EARLI SIG 6 & 7 · Zürich 2026

# Exploring learner agency in an AI-supported simulation environment for complex systems education

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# Simulations make complex systems visible

**1** **Complex systems are difficult to understand**

It requires reasoning across levels (micro and macro levels)

**2** **Computer simulations help visualize complexity**

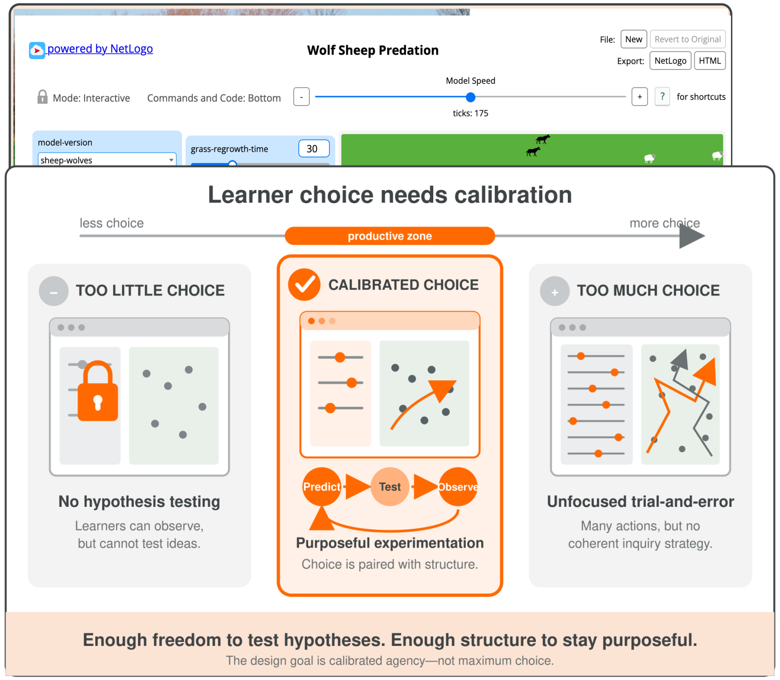
Agent-based models make micro-to-macro relations manipulable

## But…

**3** **Effective simulations require calibrated choice**

Too little restricts hypothesis testing

Too much can produce unfocused trial-and-error




Chi et al. (2012) · Jacobson & Wilensky (2006) · Hmelo-Silver et al. (2007) · Wilensky & Resnick (1999)

# AI can foster scientific modeling and metacognitive control

**1** **AI can help learners build complex systems**

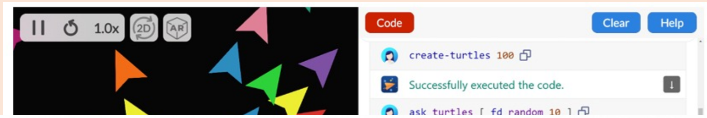
Conversational AI agent provide supports & answers on demand

