Development of an Augmented Reality Interface for Intuitive Robot Programming

Jan Gerrit Eberle

30.11.23

Final: Master Informatics: Games Engineering

Supervisor: Sandro Weber(TUM), Christoph Willibald(DLR)

In collaboration with the german aerospace centre (DLR)

Motivation

- Shortage of staff in small and medium-sized enterprises affecting efficiency and productivity.

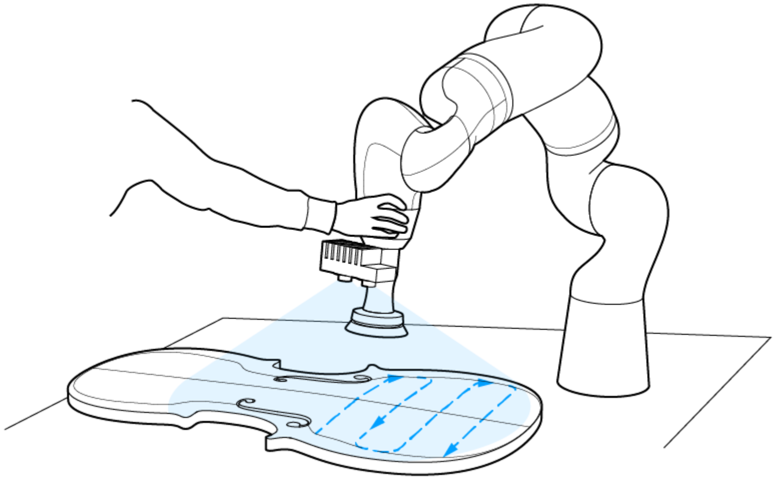
➔ Financial instability and threat to business existence.

Potential Solution: Robotics & Automation

- Free up workers from monotonous and repeating tasks
- Barriers
  - Smaller companies have a small batchsize and changing tasks.
  - Conventional programming of robots requires expertise, limiting accessibility for non-experts.

Potential Solution: Robotics & Automation

- Learning from Demonstration (LfD) allows non-experts to teach robots through intuitive demonstrations.



https://lerosh.de/

→ Quality of demonstrations depend on user **AND** Knowledge gap between users and robots exists.

The Role of Augmented Reality

Feedback as Solution

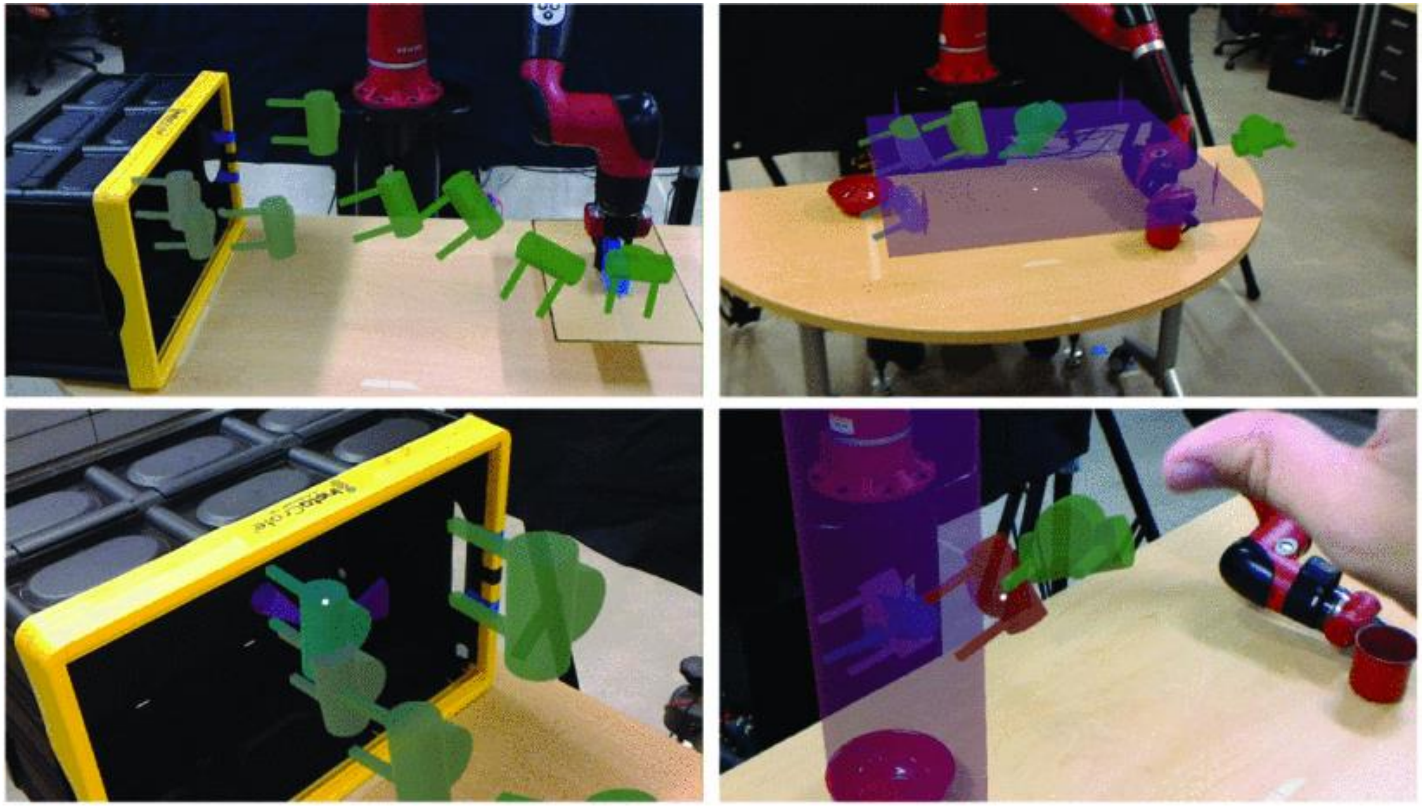
- Investigate AR feedback mechanism as a solution for intuitive robot programming for non-experts.
- Merging real and virtual worlds, providing immersive visual interfaces for the process.
- Visual feedback through AR to enhance user understanding of robot behavior.

Existing Solutions / Related Work

- Liu et al.[1] visualizes the task graph of the robot through the HoloLens for editing.

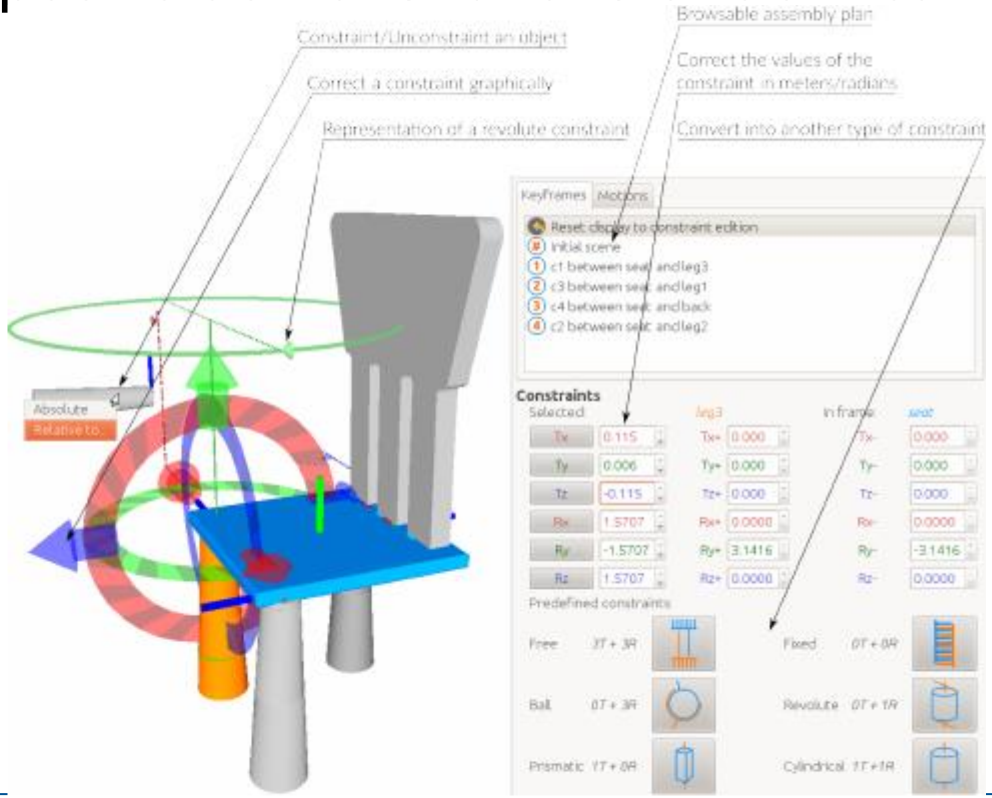
Existing Solutions / Related Work

- Luebbers et al.[2] enables the user to define constraints on the basis of which the task is then influenced.



Existing Solutions / Related Work

- Mollard et al.[3] developed an visual interface for an assembly task. The system allows the system to request specific demonstrations or clarifications from the user.



Problem Description: Issues

User-Related Problems:

- Missing intuitive solutions for non-expert users
- Immersion in the Task and Transparency

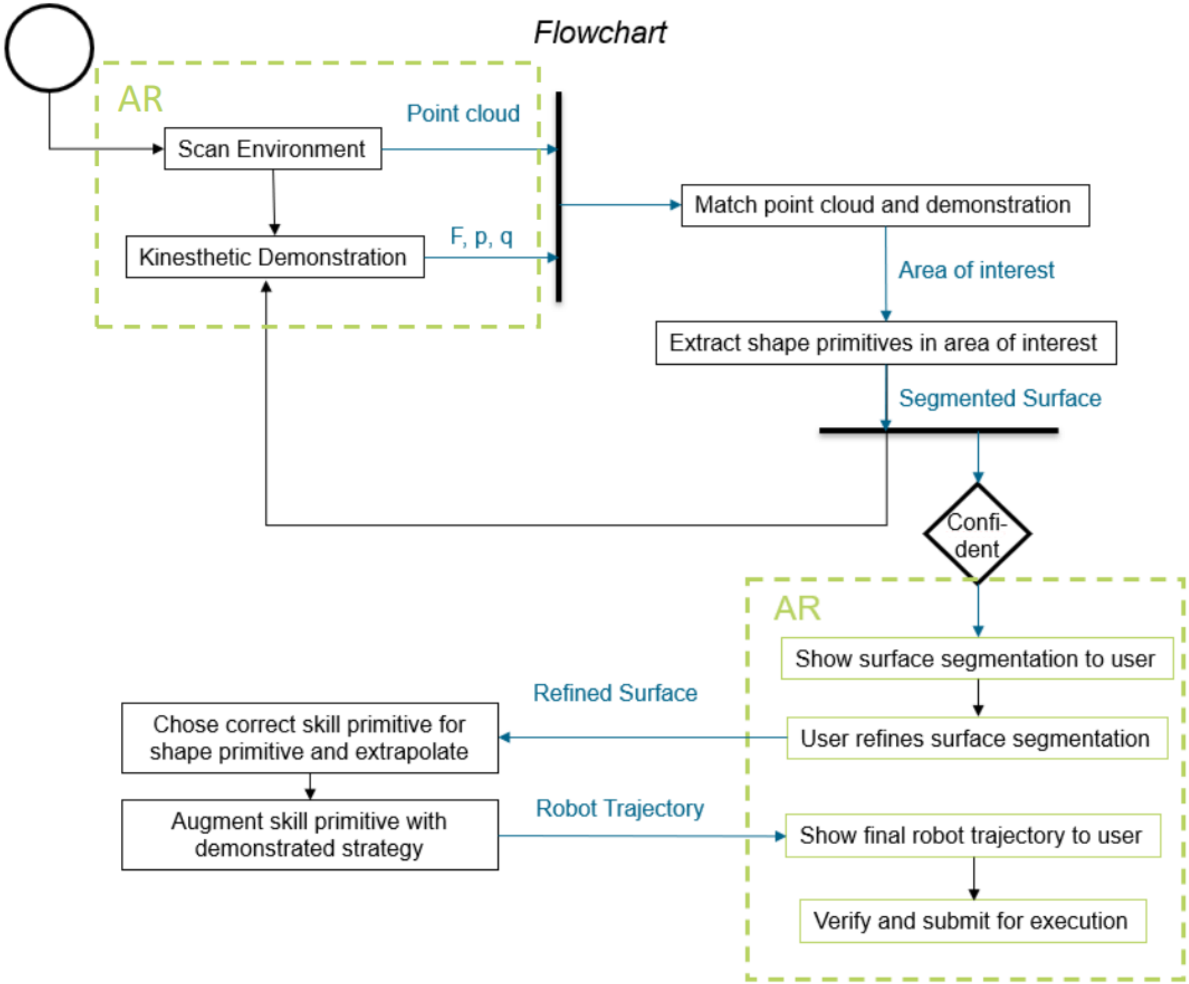
Learning from Demonstration:

- Dependence on the Demonstration
- Multiple Demonstrations Required
- Discrepancy Between User Expectations and Robot Learning

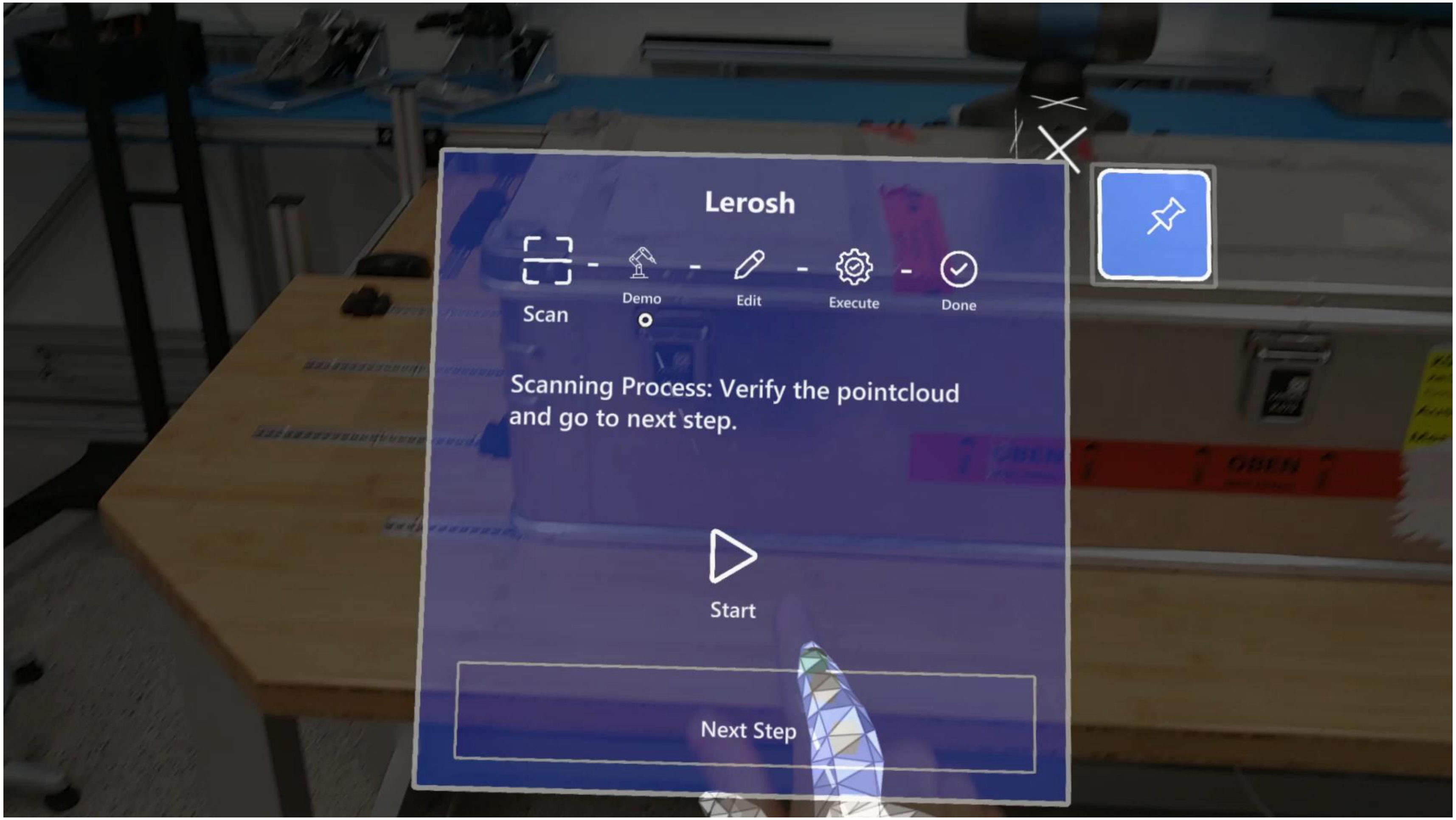
Goals of this Thesis

- Develop an feedback mechanismus that enables non-experts to programm the robot.
- Specifically develop an AR Interface

