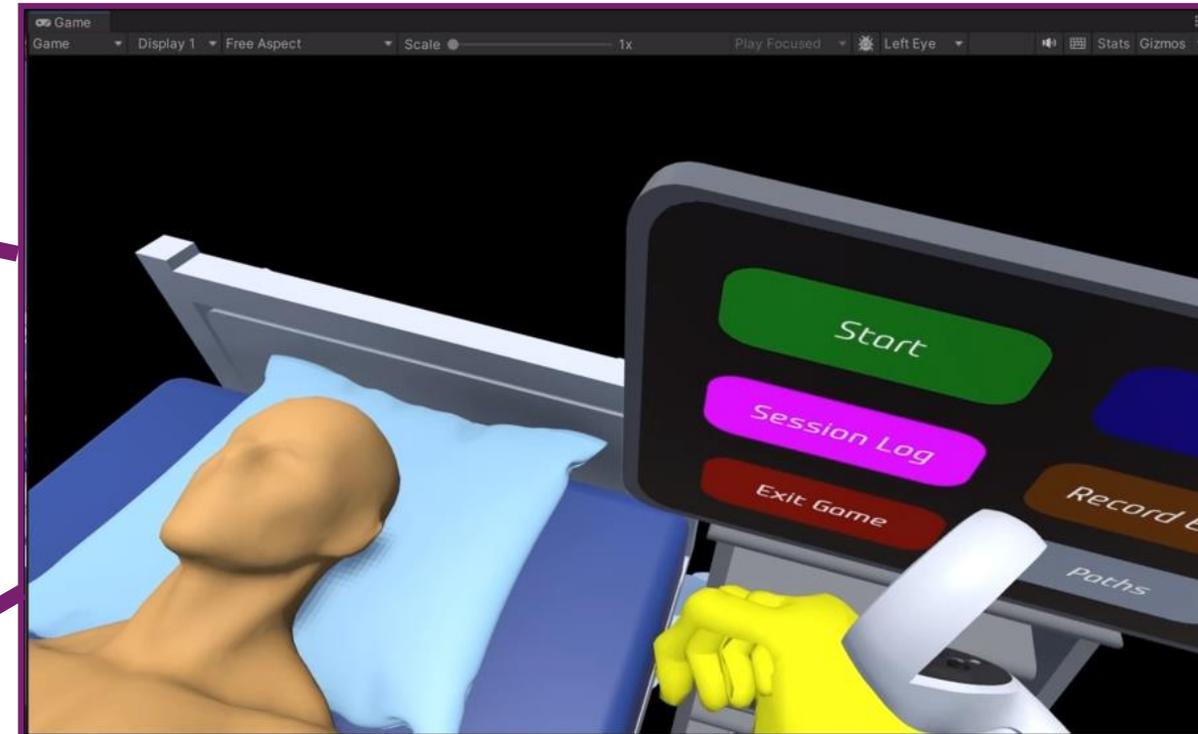
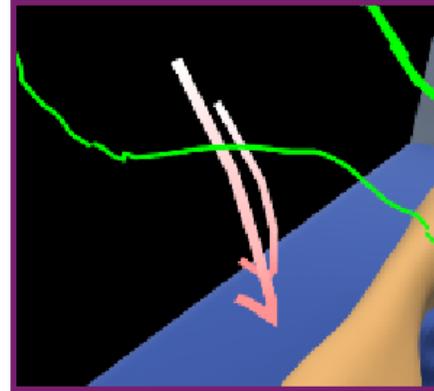
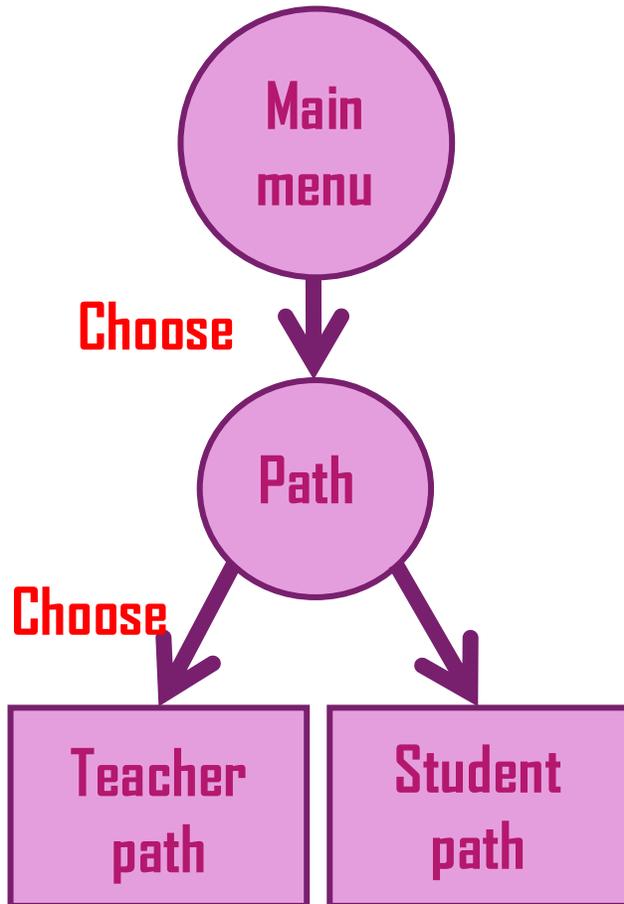
Student evaluation : in game display



