Assistive Teaching of Motor Control Tasks to Humans

Megha Srivastava, Erdem Biyik, Suvir Mirchandani, Noah Goodman, Dorsa Sadigh
Motor control tasks are everywhere...
Motor control tasks are everywhere... and are challenging to learn!
Motor control tasks are everywhere... and are challenging to teach others!
There will always be new motor control tasks to teach
What makes teaching motor control tasks challenging?
What makes teaching motor control tasks challenging?

Requires specialized instructors
What makes teaching motor control tasks challenging?

Requires specialized instructors
Individual student variations
What makes teaching motor control tasks challenging?

- Requires specialized instructors
- Individual student variations
- Diverse physical conditions
Can AI-assistance help teach humans motor control tasks?
Can we leverage expert knowledge of a motor control task to help any human learn the task themselves?
AI-Assistance has helped bring more accessible, uniform teaching for simpler domains.
Weakest words

faisant, disant, agissant, ayant, étant

STRENGTHEN
Skill identification

Weakest words:
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Skill identification

Individualization

Weakest words:

faisant, disant, agissant, ayant, étant

STRENGTHEN

Practice Weak Skills
Skill identification

Individualization

Curricula creation ("drills")
Prior work: common education domains (e.g. math, language learning)

Skills in these domains are standardized & easy to detect!

Key complexity of motor control tasks: trajectories over time
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Key complexity of motor control tasks: **trajectories over time**

**Initial State** $s_0 : (x,y)$

**Action**: $(x,y)$

**Reward**: Overlap w/ Goal Sequence

**Scenario**: $\xi$: $(s_0, r)$ initial state and reward pair (e.g. goal character sequence)

**Trajectory**: $\tau$: $(s_0, a_0) \ldots (s_T, a_T)$ sequence for a particular scenario $\xi$: $(s_0, r)$
Key complexity of motor control tasks: trajectories over time

Skill identification

Individualization

Curricula creation ("drills")
Key complexity of motor control tasks: trajectories over time

Skill identification

How do we identify motor control skills from motion trajectories?
Unsupervised Skill Discovery: CompILE [Kipf et. al. ‘19]

Boundary Network $q_{\phi}(b|a, s)$

Encoding Network $q_{\phi}(z|a, s)$

 latent code $z_1$

Decoding Network $p_{\theta}(a|s, z)$

Encoder

Decoder

Re-construction Loss Function (across set $C$ of segments in trajectory):

$$-\mathbb{E}_{q_{\phi}(b,z|a,s)} \sum_{i=1:|C|} [P(t \in C_i) * \log p_{\theta}(a|s, z_i)]$$
Unsupervised Skill Discovery: CompILE [Kipf et al. ‘19]

Extract Skills from Expert Demonstrations

\[ \tau_1^e, \tau_2^e, \tau_3^e, \tau_4^e, \ldots \]

Boundary Network
\[ q_\phi(b|a, s) \]

Encoding Network
\[ q_\phi(z|a, s) \]

Decoding Network
\[ p_\theta(a|s, z) \]

Encoder

Decoder

Trained CompILE
Unsupervised Skill Discovery: CompILE [Kipf et. al. ‘19]
Key idea: Use expert demos + unsupervised skill discovery
Key complexity of motor control tasks: trajectories over time

Individualization

How do we identify individual expertise from student motion trajectories?
Identifying Individual Student Skill Expertise

Expert Demonstration

Trained ComPILE

Skill 1

Skill 2

Skill 3

Skill 4
Identifying Individual Student Skill Expertise

Expert Demonstration

Novice Student Demonstration
Identifying Individual Student Skill Expertise

Expert Demonstration

Novice Student Demonstration
Identifying Individual Student Skill Expertise

Penalize Skill 2 more than Skill 3 and Skill 4?

*temporal decay term j*
Skill 1: 0
Skill 2: r/j
Skill 3: r/2j
Skill 4: r/3j

Identifying Individual Student Skill Expertise

Reward $r =$

$-\alpha * \text{(pixel dist. between student and expert)}$

$+\beta * \text{(highest x value of trajectory)}$
Identifying Individual Student Skill Expertise

Skill 1: 0
Skill 2: -12
Skill 3: -6
Skill 4: -4

Reward $r = -12$
Penalty $j = 1$
Identifying Individual Student Skill Expertise

Diverse Scenarios

Maximum Set-Coverage
over expert demonstrations / skills

Individual’s Most Challenging Skills

Skill 1: 0
Skill 2: -12
Skill 3: -6
Skill 4: -4

Skill 1: -12
Skill 2: -6
Skill 3: -4
Skill 4: -3

Skill 1: -12
Skill 2: -6
Skill 3: -4
Skill 4: -3

Skill 1: -9
Skill 2: -8
Skill 3: -5
Skill 4: -3
Identifying Individual Student Skill Expertise

