eXtended Reality for Education and Training

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XXXIV Cycle – Doctoral Dissertation – Computer and Control Engineering

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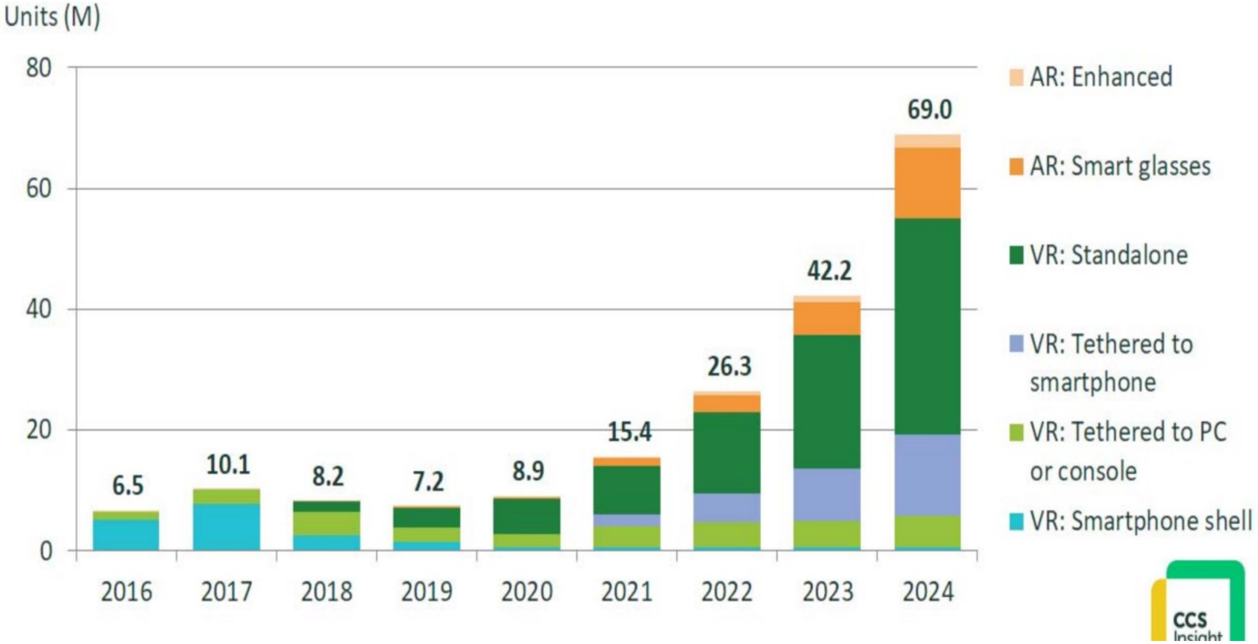
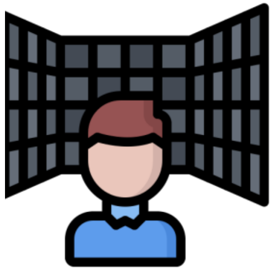
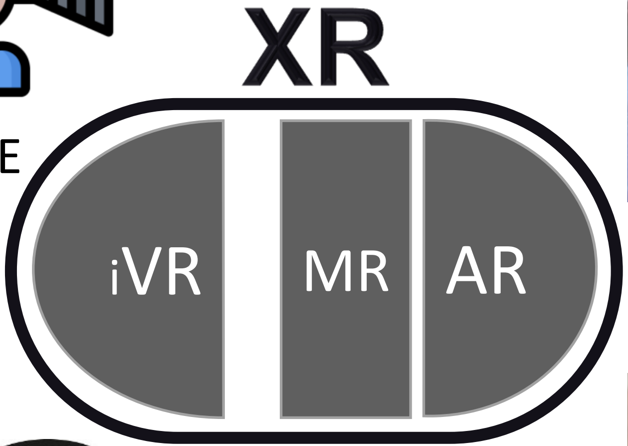
eXtended Reality Technologies and Media

VR and AR Devices Shipments Forecast, Worldwide [1]



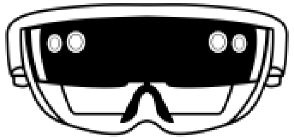


CAVE



Spatial MR/AR (projection-based)

Headworn



Headworn

Hand-held

Similar enabling technologies

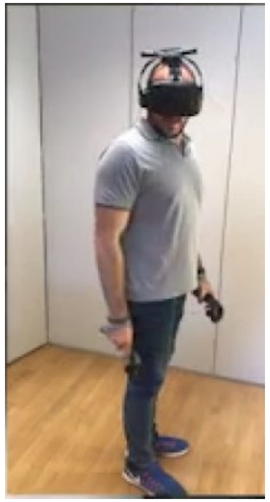
different “Language”, HMI and UX

[1] M. Koytcheva. “Pandemic makes Extended Reality a hot ticket.” CCS Insight.

XR for Simulation-based Training

Traditional
- Dangerous
- Expensive
- Variable

Simulation-based
- Safe
- Cost-effectives
- Repeatable



[2] Mossel, Annette, et al. *"VROnSite: Towards immersive training of first responder squad leaders in untethered virtual reality." IEEE Virtual Reality (VR)*, 2017
[3] Rantanen, Esa M., and Donald A. Talleur. *"Incremental transfer and cost effectiveness of groundbased flight trainers in university aviation programs."* Human Factors and Ergonomic

Open Problems | Research Gap

- Scalability
  - Human or physical resource-dependent
  - Automatic and objective assessment/evaluation
- Effectiveness
  - Controversial & task-dependent
- Limited evidence against “real-world” scenarios
  - Yet not able to fully replace traditional learning systems (when desirable)
- Sticking to traditional pedagogical models
- Focus on the trainees → overlooking training provisioners perspective
- Fidelity (Interaction, Haptics, Multiple users, …)
- …

Goal & Agenda

Pedagogical Agents

Pedagogical Models

Ecology

Scalability

Self-Learning

XRTS
(eXtended Reality Training Systems)

Explore and Expand the boundaries of XR-based tools usage in the Education and Training contexts

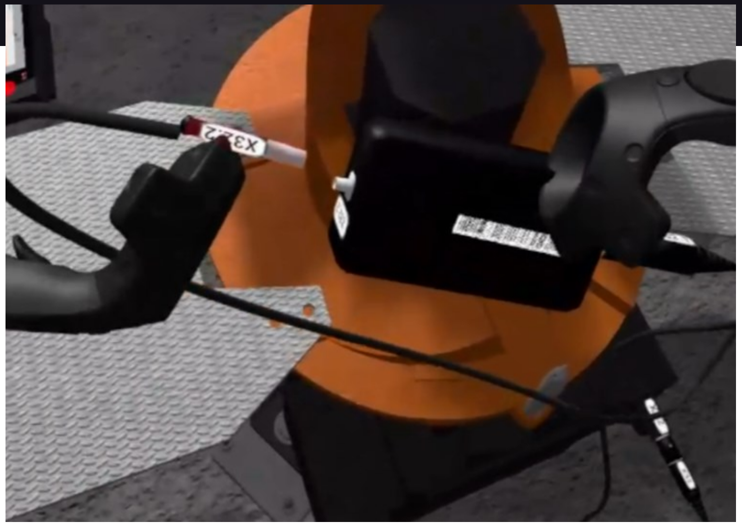
Training Provisioners' Perspective

Mockup

Scalability

Self-Learning

XRTSs for Machine Tasks (MTs)



Motivation & Research Gap:

- Automatic (no human trainer)
  - Replace traditional training
- Use cases in worforce development and Industry 4.0
  - MTs are challenging from a didactic standpoint
  - Companies’ training systems are articulated
- MR Training Systems (MRTSs) effective but not scalable
- VR Training Systems (VRTSs) lack of validation against “real-world” learning systems (for MTs)

VRTSs for Machine Tasks (MTs)

Study Goal

To frame the status of state-of-the-art Automatic VRTSs for the Self-Tuition of MTs

KUKA

Research questions addressed:

Q1: Automatic VRTS effectiveness comparable with traditional training?

Q.2: Is training experience with a self-learning VRTS less satisfactory than a human instructor-based one?

Pratticò, F. G., and Lamberti F. *"Towards the adoption of virtual reality training systems for the self-tuition of industrial robot operators: A case study at KUKA."* Computers in Industry (2021)

VRTSs – Case Study in Industrial Robotics

Scalability | Self-Learning

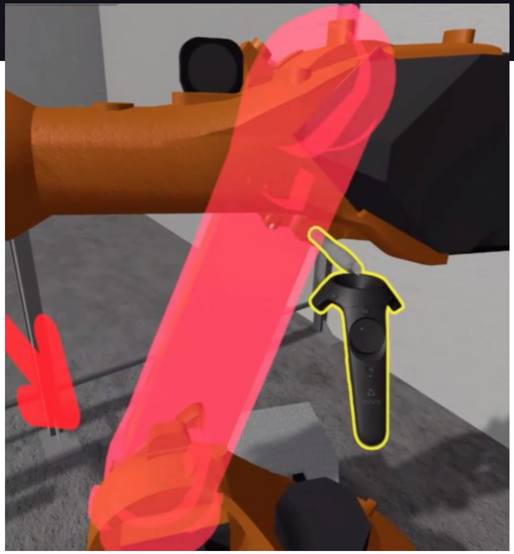
Use Case – IR Mastering Procedure (MT)

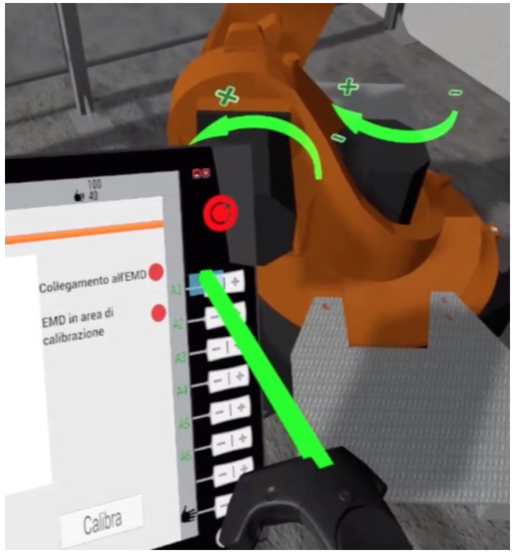
- Procedural knowledge
- Error recovery sub-procedures (analytical thinking)
- Spatial awareness/Safety evaluation
- Equipment management
- System status evaluation

Scaffolding / Guidance System

- Step-by-Step instructions
    - MR-like hints & indications
    - Voice-over

Consumer grade HMD and controllers





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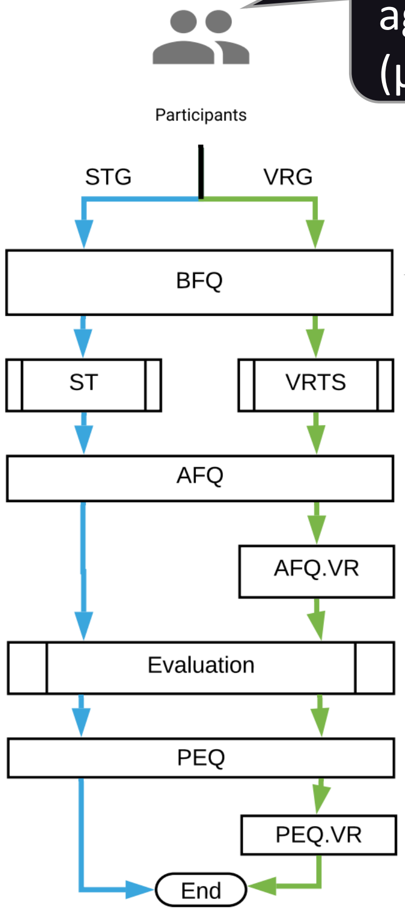
VRTSs – Case Study in Industrial Robotics