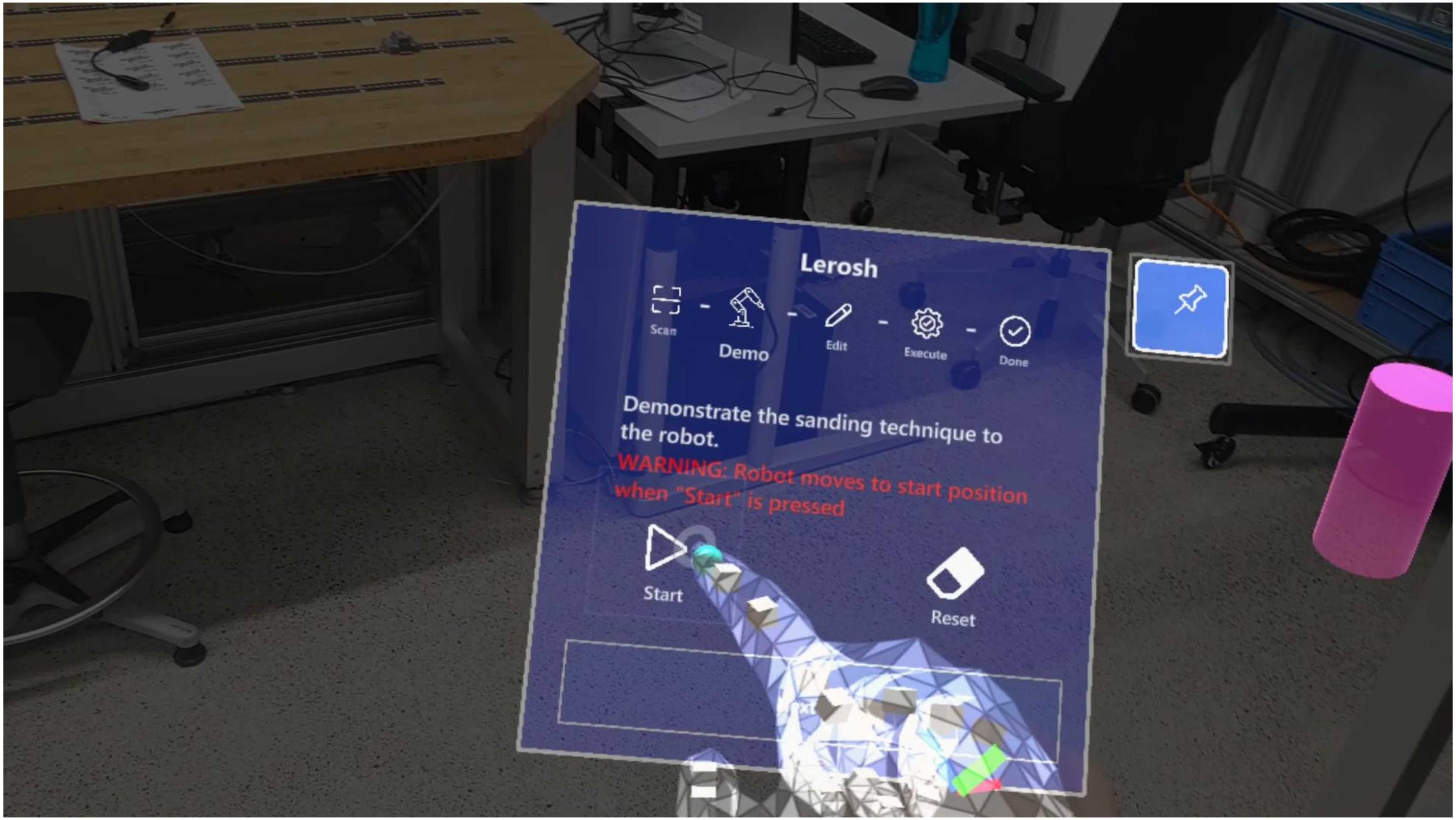
Process Flow



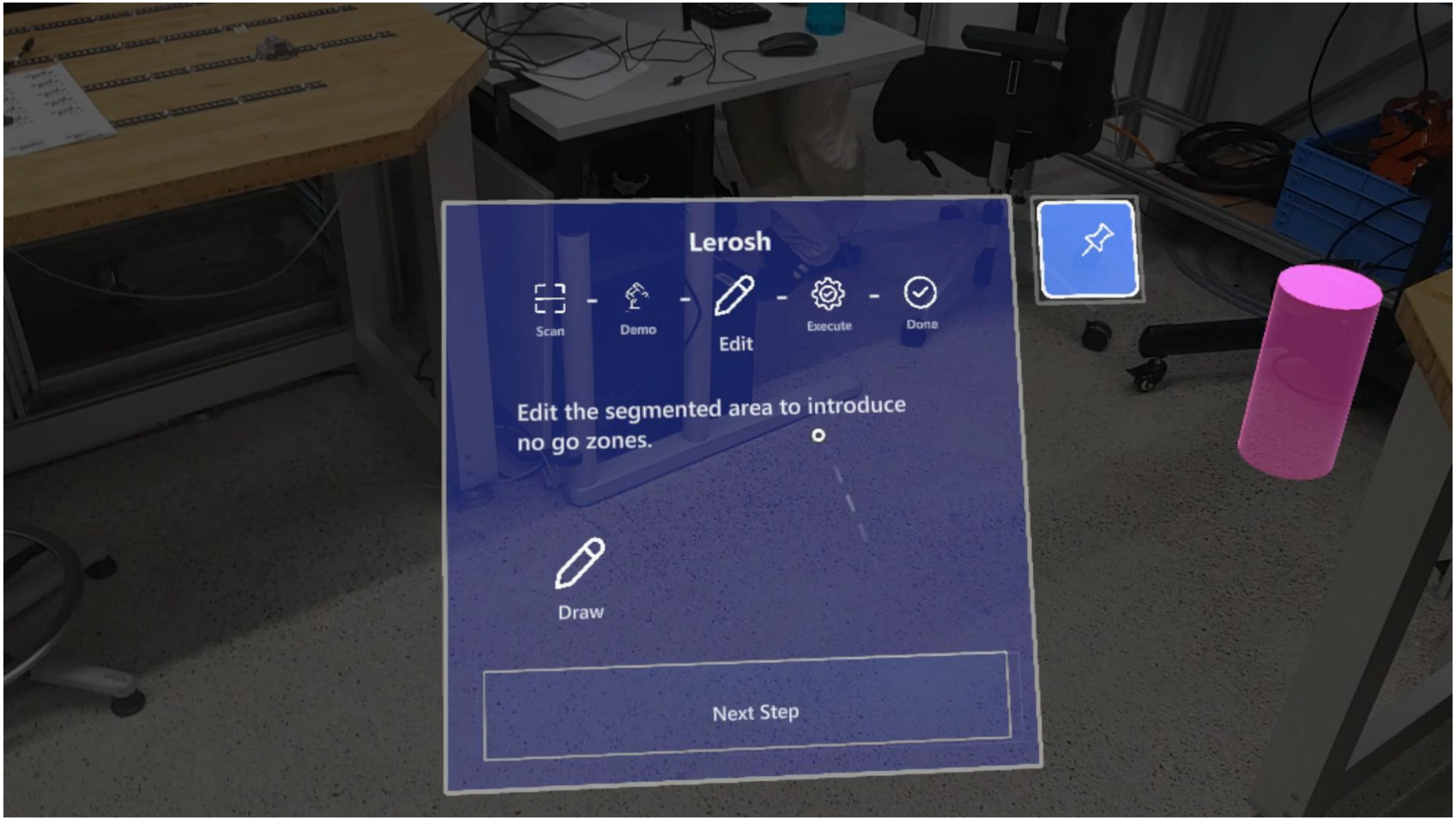
Implementation - Scanning



Implementation - Demonstration

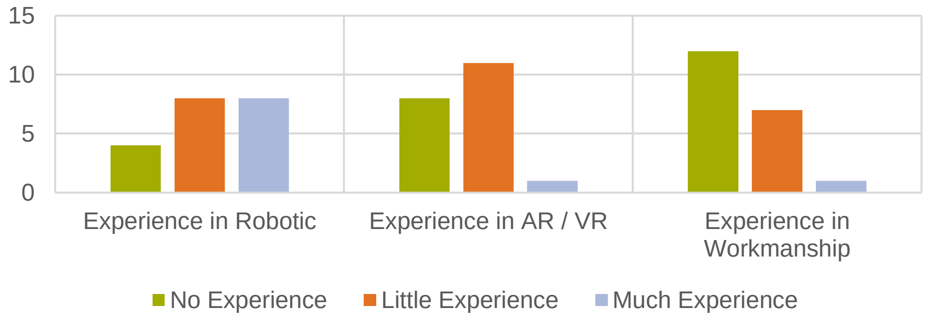


Implementation - Editing



User Study

- 20 participants /
  5 settings were tested



Setting 1: No feedback through Hololens, only robot

Setting 2/3: Update rate during the demonstration

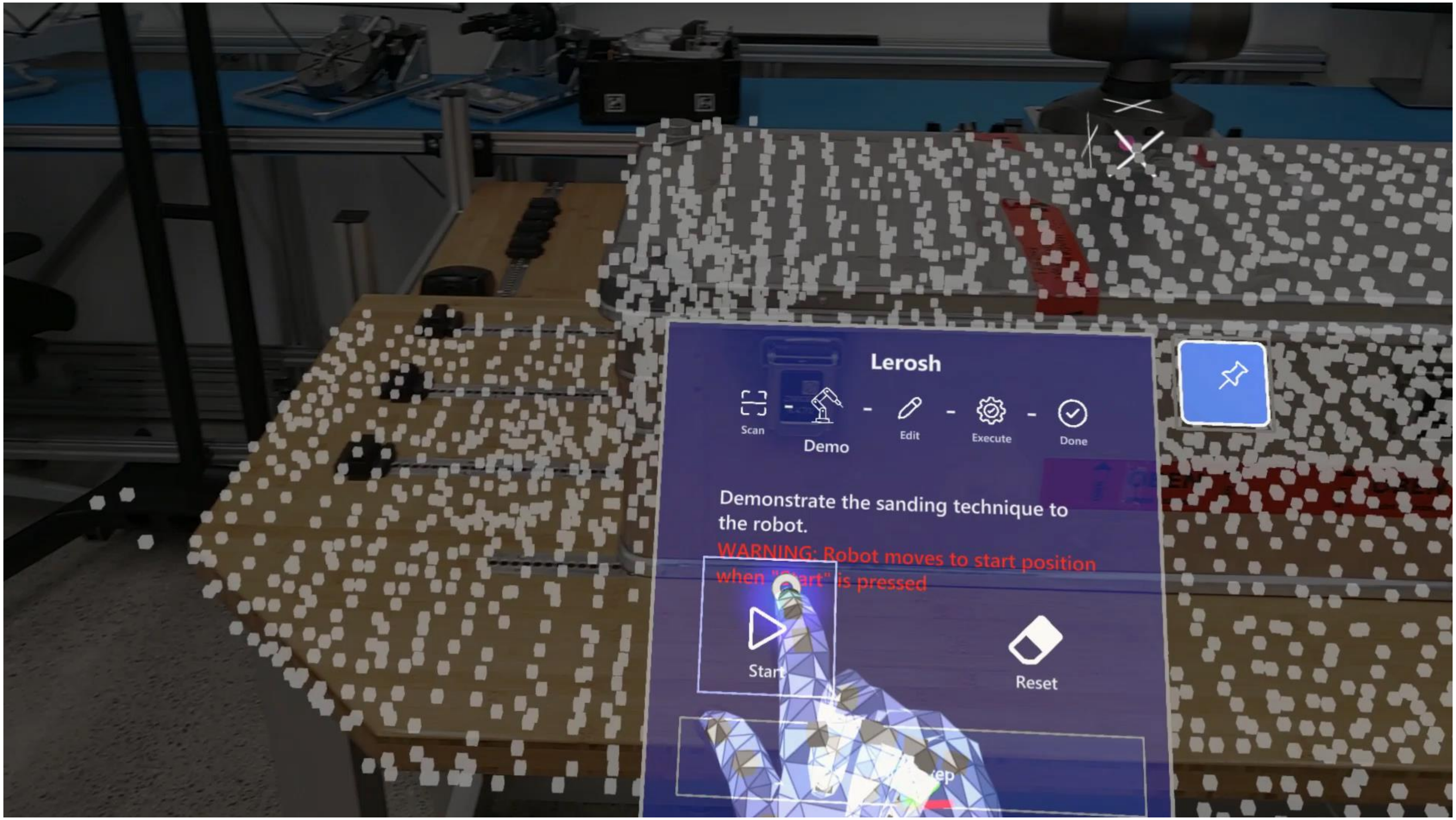
Setting 4: Demonstration per hand

Setting 5: Visualisation of the primitive form (algorithm result)

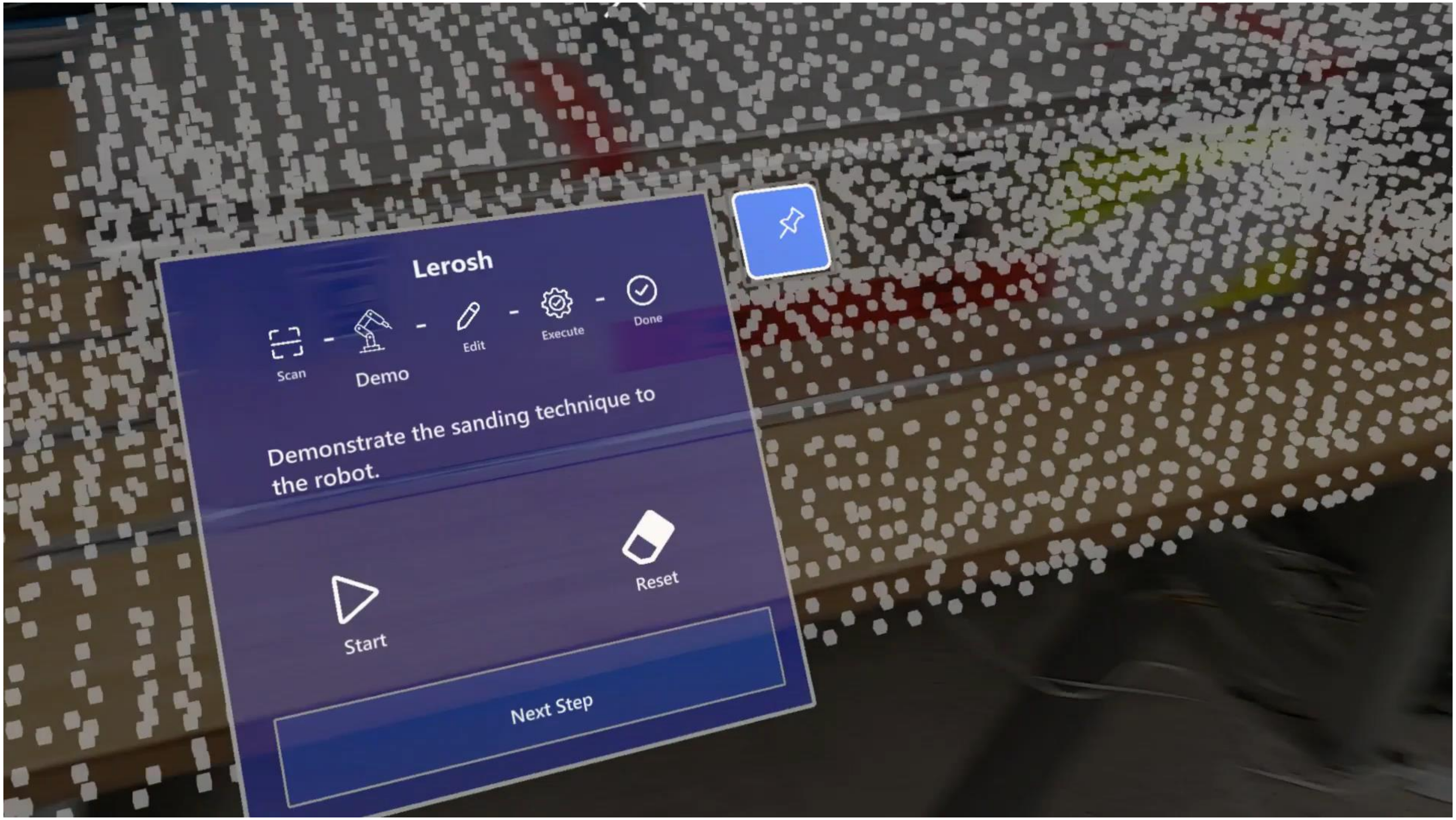
- Permutated Tests and split into Groups

	Group A	Group B	Group C	Group D
Test 1	Without Feedback		Discrete	Continuous
Test 2	Discrete	Continuous	Continuous	Discrete
Test 3	Continuous	Discrete	Without Feedback	
Test 4	Demonstration per Hand			
Test 5	Additional Information			

