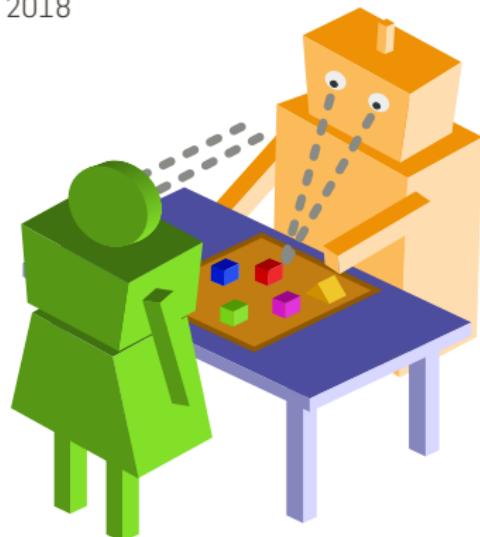




# child-robot interaction for learning

are we ready yet to push the classroom's door?

Symposium on Robots for Language Learning – 13 Dec. 2018



Séverin Lemaignan

Bristol Robotics Lab University of the West of England



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Quick poll:

**What is the greatest challenge that  
“child-robot interaction for learning” faces  
today?**

Quick poll:

**What is the greatest challenge that  
“child-robot interaction for learning” faces  
today?**

Getting our robots accepted & used in schools, without us being around...?



Experimental set-up





What about some maths now?

Yeah, yeah...

open, underspecified situations  
complex social dynamics  
rich semantics  
interplay of socio-cognitive functions  
(and ideally, a bit of actual learning)

What about some maths now?

Yeah, yeah...

Let's frame it bit

What about some maths now?

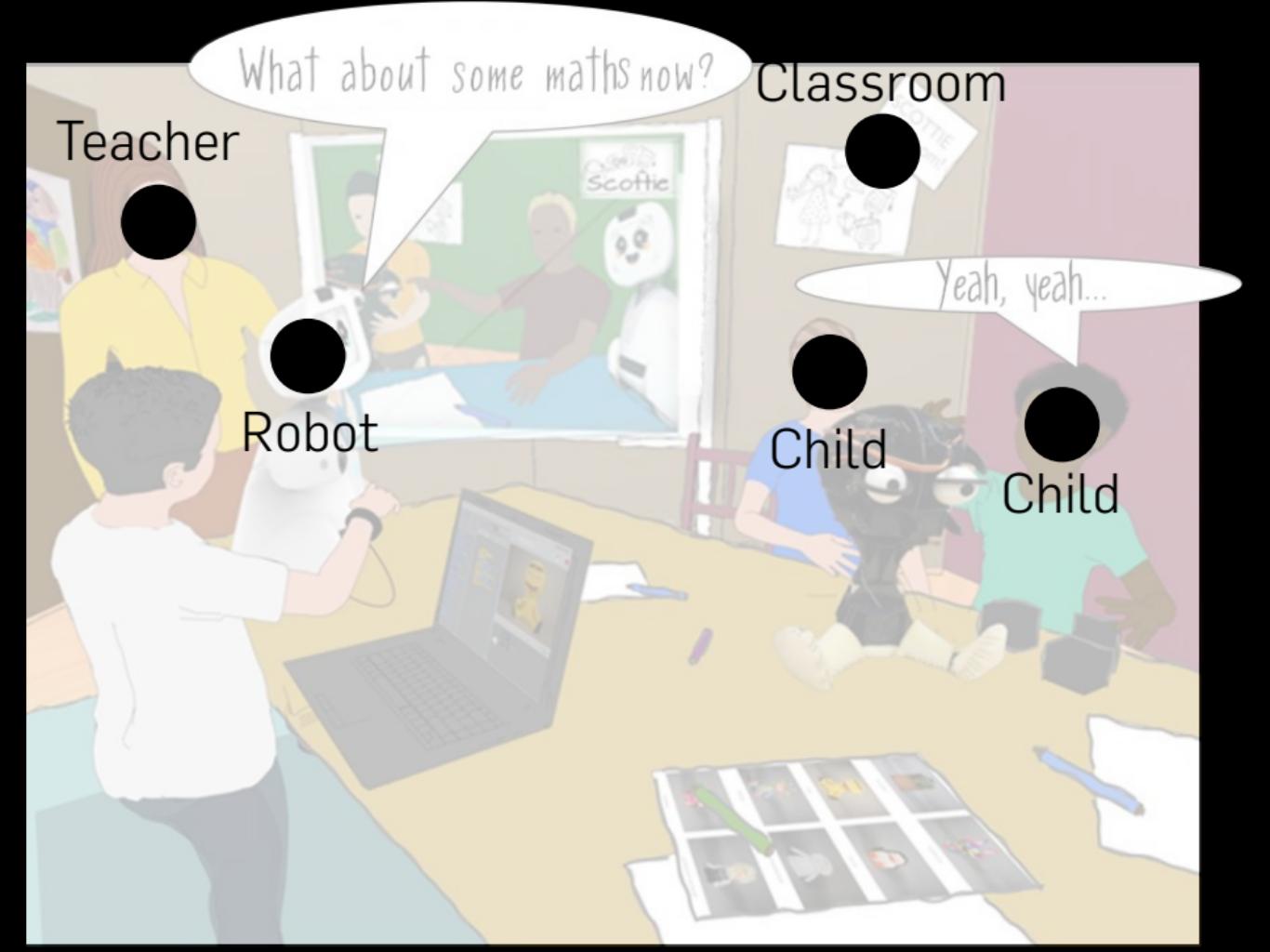
Yeah, yeah...

What about some maths now?

Yeah, yeah...

What about some maths now?

Yeah, yeah...



What about some maths now?

Teacher

Robot

Classroom

Yeah, yeah...

Child

Child

Teacher



Classroom



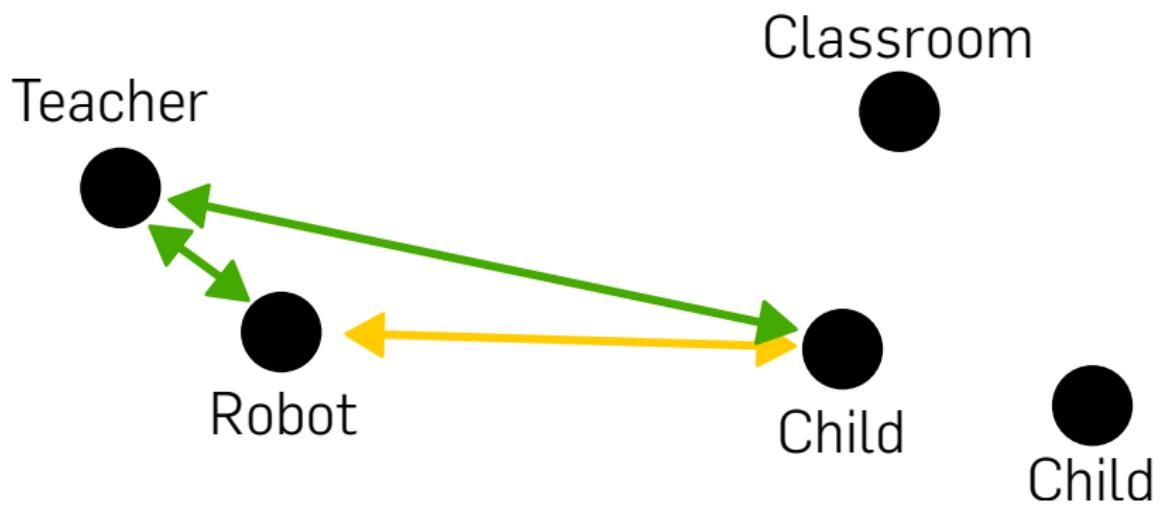
Robot

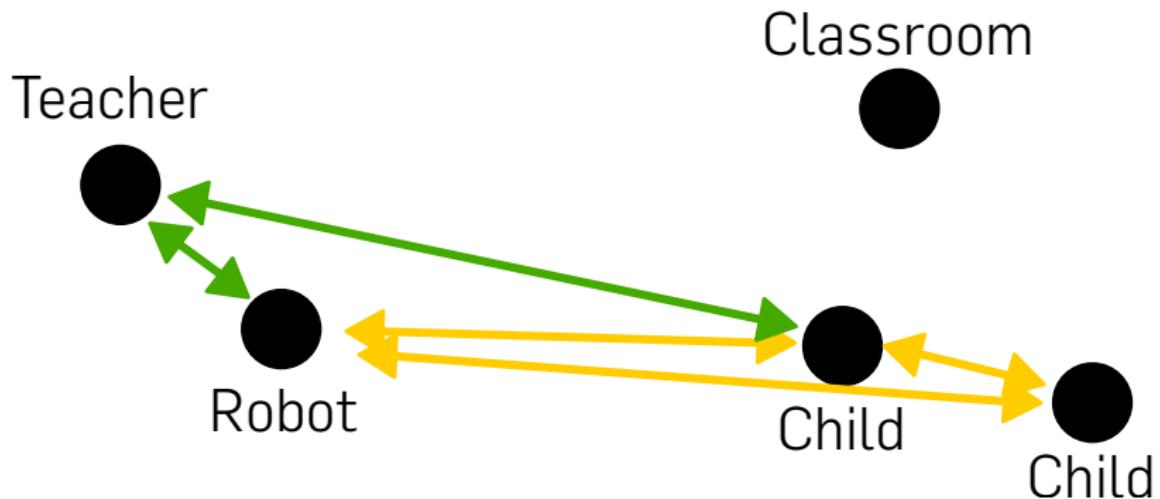


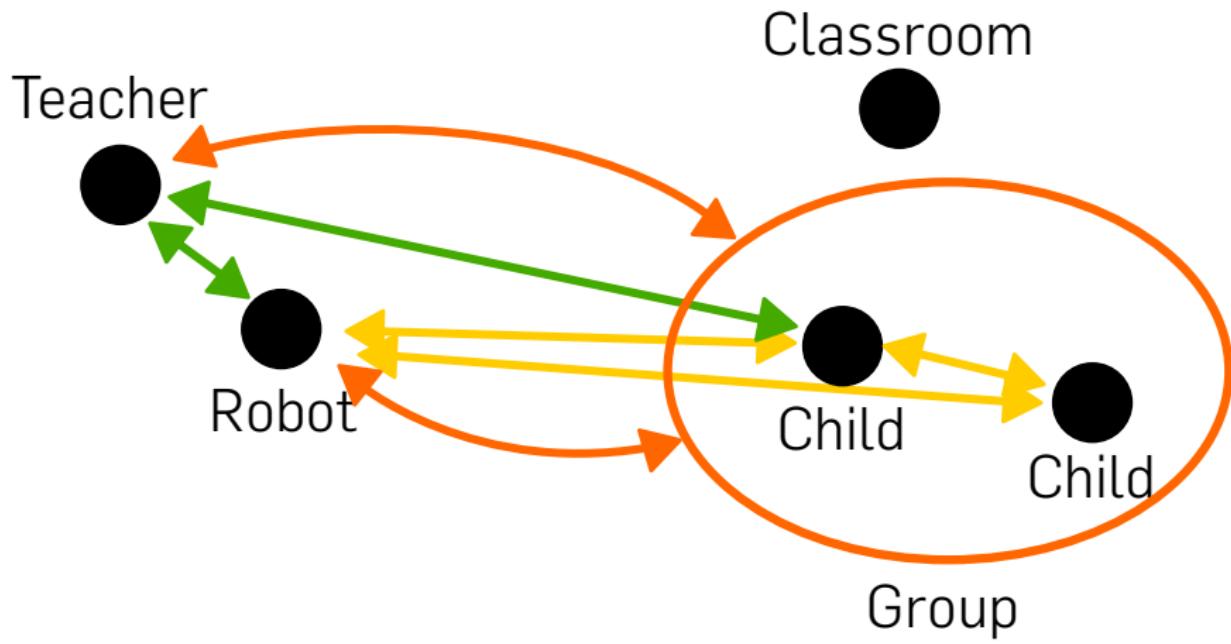
Child

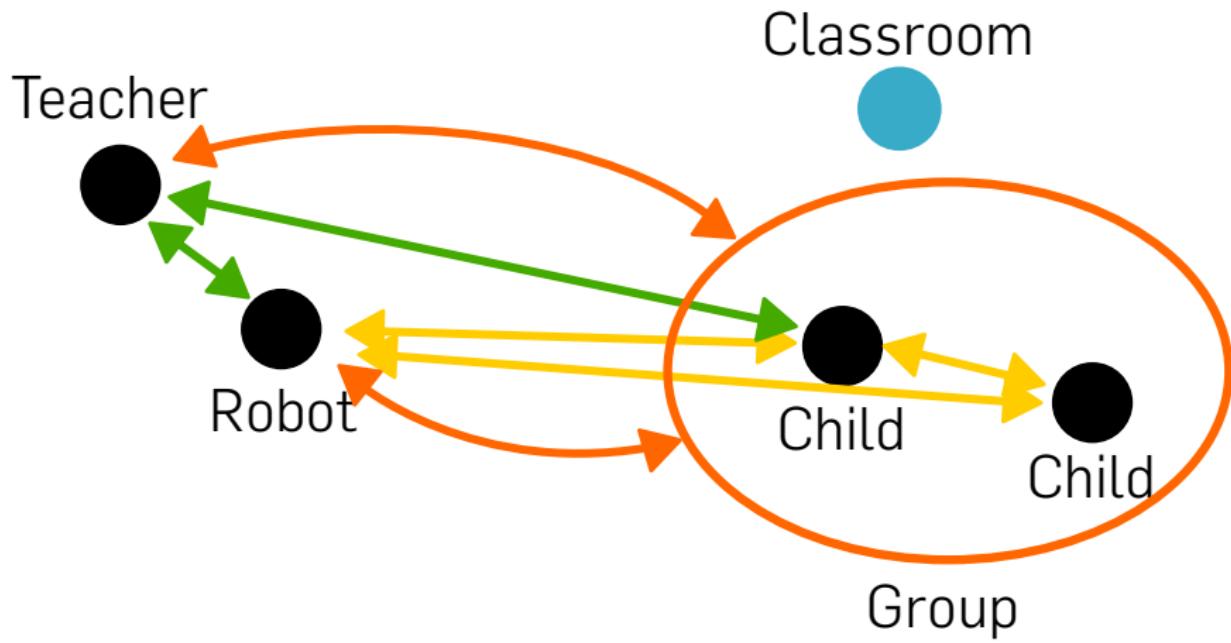
Child











# THE CLASSROOM

What is the most effective learning tool in a classroom?



## The classroom

A horizontal row of fifteen empty circles. The 6th circle from the left is filled black.

## The teacher

○○○○○○○○○○

## The children

A horizontal row of 15 small, uniform circles arranged in a single line.

Data-driven!

A horizontal row of 15 small circles, evenly spaced, used as a visual element in the document.

