# Modeling Adaptive Expression of Robot Learning Engagement and Exploring its Effects on Users during Human Demonstration

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Robot Learning from Demonstration (RLfD), an emerging human-AI interaction scenario, allows non-expert users to teach a robot new skills or tasks directly through demonstrations. Although modeled after human learning and teaching, most existing RLfD methods tend to make robots act as passive observers without the feedback of learning status in the demonstration gathering stage. To facilitate a more transparent teaching process, we propose two mechanisms of *Learning Engagement*, Z2O-Mode and D2O-Mode, to dynamically adapt robots' attentional and behavioral engagement expressions to their actual learning status. Through an online user experiment with 48 participants, we find that, compared with two baselines, the two kinds of *Learning Engagement* can provide users with a more accurate mental model of the robot's learning progress and lead to their positive perceptions of the robot and the teaching process. Finally, we offer implications for designing transparent AI systems based on the key findings from our study. Robot Learning from Demonstration (RLfD), an emerging human-AI interaction scenario, allows non-expert users to teach a robot new skills or tasks directly through demonstrations. Although modeled after human learning and teaching, most existing RLfD methods tend to make robots act as passive observers without the feedback of learning status in the demonstration gathering stage. To facilitate a more transparent teaching process, we propose two mechanisms of *Learning Engagement*, Z2O-Mode and D2O-Mode, to dynamically adapt robots' attentional and behavioral engagement expressions to their actual learning status. ynamically adapt robots' attentional and behavioral engagement expressions to their actual learning status. and D2O-Mode, to dynamically adapt robots' attentional and behavioral engagement expressions to their actual learning status. ynamically adapt robots' attentional and behavioral engagement expressions to their actual learning status.

CCS Concepts: • **Human-centered computing** → **Empirical studies in HCI**; *Empirical studies in interaction design.*

Additional Key Words and Phrases: Human-robot interaction, learning from demonstration, robot learning, robot engagement

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# Appendices

This document is the online appendix for the paper titled "Modeling Adaptive Expression of Robot Learning Engagement and Exploring its Effects on Users during Human Demonstration".

## A DEMONSTRATION MOCAP DATA AND SIMULATION ENVIRONMENT

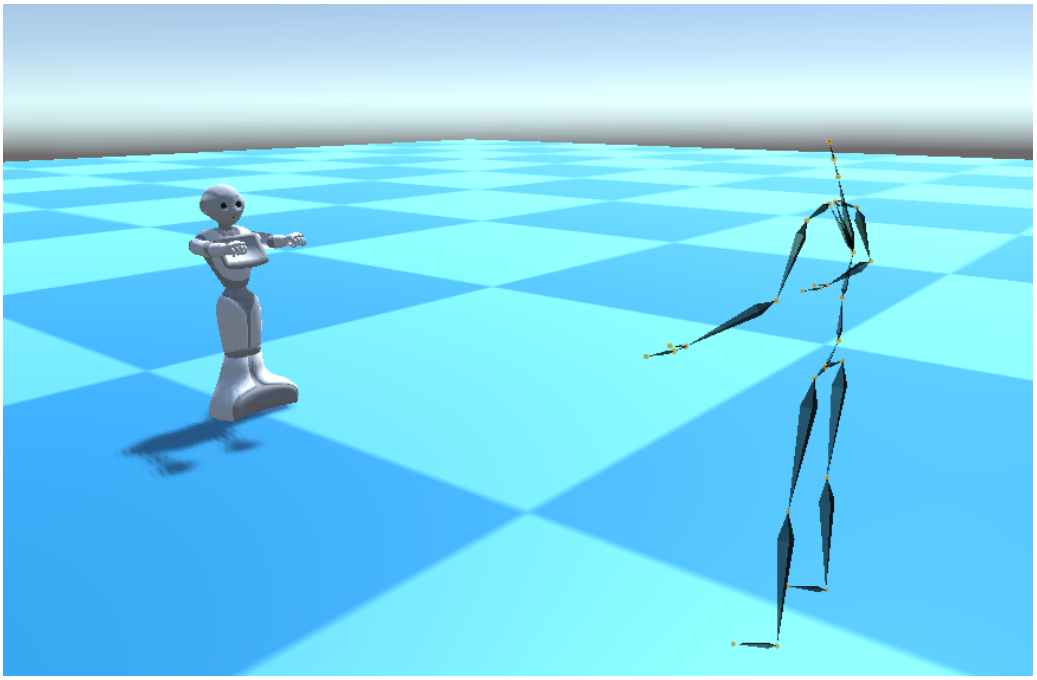

Fig. 1. The simulation environment in the Unity platform where a human avatar (in a skeleton-based form) shows a demonstration to a Pepper robot face-to-face.