► Video showing in game validation display

Methodology

Paths and data display



▶ Video showing in game path display

Experiments

Questionnaires and setup

▶ Questionnaires : IPQ and CIQ

IPQ Survey

Igroup Presence Questionnaire for Virtual Reality Research

In the computer generated world I had a sense of "being there"

not at all



0



1



2



3



4



5



6

very much

IPQ

Presence/
immerssion

CIQ

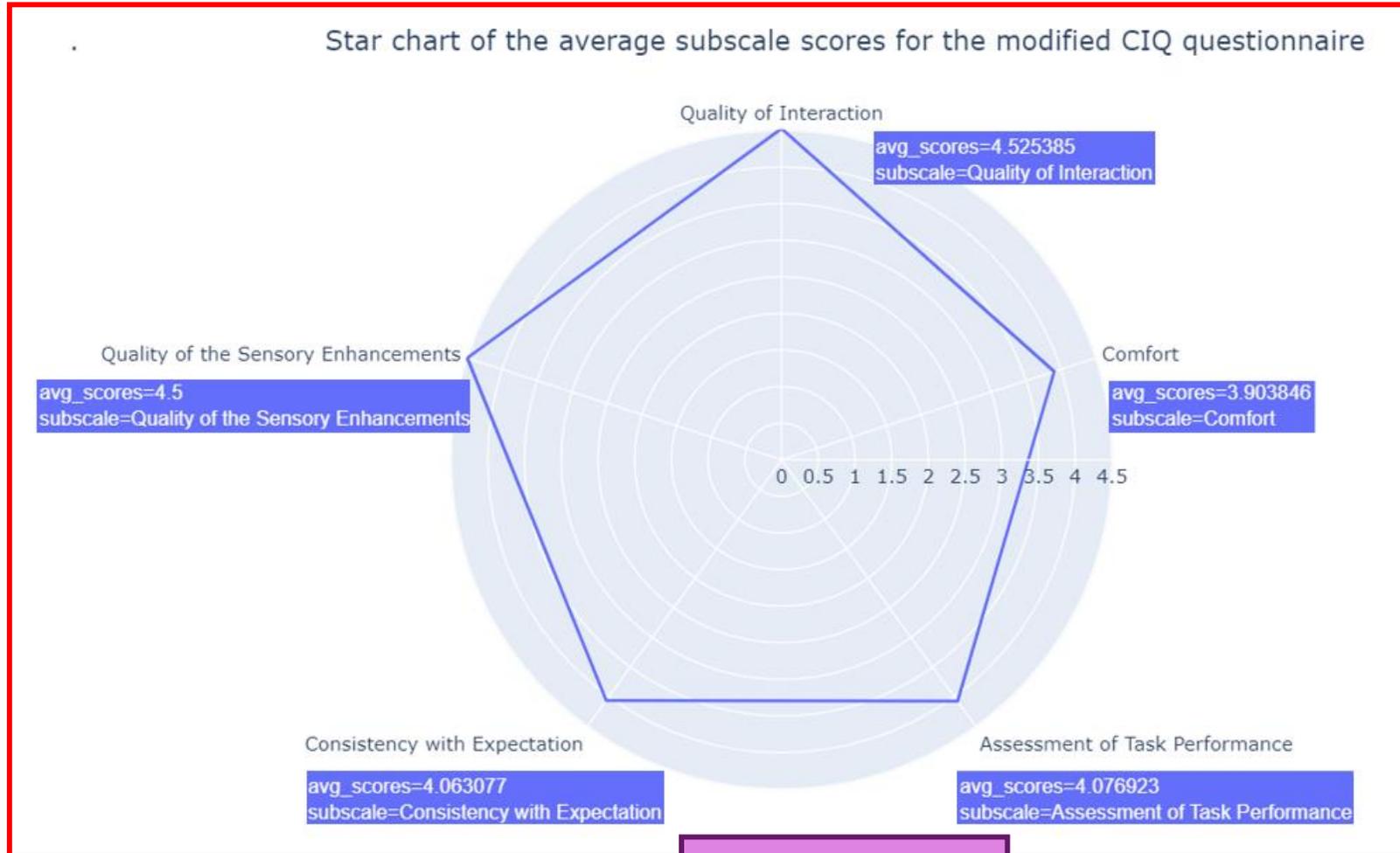
Interaction
quality



▶ User testing : 2 days / 13 people