# WHY THAT?

- **ubiquitous**: a pervasive yet unremarkable tool that blend into the daily learning routine; has to be trustworthy (i.e. reliable), readily replaceable (i.e. cheap, no affective bonding), intuitive (i.e. few simple affordances)

## WHY THAT?

- **ubiquitous:** a pervasive yet unremarkable tool that blend into the daily learning routine; has to be trustworthy (i.e. reliable), readily replaceable (i.e. cheap, no affective bonding), intuitive (i.e. few simple affordances)
- **versatile:** applicable to a broad range of learning scenarios; good tools are not overly specialised (appearance and interaction modalities do not imply or force a specific/unique use case)

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- **effective:** to gain broad acceptance in a classroom, a tool must critically represent a net educative gain and must not incur higher workload for the teacher



Pens and paper are pervasive...

...what about robots?

**What does it look like to build a pen-like robot?**

## DESIGN PRINCIPLES FOR THE CLASSROOM

- **ubiquitous:** a pervasive yet unremarkable tool that blend into the daily learning routine; has to be trustworthy (i.e. reliable), readily replaceable (i.e. cheap, no affective bonding), intuitive (i.e. few simple affordances)

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WORDMANIA





WORDMANIA



The classroom

oooooooooooo●ooooo

The teacher

oooooooooooo

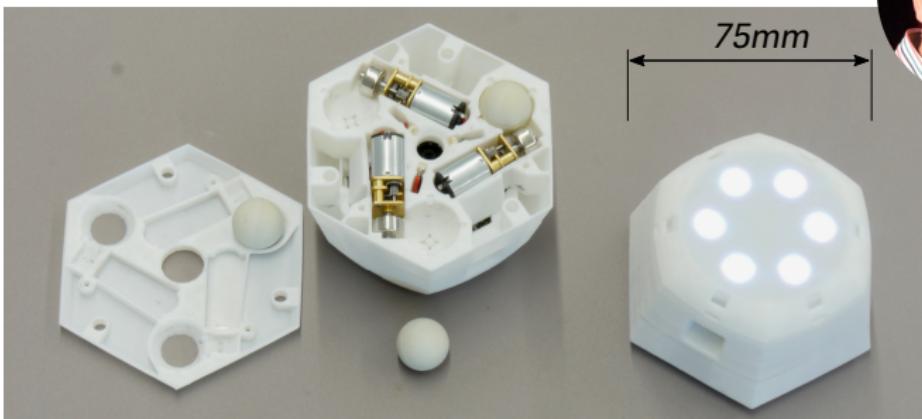
The children

oooooooooooooooooooo

Data-driven!

oooooooooooooooooooo

## CELLULO: HARDWARE



- Holonomic motion
- Sub-mm absolute localisation (no external hardware)
- Haptic feedback + tactile RGB LED buttons
- Bluetooth

The classroom

oooooooooooo●ooooo

The teacher

oooooooooooo

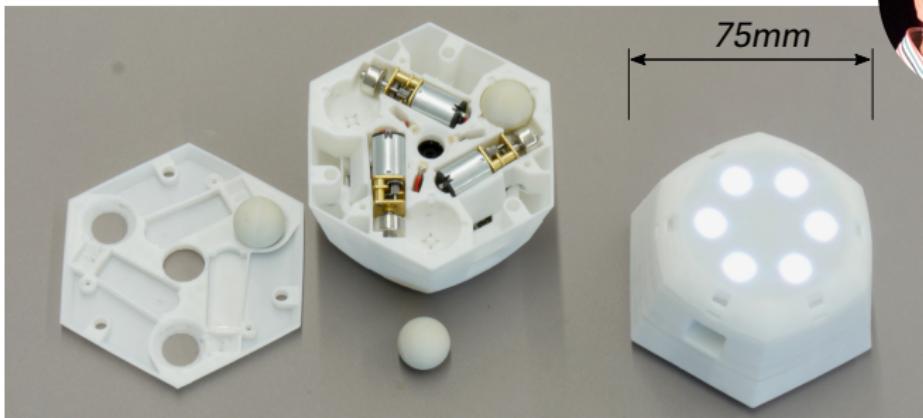
The children

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Data-driven!

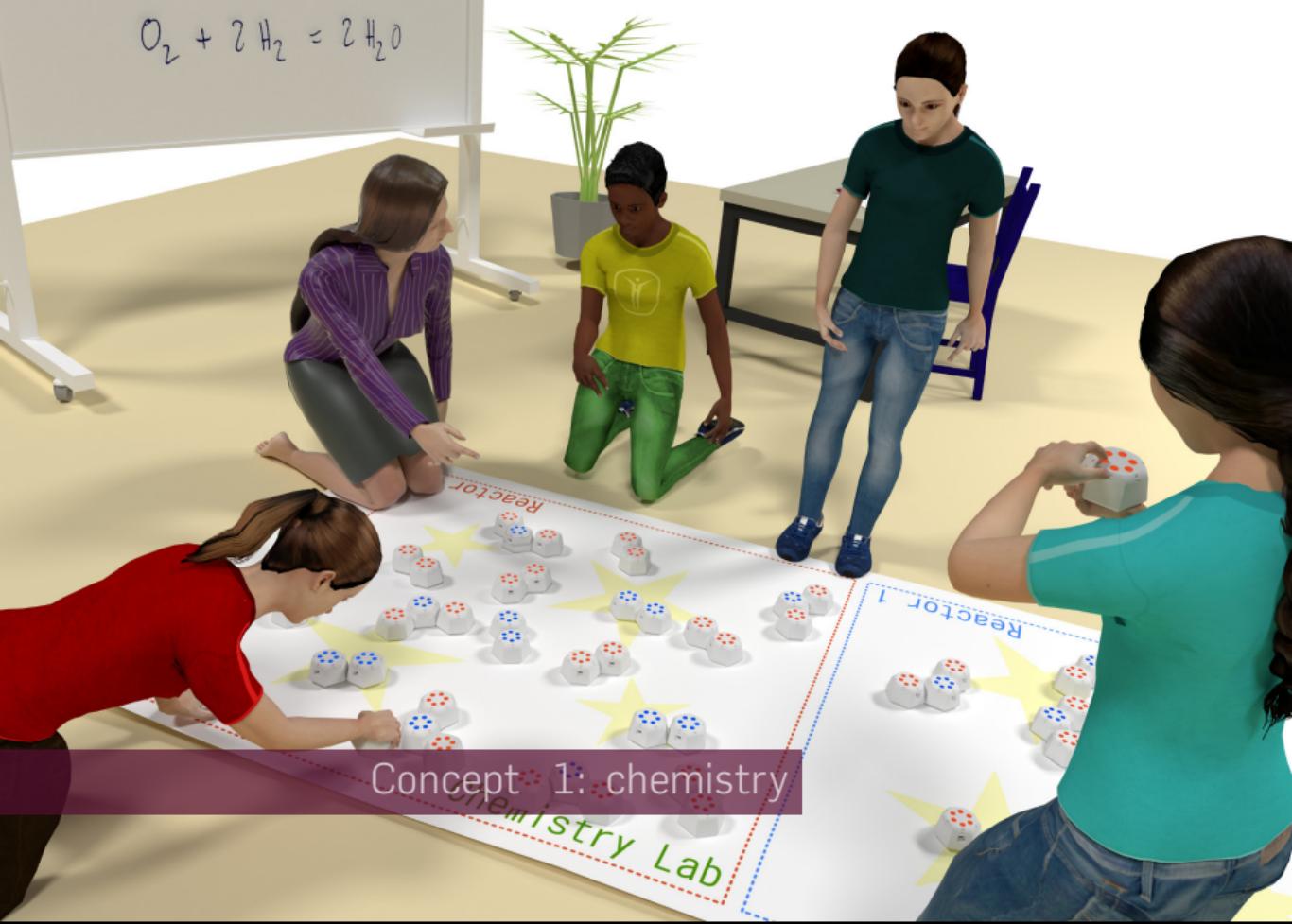
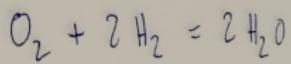
oooooooooooooooooooo

## CELLULO: HARDWARE

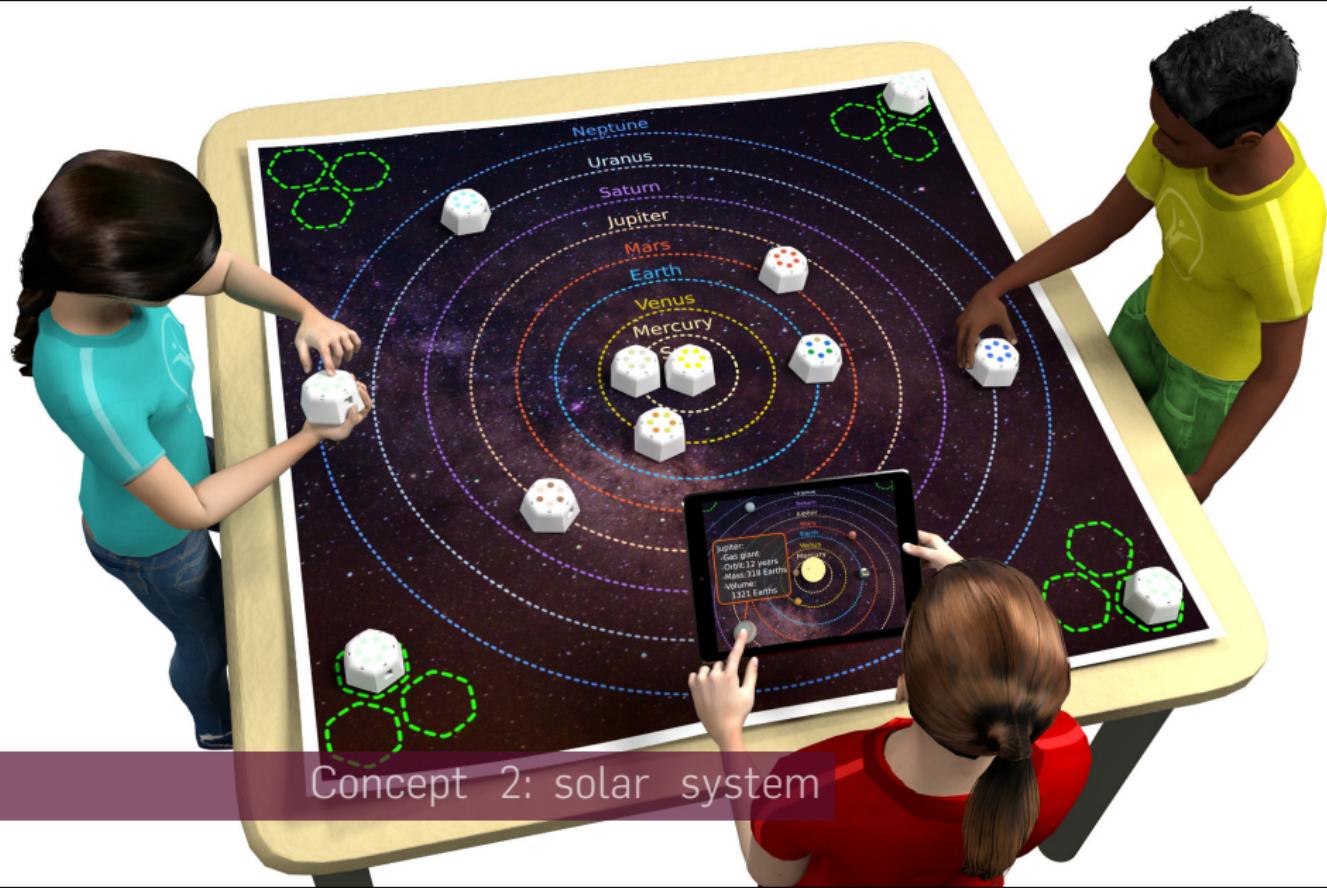


- Holonomic motion
- Sub-mm absolute localisation (no external hardware)
- Haptic feedback + tactile RGB LED buttons
- Bluetooth
- Affordable (prototype: €125)