**2** **AI agent provides more choices to the learner**

Learners can decide whether, when, and how to ask the AI agent for help

## But…

**3** **Choice does not equal to Agency**



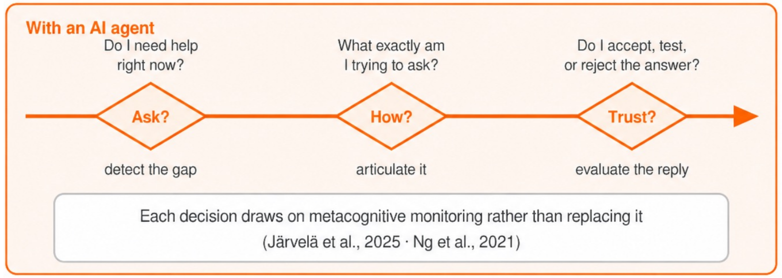
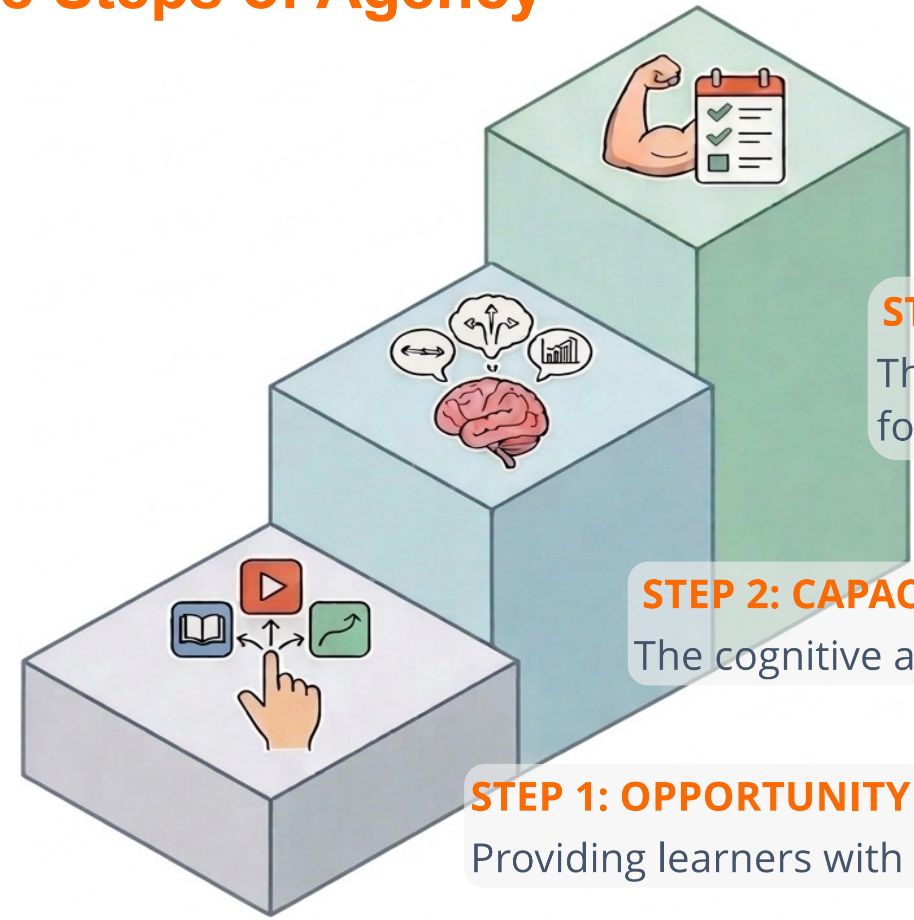




Image source: Chen, J., & Wilensky, U. (2023). ChatLogo: A large language model-driven hybrid natural-programming language interface for agent-based modeling and programming. arXiv preprint arXiv:2308.08102.

Bandura (2001) · Brod (2026) · Chen & Wilensky (2023) · Järvelä et al. (2025) · Ng et al. (2021)

# Three Steps of Agency



**STEP 3: CAPACITY TO ENACT DECISIONS**
The volitional and self-regulatory strength to follow through on choices despite difficulties

**STEP 2: CAPACITY TO MAKE DECISIONS**
The cognitive and metacognitive ability to make decisions

**STEP 1: OPPORTUNITY TO MAKE DECISIONS**
Providing learners with meaningful control

Brod (2026)

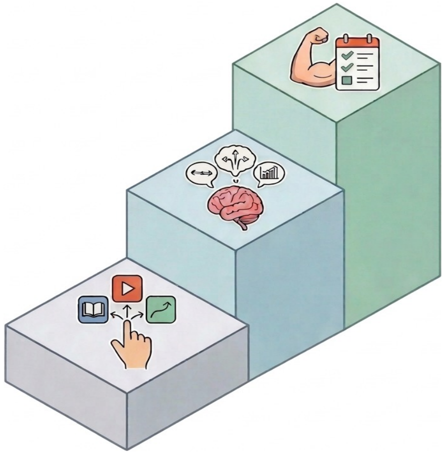
# Gap & Research Questions

### Research Gap

No empirical work in complex systems education examined learner choices at two dimensions:

- parameter control
- AI agent questioning

and measured how learners enacted their choices in simulation environment.



### RQ1

Do learning outcomes differ across choice configurations?