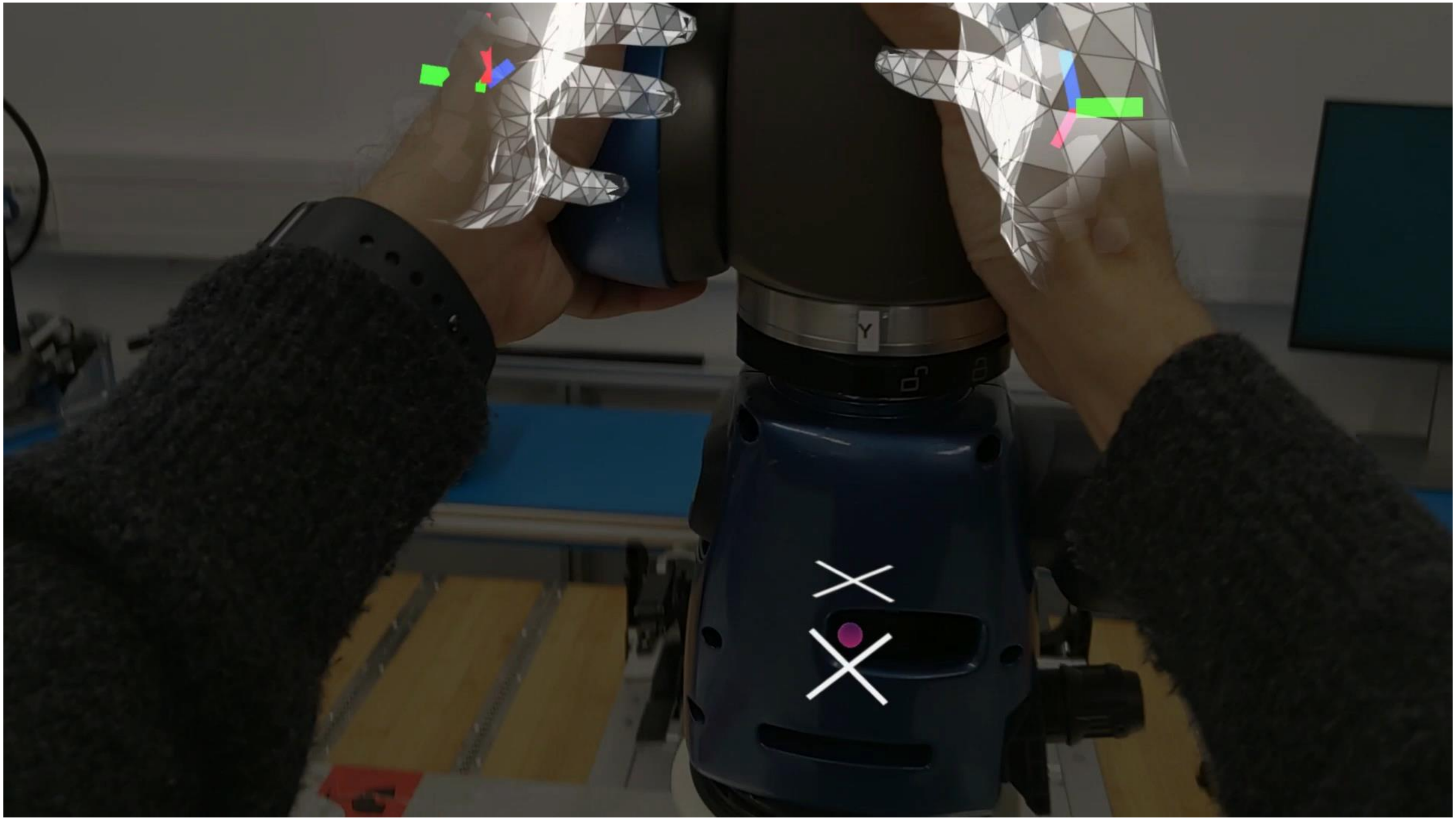
User Study - Discrete Update Rate



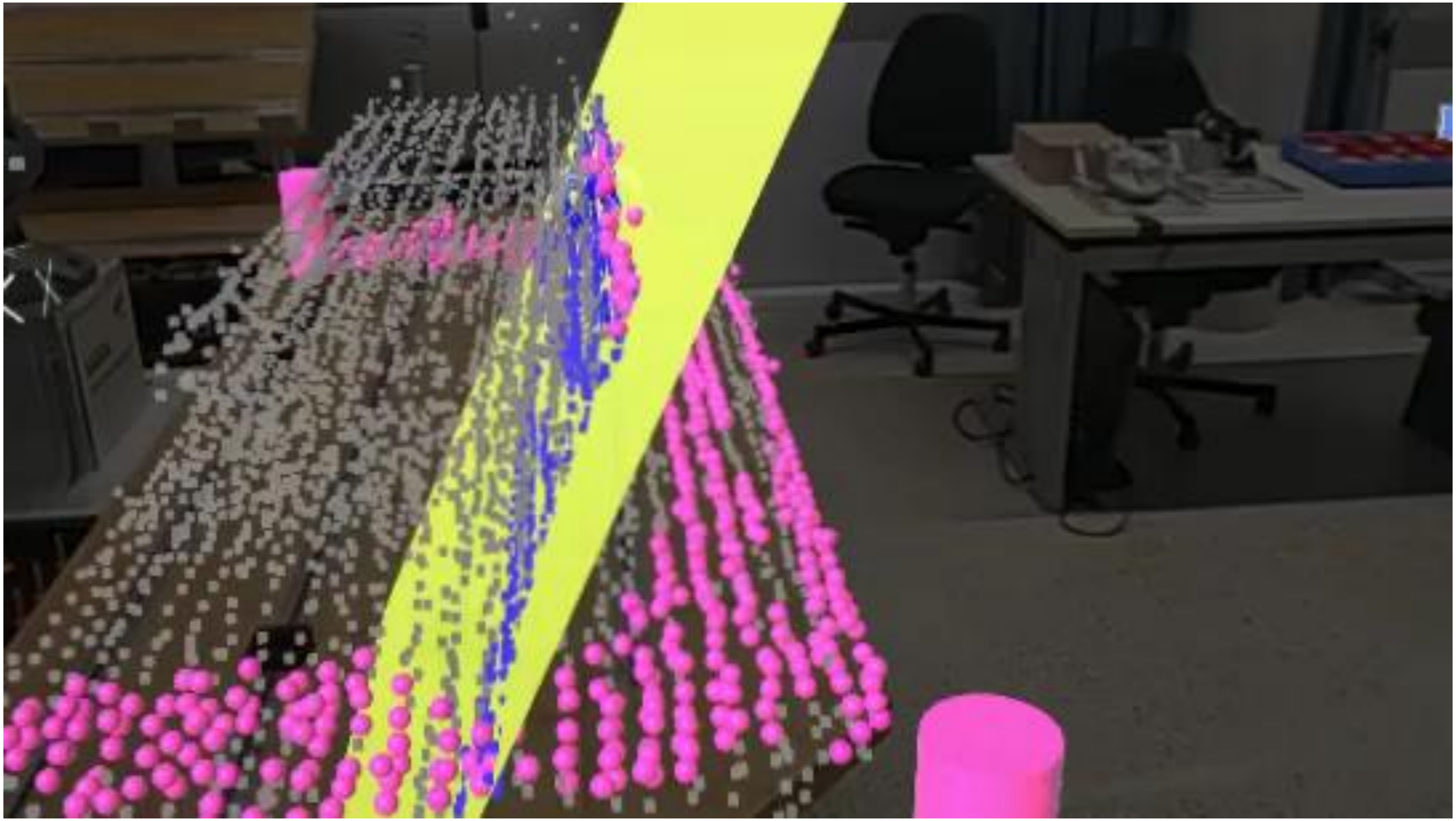
User Study - Demonstration Per Hand



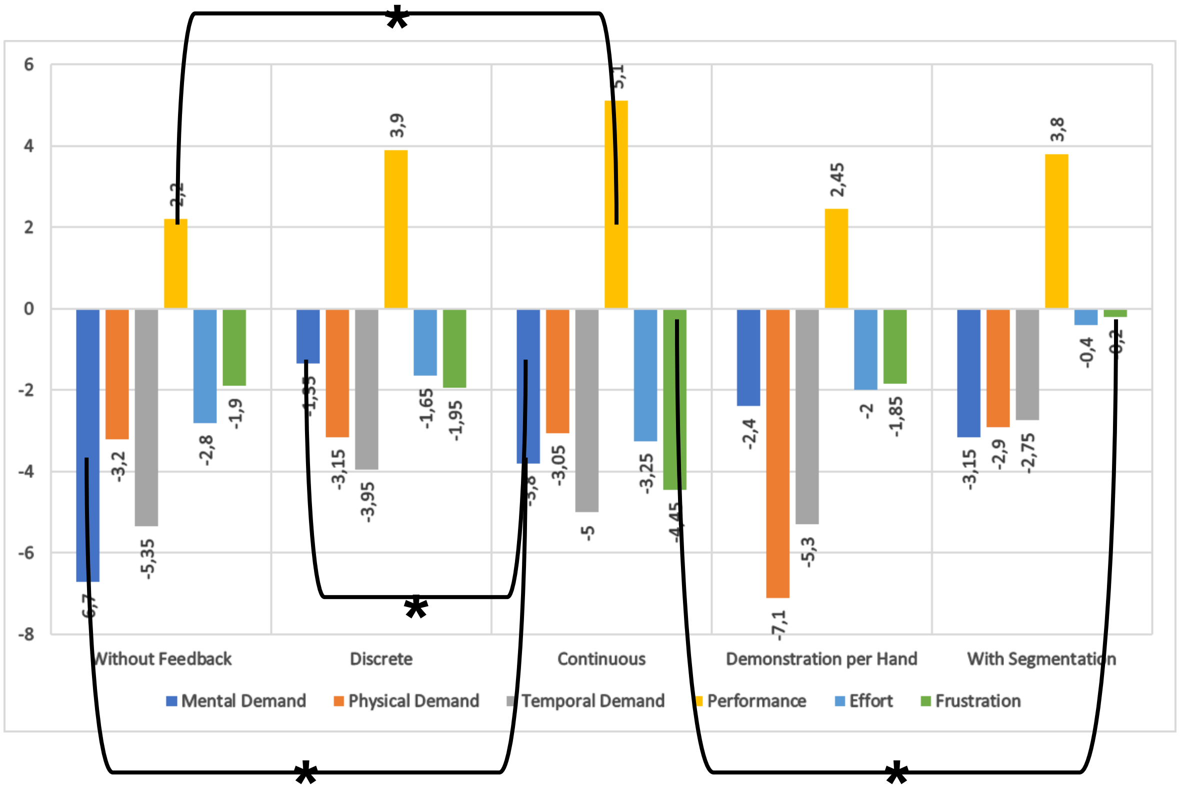
User Study - Additional Information

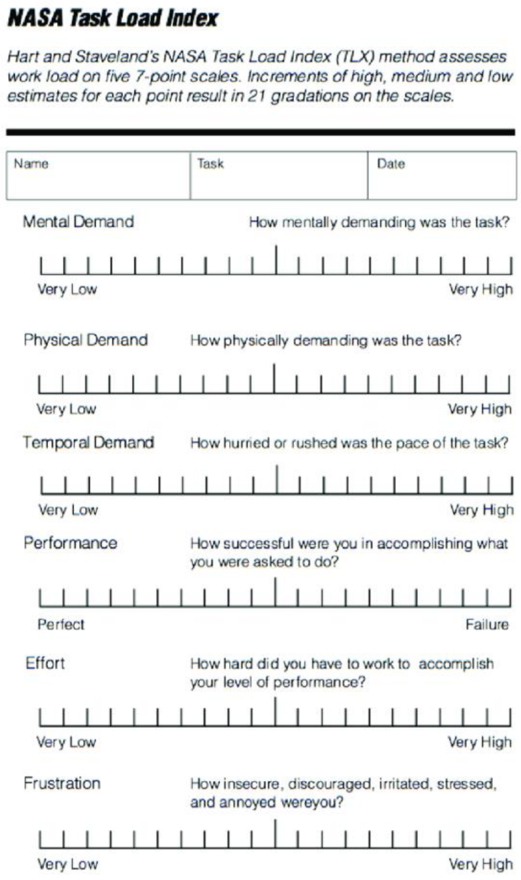


User Study - Additional Information



Results - TLX





NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

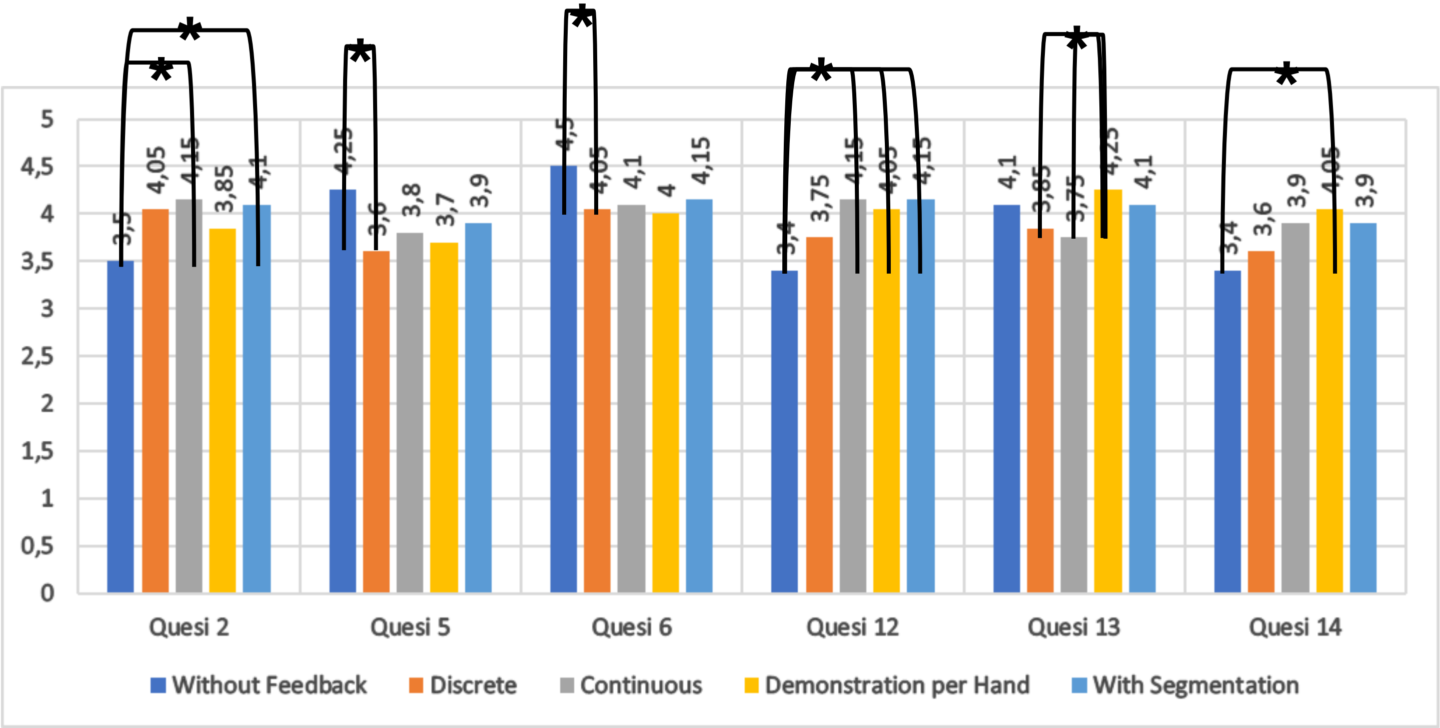
Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