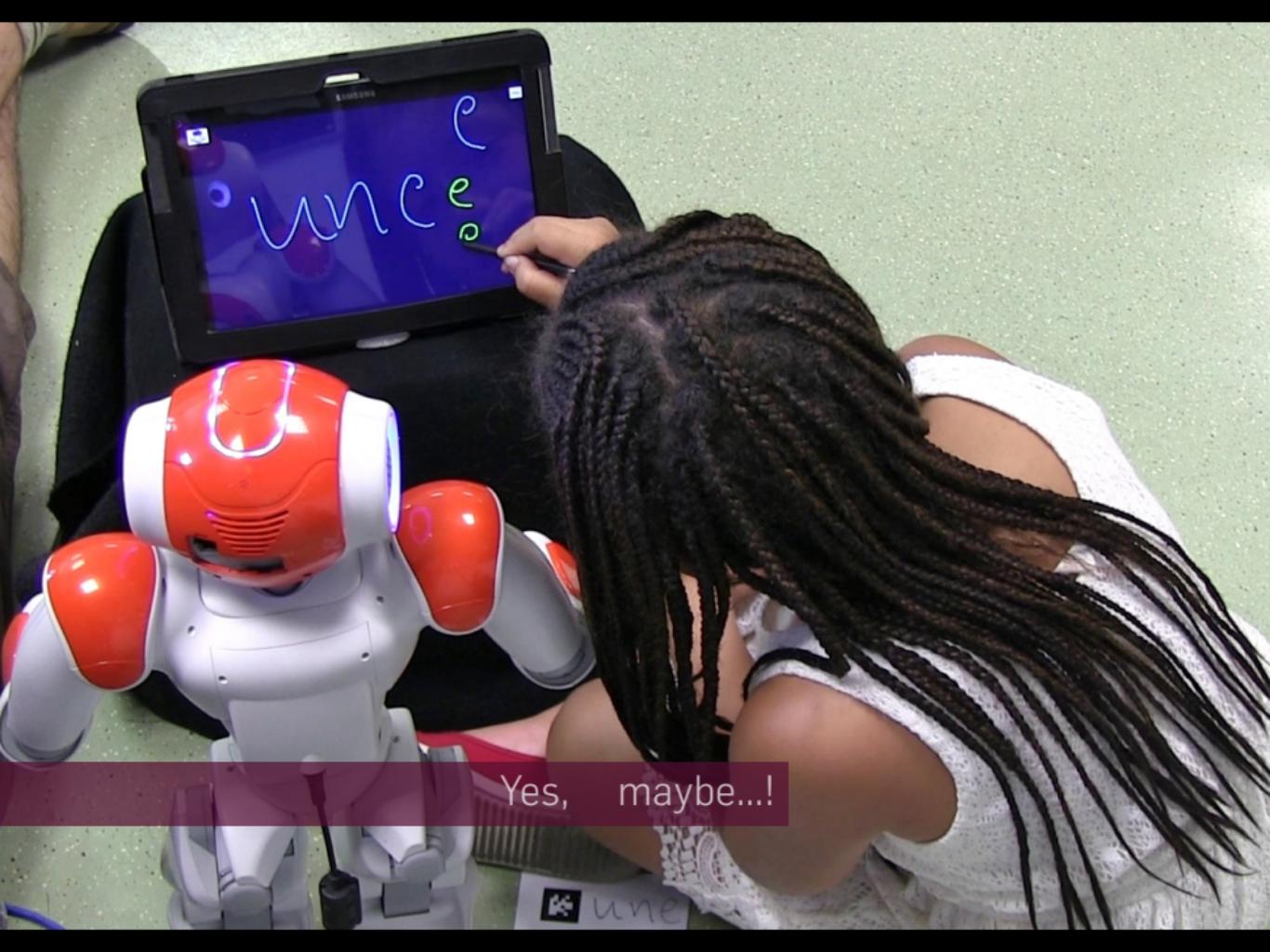




## Concept 2: solar system

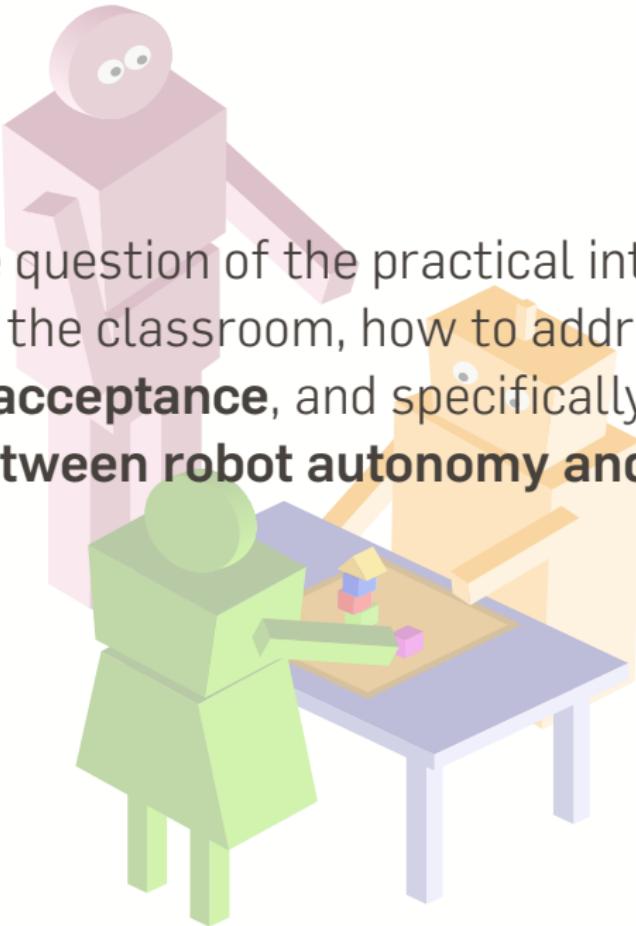


If a “pen-like” robot is actually doable,  
**...are social robots relevant at all...?**

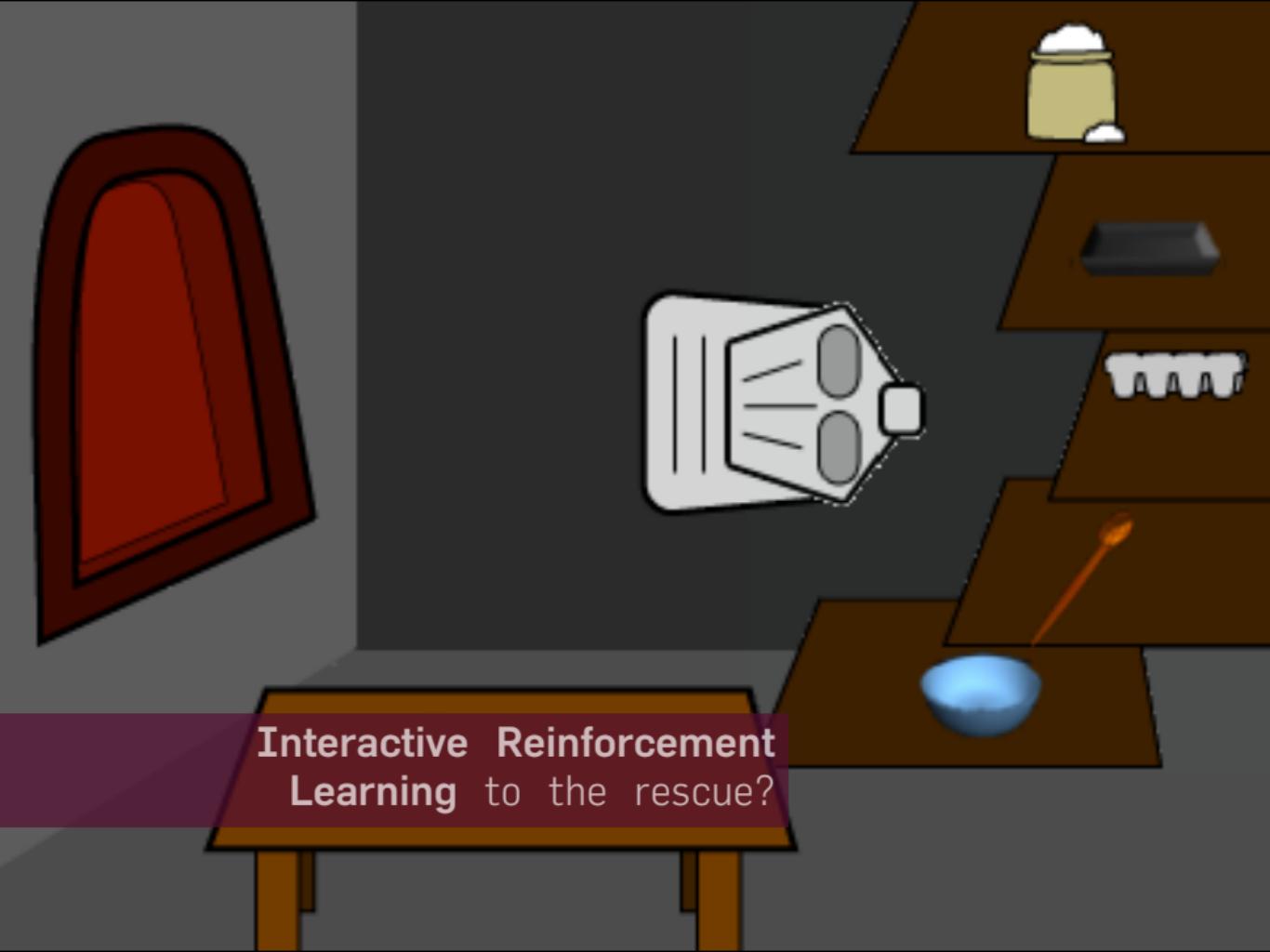


Yes, maybe...!

THE TEACHER



Beyond the question of the practical integration of robots into the classroom, how to address **teachers' acceptance**, and specifically, the **tension between robot autonomy and teacher control?**



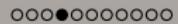
A cartoon illustration of a room. On the left, there's a red door set in a grey wall. Above it, a lamp with a brown shade and a yellow base sits on a shelf. To the right of the lamp is a white light switch with three vertical lines and two grey circles. In the bottom right corner, a blue ball sits on a brown surface, with an orange stick pointing towards it. The background is a dark grey gradient.

**Interactive Reinforcement  
Learning** to the rescue?

The classroom



The teacher



The children



Data-driven!



# AUTONOMOUS ROBOT, YET TEACHER IN THE LOOP?



To be relevant to us, we need:

- a real robot

The classroom

oooooooooooooooooooo

The teacher

ooo●oooooooo

The children

oooooooooooooooooooo

Data-driven!

oooooooooooooooooooo

# AUTONOMOUS ROBOT, YET TEACHER IN THE LOOP?



To be relevant to us, we need:

- a real robot
- a real interaction (...with a human!)

The classroom

oooooooooooooooooooo

The teacher

ooo●oooooooo

The children

oooooooooooooooooooo

Data-driven!

oooooooooooooooooooo

# AUTONOMOUS ROBOT, YET TEACHER IN THE LOOP?



To be relevant to us, we need:

- a real robot
- a real interaction (...with a human!)
- a continuous interaction

The classroom

oooooooooooooooooooo

The teacher

ooo●oooooooo

The children

oooooooooooooooooooo

Data-driven!

oooooooooooooooooooo

## AUTONOMOUS ROBOT, YET TEACHER IN THE LOOP?



To be relevant to us, we need:

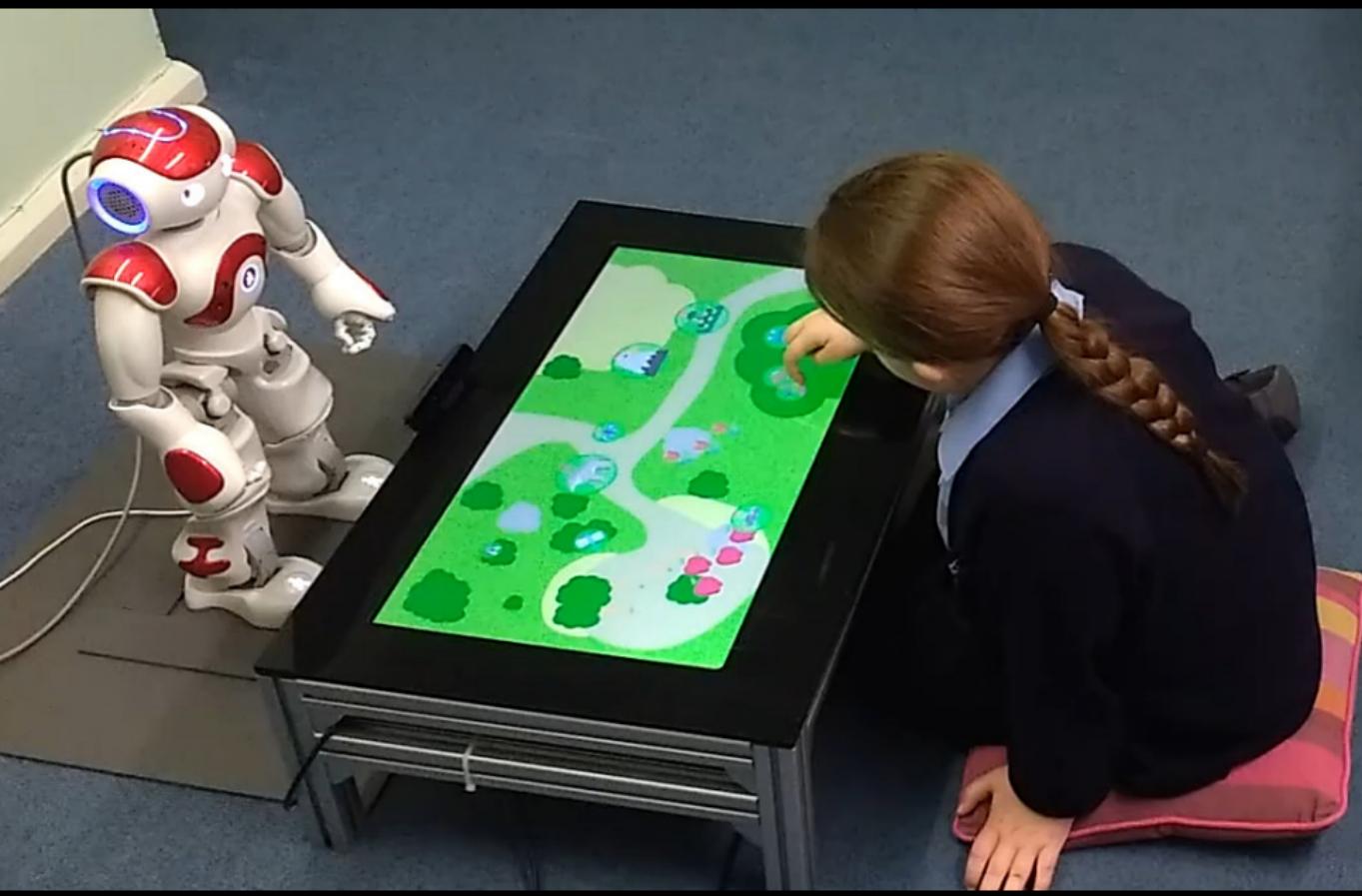
- a real robot
- a real interaction (...with a human!)
- a continuous interaction
- a realistic task (large state vector & action space)