Scalability | Self-Learning

18 volunteers [n=9] (16M, 2F)
aged [25 – 35] y.o.
(μ = 25.3, σ = 2.6)



- Poorly/Not Familiar w/ IR
- 44% Familiar w/ VR

Scored by an Instructor
Real IR

1. Classroom Learning
2. Demostrative Learning (1-N)
3. Cooperative Learning (teams)

KUKA

Potì, F. G., and Lamberti F. *"Towards the adoption of virtual reality training systems for the self-tuition of industrial robot operators: A case study at KUKA."* Computers in Industry (2021)

VRTSs – Case Study in Industrial Robotics

Scalability| Self-Learning

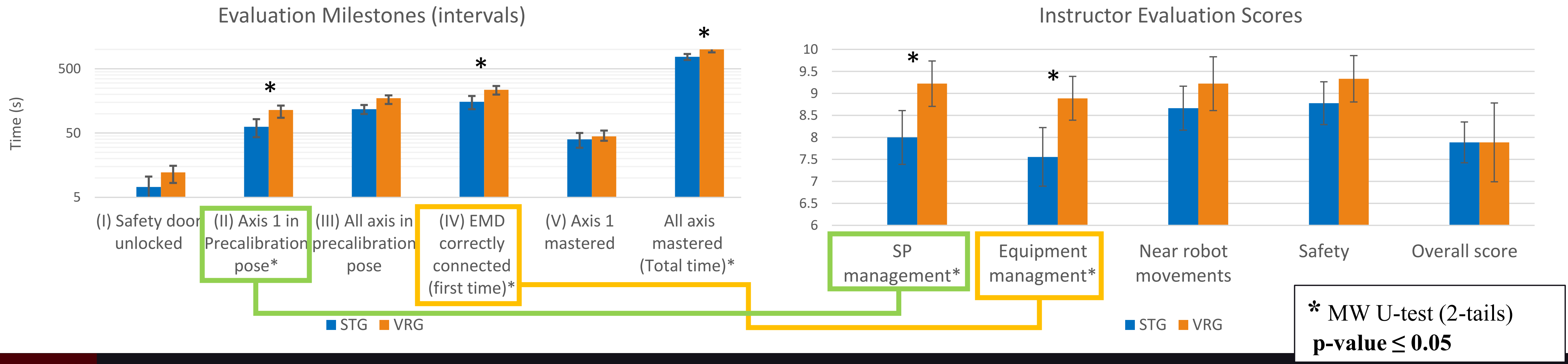
Pros/Ties

- **<u>Comparable Effectiveness (Overall score) [Q1]</u>**
- <u>Comparable Perceived Training Effectiveness and Overall Satisfaction [Q2]</u>
- Comparable Errors (major/minor) [Q1]
- Spatial Awareness [Q1]
- **<u>Remarkably shorter Training time (3x) [Q1/2]</u>**

Cons

Due to Scaffolding on **Parallax Dependent Tasks**

- Higher Mental workload (still acceptable) [Q2]
- Higher Frustration and Annoiance [Q2]
- Less effective self-efficacy boost [Q2]
- **Way too careful in equipment management**



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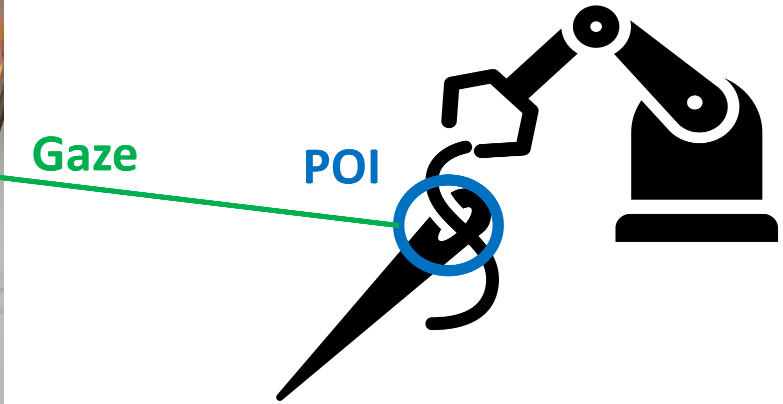
VRTSs and Parallax-Dependent Tasks (PDTs)

Scalability| Self-Learning

*“**PDTs** are a subset of machine tasks in which the operator is required not only to **look at** a specific point-of-interest (POI) but also to do that **from** a given observation point (POV)”*



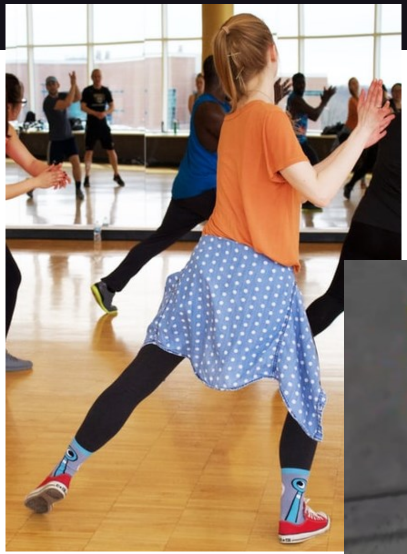
Challenges

- Enforce ***non-obvious*** head-pose matching
- Head-pose **is** a skill to transfer
- **Lazy** users (VR *Sandbox*)
- **Pleasant** training experience

Pratticò, F. G., De Lorenzis, F., & Lamberti, F. *“Look at it this way: A comparison of metaphors for directing the user's gaze in extended reality training systems”* - 7th International Conference of the Immersive Learning Research Network (*2021*)

VRTSs and Parallax-Dependent Tasks (PDTs)

Scalability| Self-Learning



Motivation & Research Gap:

- Lack of PDT-specific techniques
  - Focus on full-body pose matching
  - Focus on target location in the VE (no head-pose)
  - Focus on POIs only
- Lack of evaluation about training and learning aspects

Study Goal

Proposing 3 ***metaphors*** *to be used in XRTS to teach PDTs and evaluate them from a learning perspective*

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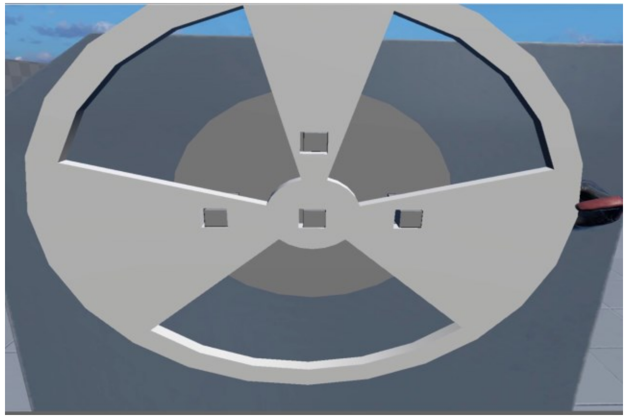
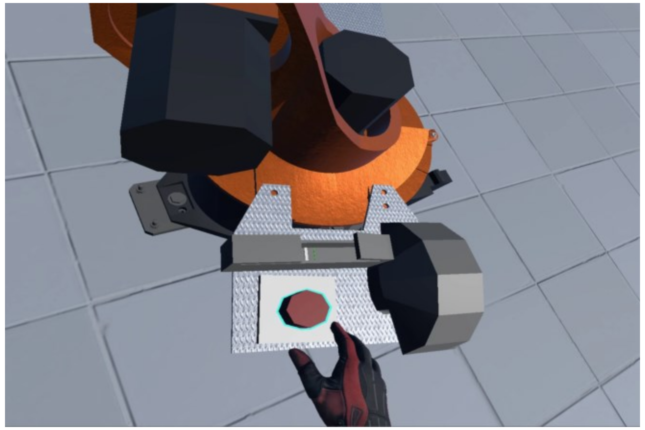
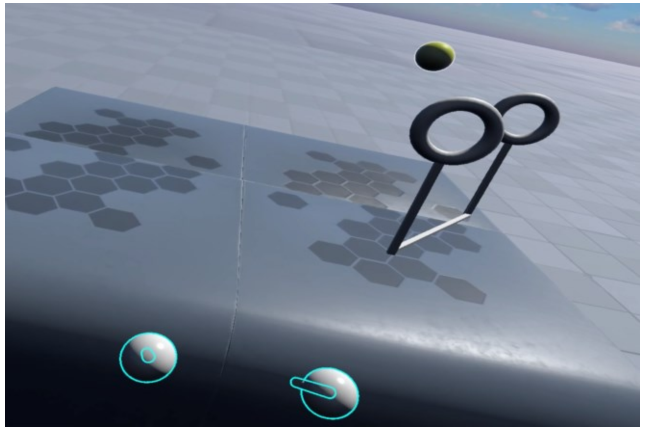
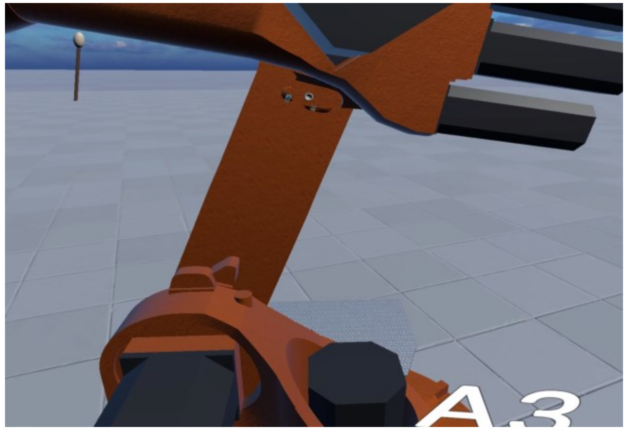
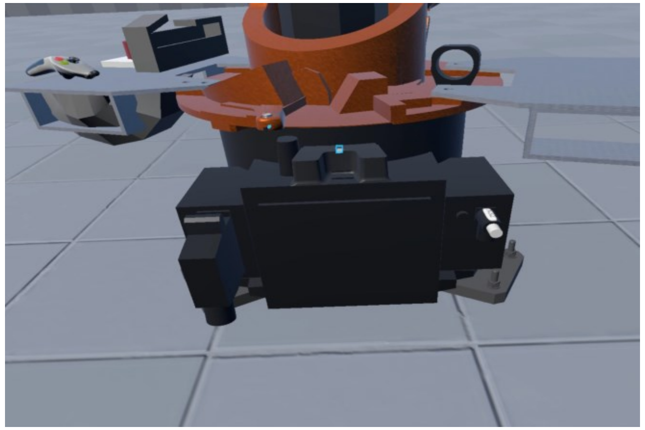
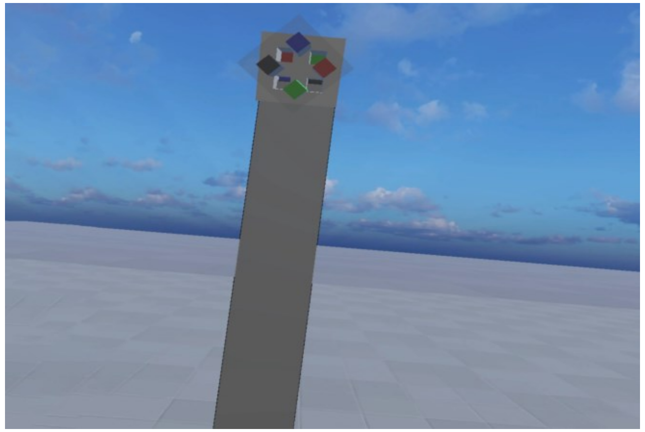
VRTSs and Parallax-Dependent Tasks (PDTs)

Scalability| Self-Learning

PDTs TESTBED	Local (L)	Spatial (S)	Body-Coordinated (C)
Direct (D)			
Remote (R)			