Experiments

Results and interpretation

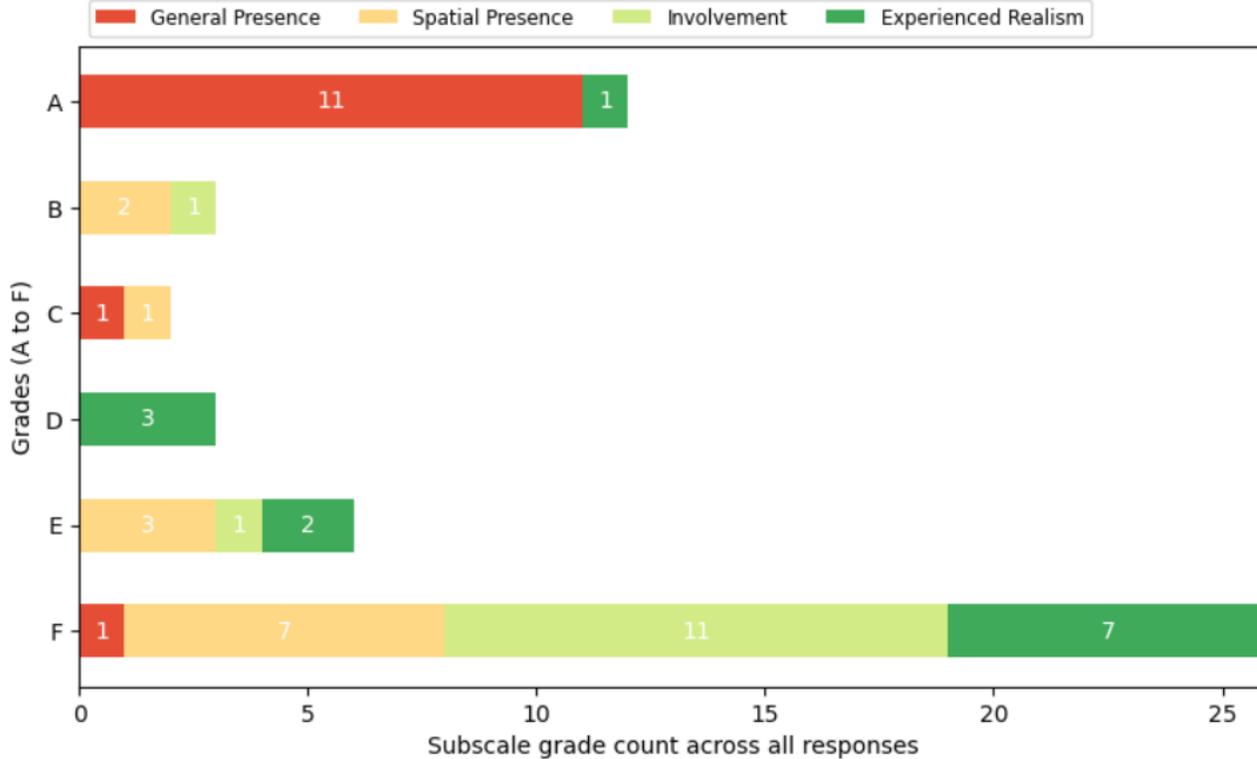


► CIQ star chart

Experiments

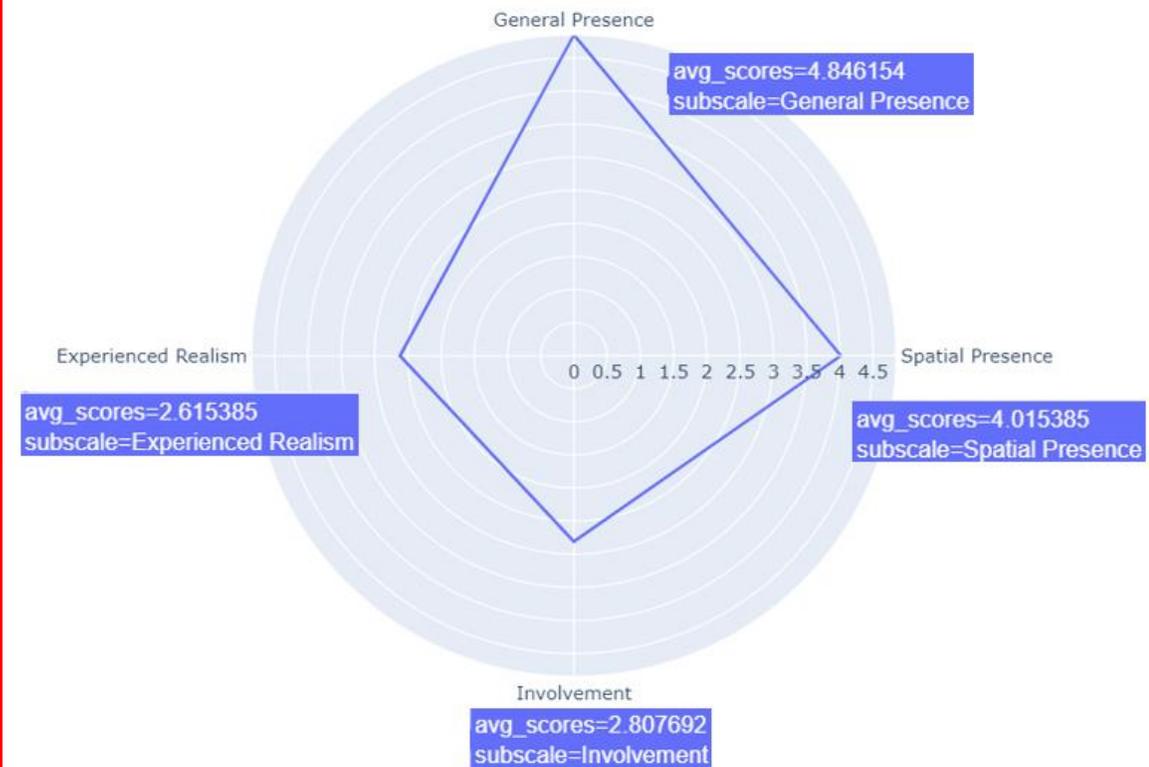
Results and interpretation

IPQ subscale score grade count horizontal bar chart (13 responses)