# AUTONOMOUS ROBOT, YET TEACHER IN THE LOOP?



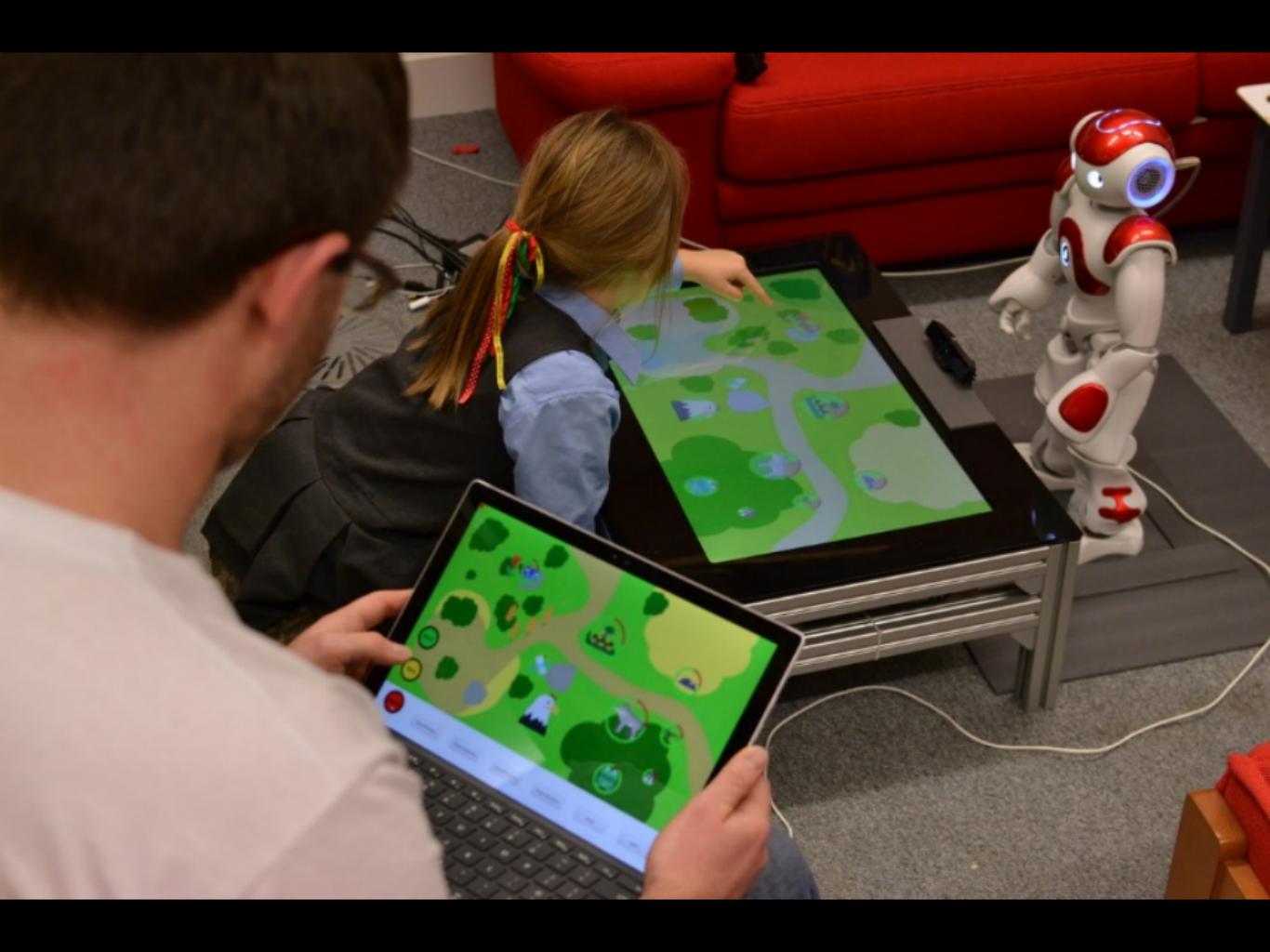
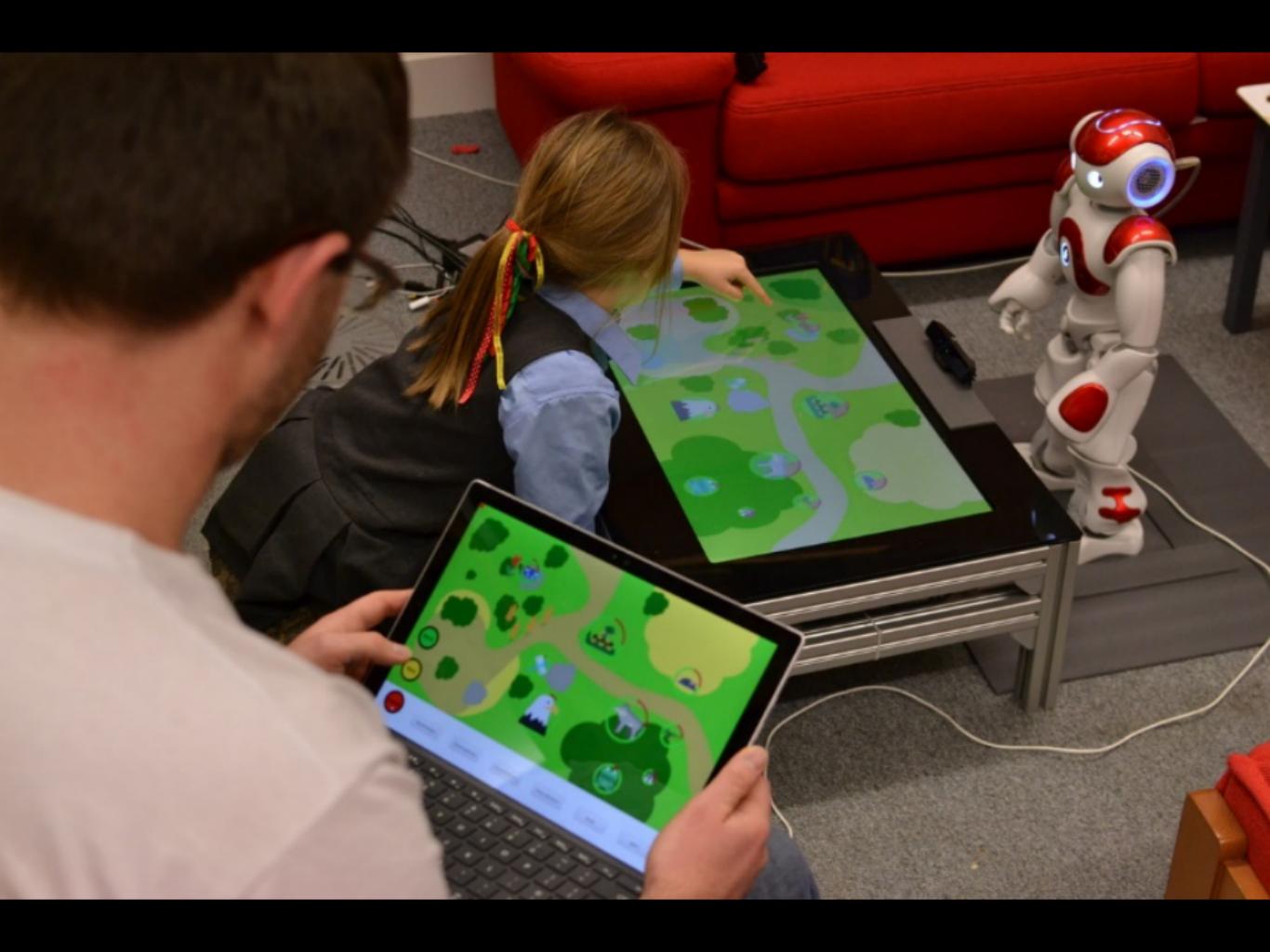
To be relevant to us, we need:

- a real robot
- a real interaction (...with a human!)
- a continuous interaction
- a realistic task (large state vector & action space)
- also including social behaviours & social dynamics

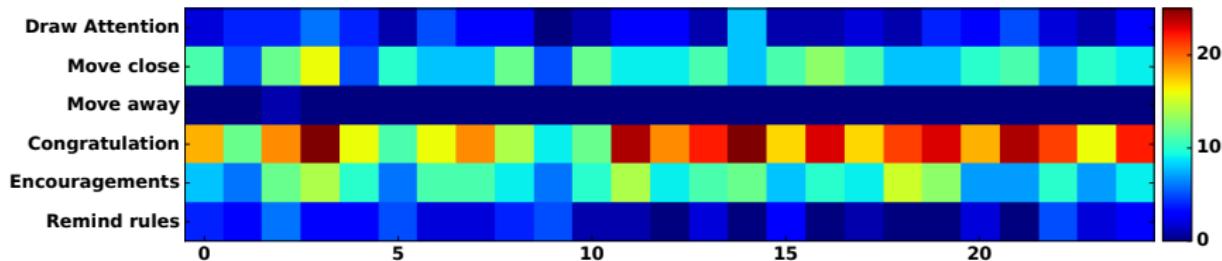




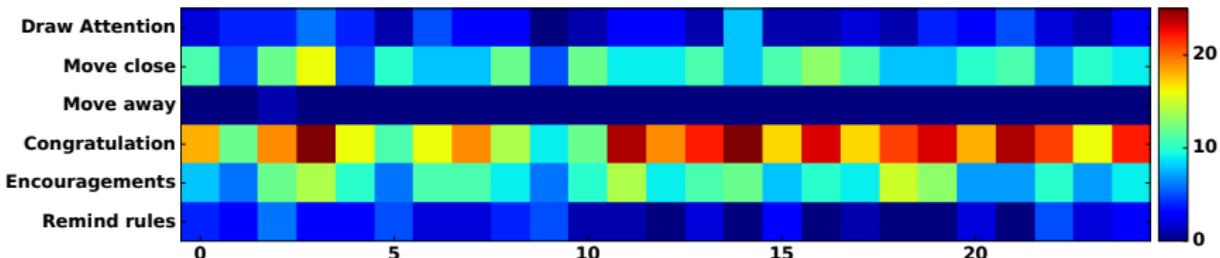
$|state| = 210$   $|action\_space| = 655$



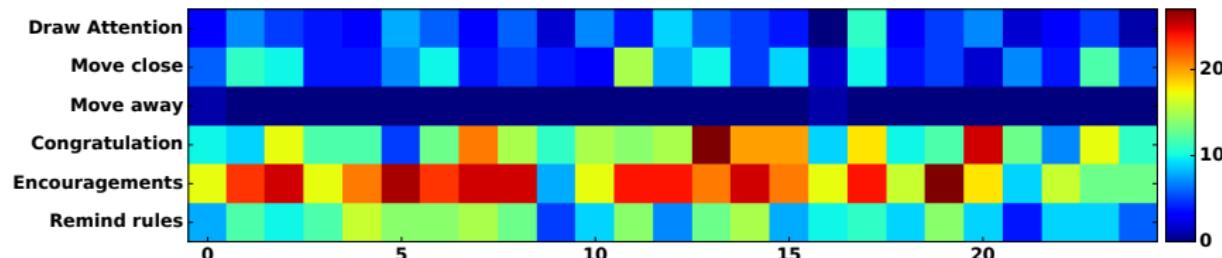
## Supervised



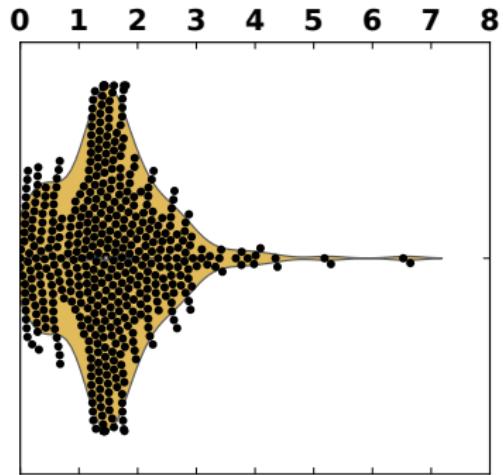
## Supervised



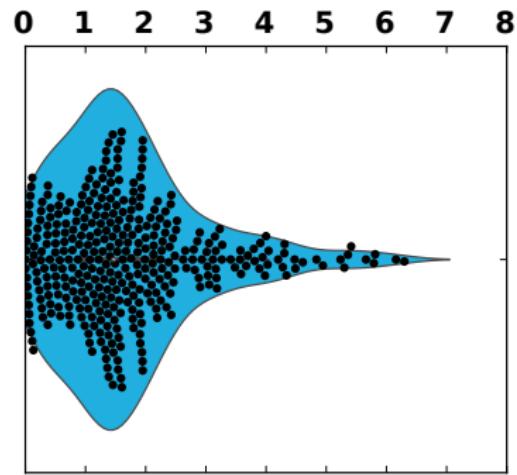
## Autonomous



Time since eating event for each congratulation action (s)

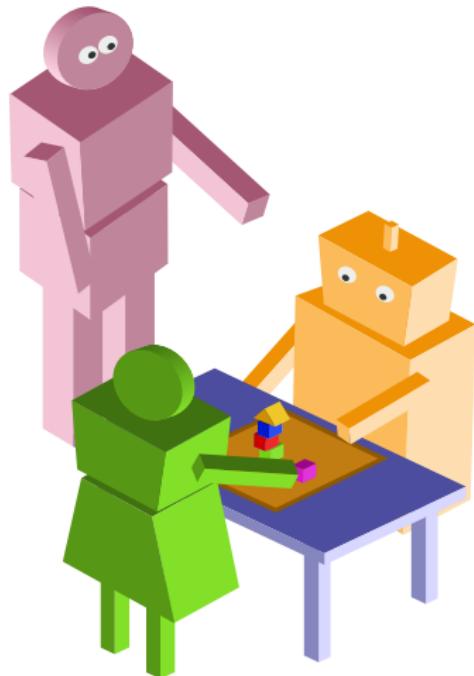


supervised



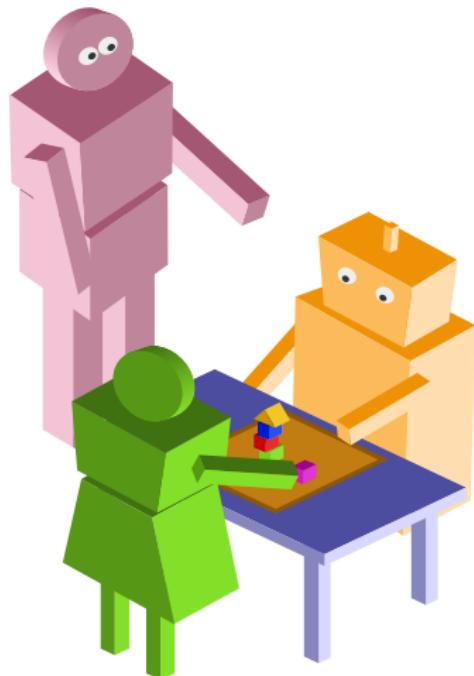
autonomous

## WHAT DOES THAT MEANS FOR THE TEACHER?



- **Progressively transferring autonomy** demonstrably works in non-trivial tutoring scenarios
- (it also learns some elements of **social behaviours** and **social timing**)

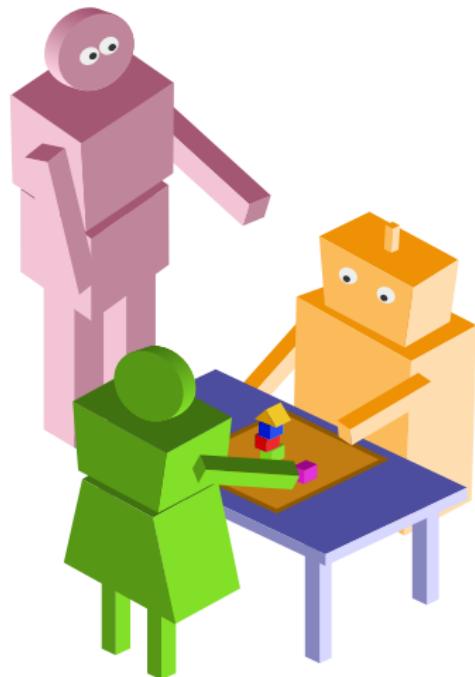
## WHAT DOES THAT MEANS FOR THE TEACHER?



Key properties:

- **progressive autonomy** yet **transparency** of the behaviour;
- **observability** and possibility to **take over**;
- because the training takes place in-situ, the robot behaviours are **co-constructed** by the teacher and the child

## WHAT DOES THAT MEANS FOR THE TEACHER?



Yet:

- Design of the input state tricky and largely task dependent;
- What about more complex social behaviours?
- Nothing yet on group dynamics

# THE CHILDREN: THE CHALLENGE OF “DOING TOGETHER”

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

●oooooooooooooooooooo

Data-driven!

oooooooooooooooooooo

# SOCIAL OR NOT SOCIAL?

Non-social



Social

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

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Data-driven!

oooooooooooooooo

# SOCIAL OR NOT SOCIAL?

Tool?