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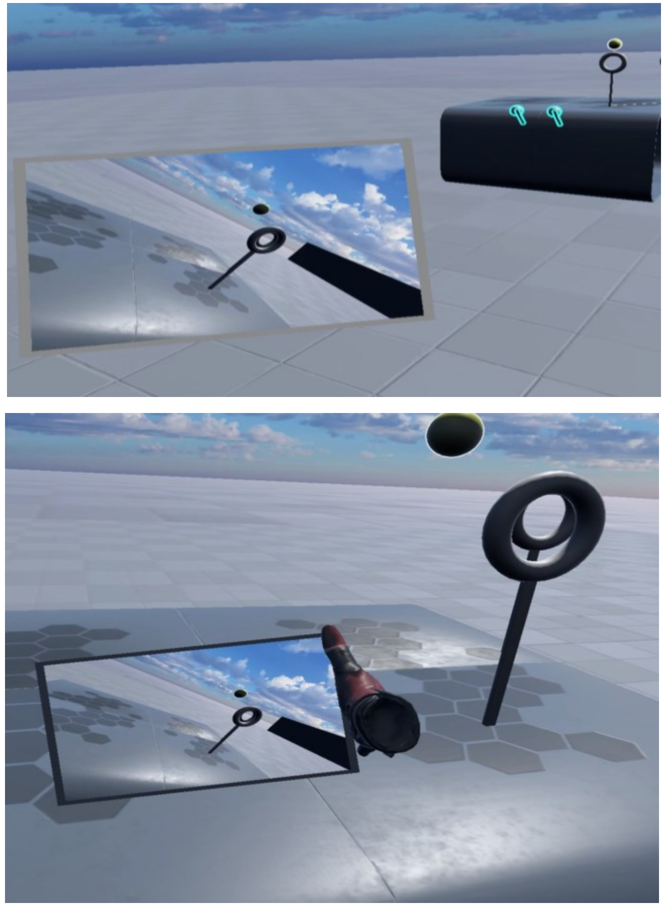
VRTSs and Parallax-Dependent Tasks (PDTs)

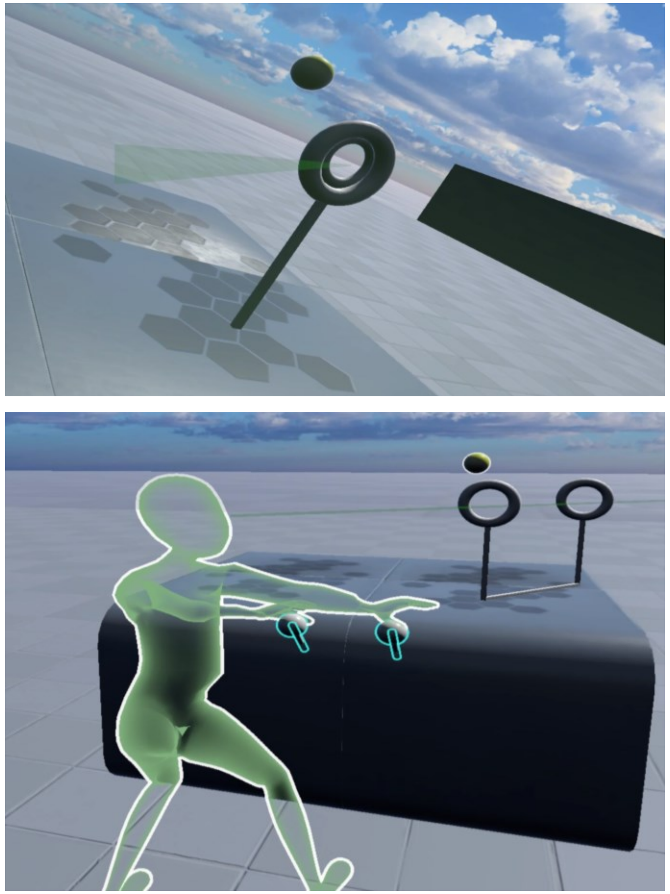
Scalability| Self-Learning

Scaffolding Metaphors for PDTs Teaching

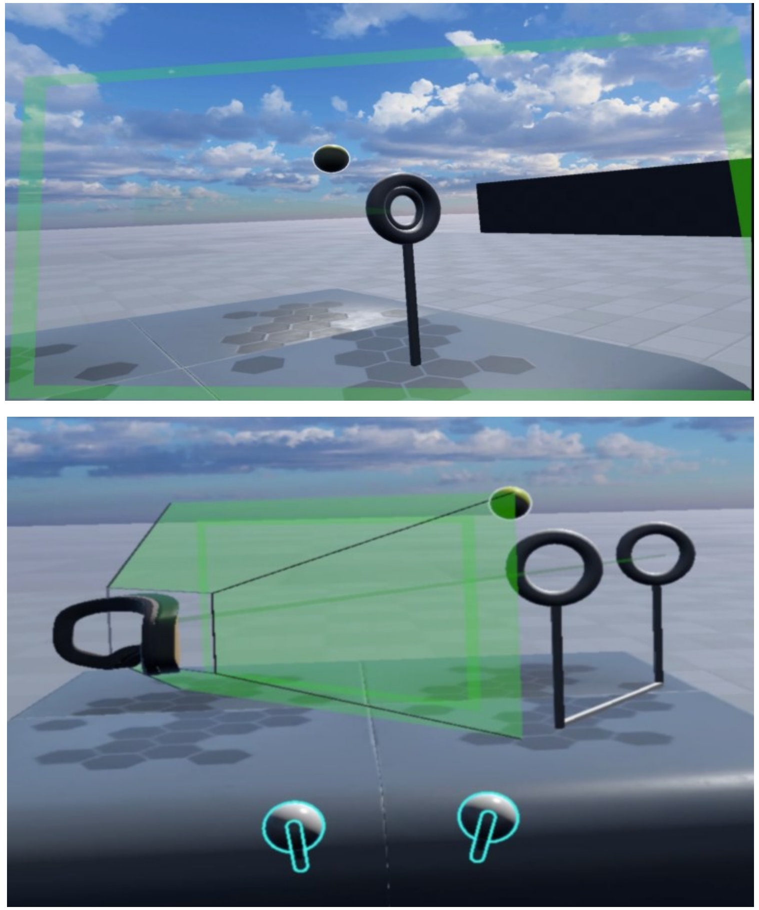
Picture-in-Picture Video (P)



Avatar (A)



Frustum (F)



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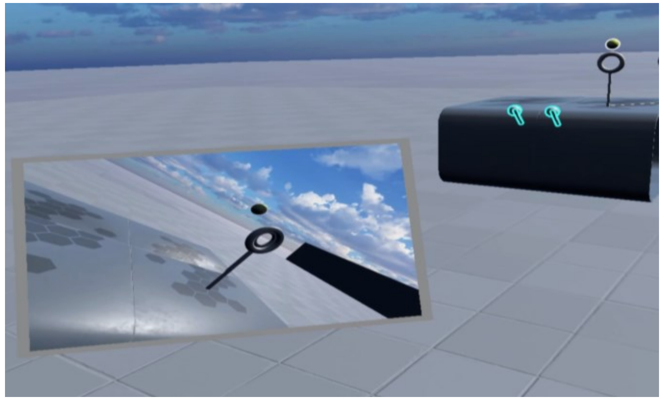
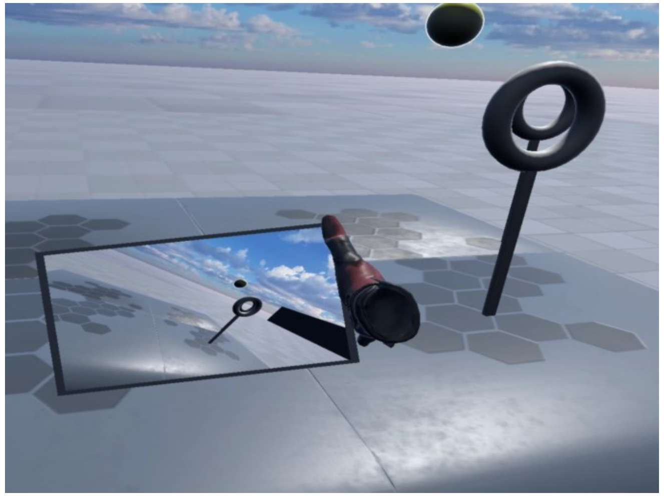
VRTSs and Parallax-Dependent Tasks (PDTs)

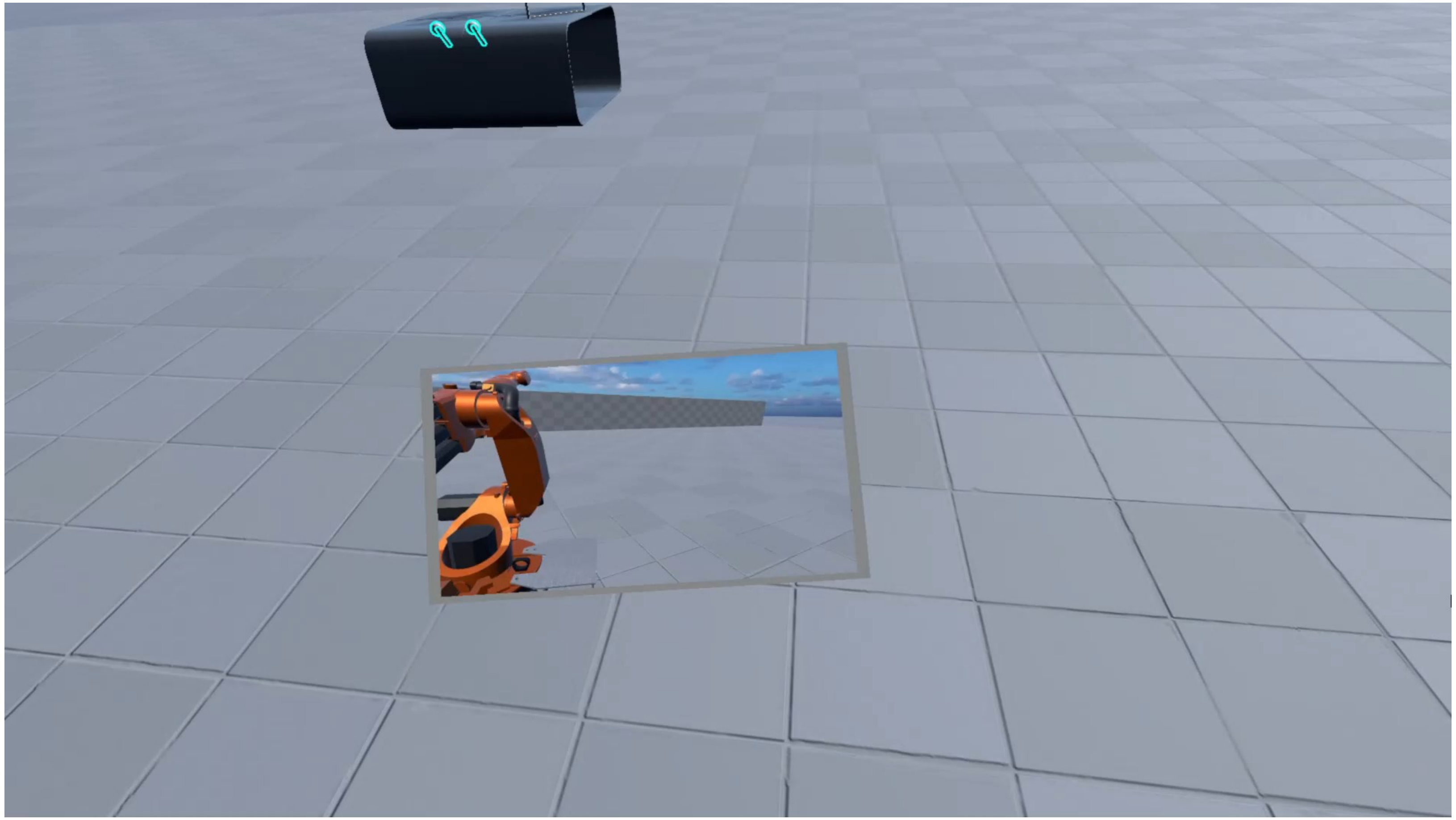
Scalability | Self-Learning

Scaffolding Metaphors for PDTs Teaching

Picture-in-Picture Video (P)