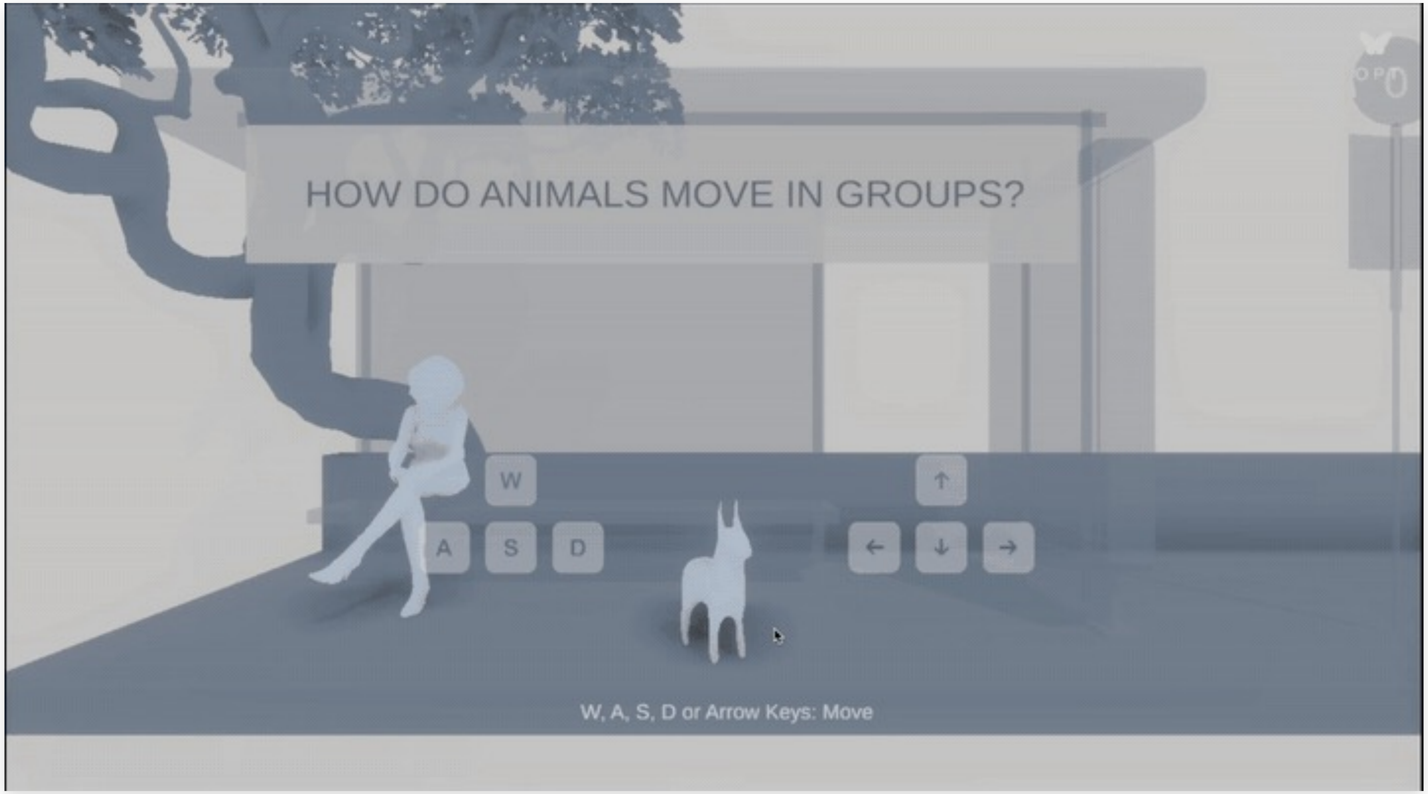
### RQ2

Among learners with parameter control:
how is their choice enacted, and does that relate to gains?

### RQ3

Among learners with AI agent questioning:
how is their choice enacted, and does that relate to gains?