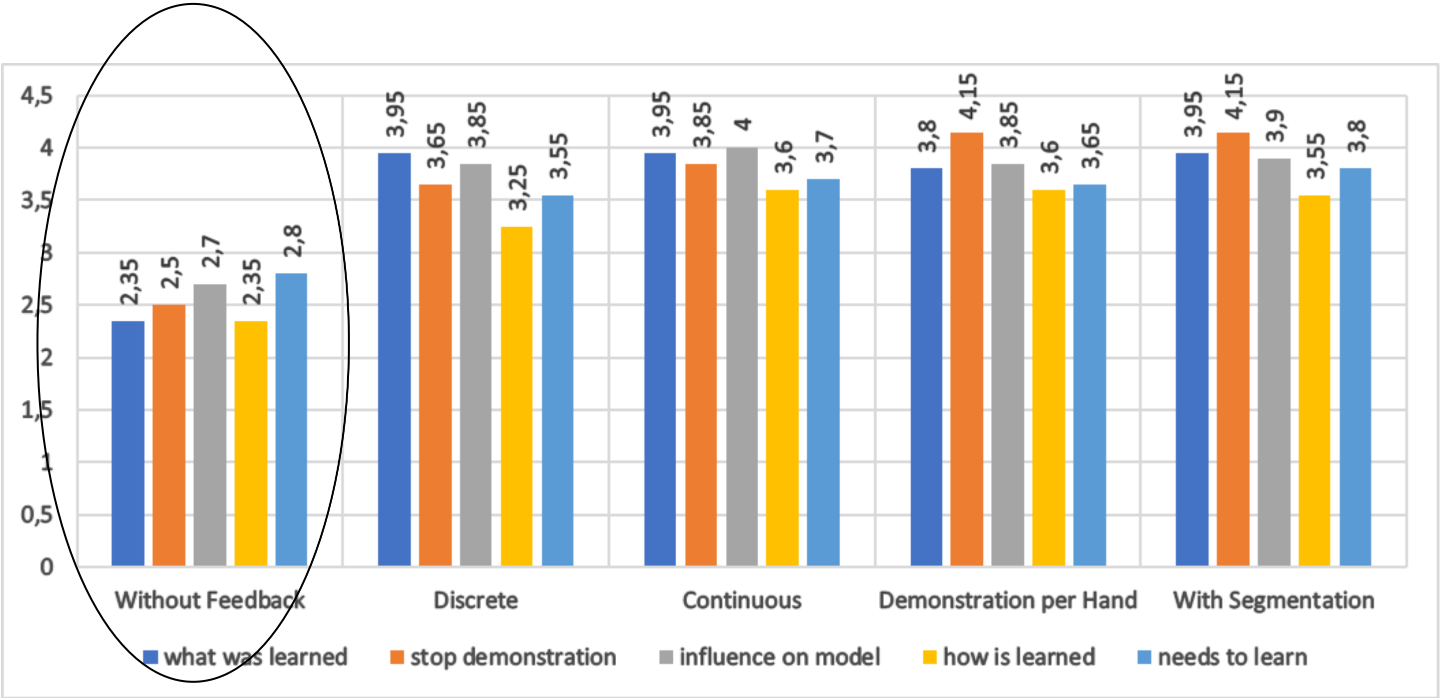
Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

Results - QUESI



Quesi 2: I achieved what I wanted to achieve with the system.
Quesi 5: No problems occurred when I used the system.
Quesi 6: The system was not complicated to use.
Quesi 12: The system helped me to completely achieve my goals.
Quesi 13: How the system is used was clear to me straight away.
Quesi 14: I automatically did the right thing to achieve my goals.

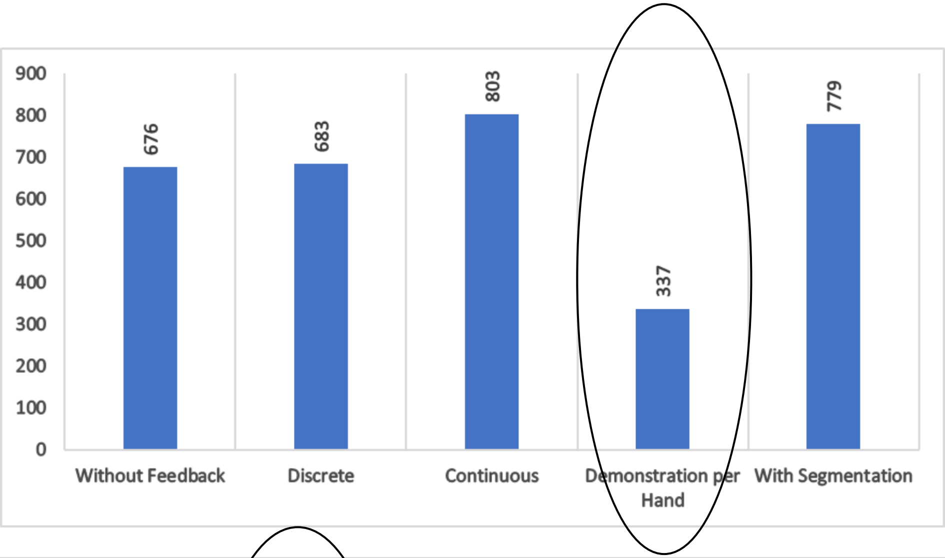
Results - Process Understanding



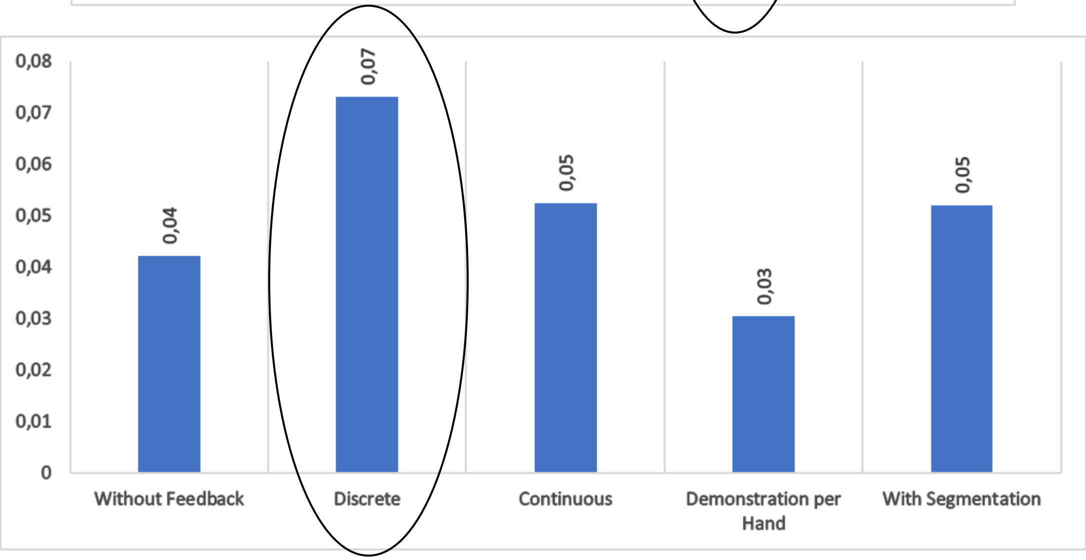
1. I understood what model the robot learned.
2. I understood when I could stop with the demonstration.
3. I understood how I influenced the model of the robot with my actions.
4. I understood how the the robot is learning.
5. I understood what the robot needs to build a model.

Results - Collected Data

Contact Points



Corner Points Deviation



Hypotheses

H1: AR interface enhances intuitive handling of LfD robot ✓

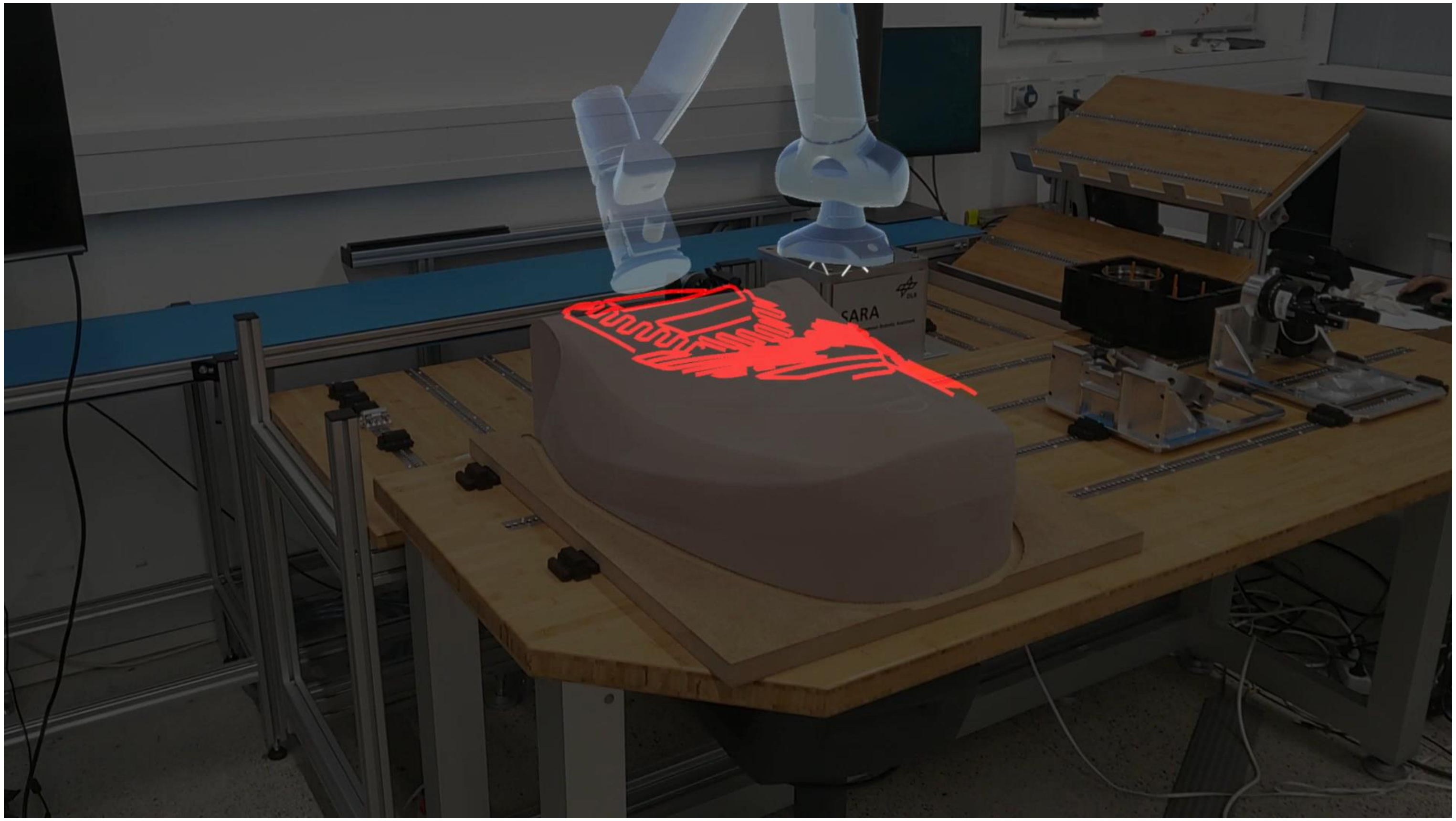
H2: Visualization of the process helps increase the accurancy of the demonstrations ✗

H3: Visual feedback reduces the knowledge gap between humans and machines -> Perceived knowledge gap ✗ ✓

H4: Compared to discrete feedback, continuous feedback can increase effectiveness in terms of quality ✗

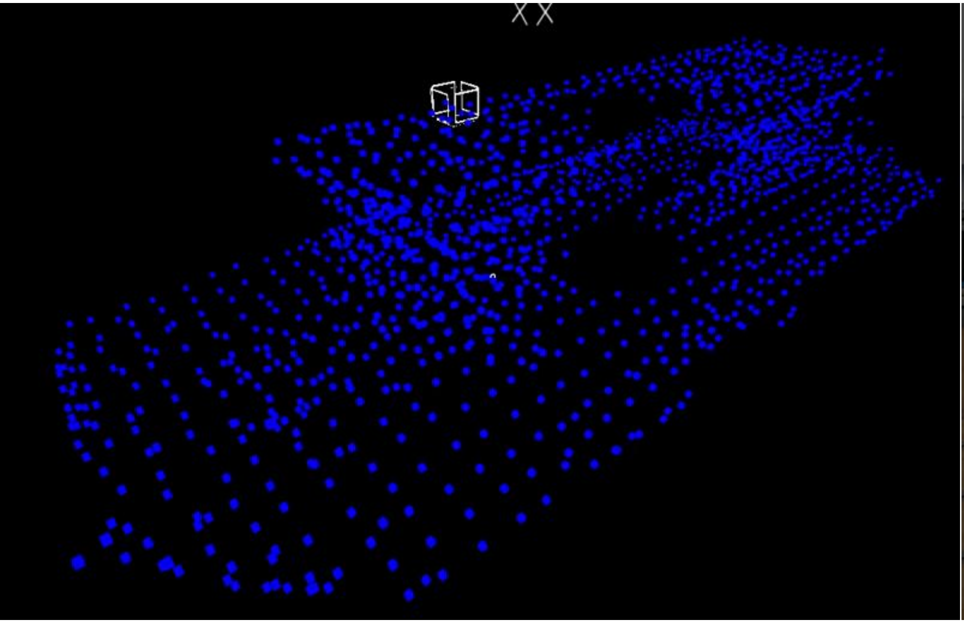
H5: Specific use of AR technologies can further improve the LfD approach and make it more intuitive ✓

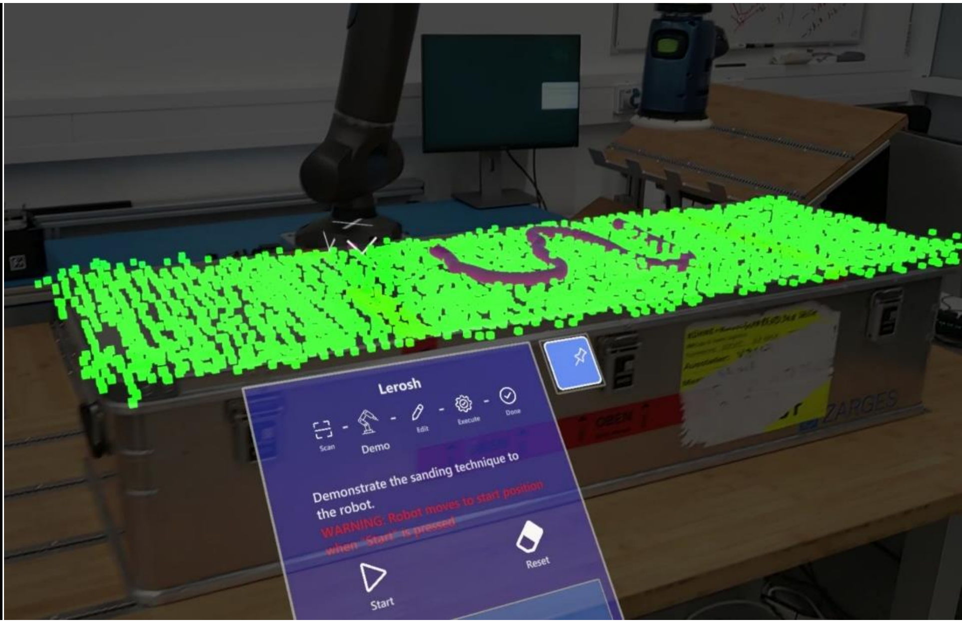
Additional Changes



- Vizualization of the progress and digital model of the robot.