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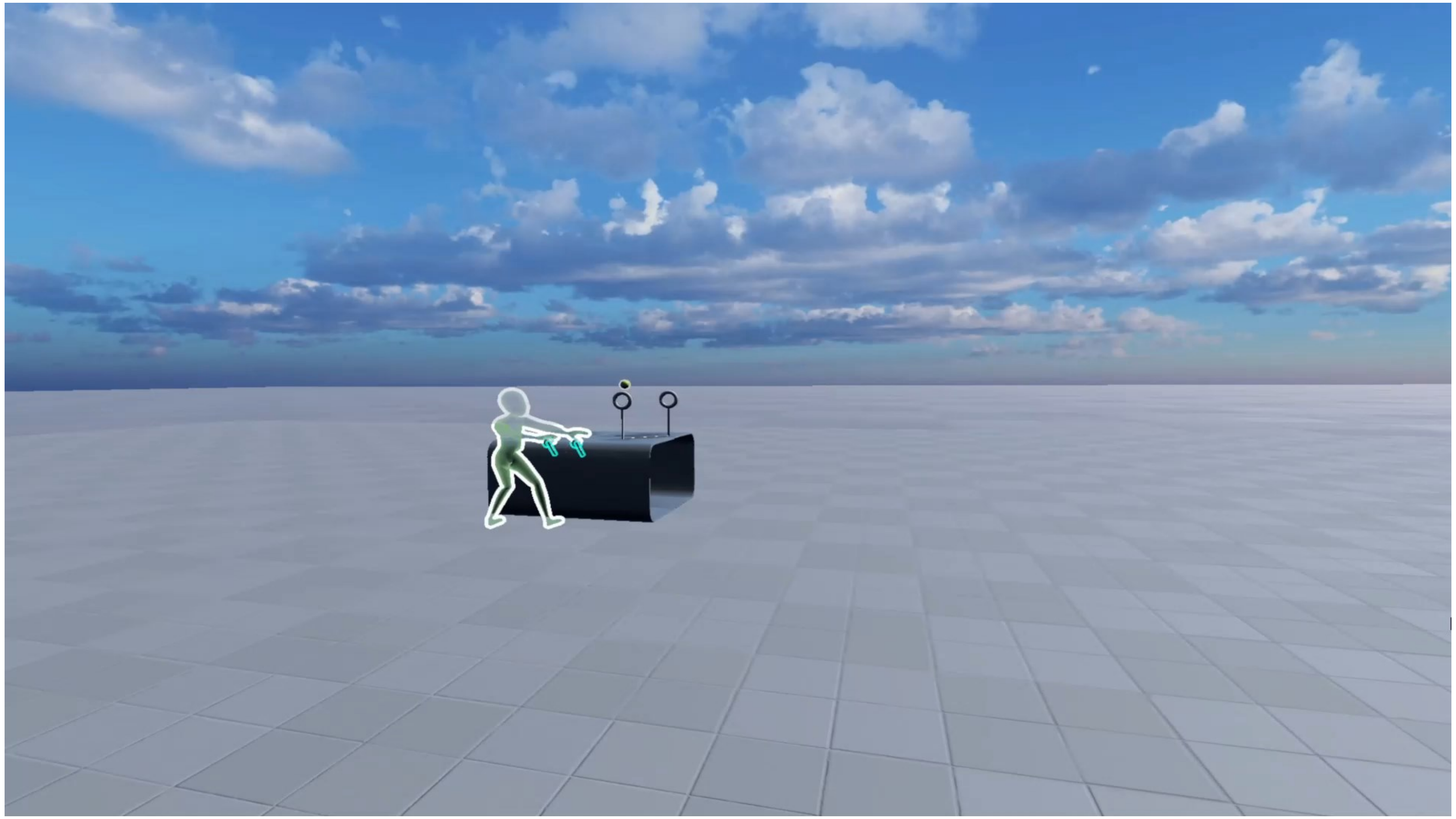
VRTSs and Parallax-Dependent Tasks (PDTs)

Scalability | Self-Learning

Scaffolding Metaphors for PDTs Teaching



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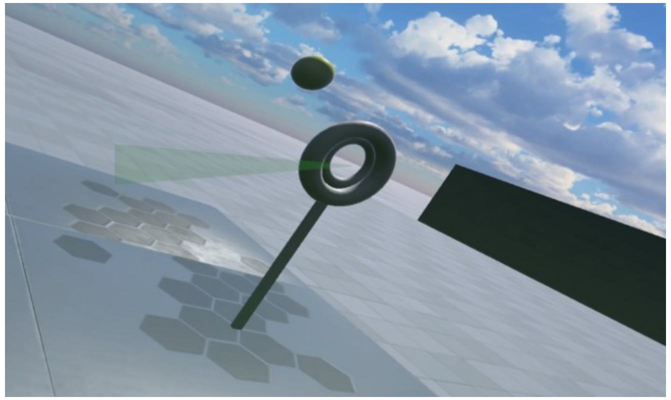

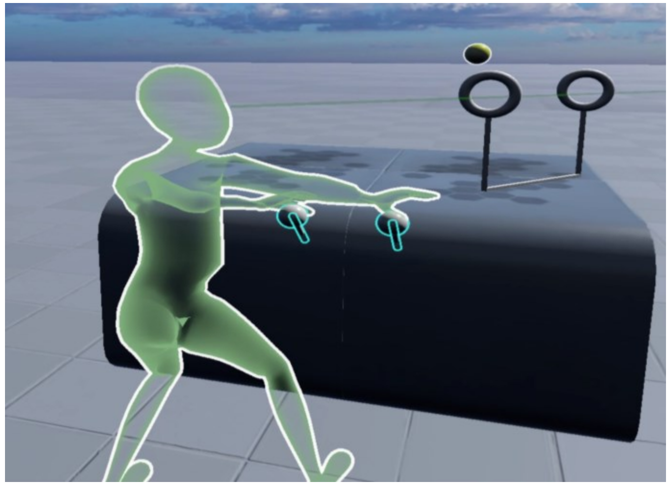

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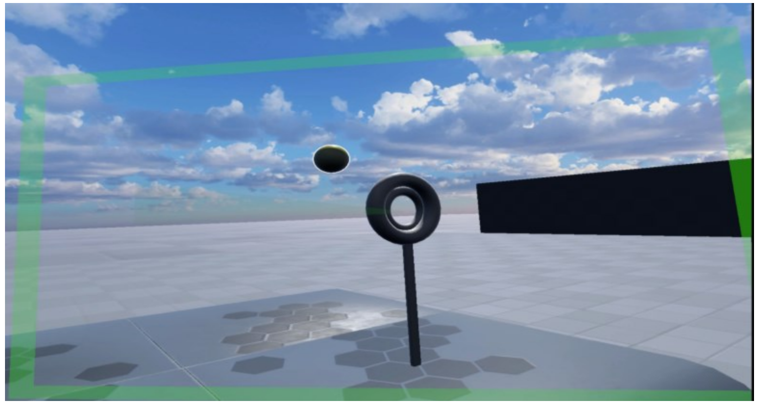
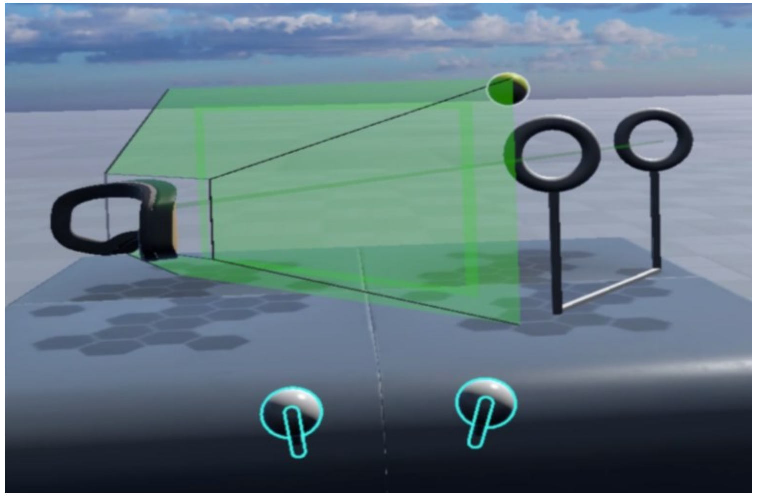
VRTSs and Parallax-Dependent Tasks (PDTs)

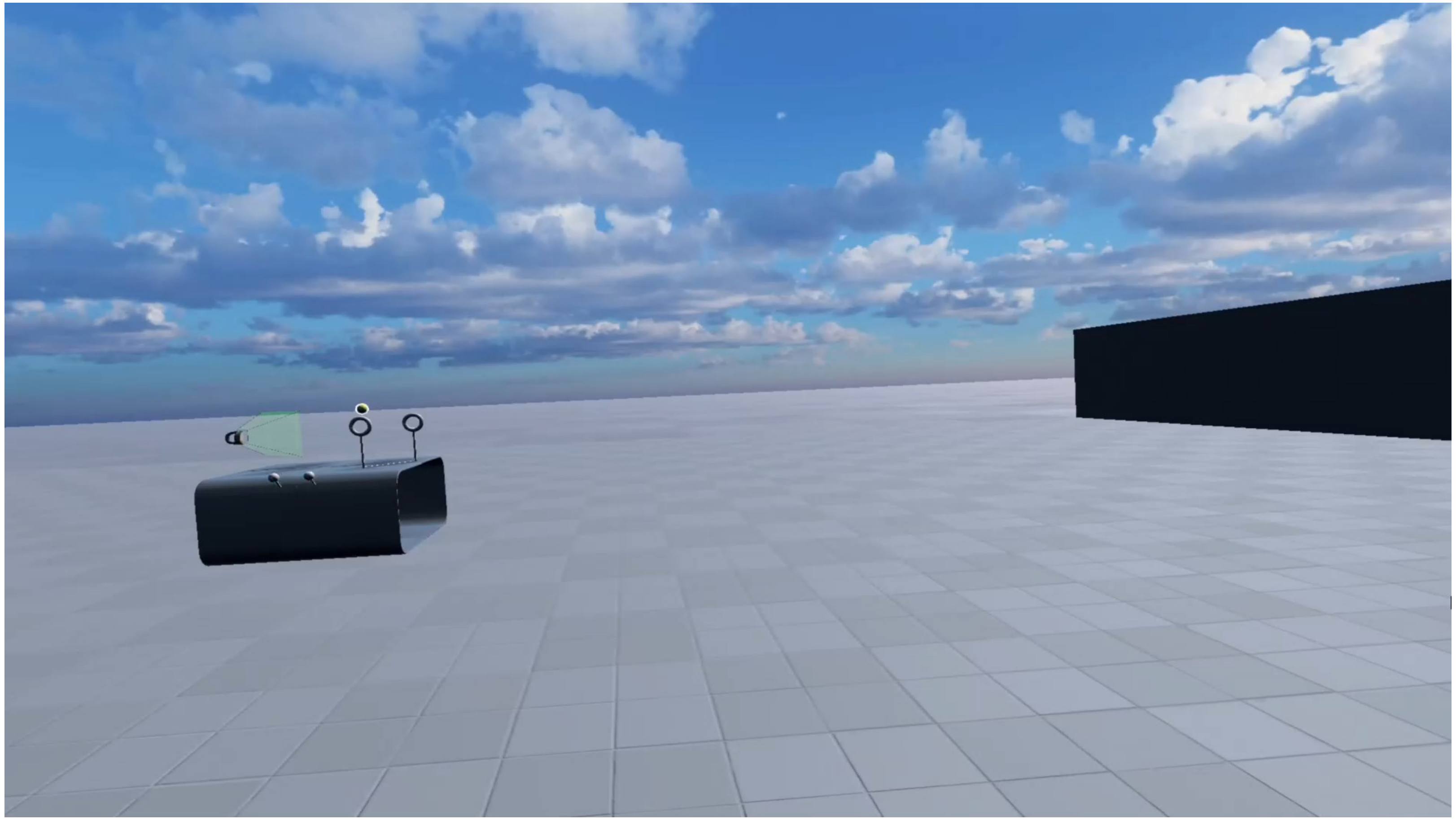
Scalability | Self-Learning

Scaffolding Metaphors for PDTs Teaching

Frustum (F)