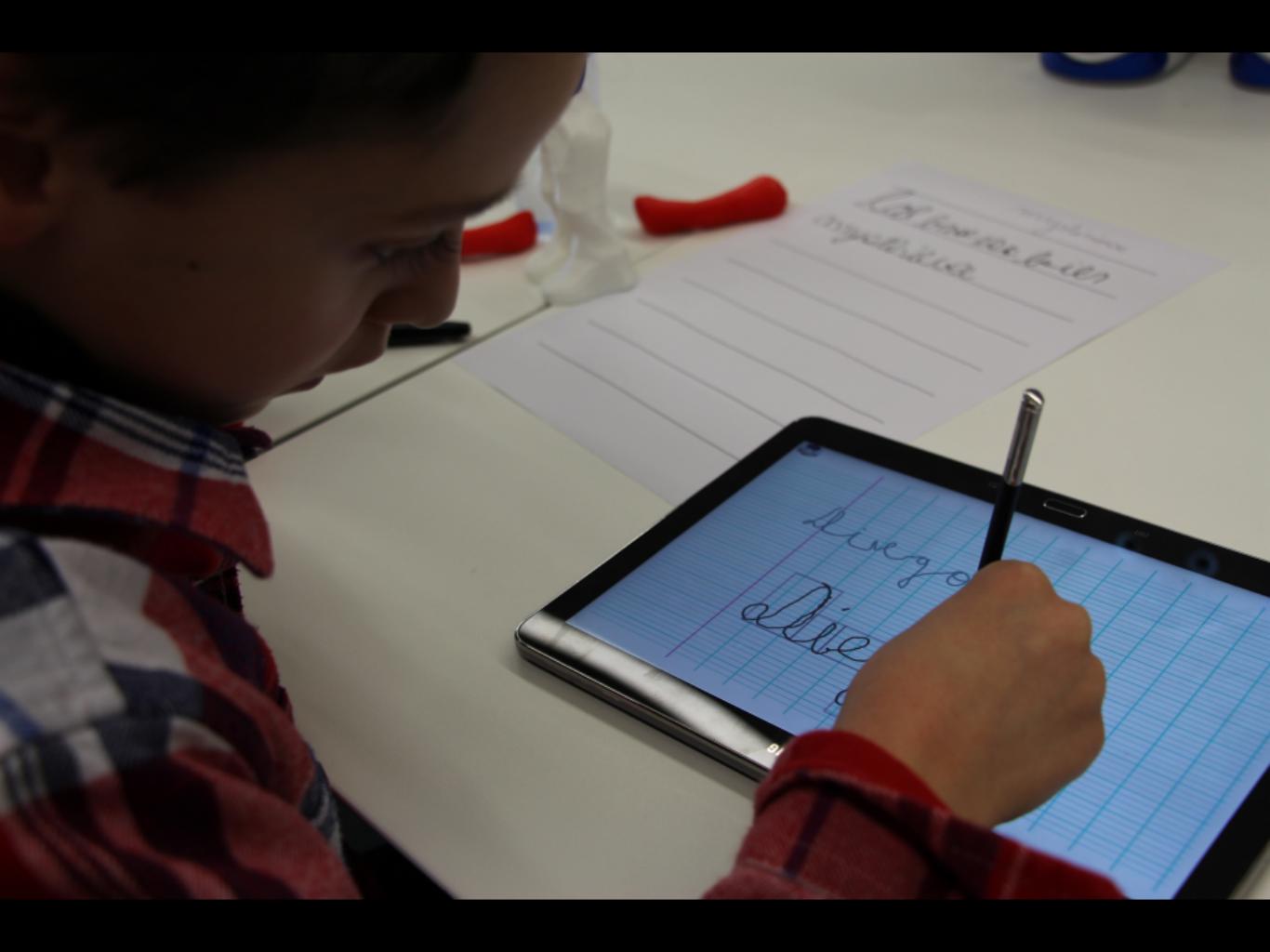


Peer/tutor?

Lithuanian  
mythica

Diego

Allie



The classroom



The teacher



The children



Data-driven!



# THE COWRITER PROJECT



Can we address children' hand-writing impairments with robots?

The classroom

oooooooooooooooo

The teacher

oooooooooooo

The children

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Data-driven!

oooooooooooooooooooo

# THE COWRITER PROJECT



Can we address children' hand-writing impairments with robots?

- Robots do not know how to write!

The classroom

oooooooooooooooo

The teacher

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The children

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Data-driven!

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# THE COWRITER PROJECT



Can we address children' hand-writing impairments with robots?

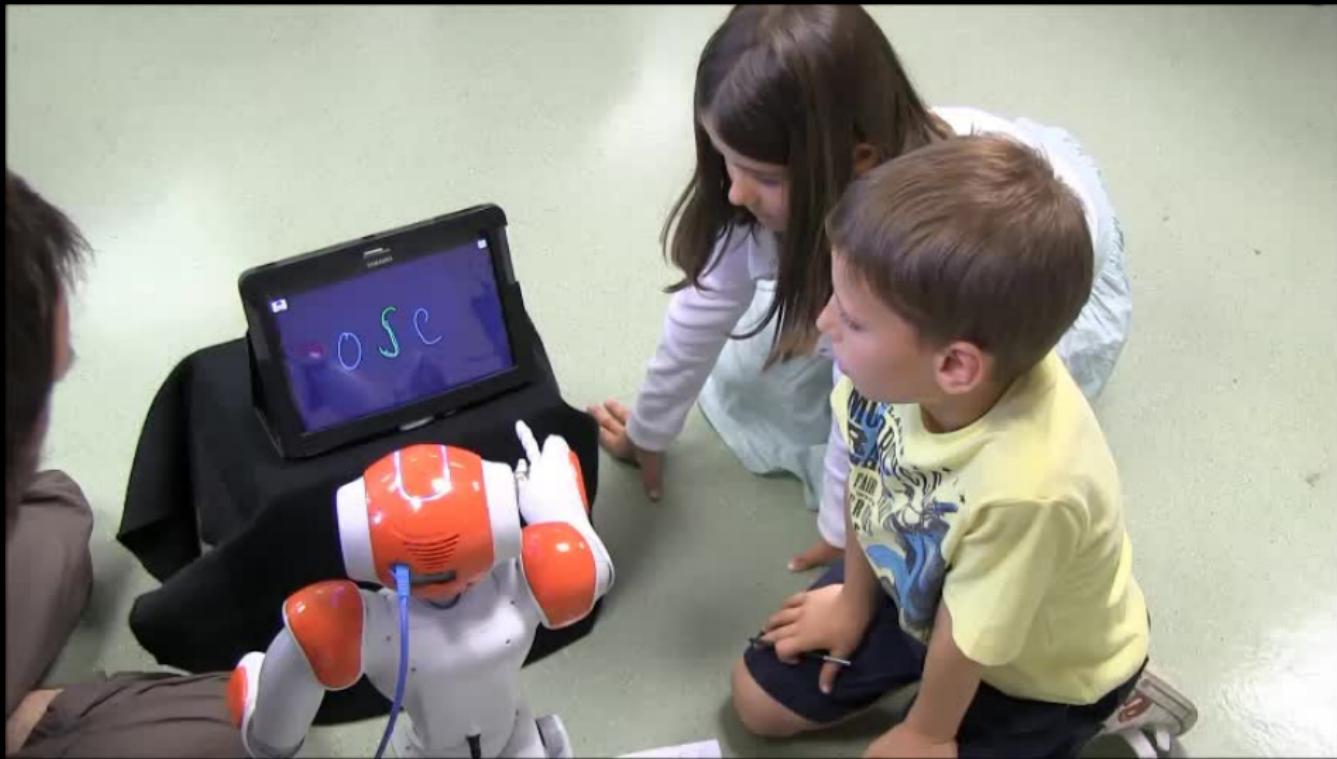
- Robots do not know how to write!
- Learning by Teaching

# THE COWRITER PROJECT



Can we address children' hand-writing impairments with robots?

- Robots do not know how to write!
- Learning by Teaching
- (nice side-effect: we can adapt to each child and each disabilities)



The classroom

oooooooooooooooo

The teacher

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The children

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Data-driven!

oooooooooooooooooooo

# LEARNING FROM DEMONSTRATION

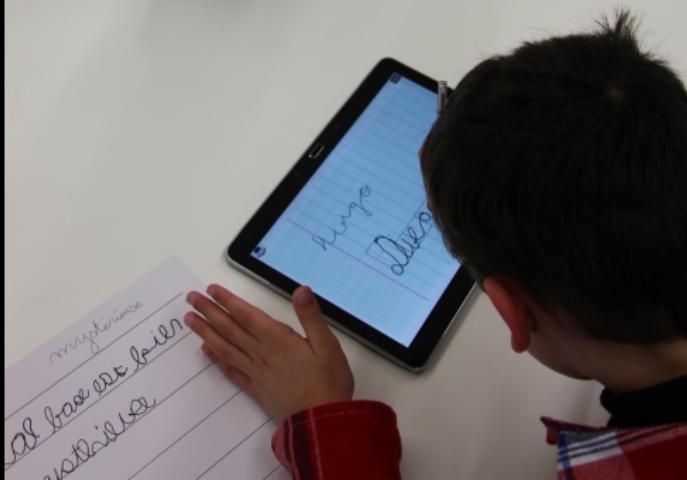


J S S J A A

{ S A A A A



Algunas personas  
que viven en la  
ciudad tienen que  
comer en restaurantes  
y no tienen tiempo  
para cocinar.



mystérieuse  
Al bâton est bâton  
mystérieuse

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

oooooooo●oooooooooooo

Data-driven!

oooooooooooooooooooo

## BEFORE – AFTER

salut mimi  
nous persons  
que c'est un  
corps  
est ce que tu penses  
croire en des  
photos de  
la vie



The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

oooooooo●oooooooooooo

Data-driven!

oooooooooooooooooooo

## BEFORE – AFTER

salut mimi  
nous pensons  
que c'est un  
corps  
est ce que tu peux  
croire des  
photos de  
la base

salut mimi  
nous pensons  
que c'est un  
corps  
est ce que tu peux  
envoyer des  
photos de  
la base



The classroom

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The teacher

oooooooooooo

The children

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Data-driven!

oooooooooooooooooooo

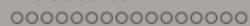
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salut mimi  
nous pensons  
que c'est un  
corps  
et que tu peux  
croire des  
photos de  
la base

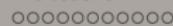
salut mimi  
nous pensons  
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corps  
est ce que tu peux  
envoyer des  
photos de  
la base



The classroom



The teacher



The children



Data-driven!



## WHAT ROLE DOES THE ROBOT PLAY HERE?

- The robot as 'cognitive agent' is key here (Protégé effect, metacognition)

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

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Data-driven!

oooooooooooooooooooo

## WHAT ROLE DOES THE ROBOT PLAY HERE?

- The robot as 'cognitive agent' is key here (Protégé effect, metacognition)
- (note: a tool for the teacher vs a social agent for the child!)

**But this is turn by turn!**

**What about less structured, “messy” interactions?**

**But this is turn by turn!**

**What about less structured, “messy” interactions?**

...we are not yet very good at modelling real-world social dynamics...

*Joint action* offers nevertheless a possible framework to reason about it.



# MODEL-BASED JOINT ACTION



1. establish a joint goal
2. plan for the robot
3. plan for the human in order to build a set of priors
4. execute the robot plan
5. monitor progress of the partner towards the goal

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⇒ **explicit cognitive steps**

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2. plan for the robot
3. plan for the human in order to build a set of priors
4. execute the robot plan
5. monitor progress of the partner towards the goal

⇒ **explicit cognitive steps**

*...hard ones, though:*

- *how to communicate/agree on goals & plans?*
- *what about the human's own plans?*
- *monitoring/recognising error situations*
- *what to do when we're going 'off track'?*
- ...

The classroom

ooooooooooooooo

The teacher

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The children

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Data-driven!

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## WE CAN DO A BIT ALREADY



The classroom

ooooooooooooooo

The teacher

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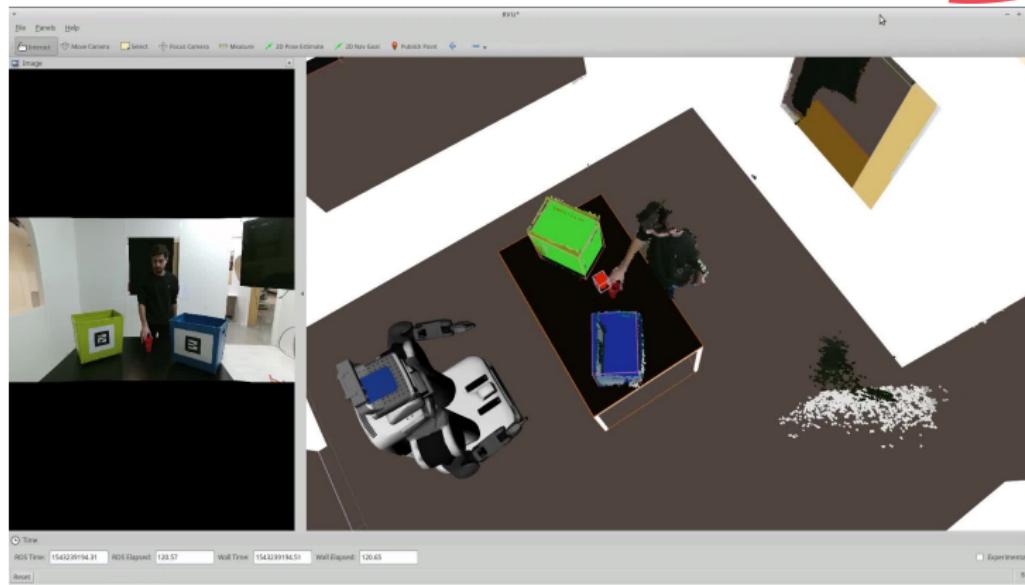
The children

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Data-driven!

oooooooooooooooooooo

# WE CAN DO A BIT ALREADY



The classroom



The teacher



The children



Data-driven!



## HOW DO HUMANS PERFORM TASKS TOGETHER?

**Collaborating is a costly socio-cognitive activity.**

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

oooooooooooo●ooooo

Data-driven!

oooooooooooooooooooo

## HOW DO HUMANS PERFORM TASKS TOGETHER?

**Collaborating is a costly socio-cognitive activity.**

Humans are good at it.

They are also really good at minimizing the cost involved.

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

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Data-driven!

oooooooooooooooooooo

## HOW DO HUMANS PERFORM TASKS TOGETHER?

**Collaborating is a costly socio-cognitive activity.**

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The key mechanism: **prefer implicit to explicit**

The classroom

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The teacher

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The children

oooooooooooo●oooooo

Data-driven!

oooooooooooooooooooo

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**Collaborating is a costly socio-cognitive activity.**

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They are also really good at minimizing the cost involved.

The key mechanism: **prefer implicit to explicit**

...which is closely related to: **be lazy**

First, go for the simple – if possibly ambiguous – actions; and, if  
really needed, repair

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

oooooooooooo●oooooo

Data-driven!

oooooooooooooooooooo

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...which is closely related to: **be lazy**

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**What does “be lazy” mean for robots?**

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

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Data-driven!