Additional Changes





- Animating the segmented area to vizualise change
- Changing color for more contrast

Conclusion

- AR technologies offer enormous potential for enriching the LfD approach, improving human-machine interaction and use in small companies to.
- Technical challenges and user preferences must be taken into account when developing optimal solutions.

Future Outlook

Next research steps:

- Userstudy with the Changes Made to the Interface
- More Complex Tasks
- Different Display Methods
- Different Interaction Methods

List of References

1. H. Liu, Y. Zhang, W. Si, X. Xie, Y. Zhu, and S.- C. Zhu. “Interactive Robot Knowledge Patching Using Augmented Reality.” In: 2018 IEEE International Conference on Robotics and Automation (ICRA). 2018, pp. 1947–1954. doi: 10.1109/ICRA.2018.8462837.
2. M. B. Luebbers, C. Brooks, M. Kim, D. J. Szafir, and B. Hayes. “Augmented Reality Interface for Constrained Learning from Demonstration.” In: 2019.
3. Y. Mollard, T. Munzer, A. Baisero, M. Toussaint, and M. Lopes. “Robot Programming from Demonstration, Feedback and Transfer.” In: Sept. 2015, pp. 1825–1831. doi: 10.1109/IROS.2015.7353615.

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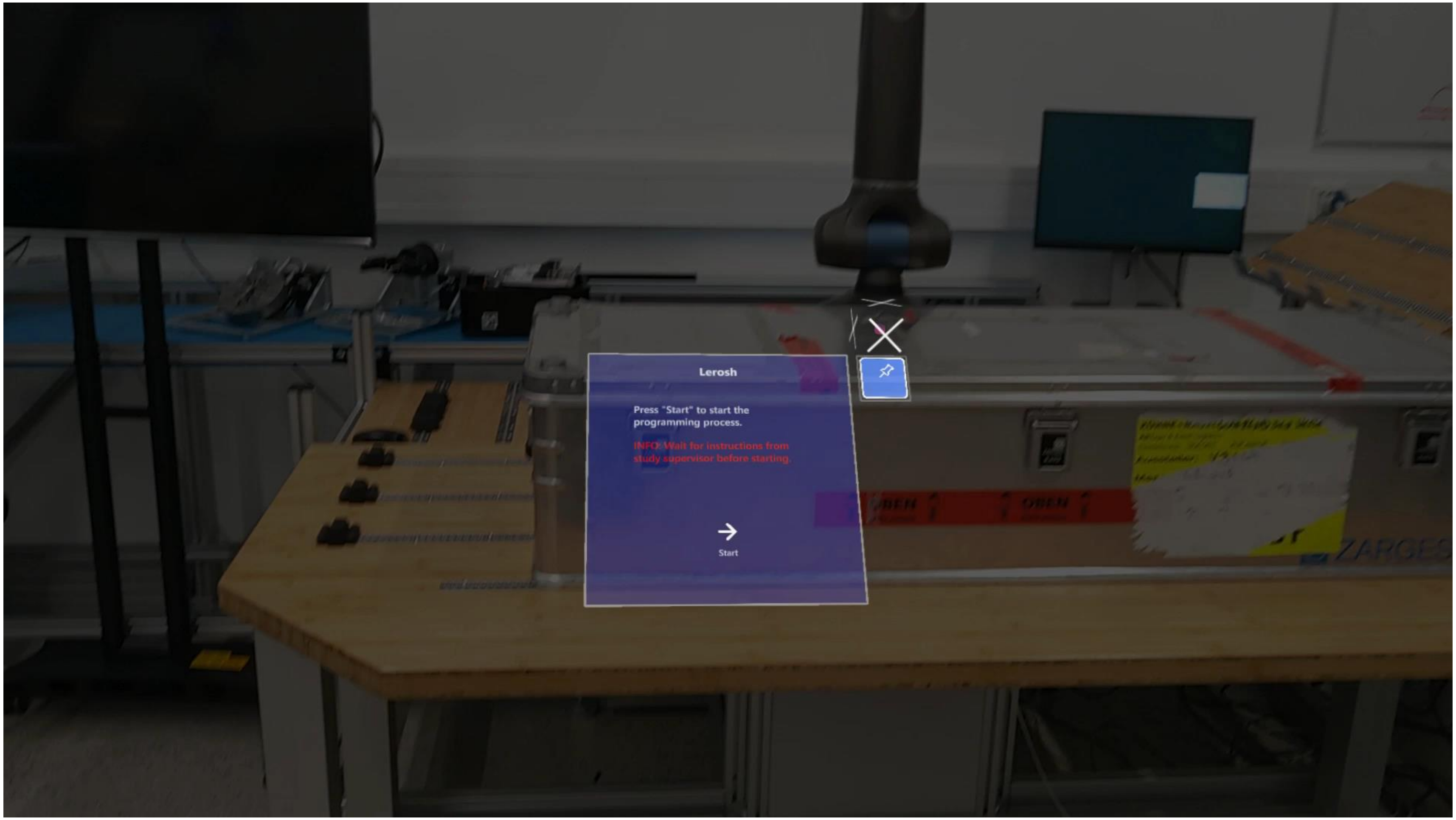
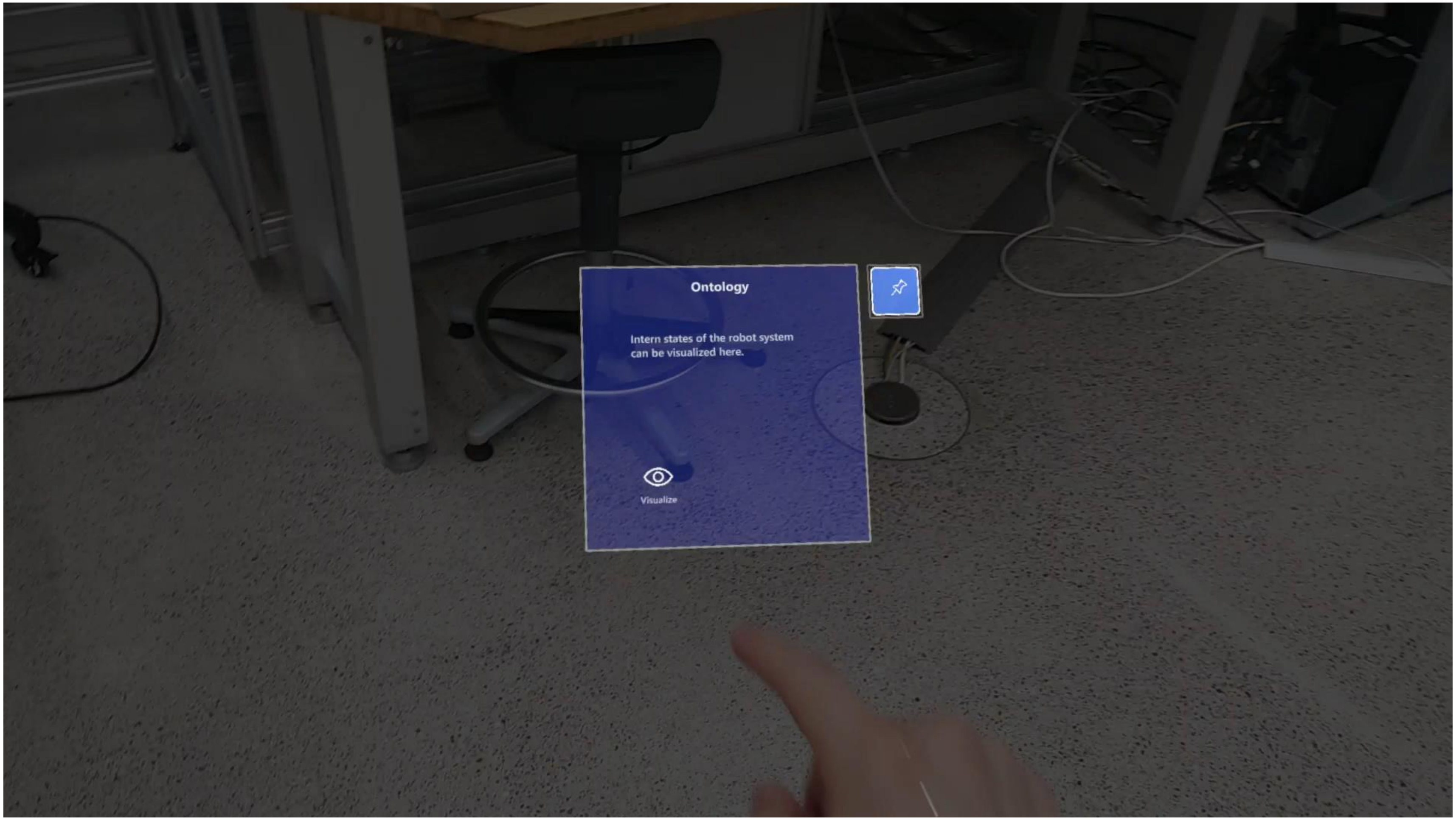
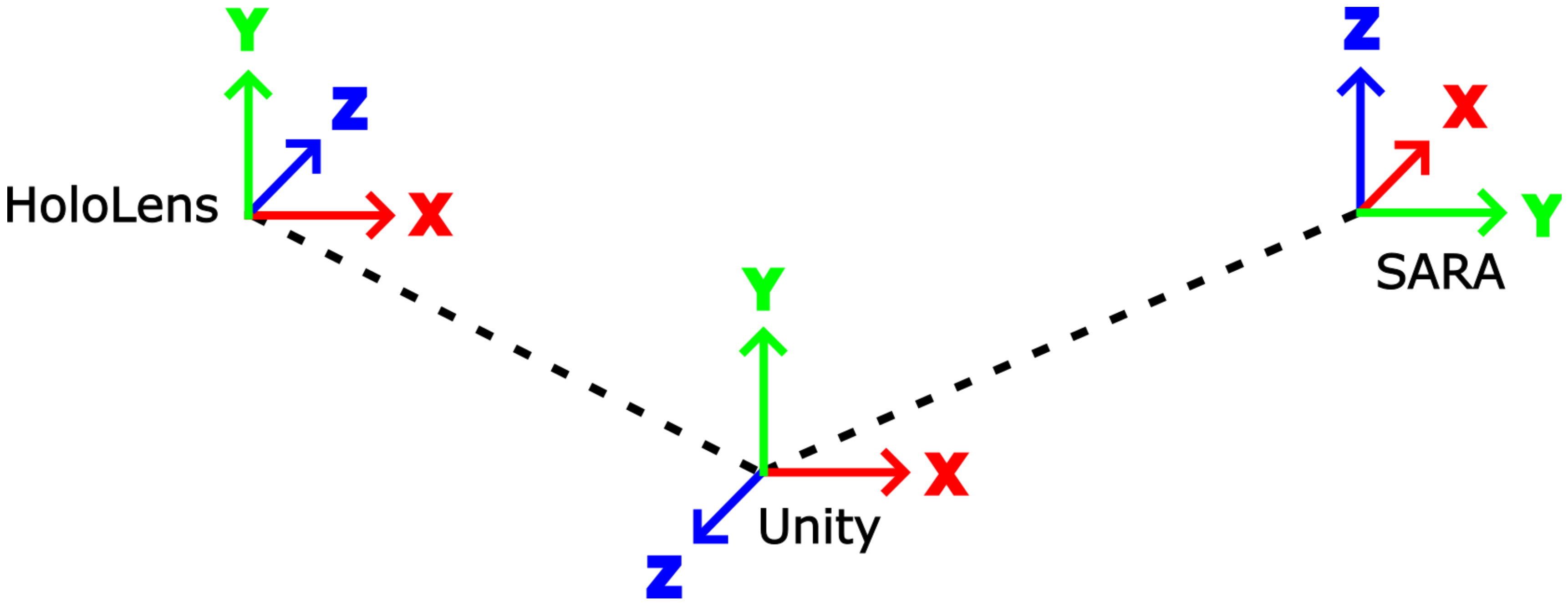
Backup – Lerosh Process