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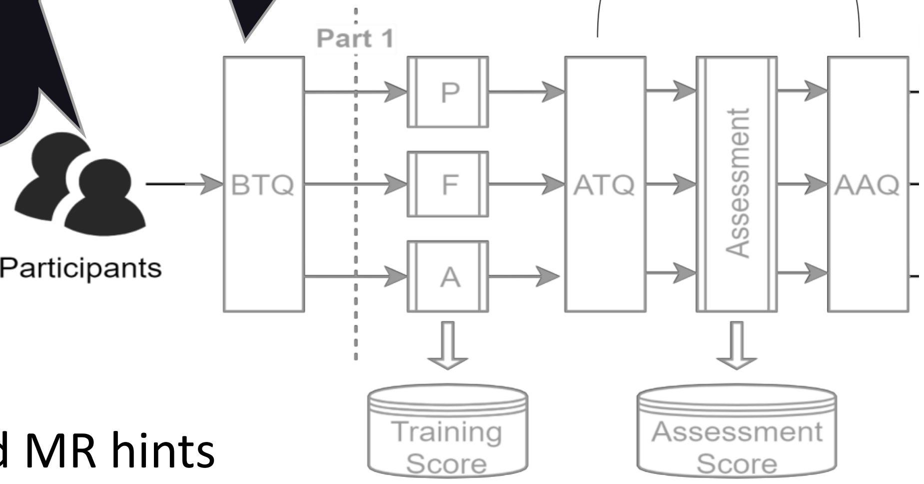
VRTSs and Parallax-Dependent Tasks (PDTs)

Scalability| Self-Learning

15 volunteers (13M, 2F)
aged [24 – 30] y.o.
($\mu = 26.87$, $\sigma = 2.47$)
height [160cm-189cm]
($\mu = 175.2$cm , $\sigma = 6.9$)

47% Familiar w/ VR

SUBJECTIVE
- Perceived training quality
- Presence



SUBJECTIVE
HCI aspects

QUANTITATIVE
- Head pose matching
- Skill transfer

Training Mode
(Trainee Scaffolding)

For each task:
- Activate the Metaphor
- Instruct via Voice-overs and MR hints
- Audio feedback on task completion

Assessment Mode

For each task:
- Audio feedback on task completion

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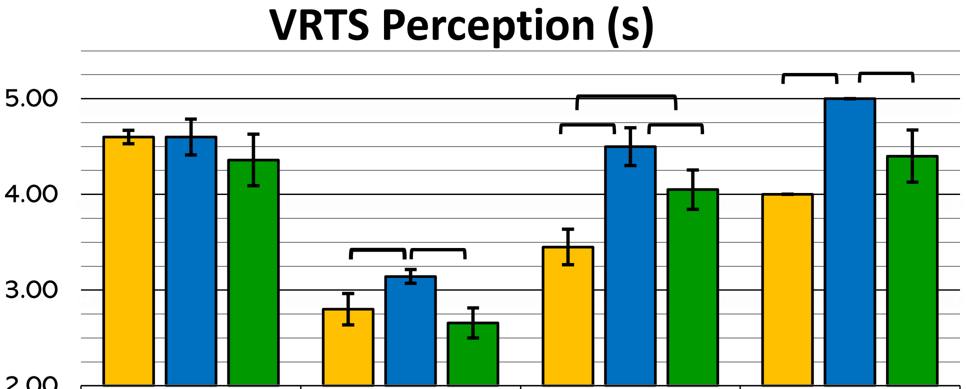
VRTSs and Parallax-Dependent Tasks (PDTs)

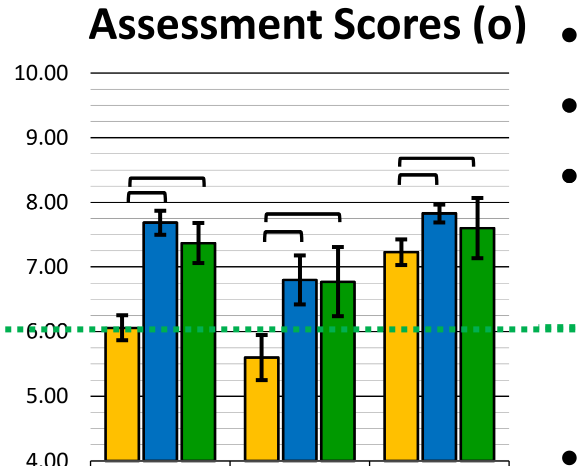
Scalability| Self-Learning

VRTS Perception (s)



	Engaging	Clear	Metaphor Suitability	Overall
P	4.60	2.80	3.45	4.00
F	4.60	3.14	4.50	5.00
A	4.36	2.66	4.05	4.40

Assessment Scores (o)



	POV	POI	MARK
P	6.06	5.60	7.23
F	7.69	6.80	7.83
A	7.37	6.77	7.60

- F and A surmounted P
- **No** clear winner in HCI between F-A
- F performing better than A in
  - VRTS Perception (**suitability**, overall)
  - Objective Scores (**POV <R,S>**)
- A-F-P Comparable information recall
  - **P** trainees sometimes successfully recalled a **WRONG head-pose**

HCI Aspects (s)

	P	F	A	P-F-A	P-F	P-A	F-A
Overall	3	1	2	**<.001**	**.003**	**.012**	.751
Assertive	3	2	1	**<.001**	**.009**	**.002**	.643
Learnability	3	2	1	**.003**	**.044**	**.032**	.930
Affordance	3	1	2	**<.001**	**.003**	**.012**	.751
Mental workload*	3	1	2	**.010**	**.044**	.113	.850
Efficiency	3	1	2	**<.001**	**.003**	**.012**	.751
Ambiguity*	3	1	2	**<.001**	**.009**	**.012**	.982
Ease of use	3	2	1	**<.001**	**.003**	**.012**	.751
Latency*	3	2	1	**<.001**	**.009**	**.005**	.930
Frustration*				.642	.982	.643	.751
Boredom*	3	2	1	**.010**	.113	**.044**	.850
Visibility				.778	.751	.930	.930
SUS score (SD)	74.8(17.4)	86.3(7.5)	86.0(7.3)	**.031**	**.030**	**.021**	.599

[*
Kruskal-Wallis - Friedman & Conover post-hoc

p-value ≤ 0.05

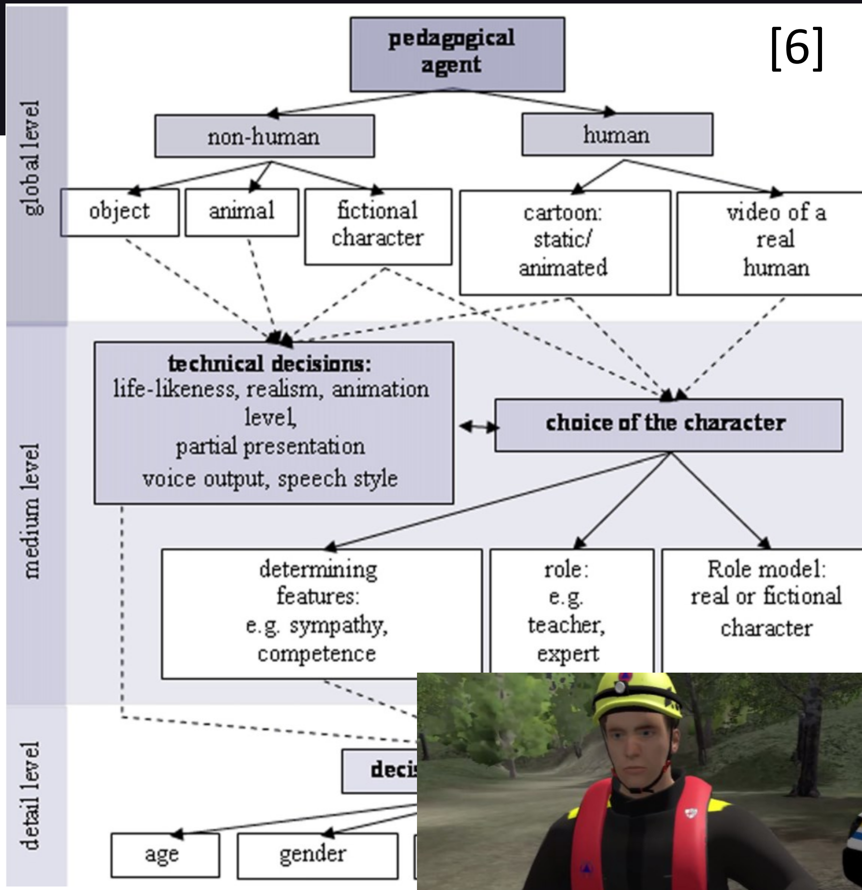
...amberti, F. *“Look at it this way: A comparison of metaphors for directing the user's gaze in* ... - 7th International Conference of the Immersive Learning Research Network (*2021*)

Pedagogical Agents

Pedagogical Models
Ecology

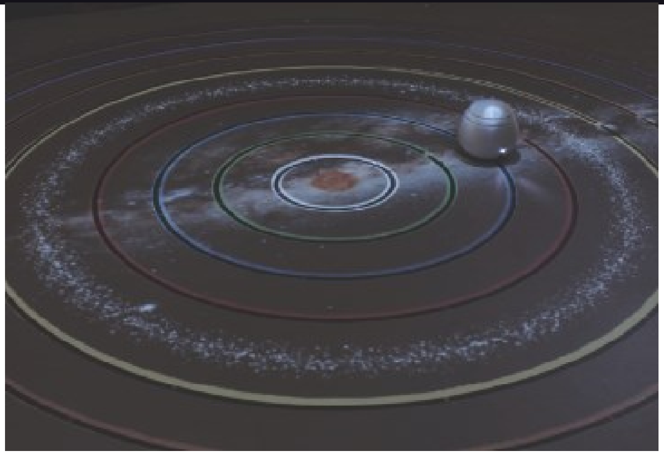
Pedagogical Agents (PAs) in XRTSs

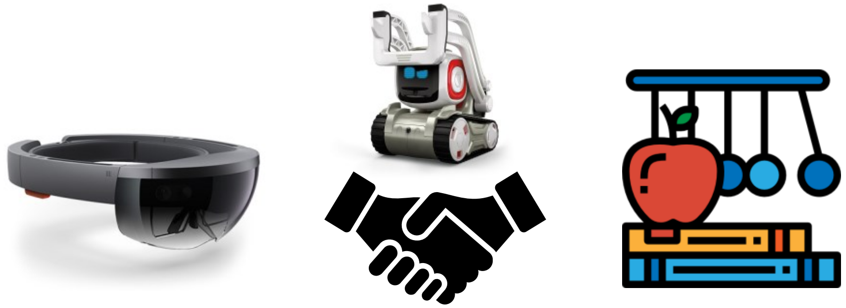
- Social elements of training experience
  - Reintroducing the human counterpart
- PAs → Life-like characters
  - Self-tutor, Motivator, Mentor, Learning companion, …
  - Social agency theory → priming social presence
- PAs in XRTSs:
  - Controversial effectiveness, e.g., Teacher PA boosts conceptual learning gains but dwindle factual information grasping [5]
  - Mostly limited to the **teacher role** or Non-Player Characters (NPC)