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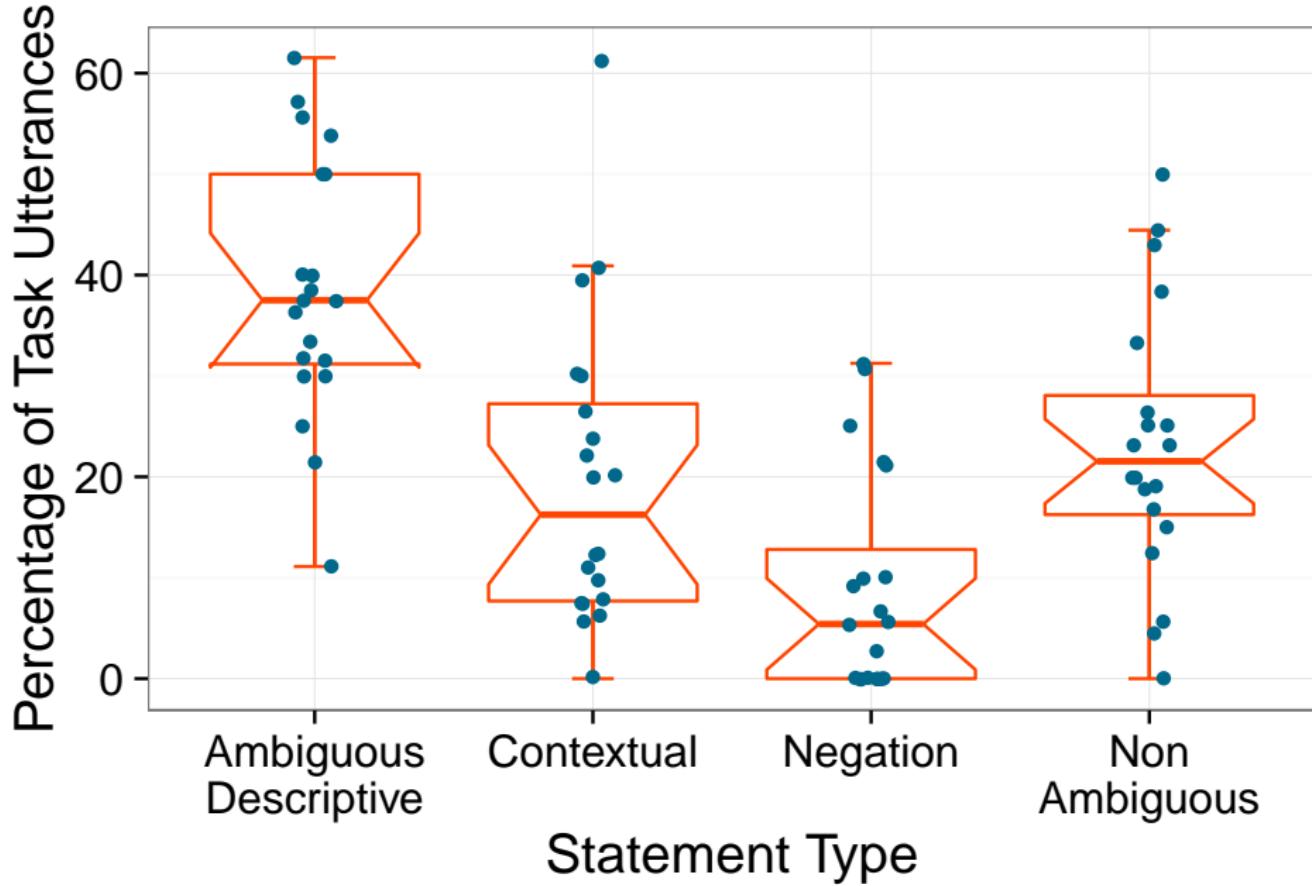
## ONE EXAMPLE: GROUNDING OF SPATIAL LANGUAGE



Ambiguities arise easily when describing spatial scenes.

How do we solve them?





## SURFACE ALIGNMENT; GROUNDING CRITERION

Psycholinguistics provides a lot of the foundational work on these questions.

- *Communication is a dynamic social process:* the partner often signal missing/misunderstood informations

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- Repairing is generally less costly than avoiding ambiguities in the first place
- You only ever need to reach the *grounding criterion*, ie *enough* mutual understanding for the task
- ⇒ we typically only reach *partial (or surface) alignment* – full alignment is usually not required

# IN SOCIAL HUMAN-ROBOT INTERACTION

Well studied in communication (cf back-channeling)

Can we expand this line of thought to sHRI in general?

Most of our social and behavioural alignment comes from  
sub-conscious social mechanisms:

- entrainment (coupling),
- mimicry,
- implicit turn-taking,
- joint attention
- ...and others

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Most of our social and behavioural alignment comes from  
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- entrainment (coupling),
- mimicry,
- implicit turn-taking,
- joint attention
- ...and others

Can we model & generate them?

The classroom

ooooooooooooooo

The teacher

ooooooooooooo

The children

oooooooooooooooooooo●

Data-driven!

oooooooooooooooooooo

## THE PROBLEM

- These mechanisms are unfortunately often ill-defined, and particularly difficult to turn into equations (or controllers, in our case)
- no close-form equation of social interactions ⇒ data-driven approaches?

# TOWARDS THE DATA-DRIVEN STUDY OF SOCIAL DYNAMICS

The classroom

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The teacher

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The children

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Data-driven!

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# DATA!

If we want to use machine learning, we need data (relevant to child-robot interactions in a learning environment).

The classroom

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The teacher

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The children

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Data-driven!

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# DATA!

If we want to use machine learning, we need data (relevant to child-robot interactions in a learning environment).

...a task that exhibits:

- complex social dynamics
- open, underspecified situations
- natural interactions
- rich semantics
- interplay of many socio-cognitive functions

# DATA!

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...a task that exhibits:

- complex social dynamics
- open, underspecified situations
- natural interactions
- rich semantics
- interplay of many socio-cognitive functions

while being...

- reproducible/replicable experimental procedure
- clear quantitative metrics
- practical

## FREE PLAY

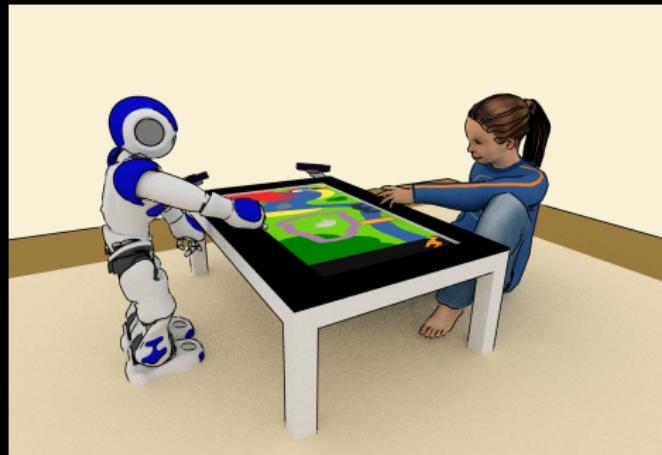
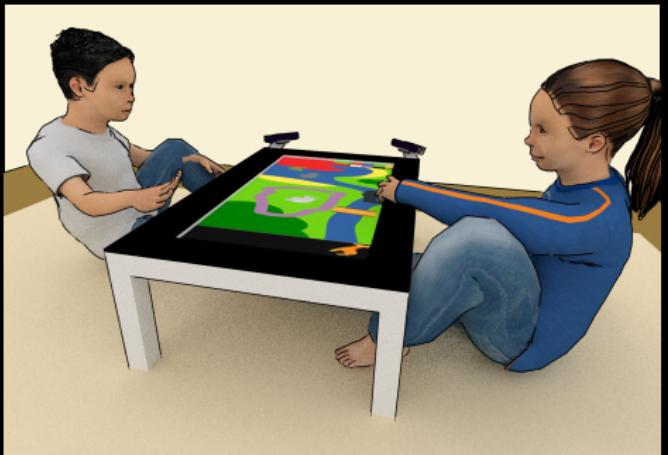
“Just play! Enjoy yourselves!”

- **rich set of cognitive and social dynamics;** importance of motivation/drive; **uncertain and unexpected situations**
- what is the right action policy? Focus instead on the **social policy**

## FREE PLAY

“Just play! Enjoy yourselves!”

- **rich set of cognitive and social dynamics;** importance of motivation/drive; **uncertain and unexpected situations**
- what is the right action policy? Focus instead on the **social policy**
- focus on children
- with a little bit of scaffolding & framing



## THE PINSORO DATASET

- 120 children, 4 to 8 years old
- 75 interactions
  - 90 children playing with another child,
  - 30 playing with a robot
- About 45h+ of recordings; 2M+ frames;  $\approx$  2TB
- average duration of freeplay interactions: 24min in child-child condition; 19min in child-robot condition

Large open dataset: **[freeplay-sandbox.github.io](https://freeplay-sandbox.github.io)**

The classroom

ooooooooooooooo

The teacher

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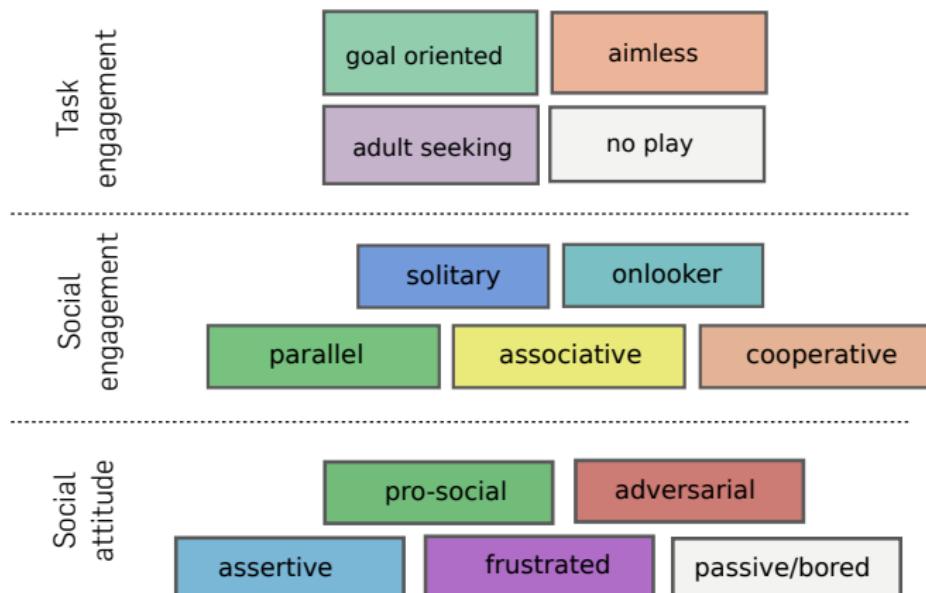
The children

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# 13000+ ANNOTATIONS



Attitude: passive

Social engag.: onlooker

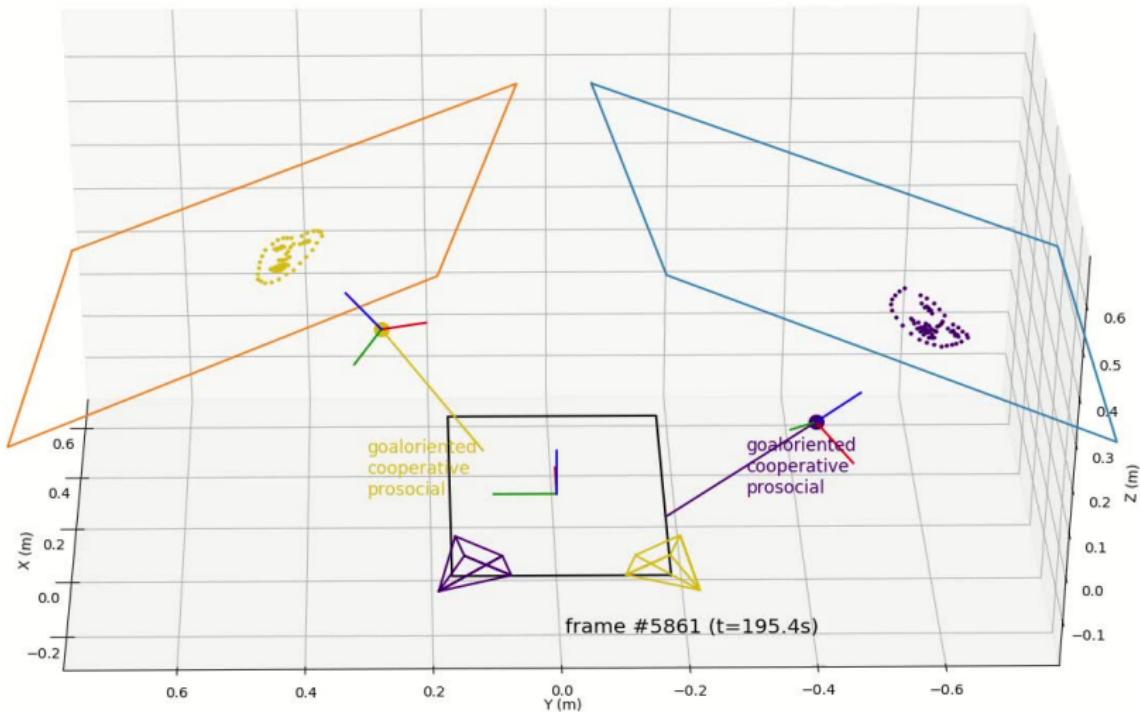
Task engag.: no play

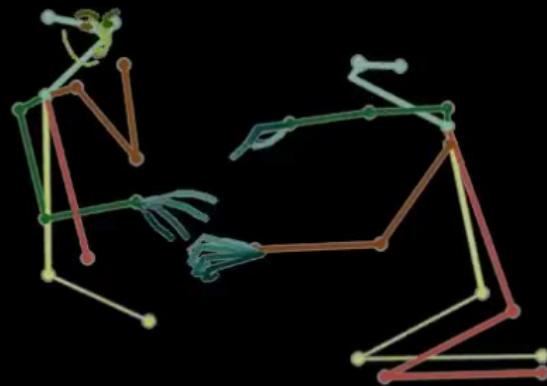
Attitude: passive

Social engag.: solitary

Task engag.: goal oriented













The classroom

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The teacher

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The children

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ULTIMATELY...

**Real-time identification** by the robot of...

- the **task engagement**  
is my partner 'on task' or not?

The classroom

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The teacher

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Data-driven!

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## ULTIMATELY...

**Real-time identification** by the robot of...

- the **task engagement**  
is my partner 'on task' or not?
- the **interaction flow & situation awareness**  
what is happening right now? should I do something?

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Social behaviours; Social dynamics: **generation as well!**

## WHAT DOES THAT MEAN FOR CRI & LEARNING?

- We can reduce the socio-cognitive cost of collaboration by relying as much as possible on **implicit (sub-conscious) social mechanisms**



## WHAT DOES THAT MEAN FOR CRI & LEARNING?



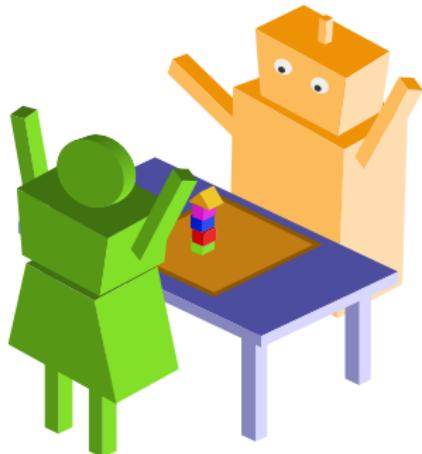
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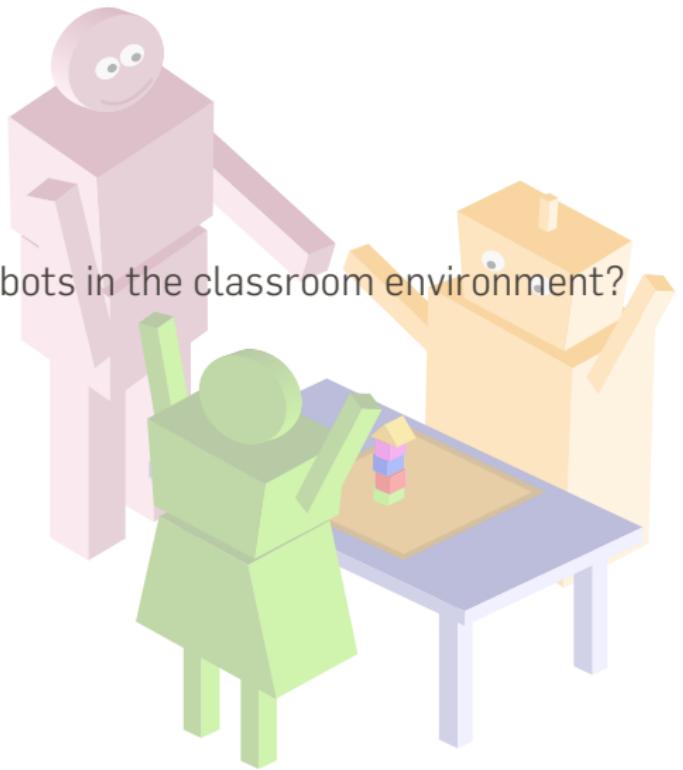
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- The robot needs to learn to recognise and interpret those social cues, hidden within complex social dynamics (in real-time!)
- We have some raw material. Time to process it together!