Backup - Ontology

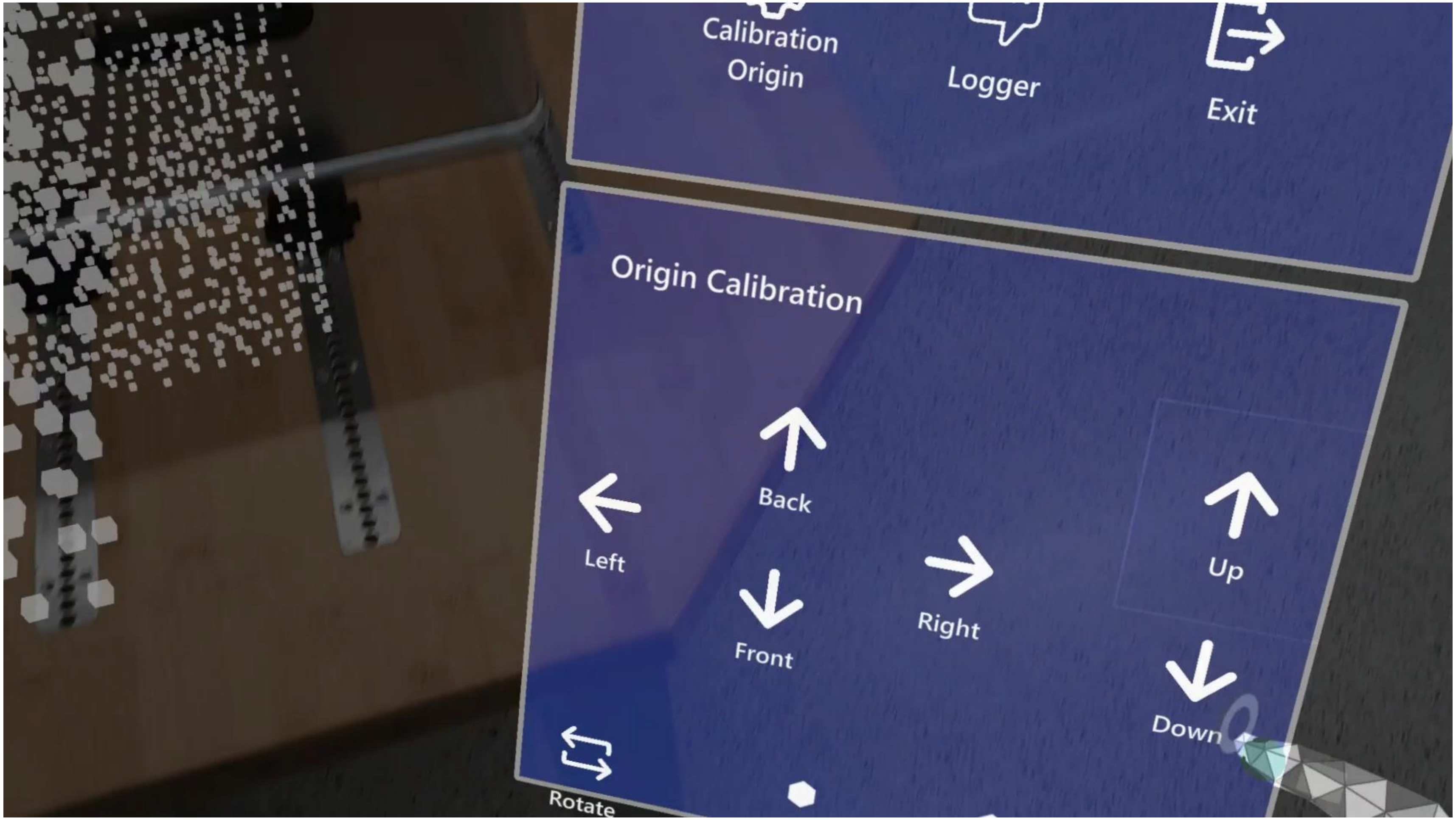


Backup - Calibration

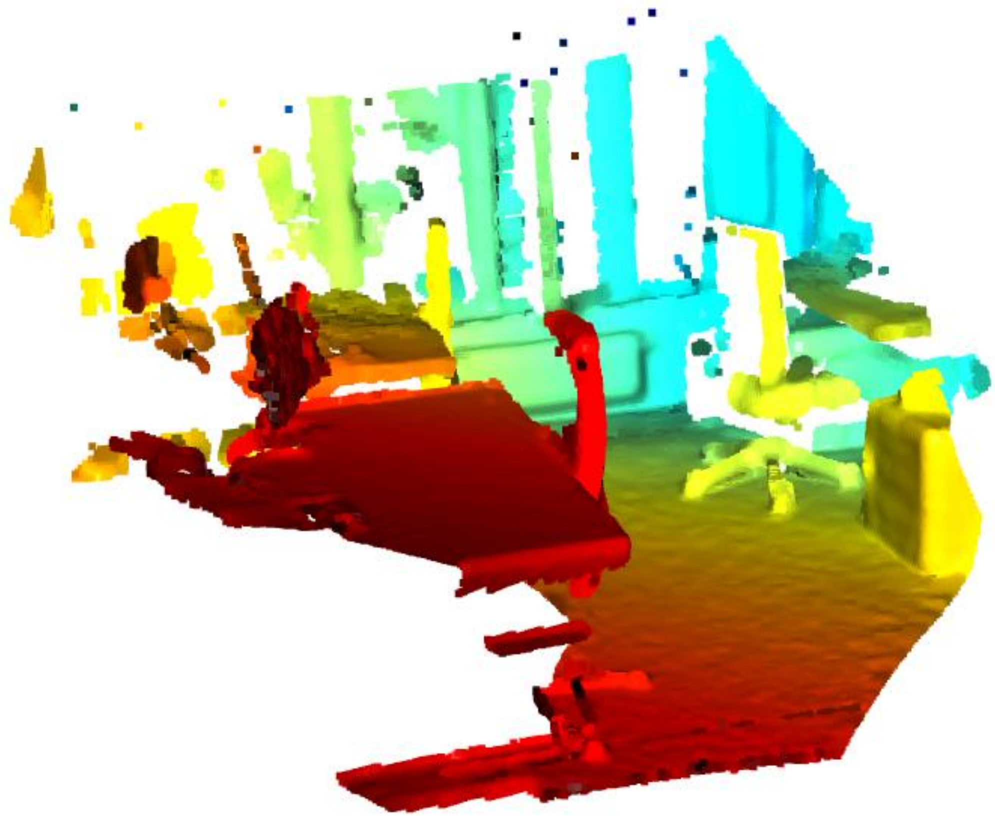


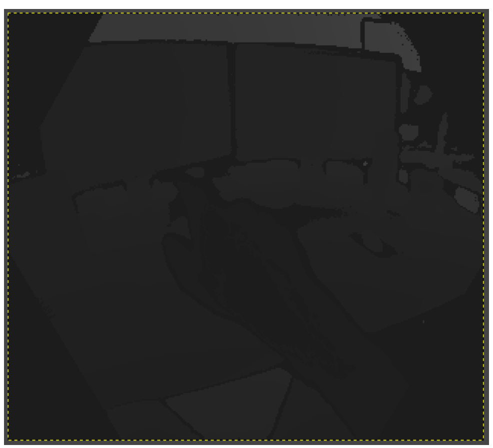
Backup - Calibration (Workbench)

Backup - Calibration (Pointcloud)



Backup - Scanning





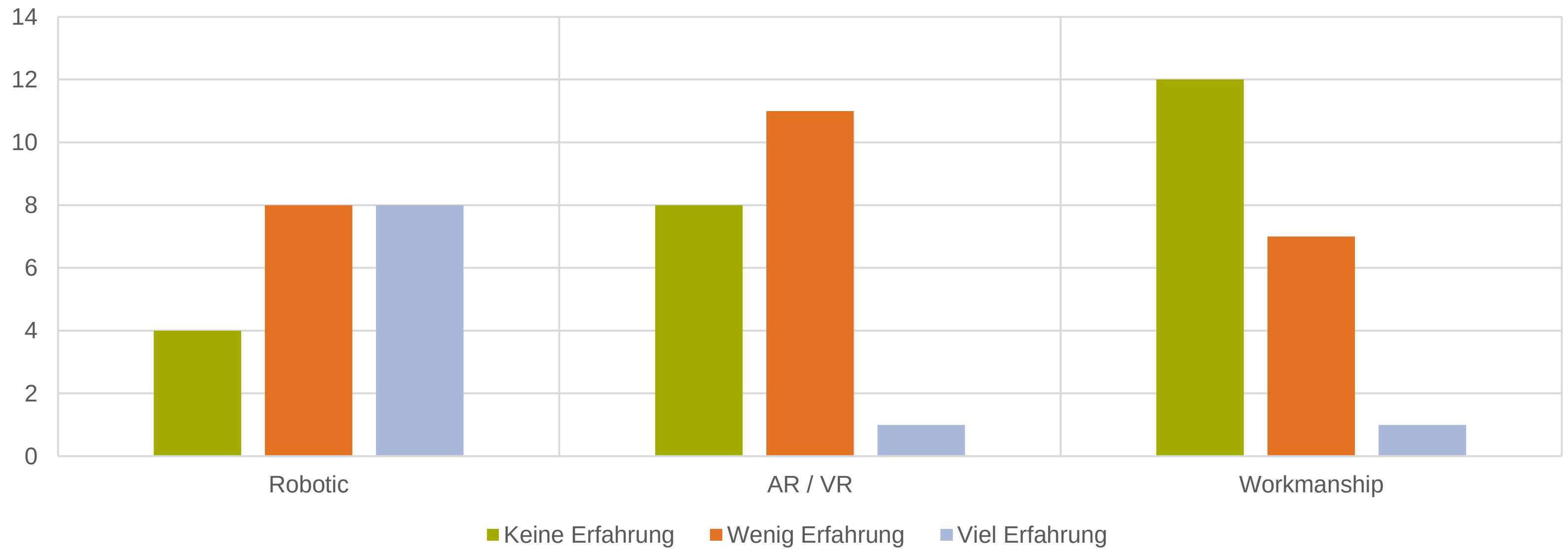
Backup - Limitations Implementation

- Manual Calibration
- Calibration Stability
- Calibration Quality
  - Vuforia tracking accuracy
- Performance
  - Update rate
- Hardware issues