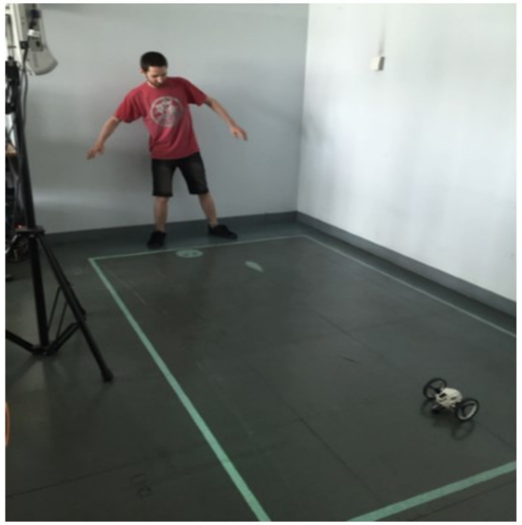
[5] Petersen, G. B., Mottelson, A., & Makransky, G. *"Pedagogical agents in educational VR: An in the wild study"*, CHI 2021
[6] Heidig, S., & Clarebout, G. "Do pedagogical agents make a difference to student motivation and learning?. Educational Research Review, 2011

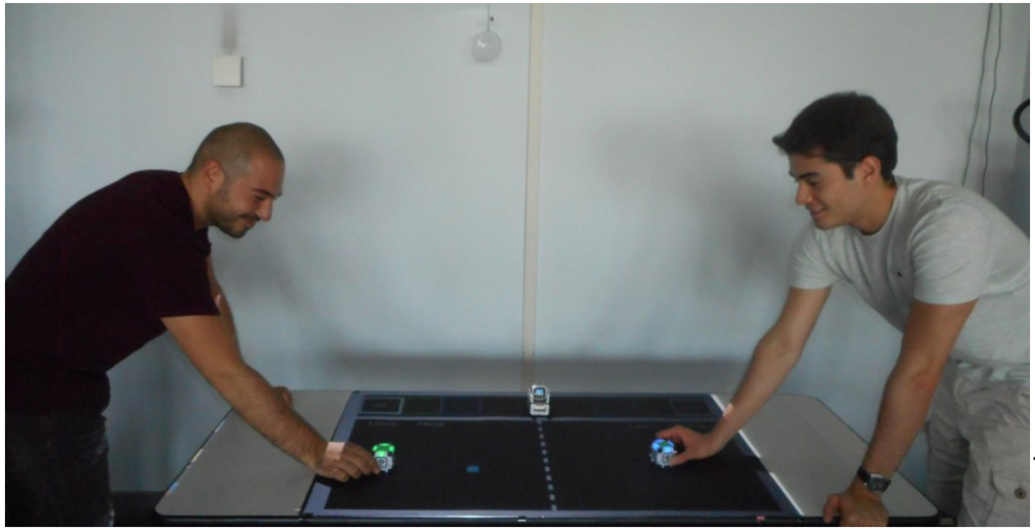
Robots as PAs in MRTSs

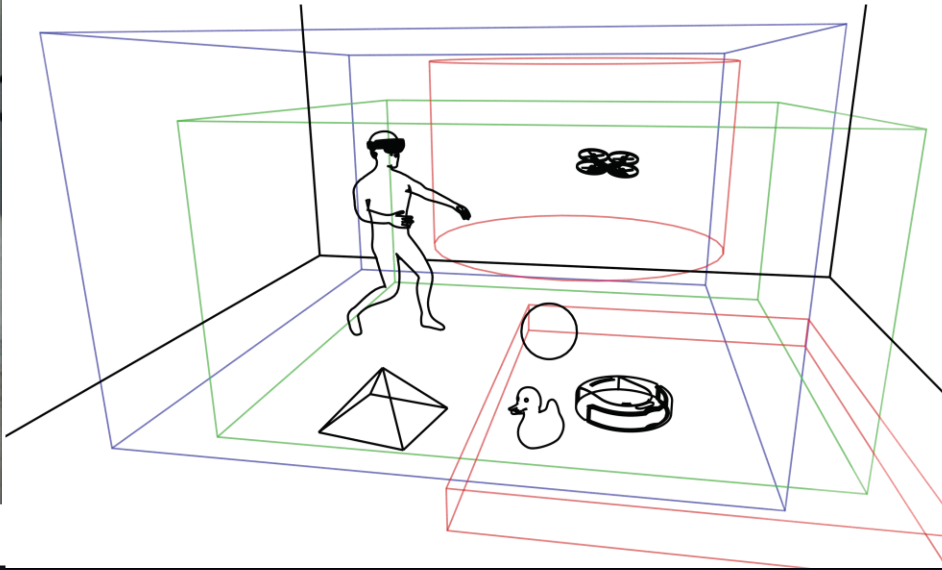




Meet-in-the-Middle
Digital - Physical World



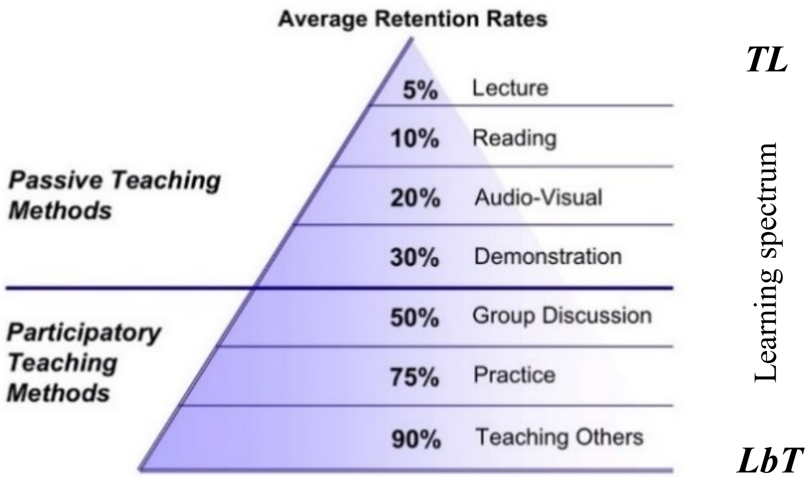




Pedagogical Models in Intelligent Training Systems

Traditional Learning (TL)

Learning-by-Teaching (LBT)



Scaffolding (Guidance System)

[Robotic] Teachable Agents (RTAs)

Learning-by-Teaching with Robotic PA in MRTSs

Pedagogical Agents| Pedagogical models

Motivation & Research Gap:

- LBT *vs* TL (previous work, people & RTA)
  - Slightly better knowledge transfer
  - Way better long-term knowledge retention
  - More time consuming (Inefficient)
- Previous studies on RTAs are promising
- The addition of MR can be harmful for the LBT approach (social agency)?

Study Goal

*To evaluate, by employing a Robotic PA, the **training effectiveness** of a MRTS that implements the LBT paradigm, **comparing it** to a TL version*

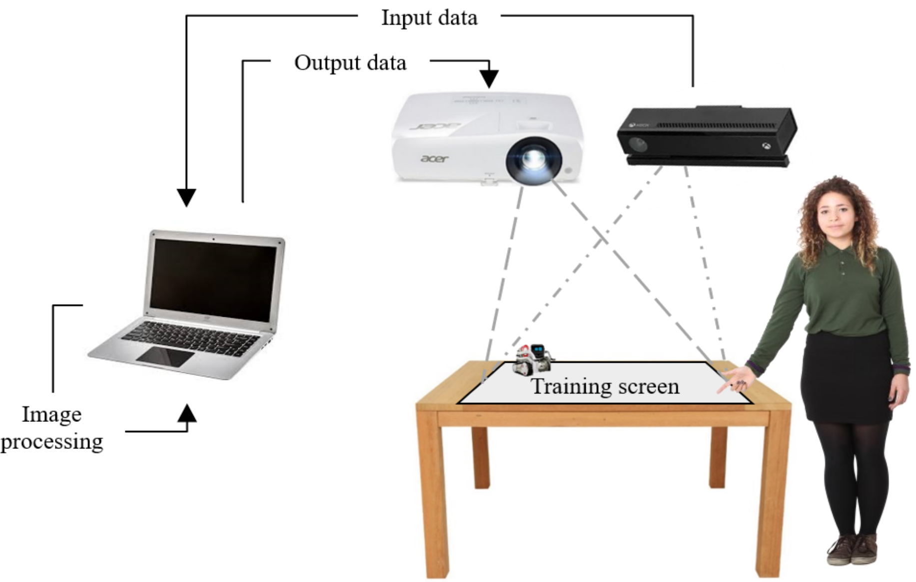
F. G. Pratticò, F. N. Merino, and F. Lamberti, *"Is Learning by Teaching an Effective Approach in Mixed-Reality Robotic Training Systems?", Intetain 2020* (Best Paper Award)

Learning-by-Teaching with Robotic PA in MRTSs

Pedagogical Agents| Pedagogical models

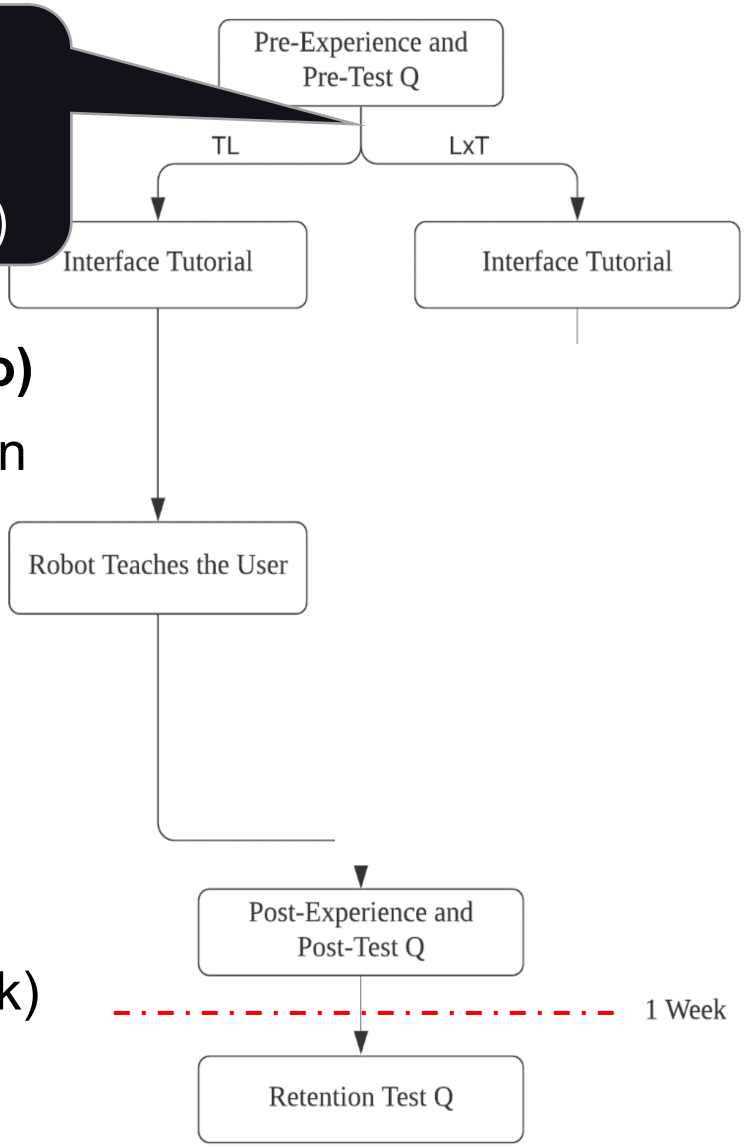
After Screening:
6 volunteers [n=3]
aged [22 – 25] y.o.
(μ = 23.83, σ = 1.07)