# Design: an open-world 3D environment



## Self-paced exploration components

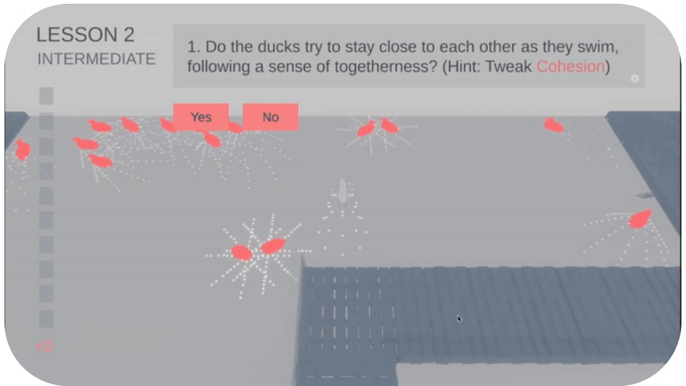
Gallery walk


Hidden system under water

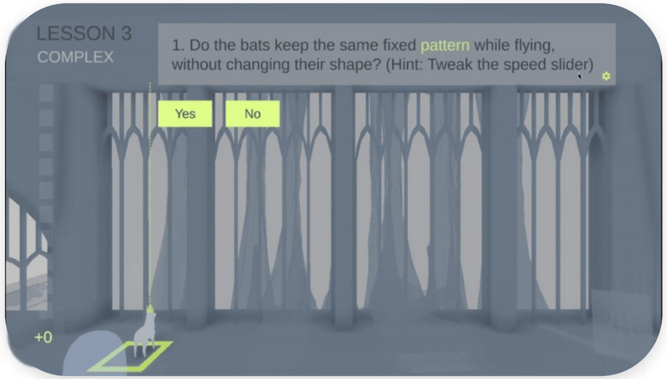
Exhibit area

## Guided inquiry components

Lesson 1: Sheep flocking

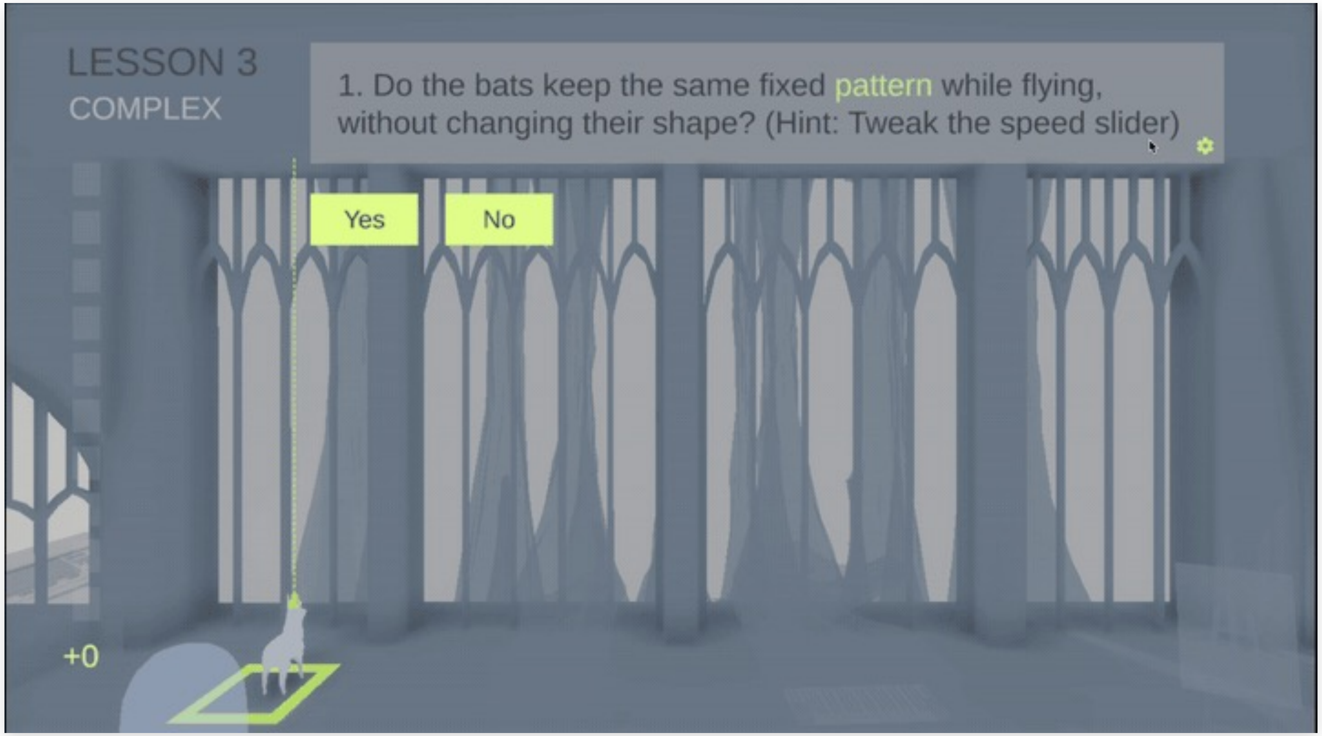



Lesson 2: Ducks flocking




Lesson 3: Bats flocking

# Main Affordance 1: Parameter control




*Lesson 2 (ducks): the first three | Lesson 3 (bats): alignment · cohesion · separation · speed*

## Gradual complexity

Three parameters in Lesson 2,
Four parameters in Lesson 3

## Real-time coupling

Micro rule to macro pattern, made visible.