Backup - Userstudy Participants

	Min	Max
Age	19	35

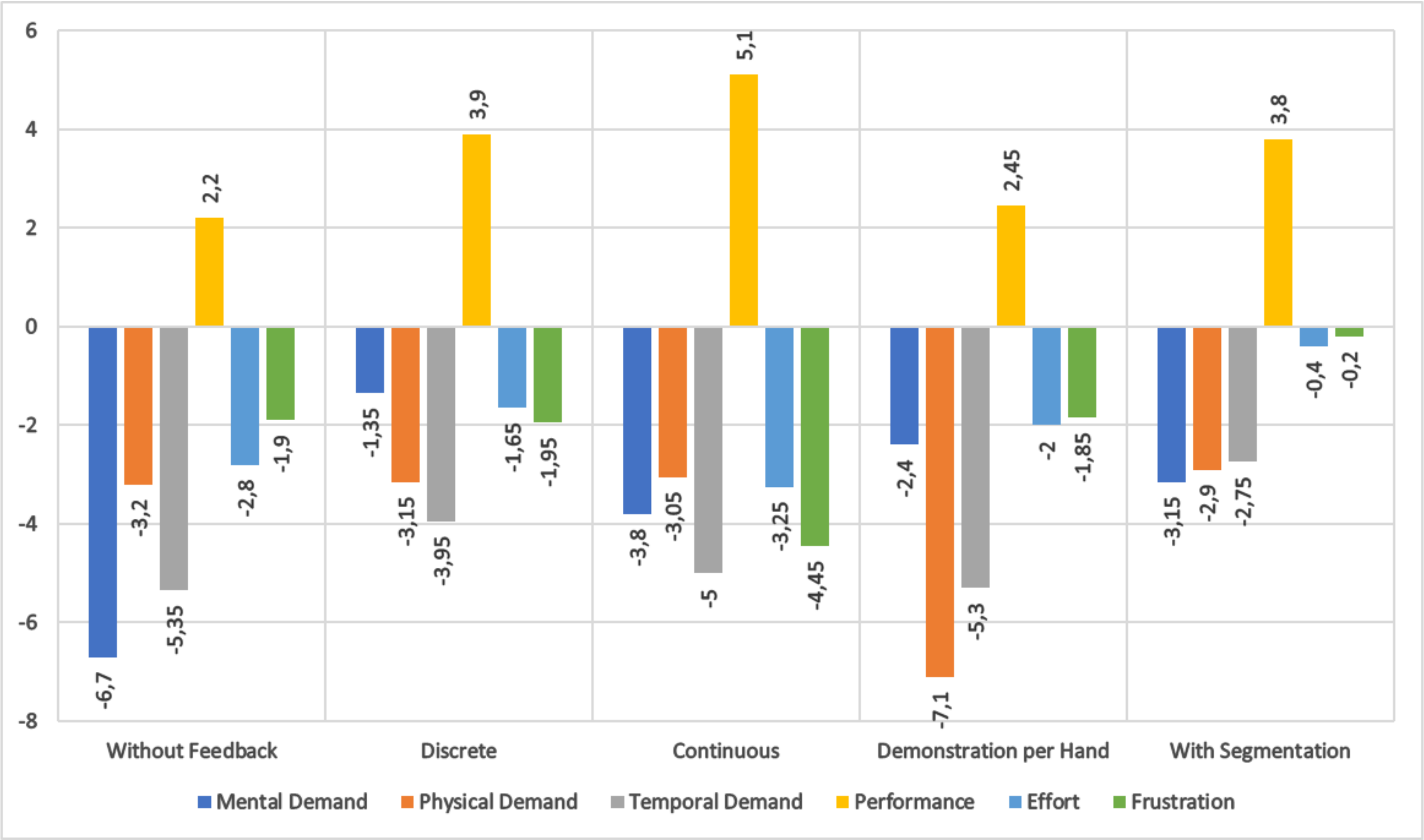
	F	M	D
Gender	4	16	0



Backup - Limitations Userstudy

- Limited number of users
- Missing subject-unrelated testers
- Lack of opportunity for independent testing
- Controlled Laboratory Environment
- Lack of variation in tasks

Backup - TLX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-3,25
-4,45
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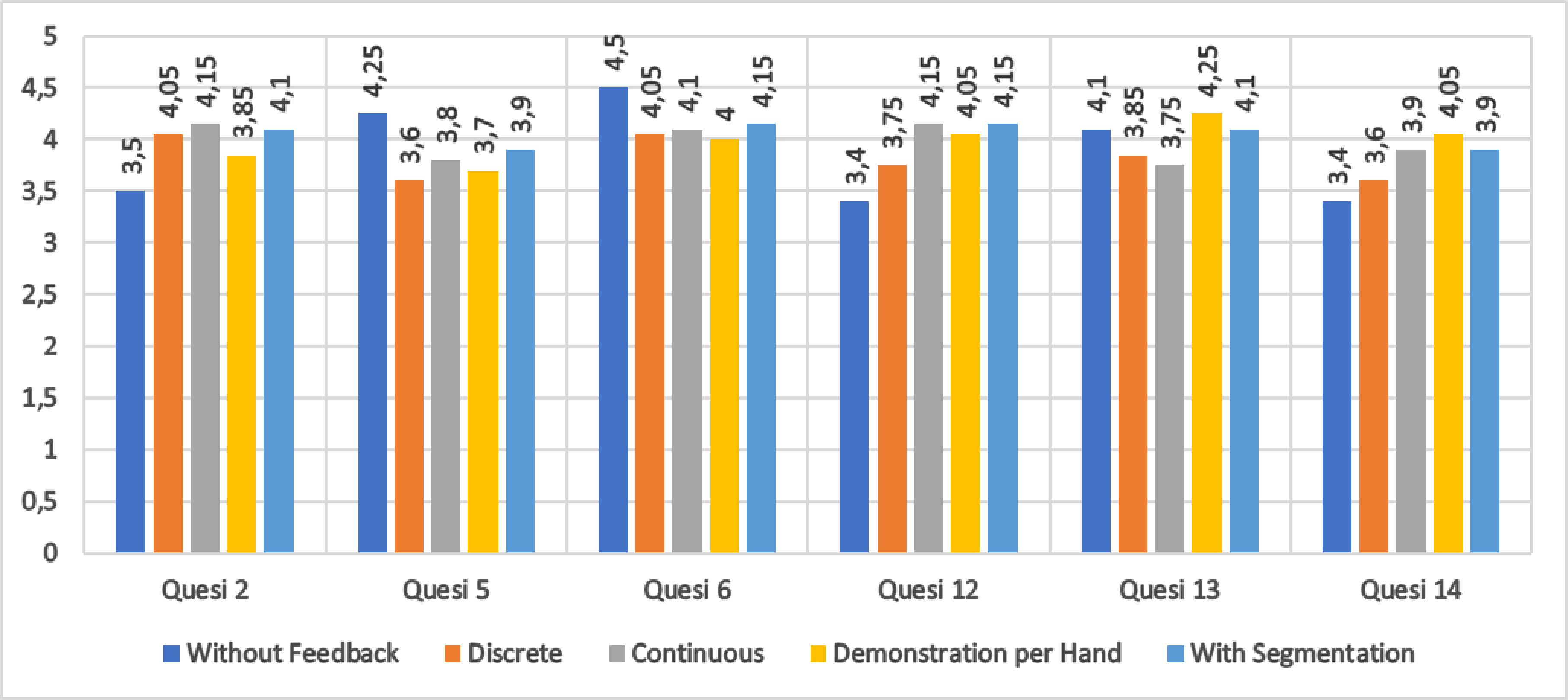
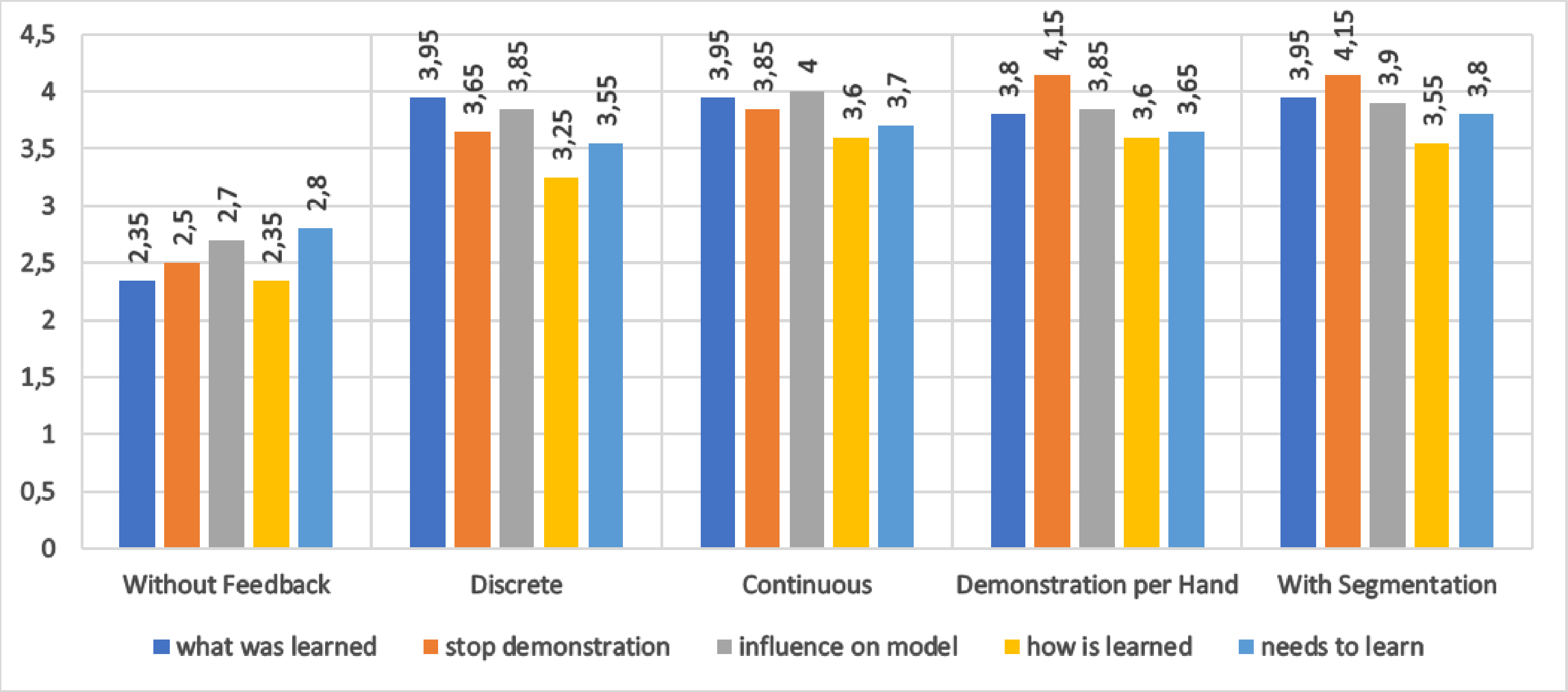
-2,4
-7,1
-5,3
-2
-1,85
3,8
-3,15
-2,9
-2,75
-0,4
-0,2
Without Feedback
Discrete
Continuous
Demonstration per Hand
With Segmentation
Mental Demand
Physical Demand
Temporal Demand
Performance
Effort
Frustration

Backup - QUESI

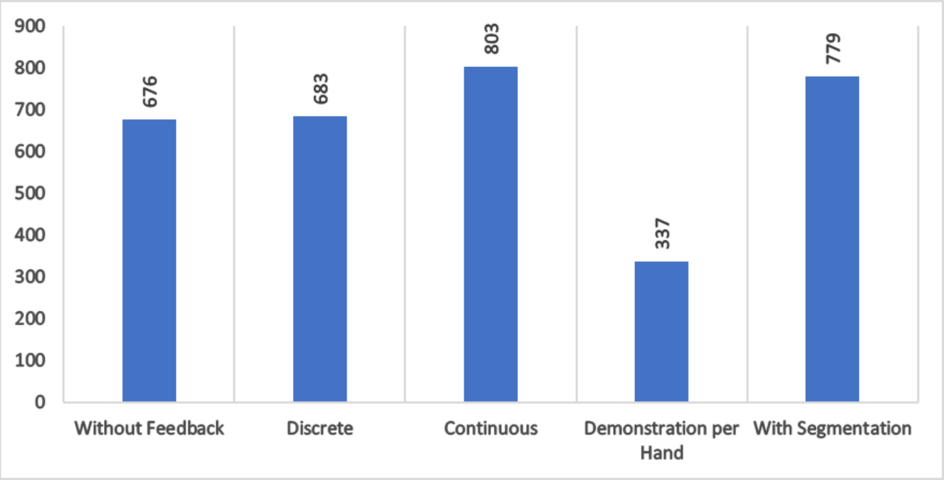


Backup - Process Understanding



Backup - Collected Data

Contact Points



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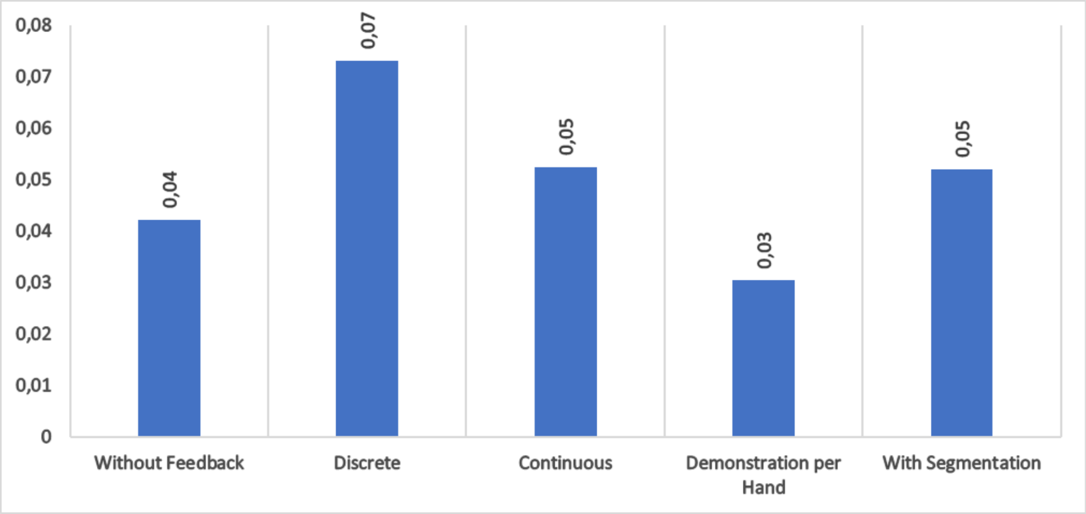

Backup – Corner Point Deviation