MireLab – SpatialMR Setup
Lecture on the *Thévenin's Theorem*



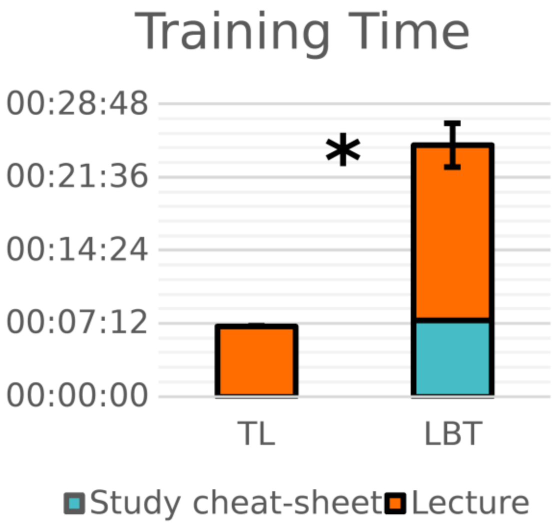
The 4 Milestones of LBT (How-To)

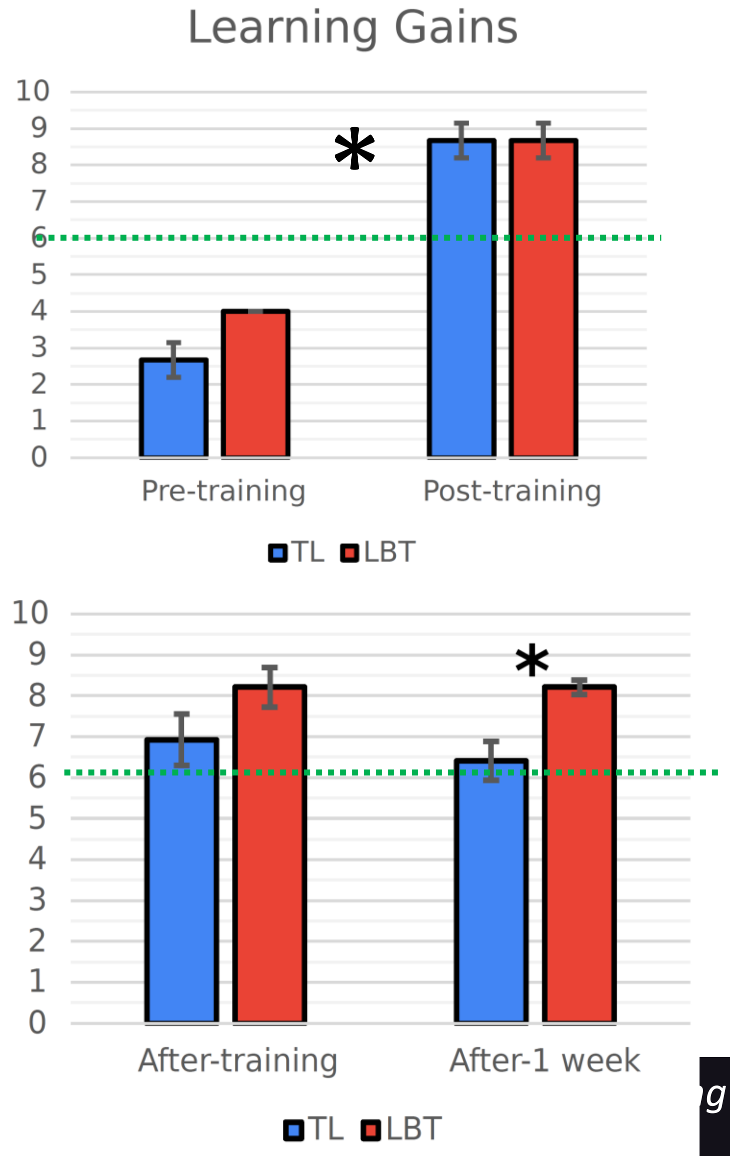
1. Preparing to teach (expectation to teach)
2. Explaining to others/RTA (teaching)
3. Interacting with others/RTA (Q&A, feedback to RTA)
4. Observing the others/RTA spending the acquired knowledge (recursive feedback)



Learning-by-Teaching with Robotic PA in MRTSs

Pedagogical Agents| Pedagogical models





* MW U-test (2-tails)
p-value ≤ 0.05

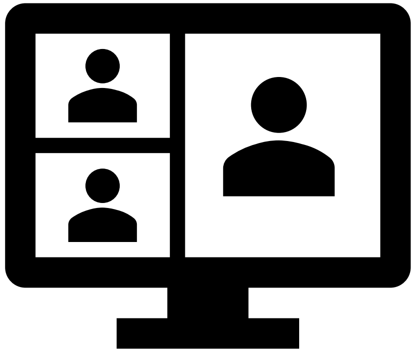
- LBT higher
  - Self-efficacy
  - Confidence about knowledge
- LBT comparable to TL
  - Perceived training quality and satisfaction
- Both TL and LBT effective learning gains
- LBT superior long-term retention
  - In line with non-immersive ITSs
  - Viable approach in MRTSs w/ RTA

F. G. Pratticò, ... *g by Teaching an Effective Approach in Mixed-Reality Robotic Training Systems?", Int...*

Synchronous Remote Learning

Motivations & Research Gap:

- Easier to deploy vs. Asynchronous (MOOC), especially as temporary/transistional/fallback solution
  - More similar to traditional classroom
  - Video conferencing platforms (& Social-VR)



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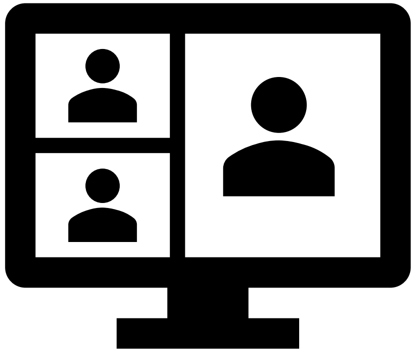
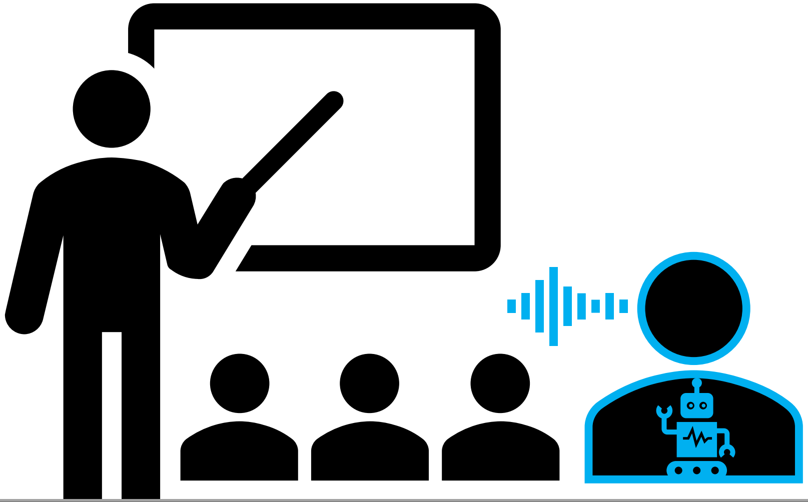


- Social-related issues
  - Emotional/empathic barriers
  - Bashful students
  - Higher social pressure → Less teacher-student interactions

Stimulating Student Participation with a Peer PA

Pedagogical Agents| Ecology



Study Goal

Stimulate *the* ***interaction*** *between the teacher and the students in synchronous VR-based remote learning platforms by means of an ``**undercover**" Conversational Agent (**CA**) acting as a **participating student***

Speculation

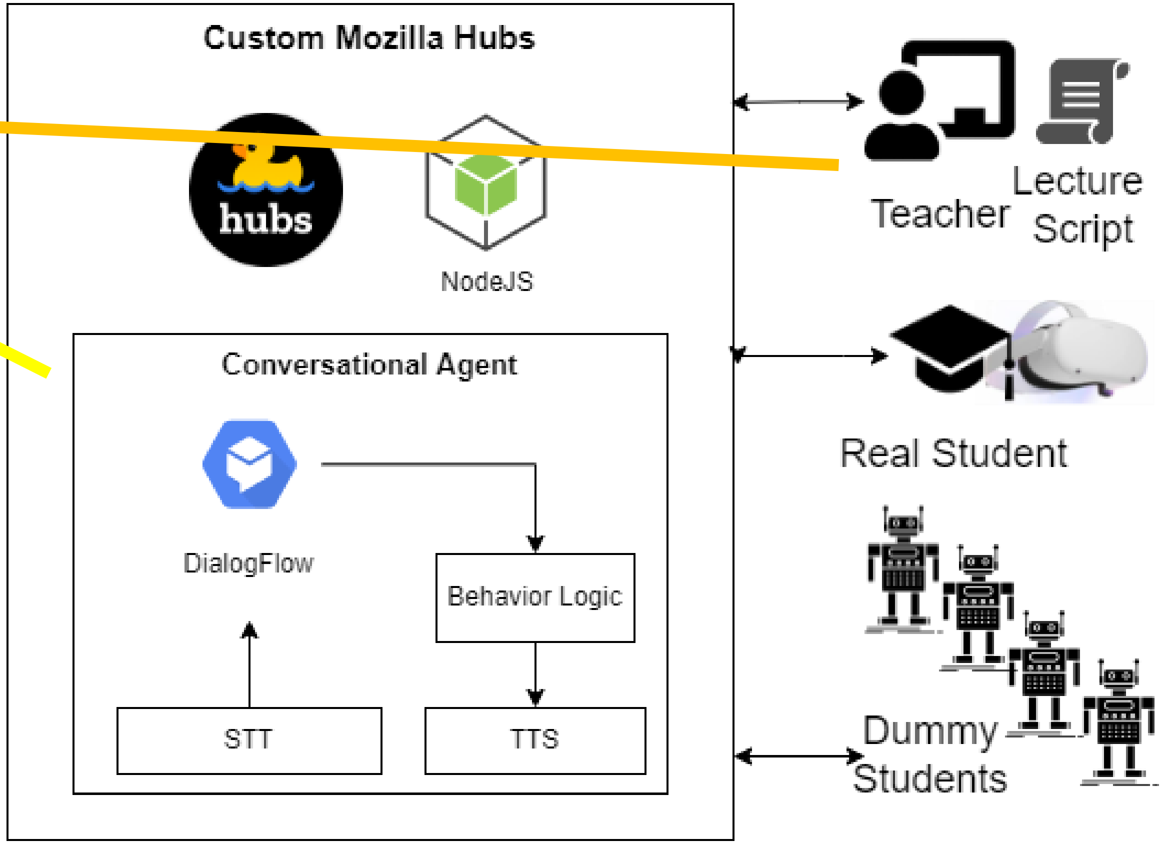
Using a Bot (*Conversational Agent*) - *b*ehaving as an "exemplar" student:

- Interaction Ice-breaker
- Break awkward silence
- Relieving social pressure
- Stimulate interaction of real-students

F. G. Pratticò, J.A. Shabkhoslati, N. Shaghaghi, and F. Lamberti, *"Bot Undercover: On the Use of Conversational Agents to Stimulate Teacher-Students Interaction in Remote Learning", IEEE VR Workshops 2022*