# Main Affordance 2: AI agent Questioning


*Context-aware, non-intrusive, grounded in PAIR-C framework; answers only when asked (GPT-4o + scene context)*

## The learner decides

- whether to ask at all
- when in the exploration to ask
- how to formulate the question
- what to do with the answer

Aleven et al. (2003; 2016) · Su et al (2026)

# Research Design

**2 × 2 between-subjects, pre/post, block-randomized**

## Questioning AI agent

| Parameter control | Off | On |
|---|---|---|
| **Off** | **C0** n = 17<br>parameter control<br>AI agent | **C2** n = 17<br>parameter control<br>AI agent |
| **On** | **C1** n = 17<br>parameter control<br>AI agent | **C3** n = 18<br>parameter control<br>AI agent |

**N = 69**

## Participants

German university; M age 24.4;
97% computer science;
mostly master's students

69 completed all phases
→ 55 analysed after validity screening
(ceiling pretest, non-effortful posttest, < 45 min on task)

## Measures

**Questioning AI agent**

| Parameter control | Off | On |
|---|---|---|
| Off | **C0** n = ~~17~~ 14<br>parameter control<br>AI agent | **C2** n = ~~17~~ 14<br>parameter control<br>✓ AI agent |
| On | **C1** n = ~~17~~ 11<br>✓ parameter control<br>AI agent | **C3** n = ~~18~~ 16<br>✓ parameter control<br>✓ AI agent |

**N = 55**

### Knowledge test on flocking

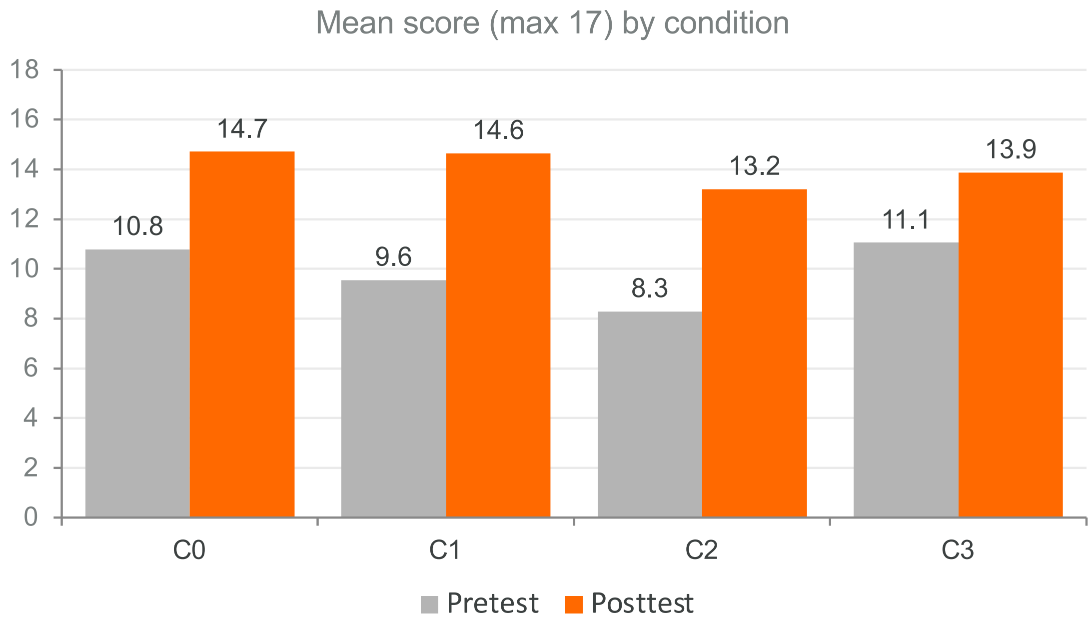
7 items, max 17 pts, built on Khodr et al. (2022);
α = .71 / ω = .74 at pretest