Skill 1: -1  
Skill 2: -4  
Skill 3: -1  
Skill 4: 0

Skill 1: -1  
Skill 2: -10  
Skill 3: -5  
Skill 4: -7

Skill 1: -9  
Skill 2: -8  
Skill 3: -5  
Skill 4: -3
Key complexity of motor control tasks: trajectories over time

Curricula creation ("drills")

How do we create novel drills that improve learning from motion trajectories?
Drills: **Repetitive** sequences that targets skills in their most common contexts
Drills: Repetitive sequences that targets skills in their most common contexts

Skill 1: -9  
Skill 2: -8  
Skill 3: -5  
Skill 4: -3

Skill 1  (from CompILE!)

Drill Creator

$N_{\text{rep}} = 3 \quad n = 2$
Drills: Repetitive sequences that targets skills in their most common contexts

Skill 1: -9  
Skill 2: -8  
Skill 3: -5  
Skill 4: -3

Drill Creator

Skill 1  
(from CompILE!)

$N_{rep} = 3 \quad n = 2$

Individualized Drill to Practice
1. Extract Skills from Expert Demonstrations

2. Select Scenarios with Diverse Skills

3. Identify Individual Student Skill Expertise

4. Automatically Create Individualized Drills
Experiments: Parking & Writing

**Parking**

Round 3 of Phase III. Remember to use the joystick on the screen to control the vehicle. Park the car in the blue square.

**Writing**

Next round: This is a PRE-TEST round. Trace the characters from left to right, holding down your mouse until you are done. The round is over either when the timer ends, or you release your mouse.
Writing Task

Goal: Trace Balinese characters

Control: continuous mouse control

Timer

Expert: human trajectories from Omniglot dataset

Next round! This is a PRE_TEST round. Trace the characters from left to right, holding down your mouse until you are done. The round is over either when the timer ends, or you release your mouse.
State (2-d): x-y positions

Action (2-d): x-y movement

Next round! This is a PRE_TEST round. Trace the characters from left to right, holding down your mouse until you are done. The round is over either when the timer ends, or you release your mouse.
Parking Task

**Expert:** Optimal Soft-Actor Critic Agent

**Goal:** Park yellow car on blue spot

**Control:** continuous mouse control

Round 3 of Phase III. Remember to use the joystick on the screen to control the vehicle. Park the car in the blue square!
Parking Task

State (6-d):
- position,
- velocity,
- heading

Action (2-d):
- acceleration,
- heading

Round 3 of Phase III. Remember to use the joystick on the screen to control the vehicle. Park the car in the blue square!
Are skills returned from CompILE useful for learning?
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- Prolific user study (n=20 parking, n=25 writing)

- Reward Improvement: \[
\frac{\sum_{i} r_{i}^{\text{eval}}}{n_{\text{eval}}} - \frac{\sum_{i} r_{i}^{\text{pretest}}}{n_{\text{pretest}}}
\]

- **CompILE Skills** outperform **Full Trajectory**, **Time Heuristic** inconsistent!
Do individualized drills help students learn?
Do individualized drills help students learn?
Distribution of hardest skills across individuals
Do individualized drills help students learn?

Individualized drills generally improve student performance.
Do individualized drills help students learn?

**Parking**

- **Δ Reward**: Skills (0.8), Drills (1.0), Ind. Drills (1.2)
- **Helpfulness**: Skills (3.5), Drills (2.5), Ind. Drills (1.0)

**Writing**

- **Δ Reward**: Skills (180), Drills (150), Ind. Drills (250)
- **Helpfulness**: Skills (5.0), Drills (5.0), Ind. Drills (5.0)

* indicates a significant difference
Do individualized drills help students learn?

Participants significantly prefer ind. drills for Writing
Do individualized drills help students learn?

Participants significantly prefer skills over ind. drills for Parking *despite performing better w/ drills!*

Participants significantly prefer ind. drills for Writing
Optimal Expert Action: Reverse (tricky!)

No Individualization: 27% of students try to reverse

Individualization: 53% of students try to reverse but find it hard!

Students learn to more closely follow expert
Key Take-Aways

- AI-Assistance for skill discovery, individualization, and drill-creation
- Easier to “do” than “teach” \(\rightarrow\) expert demonstrations can come from anyone!
- Participants benefited from AI-Assistance for two different control tasks
Future Directions

Stronger models of student motor learning

Half-Trained Student

Reversing Difficulty Student
Future Directions

Risks of expert-student mismatch & accounting for preferences

"I hope this becomes a learning tool for writing new scripts. Really cool concept just hard to get to grips with when I have a disability."
- User Study Participant