▶ IPQ horizontal bar chart

Star chart of the average subscale scores for the IPQ questionnaire

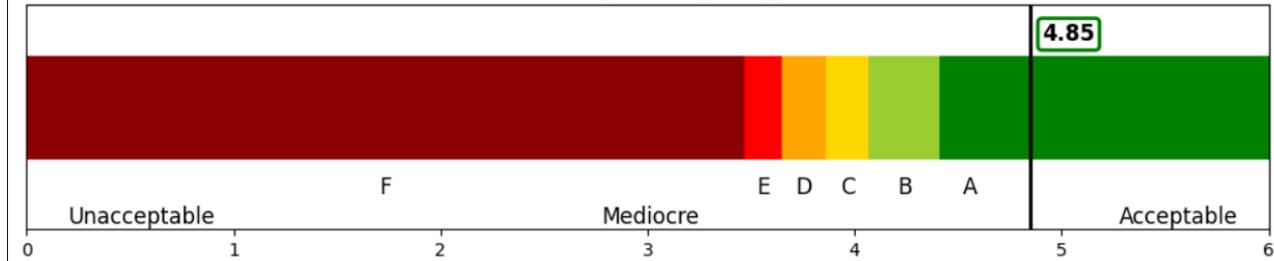


▶ IPQ star chart

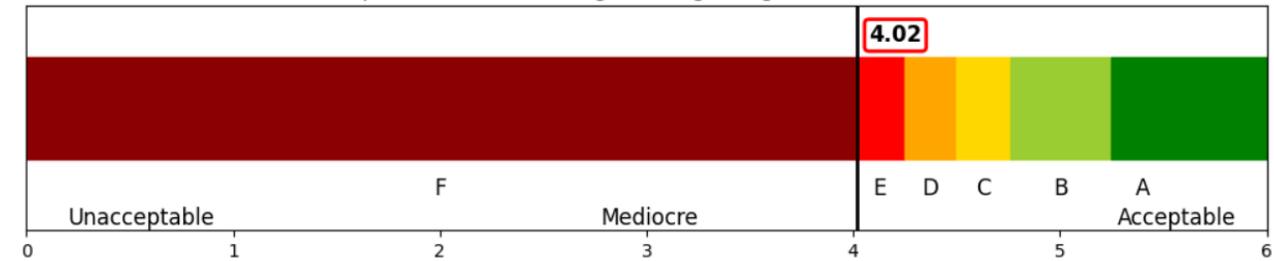
Experiments

Results and interpretation

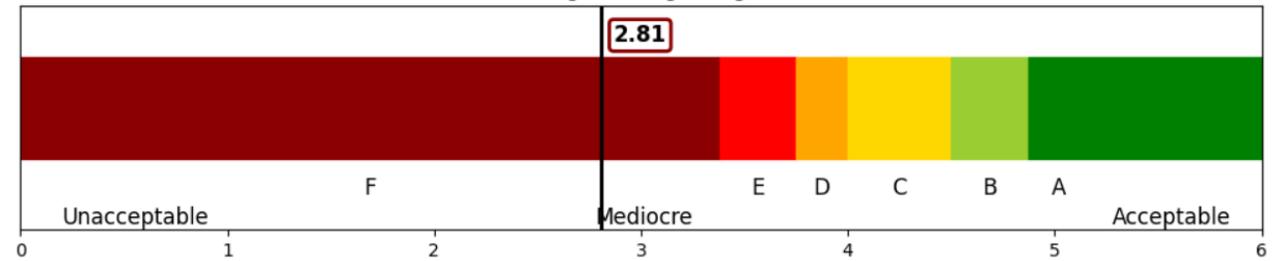
General Presence average score grading SUS chart (IPQ)