### Interaction logs

Parameter changes
Learner- AI Agent dialogues
Time on tasks

## RQ1 Do learning outcomes differ across choice configurations?

## Distributing more options did not produce a large learning advantage




| C0 | C1 | C2 | C3 |
| --- | --- | --- | --- |
| ⃠ parameter control | ✔ parameter control | ⃠ parameter control | ✔ parameter control |
| ⃠ AI agent | ⃠ AI agent | ✔ AI agent | ✔ AI agent |

**All four conditions gained**
all *ps* < .01

**2 × 2 ANCOVA on posttest**

**Pretest (covariate)**
$F(1,50) = 6.33$, $p = .015$, $\eta p^2 = .11$

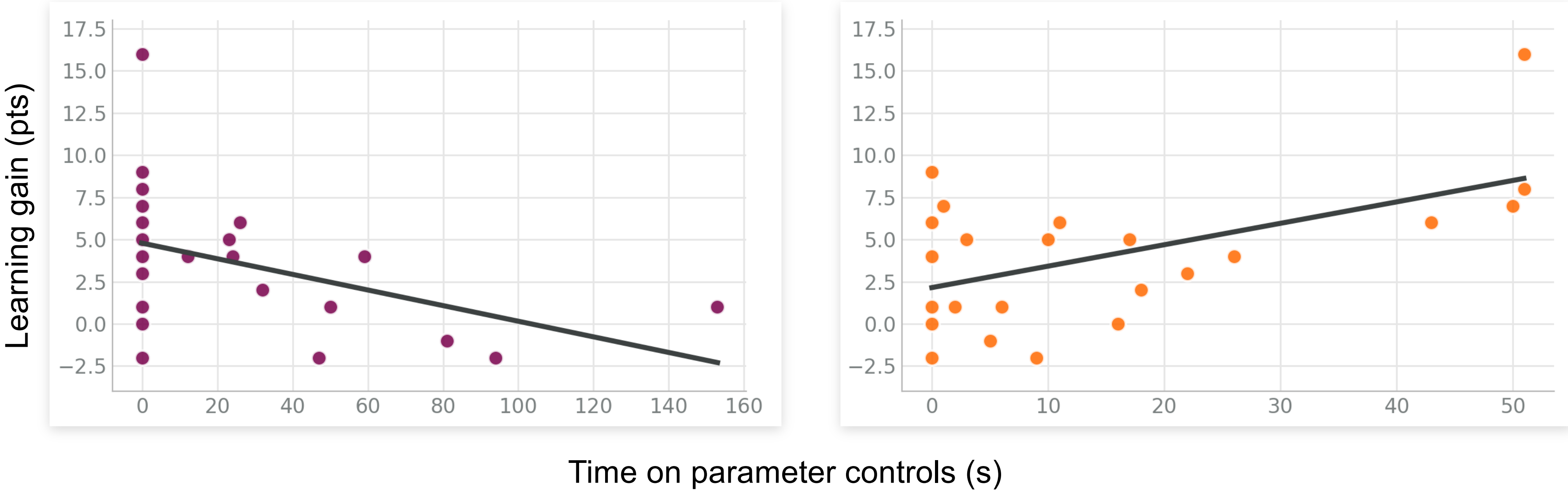
**Main effect of parameter-control**
$F(1,50) = 0.04$, $p = .849$, $\eta p^2 < .01$