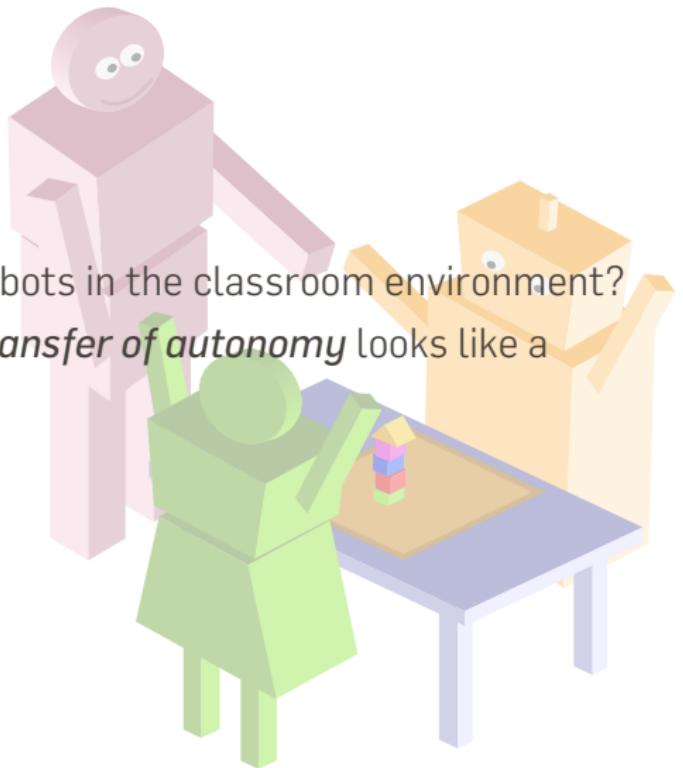
In summary:

- Integration of *social* robots in the classroom environment?



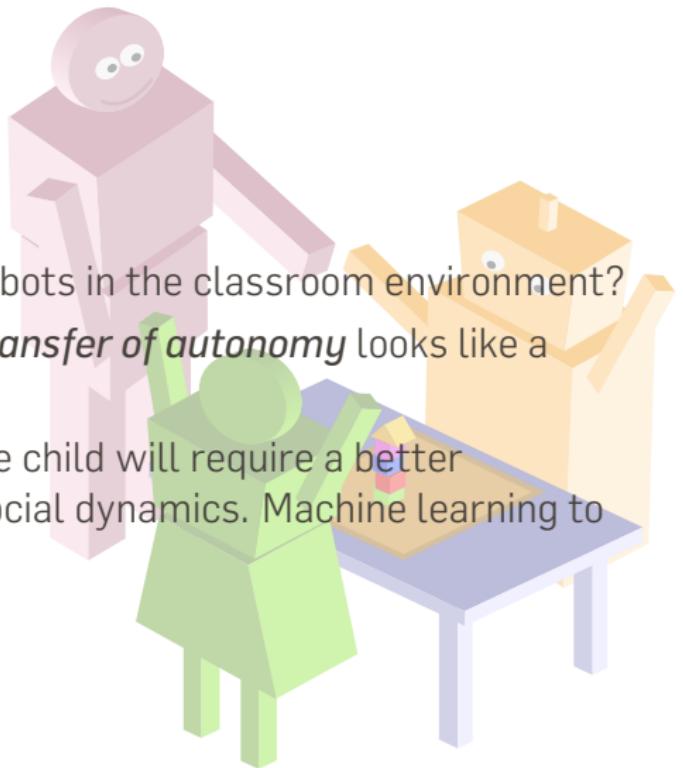
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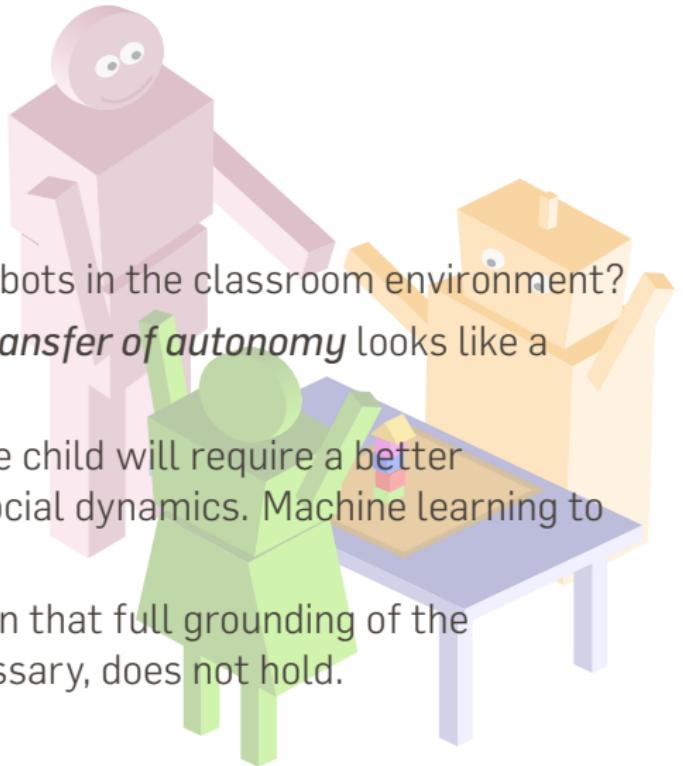
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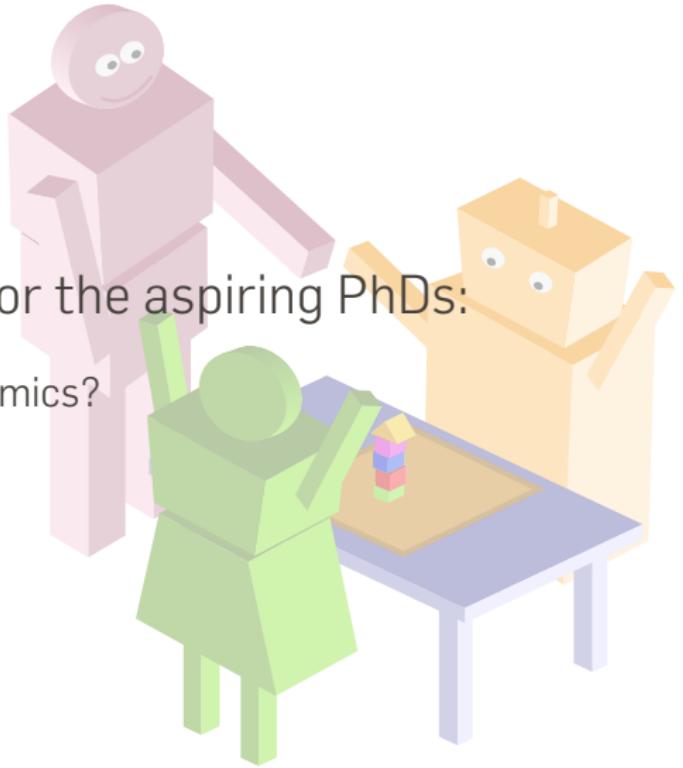
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- Integration of *social* robots in the classroom environment?
- Role of the teacher? *Transfer of autonomy* looks like a promising lead.
- *Doing together* with the child will require a better understanding of the social dynamics. Machine learning to the rescue?
- ...but the old assumption that full grounding of the communication is necessary, does not hold.



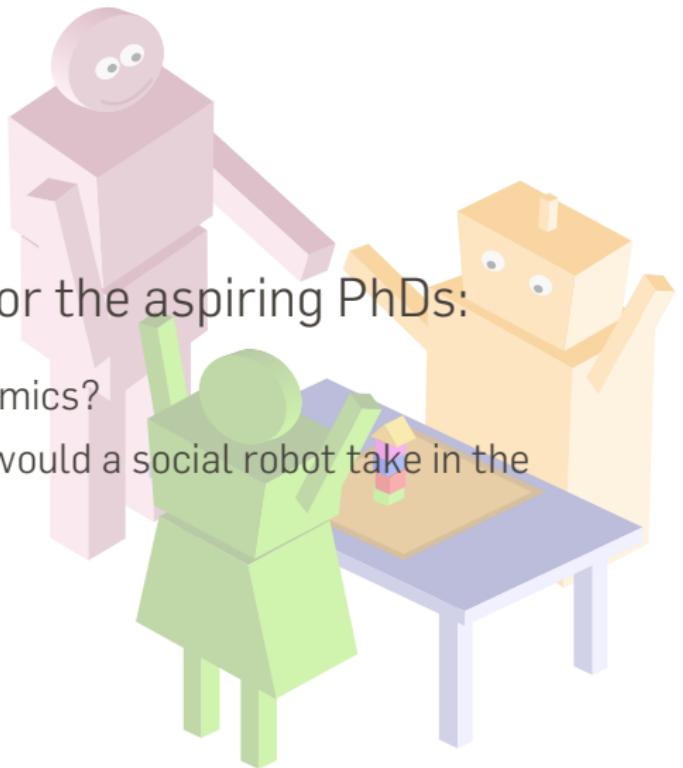


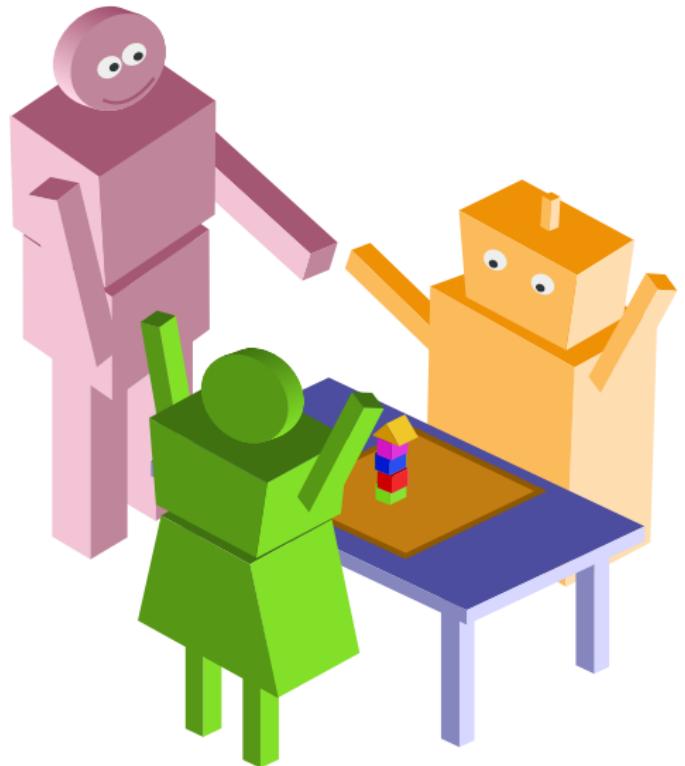
Two open questions for the aspiring PhDs:

- What about group dynamics?

## Two open questions for the aspiring PhDs:

- What about group dynamics?
- Over time, what place would a social robot take in the classroom?





Thank you!

SOME MORE STUFF

## SOME BUILDING BLOCKS EXISTS

- **Multi-modal fusion**

e.g. Noda et al. **Multimodal integration learning of robot behavior using DNN**, Robotics and Autonomous Systems 2014

- **Behavioural sequences recognition**

How et al. **Behavior recognition for humanoid robots using long short-term memory**, IJARS 2016 → *LSTM to recognise Nao behaviours*

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### **DBSoC: Deep Behavioural Social Cloning – LfD + CNNs + LSTM**

Two tasks for a telepresence robot:

1. position itself in a (dynamic) group of persons
2. follow 2 persons

The classroom

oooooooooooooooo

The teacher

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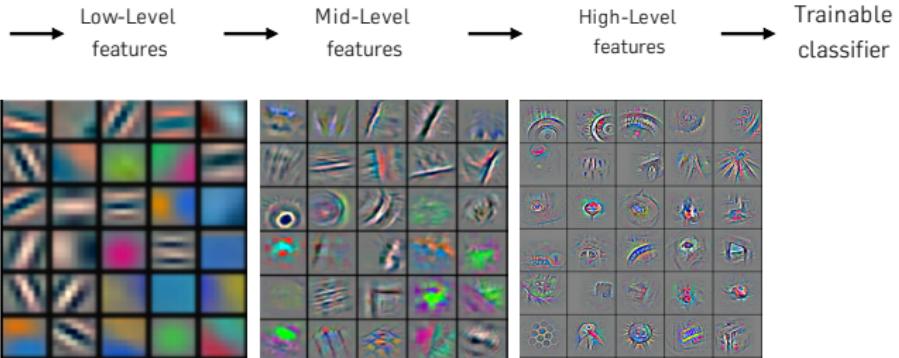
The children

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Data-driven!

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# DEEP NETWORKS $\equiv$ BLACK BOXES?



The classroom

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The teacher

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The children

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Data-driven!

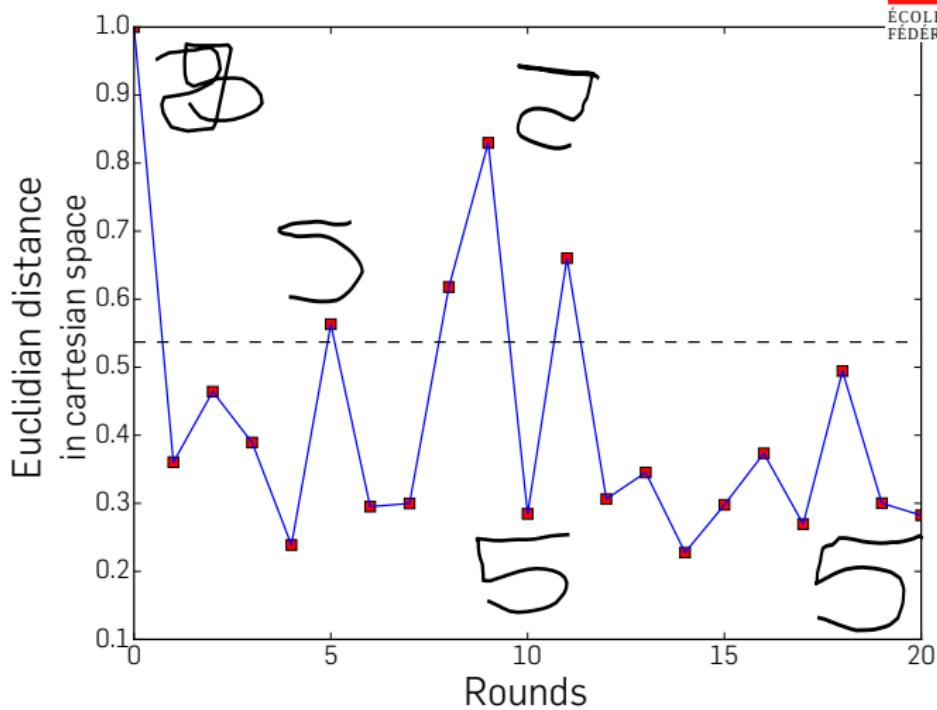
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# DEEP NETWORKS $\equiv$ BLACK BOXES?