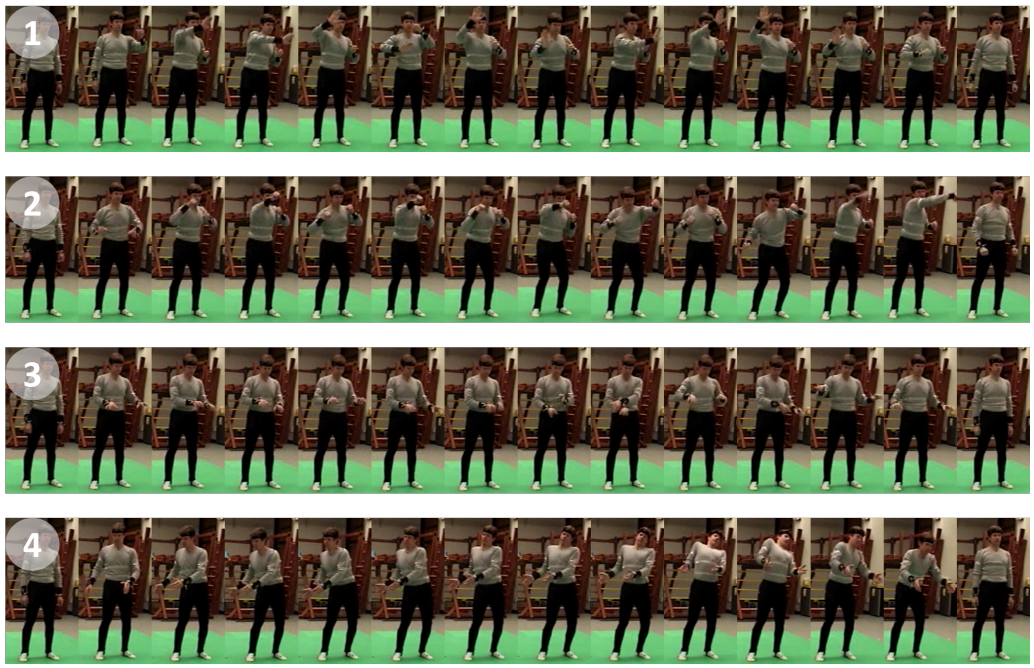


Fig. 2. The video shots of skills to demonstrate, 1) washing a window, 2) boxing, 3) playing piano, 4) moving a heavy box.

## B TIMING AND MOTIVATION OF RE-DEMONSTRATION AND RE-WATCHING BEHAVIORS

Besides the frequency, the timing of re-demonstration and re-watching also have different distribution when teaching robots in different engagement modes. We try to find the patterns and explore the reasons behind them.

First, for the timings of the re-demonstration, we plot participants' re-demonstration behaviors in each teaching interval (the interval means a participant just completed one teaching round and will start the next round) when teaching robots in the four engagement modes (shown in Figure 3 (a)). **1) For Z2O-Mode**, we can see clearly that the probabilities of the timing at which the re-demonstration behavior occurred during each teaching interval are ranked, in descending order, as *interval 1* > *interval 3* > *interval 2* > *interval 4*. Informative reason can be found in users' instant verbal feedback and interview. Usually, participants will demonstrate again after the first teaching round as they did not observe any feedback from the robot. For example, P38 (male, age: 25) said *"I need to demonstrate again because the robot did not move."* While for the second interval, when participants see that the robot has a little feedback, they think their demonstration is effective and usually choose to stop the re-demonstration and watch another round of learning. For example, P13 (male, age: 25) stated *"Now the robot should have caught my demonstration action. Let it learn for one more round."* For the third interval, participants want to adjust the demonstration again, hoping that the robot could learn much better. For instance, P6 (female, age: 25) mentioned *"The robot was improving. I felt that my demonstration action was still a little insufficient. I wanted to adjust it again to see if the robot can learn better."* However, most of the participants choose not to re-demonstrate in the fourth interval because they think the demonstration is good enough, and the robot seems to learn well. For example, P46 (male, age: 25) said *"There was nothing to adjust in my demonstration and the robot was learning with my actions."* **2) For D2O-Mode**, the re-demonstration behavior most occurred in the first and second intervals. This is mainly because some participants find that the robot's movements