**Main effect of AI agent**
$F(1,50) = 2.68$, $p = .108$, $\eta p^2 = .05$

**Interaction**
$F(1,50) = 0.01$, $p = .917$, $\eta p^2 < .01$

**RQ2** Among learners with parameter control:
how is their choice enacted, and does that relate to learning gains?

**Lesson 2 (Intermediate)** $\beta = -0.04$, $p = .047$ **Lesson 3 (Complex)** $\beta = 0.11$, $p = .007$

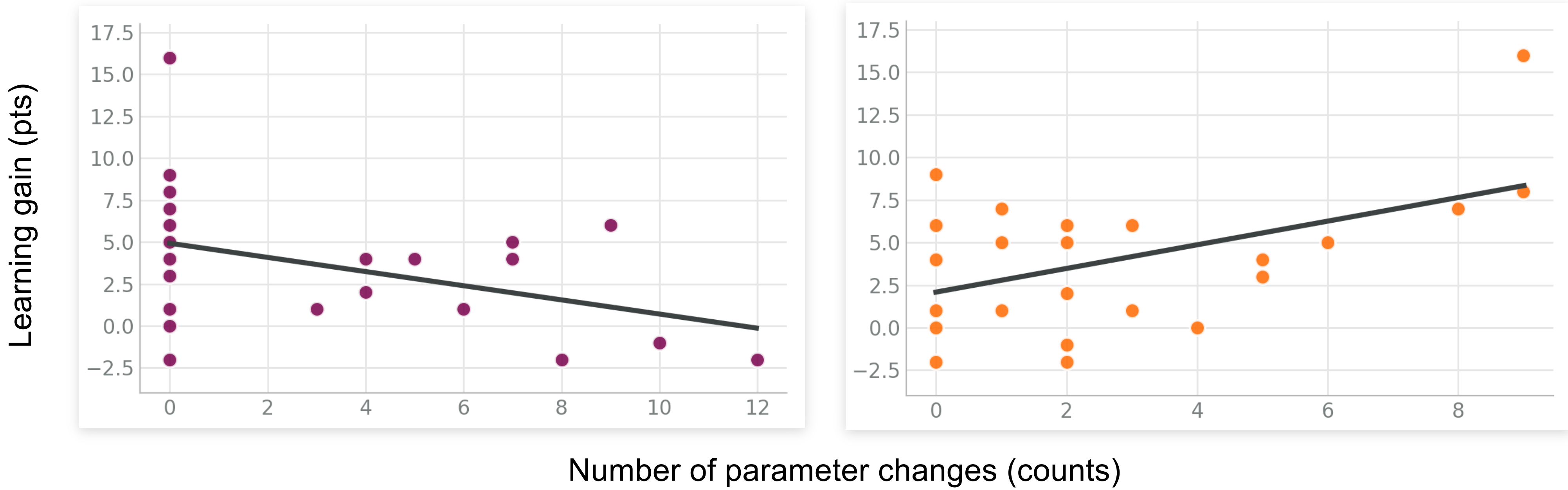



Model $R^2$ = .406 (adj. .358).

## RQ2 Among learners with parameter control: how is their choice enacted, and does that relate to learning gains?

## Enactment predicts gains but only where the concept is hard

**Lesson 2 (Intermediate) $\beta = -0.35$, $p = .057$** **Lesson 3 (Complex) $\beta = 0.62$, $p = .013$**




Model $R^2$ =.356 (adj. .303).

**RQ3** Among learners with AI agent questioning:
how is their choice enacted, and does that relate to learning gains?

## Overall

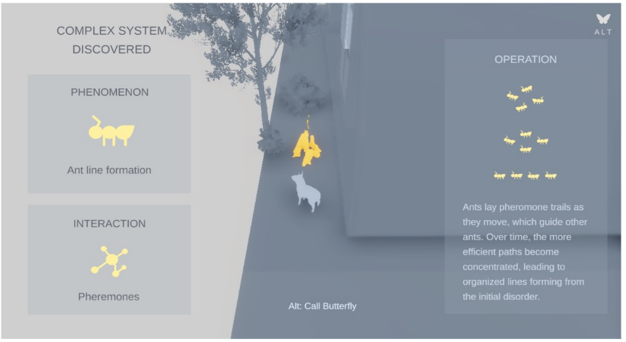
| 235 | 0 – 32 | 6.7 |
|---|---|---|
| inputs to the agent | queries per learner | mean |

## What?

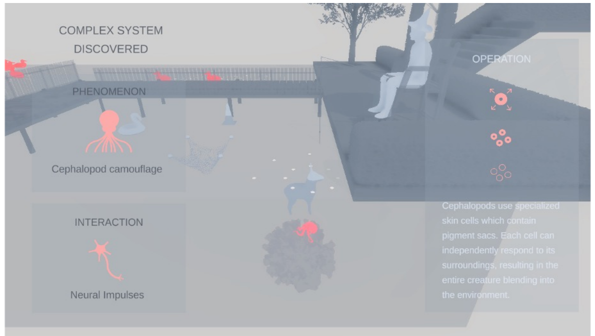
| Input Type | Proportion | Example |
|---|---|---|
| Content-focused | 35.7% | “What is flocking?” |
| Meta | 28.5% | “Can I redo tests?” |
| Peripheral | 26.8% | “You are a true friend” |
| Greeting | 7.7% | “Goodbye” |
| Unrelated | 1.3% | “I have exams soon” |