[taken from a NIPS2015 tutorial by Geoff Hinton, Yoshua Bengio & Yann LeCun]

## LEARNING TO DRAW A 5



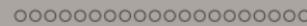
The classroom



The teacher



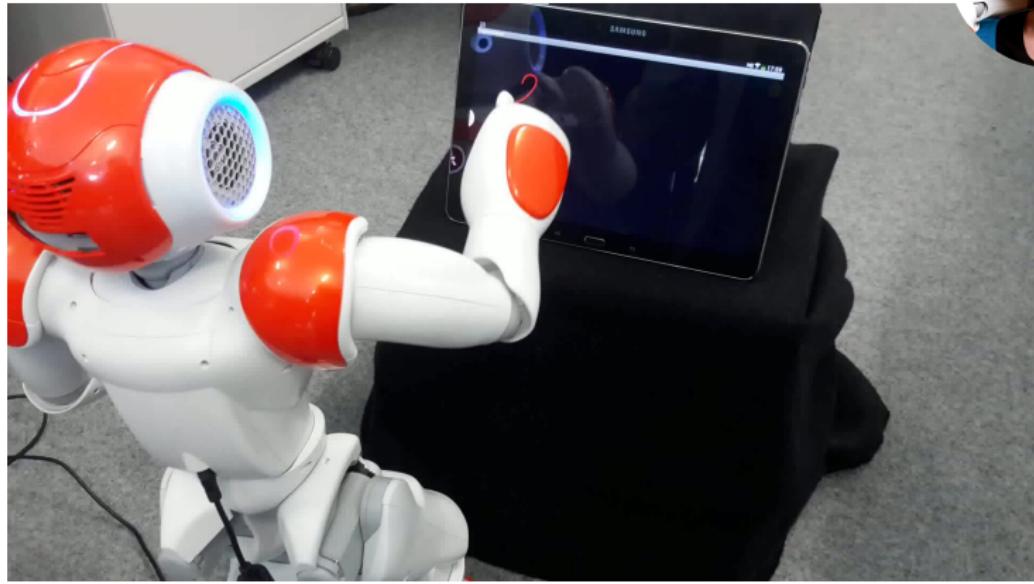
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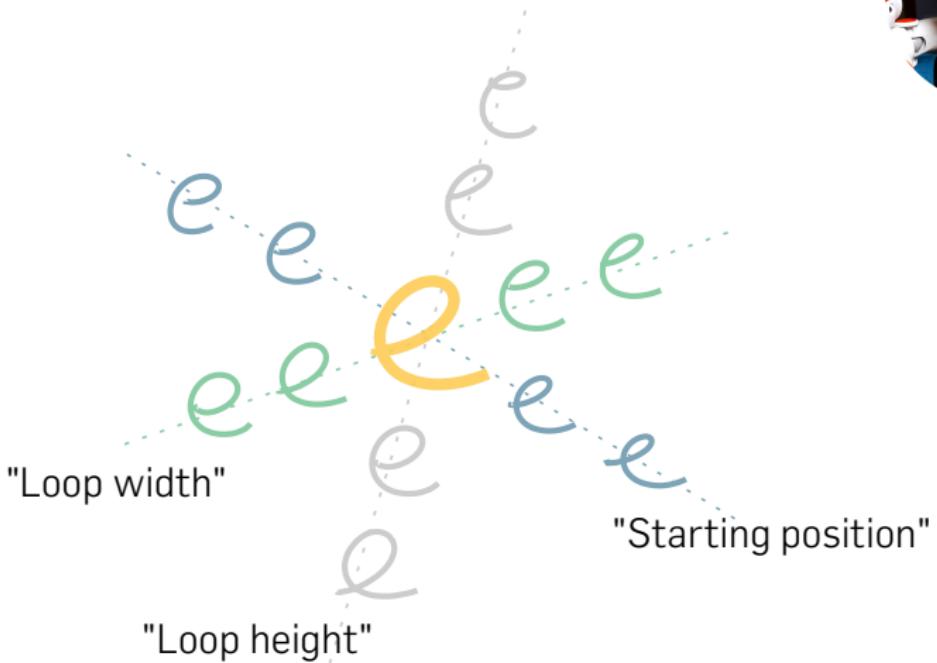
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# COWRITER IMPLEMENTATION



# COWRITER IMPLEMENTATION



The classroom

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The teacher

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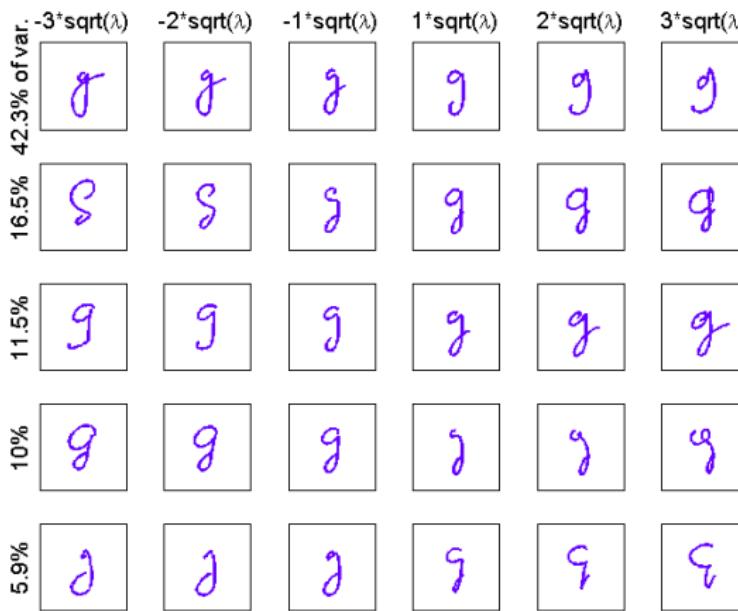
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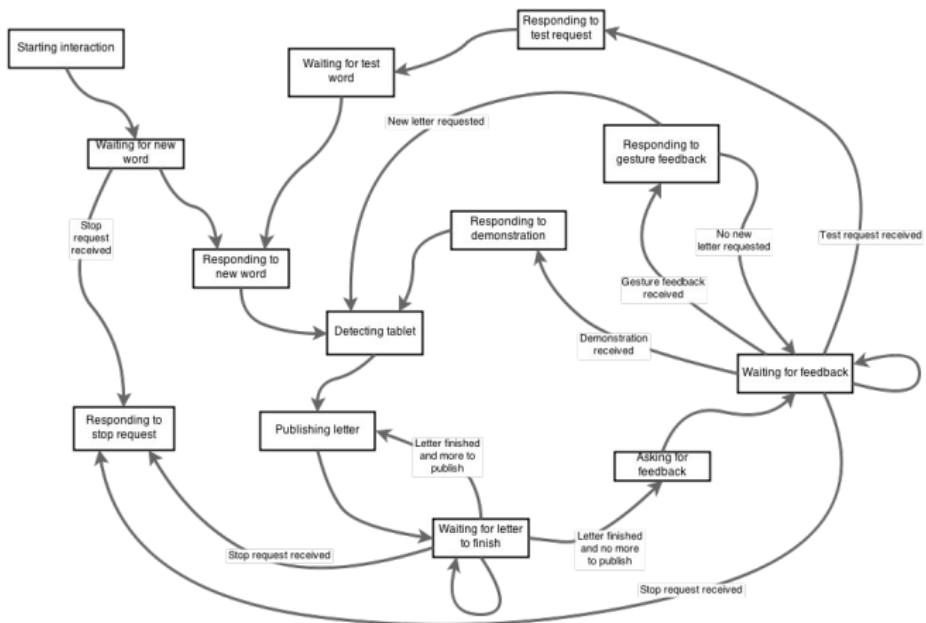
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## COWRITER IMPLEMENTATION



J S S J A A

S S A A A A



The classroom



The teacher



The children



Data-driven!



## INTERACTION WITH THE PAPER



Critically, Cellulo is meant as an **interaction between (classroom-friendly) paper and the robots**.

The classroom

oooooooooooooooo

The teacher

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The children

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Data-driven!

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Critically, Cellulo is meant as an **interaction between (classroom-friendly) paper and the robots**.

Achieved through a **paper-based absolute localisation system**

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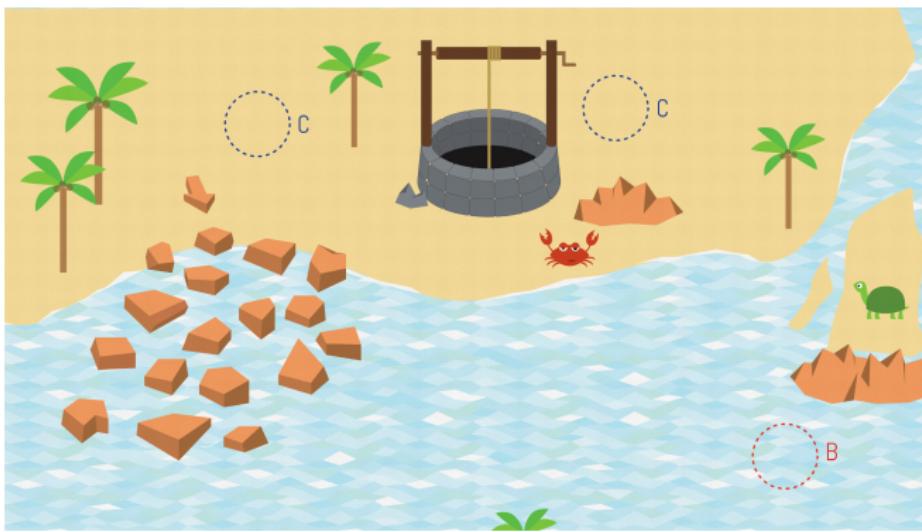
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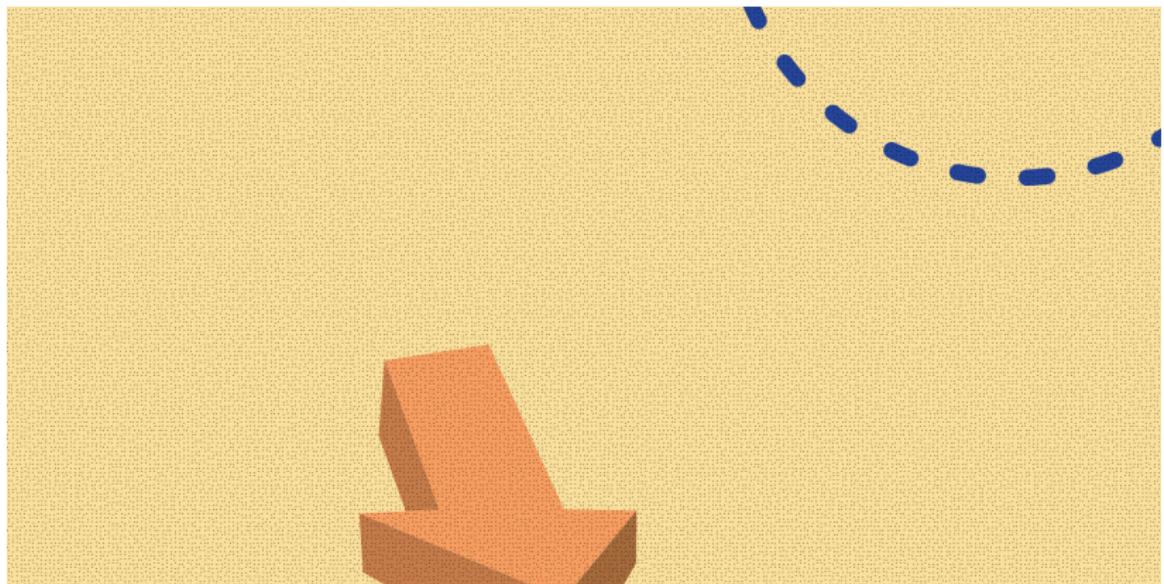


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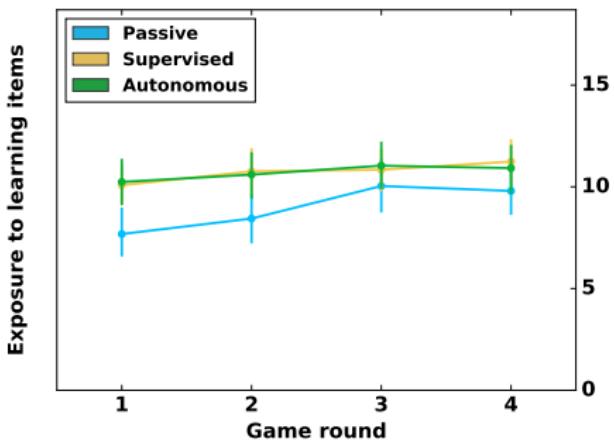
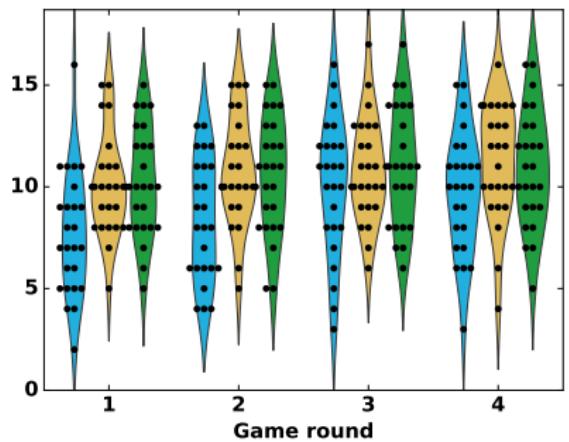
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- even more than 'classroom-friendly', paper is 'teacher-friendly'
- easy to manipulate, copy, print, cutout, dispose...
- unique activity IDs: drop the robots onto the sheet, it recognizes the activity



Learning-related game actions

The classroom

ooooooooooooooo

The teacher

oooooooooooo

The children

oooooooooooooooooooo

Data-driven!

oooooooooooooooooooo

## WHAT DID WE RECORD?

Domain	Type	Details
child × 2	audio	16kHz, mono, semi-directional
	face (RGB)	qHD (960x540), 30Hz
	face (depth)	VGA (640x480), 30Hz
	facial features	70 2D points, 30Hz
	skeleton	15 2D points, 30Hz
	hands	20 x 2 2D points, 30Hz
environment	RGB	qHD (960x540), 29.7Hz
touchscreen	background drawing (RGB)	4Hz
	touches	6 points multi-touch, 10Hz
	items position and orientation	(x,y,theta), 10Hz
annotations	timestamped annotations of social behaviours	
+ post-process	optical flow, audio features facial action units...	