are messy in the first round, so they want to adjust the demonstration. For example, P33 (female, age: 29) said *"The robot couldn't keep up with me in the first round. Maybe it was due to my demonstration problem. I had to do it again."* While some participants felt that the robot could move at the beginning, indicating that the demonstration should work, so they wanted to observe the follow-up learning of the robot. For example, P11 (male, age: 25) stated *"The robot gave me feedback in the first round. Although it is disorderly, I think I can let it learn more and then decide whether to re-demonstrate."* In the later teaching, participants think that there is no problem in their demonstration, and the robot is also learning seriously, so the behavior of re-demonstration happened less often than in the previous teaching. **3) For Full-Mode**, the behavior of re-demonstration occurs more often in the middle of the teaching process. Because at first, participants receive positive feedback from the robot and think that their demonstration action is satisfactory. However, with the progress of teaching, they will find that the robot's feedback does not change, so they will choose to demonstrate it again. For example, P1 (male, age: 25) said *"At first, I thought the robot was good, so I wanted to continue to observe its learning process. Later, when I saw that the robot's behavior did not change compared with the previous round, I began to doubt that there were problems in my demonstration, so I chose to re-demonstrate in the third and the fourth round of teaching."* **4) For None-Mode**, the frequency of re-demonstration decreased with the teaching process. This is because, in the beginning, participants usually reflect on or doubt their demonstration, but with the progress of teaching, they gradually give up re-demonstration. For example, P27 (male, age: 25) said *"In the previous teaching, when I saw that the robot had no feedback, I suspected that there was something wrong with my demonstration. However, after I adjusted the demonstration action twice, the robot still did not participate in my teaching process. This robot was like a student who did not want to learn with me, so I was disappointed and gave up the demonstration."*

Then, for the timings of the re-watching, we plot participants' re-watching behaviors in each teaching round when teaching robots in the four engagement modes (shown in Figure 3 (b)). We can observe that the re-watching behavior occurs more at the beginning and end of teaching, and less in the middle period. From the qualitative analysis, we find that this is because, in the beginning, participants are usually not familiar with the current level of the robot, so they hope to observe the robot's behavior more carefully by watching it several times. With the progress of the teaching process, they gradually understand the learning status of the robot, so the number of re-watching behaviors becomes less. Towards the end of the teaching, they want to confirm the robot's learning status, which leads to the number of re-watching behaviors rising again.

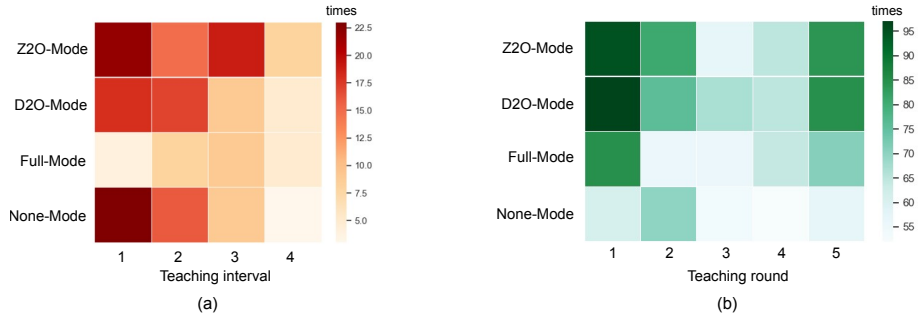


Fig. 3. Heatmaps of the timings of the re-demonstration behaviors and the re-watching behaviors. a) Heatmap of the re-demonstration behaviors in each teaching interval (four intervals in the five teaching rounds) of the four engagement modes. b) Heatmap of the re-watching behaviors in each teaching round of the four engagement modes.

## C VIDEO ILLUSTRATION

To help readers better understand our design and the experimental procedure, we have recorded the demonstrations of the four engagement modes we designed at different stages in different skill learning into videos and made an example video to illustrate the entire experimental process.

One video is named "EngagementExpressions.mp4" which demonstrates the proposed four kinds of engagement cues for readers to better understand. The other video is named "UserStudyProcedure.mp4" which illustrates the whole process when users participate in our experiment in the online simulated platform.

The video links are:

https://userstudy.link/OnlineAppendix/videos/UserStudyProcedure.mp4

https://userstudy.link/OnlineAppendix/videos/EngagementExpressions.mp4