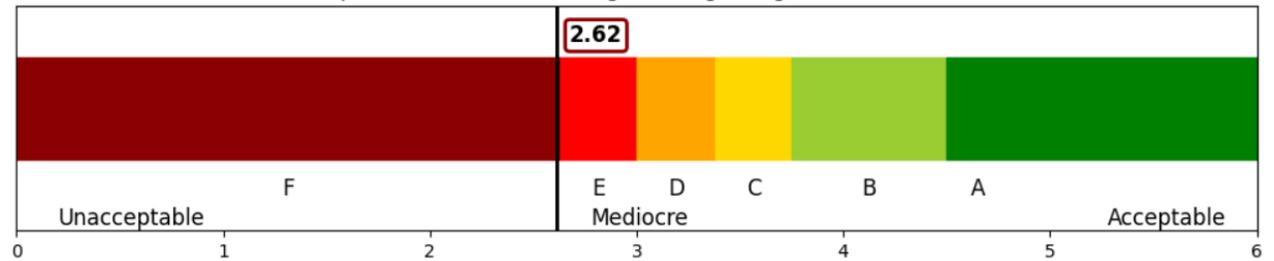
Spatial Presence average score grading SUS chart (IPQ)



Involvement average score grading SUS chart (IPQ)



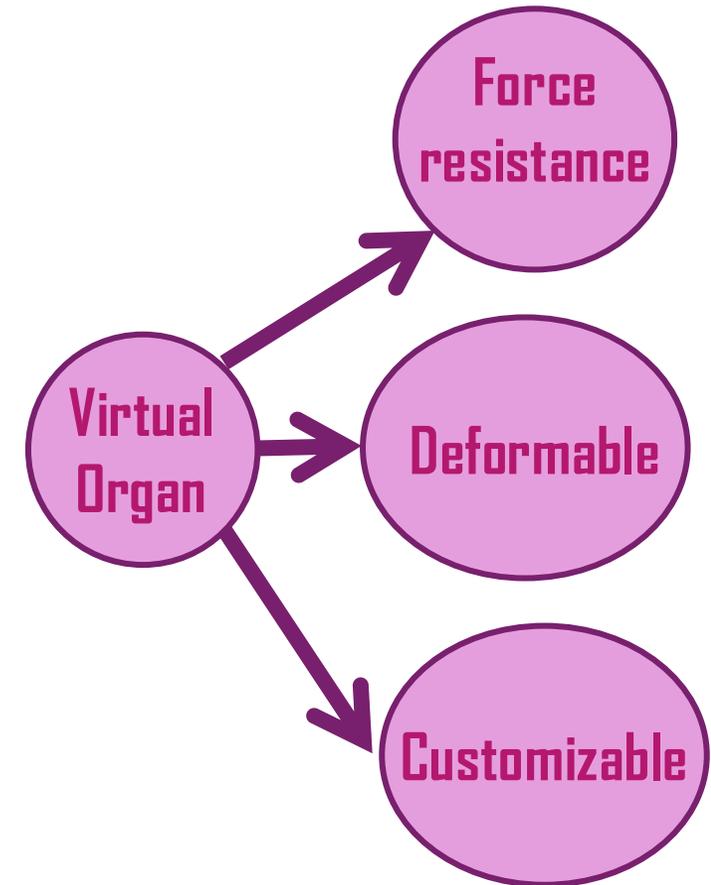
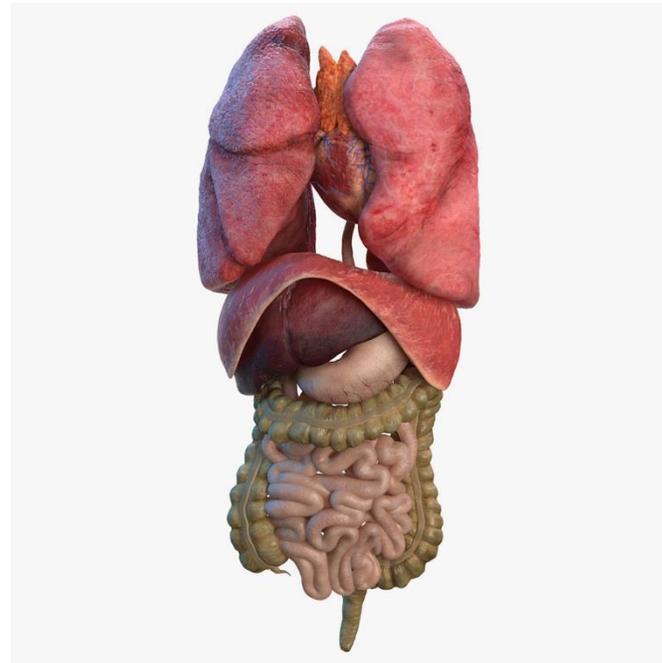
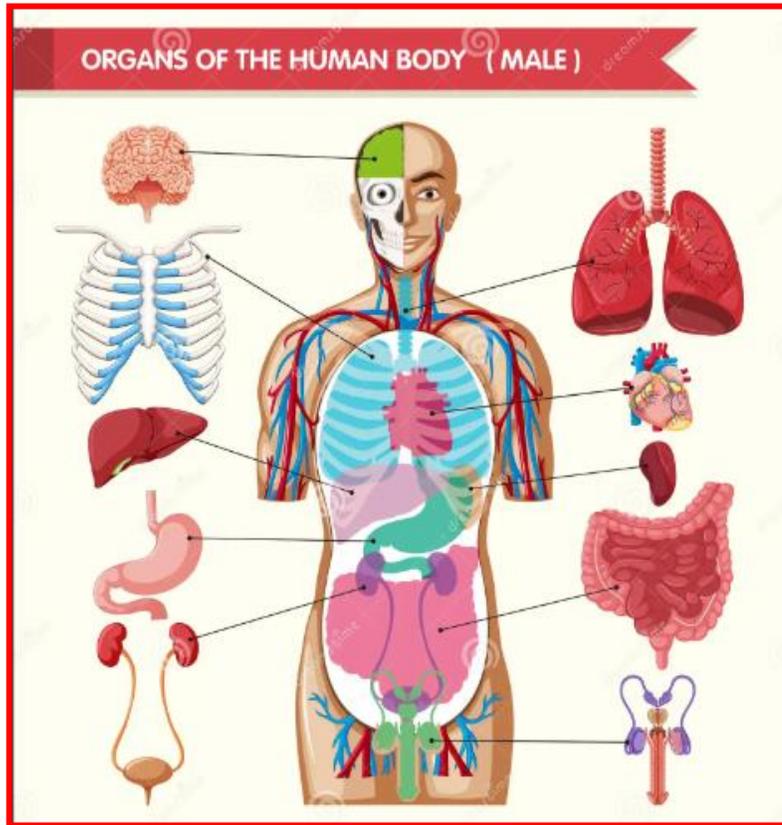
Experienced Realism average score grading SUS chart (IPQ)



► IPQ SUS charts

Limitations and future work

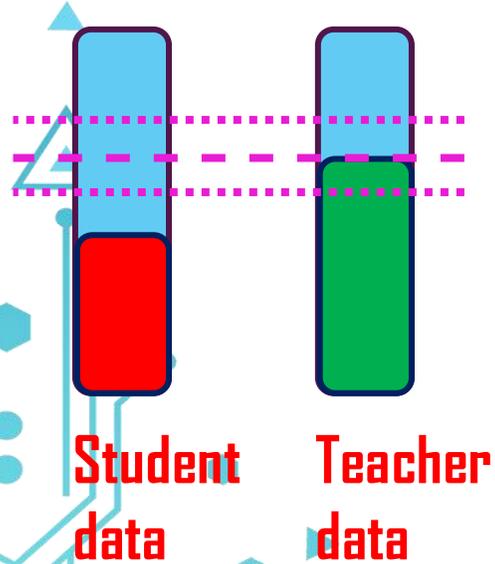
Problems and improvements



► Virtual organs

Limitations and future work

Problems and improvements



▶ Evaluation tutorial



- ▶ New glove with :
 - sensors around fingers;
 - two hands;
 - use temperature and texture ;



wearit

Main Conclusion