Stimulating Student Participation with a Peer PA

Pedagogical Agents| Ecology



(CA) Student-Teacher Interaction Patterns

1. Student (asking for) Clarification
2. Teacher Question (incl. redirect of *1*)
3. Student Answer (to *2*)
4. Teacher Lecture (incl. answer to 1)

F. G. Pratticò, J.A. Shabkhoslati, N. Shaghaghi, and F. Lamberti, *"Bot Undercover: On the Use of Conversational Agents to Stimulate Teacher-Students Interaction in Remote Learning", IEEE VR Workshops 2022*

Stimulating Student Participation with a Peer PA

Pedagogical Agents| Ecology

Sample:
16 volunteers (n=8)
Aged [16 - 52] y.o. ($\mu = 23.5$, $\sigma = 5.0$)

Between-Subjects Design:

- [CAG] Group with the active CA
- [NCAG] Group without the CA, replaced with an additional Dummy student

Objective Metrics:

- Learning Gain (QUIZ)
- N° Interactions
- [Activity Rate] $AR_{ST/CA} = \frac{n^{\circ}\, utterance\ (ST|CA)}{n^{\circ}\, utterance\ Teacher}$

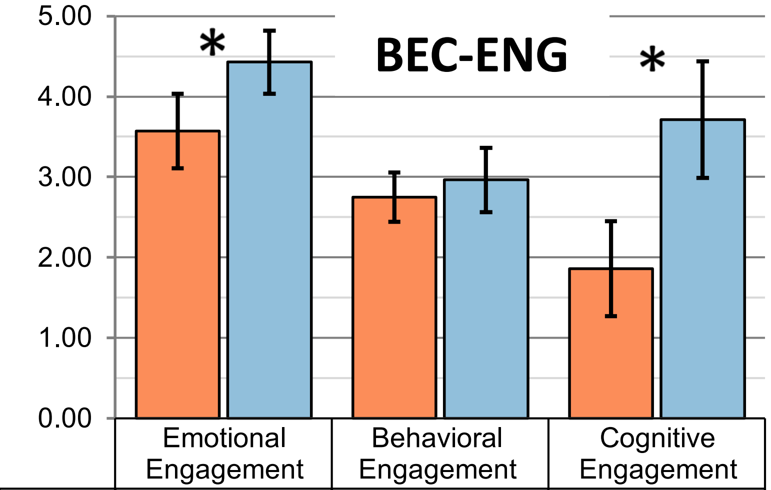
Subjective Metrics:

- Behavioral, Emotional, Cognitive Engagement (BEC-ENG)
- Perceived Features of the CA (Godspeed-Q)
- [Interference of CA on] Social Presence of the Teacher (NMMSQ)
- Social Pressure, CA’s Perceived Value, CA’s impact on Learning Experience, Overall Satisfaction (*AD-HOC*)

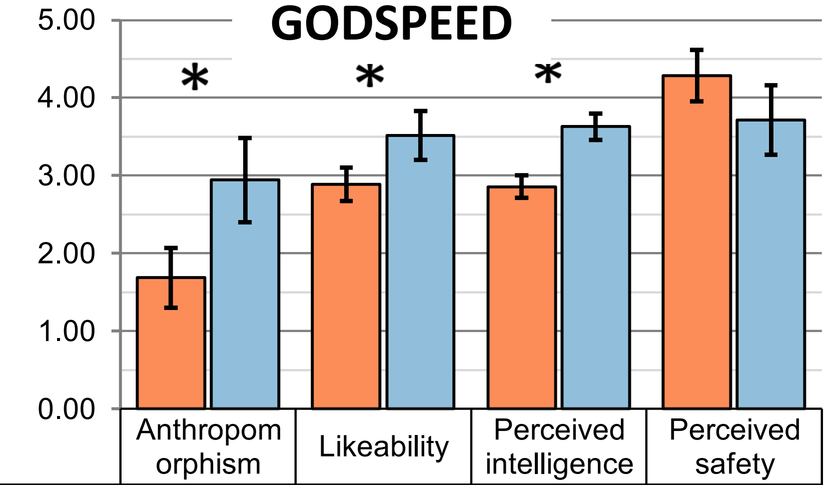
F. G. Pratticò, J.A. Shabkhoslati, N. Shaghaghi, and F. Lamberti, *“Bot Undercover: On the Use of Conversational Agents to Stimulate Teacher-Students Interaction in Remote Learning”, IEEE VR Workshops 2022*

Stimulating Student Participation with a Peer PA

Pedagogical Agents| Ecology



	Emotional Engagement	Behavioral Engagement	Cognitive Engagement
NCAG	3.57	2.75	1.86
CAG	4.43	2.96	3.71



	Anthropom orphism	Likeability	Perceived intelligence	Perceived safety
NCAG	1.69	2.89	2.86	4.29
CAG	2.94	3.51	3.63	3.71

- CAG more enjoyable class experience
- CAG more prone to ask for clarification
- CAG lower social pressure
- CAG agent aided understanding the teacher
- CAG perceived better learning performance vs. NCAG
  - NOT confirmed by objective metrics
- No Sig. difference for the Social Presence (NMMSQ)
  - No influence on reciprocal social presence (teacher-student)
- CA Perceived as:
  - Intelligent, friendly peer
  - Not distracting
  - Perceived as controlled by a human
  - Not in cahoots with the teacher

* MW-U test (2 tails)
***p*-value ≤ 0.05**

Shaghaghi, and F. Lamberti, *"Bot Undercover: On the Use of Conversational Agents to*
tion in Remote Learning", IEEE VR Workshops 2022

Training Provisioners’ Perspective

Mockup

Training Provisioners' (TPs) Perspective

Motivations & Research Gap:

- So far, main focus on learners
- Raising interest in authoring tools to help TPs with XRTSs design
  - E.g., "no-code" solutions, for unskilled TPs
- Design requirements may vary based on the training context

Study Goal

*Explore the use of a VRTS as **mock-up** tool to support Training Provisioners in the design of **experiential** courses, and evaluate it against a commonplace training design approach, Dramaturgy Prototyping.*

Training Provisioners’ Perspective
Mockup

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Use Case: High Capacity Pumping

- Arranging a exercise to be deployed in the real-world
- Integrating “lessons from the past”
- Outdoor
  - Large-scale
  - Cumbersome equipment and noisy/polluting machines
- Multi-operator coordination and teamwork

applied sciences

Pratticò F.G., De Lorenzis F., Calandra D., Cannavò A., and Lamberti F. *“ Exploring simulation-based Virtual Reality as a mock-up tool to support the design of first responders training ”* Applied Sciences (2021)

Training Provisioners’ Perspective
Mockup

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VR Mockup Tool (VRMT) implementation

Use Case: High Capacity Pumping

- Arranging a exercise to be deployed in the real-world
- Integrating “lessons from the past”
- Outdoor
  - Large-scale
  - Cumbersome equipment and noisy/polluting machines
- Multi-operator coordination and teamwork

applied sciences

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Training Provisioners' Perspective
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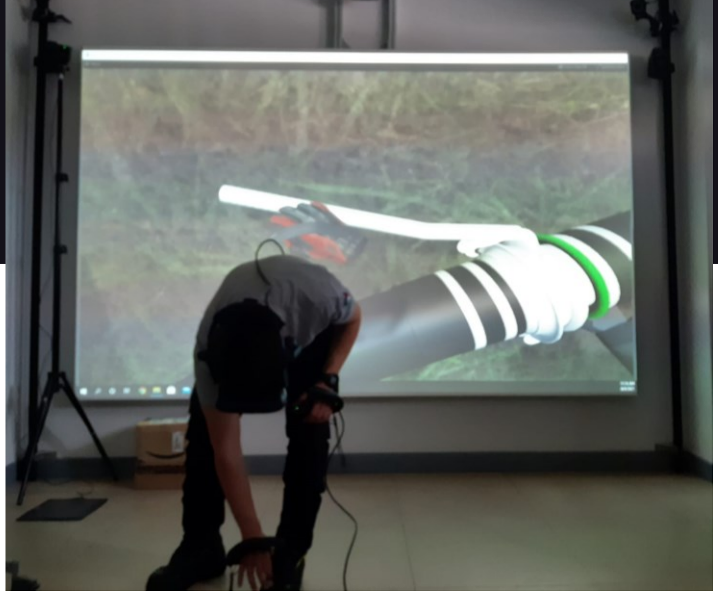


Sample:

2 Experienced Trainers

Within-Subjects Design:

- [DP] Executing the DP
- [VRMT] Observing 3 trainees with different levels of proficiency

The 5 Steps of Dramaturgy Prototyping (DP)

1. Location and material setup (blackboards, stationery, cardboard props, etc.)
2. Deliberate Objectives, Brainstorming, and Outline (notes, sketches, and reference material can be used)
3. Gaining consensus on a peer-drafted storyboard
4. Acting the designed training procedure
5. Iterate *2-4* till satisfied by the resulting design

Pratticò F.G., De Lorenzis F., Calandra D., Cannavò A., and Lamberti F. *" Exploring simulation-based Virtual Reality as a mock-up tool to support the design of first responders training "* Applied Sciences (2021)

Training Provisioners' Perspective
Mockup

Key Findings

- TPs found the VRMT as valuable in backing training design
  - «as-is» deployability
- TPs able to analyze and dissect factors contributing to operators' mistakes
- VRMT better than DP
  - Validating training structure and organization
  - Identifying setbacks and flaws
- DP better than VRMT
  - Faster iteration on the prototype

Conclusions

Conclusions

Scalability
Self-Learning

- XRTSs’ learning perfomance on a par w/ «real-world» TL for *mixed-task* training
- Guidance Systems can be successfully adapted to peculiar tasks (PDTs)

- GS lacks flexibility and social-related aspects

Pedagogical Agents
Pedagogical Models
Ecology

- Potential for roles different than the pedagogue
- Effectively enables different pedagogical models (LBT)
- Ameliorate social aspects and virtuous students’ behavior
    - Attention
    - Enjoyability
    - Participation

Training Provisioners’ Perspective
Mockup

- Effectively aid training design

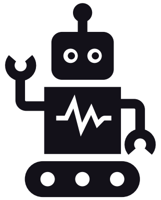
- Need to provide authoring tools to iterate faster
- Allow more freedom to TPs when revising

Future Work

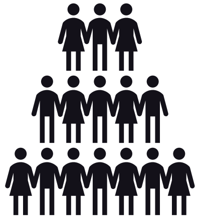
Limitations

Authoring tools
for XRTSs

Adaptive
Scaffolding



Pedagogical agents AI
and real-time adaptation



Further validation with
larger/fitter samples

Main Achievements

Ph.D.

Research Output

8 Journal papers (+2 UR)

19 Conference papers

2 Book chapters

Learning Activities

129 hard skills hours

55 soft skills hours

Teaching Activities

Teaching Assistant for *Computer Science* and *Computer Animation* Courses

Participation to Research Projects

3 Funded by Companies

1 Funded by Piedmont Region

Dissemination Activities

7 Physical Events (Turin, Rome)

2 Online (during pandemic)

Awards and Prizes

2 Quality Awards assigned by the Board of our PhD program

2 Best Paper Awards

Contribution to the scientific community

1. Reviewer for Journals (16 papers)
2. Reviewer for Conferences (32 papers)
3. Invited member of the "Virtual Reality, Augmented Reality, and Displays (**VAR**)" Technical Committee of the IEEE Consumer Technology Society (CTSoc)
4. Serving as Technical Program Committee (**TPC**) member of 3 Conferences
5. **Session Chair** in ICCE-Berlin 2019 Conference
6. Serving as Awards Chair (**Organizing Commitee**) for iLRN 2023

Politecnico di Torino

VR@POLITO

Q & A

eXtended Reality for Education and Training

Ph.D. candidate – Filippo Gabriele Pratticò