**RQ3** Among learners with AI agent questioning:
how is their choice enacted, and does that relate to learning gains?

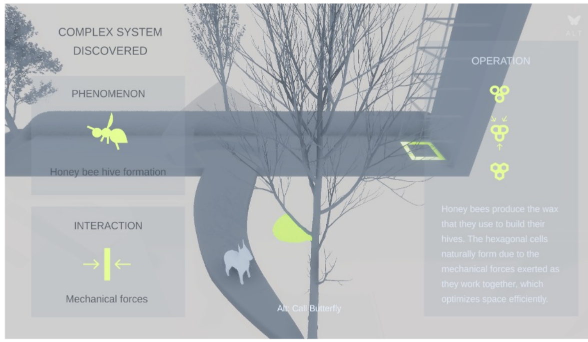
# Where and for how long?




Hidden System 1




Hidden System 2




Hidden System 3

| No. Learners who asked | Questions asked M (SD) · median · range | Time with the agent M (SD) · median · range |
|---|---|---|
| 12 | **6.33 (3.06)** Mdn 6 · 2–12 | **86.75 s (63.30)** Mdn 74 · 22–237 |

**RQ3** Among learners with AI agent questioning:
how is their choice enacted, and does that relate to learning gains?

## Where and for how long?

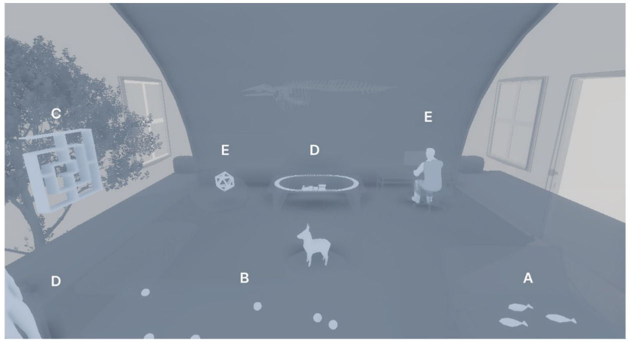



Exhibit Area 1

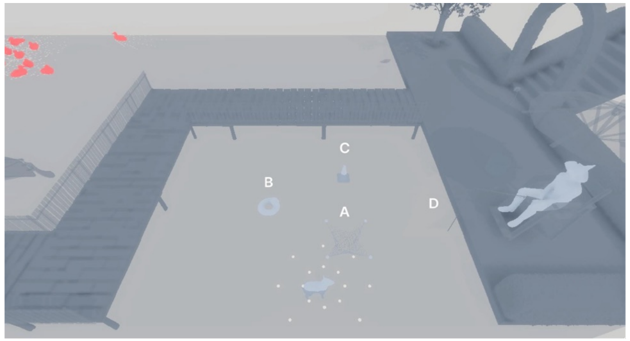



Exhibit Area 2

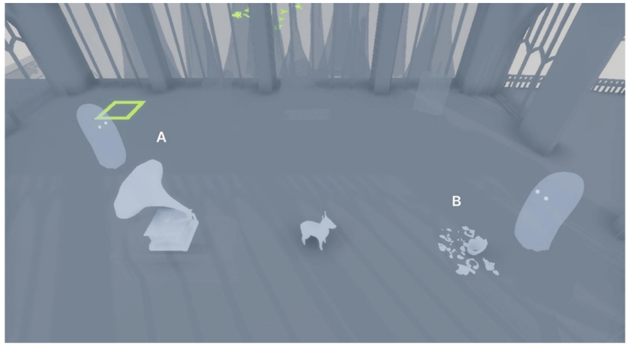
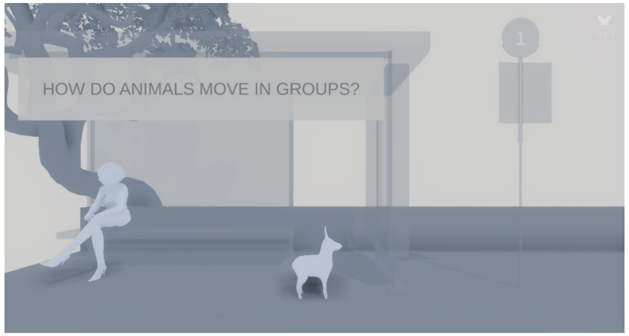



Exhibit Area 3

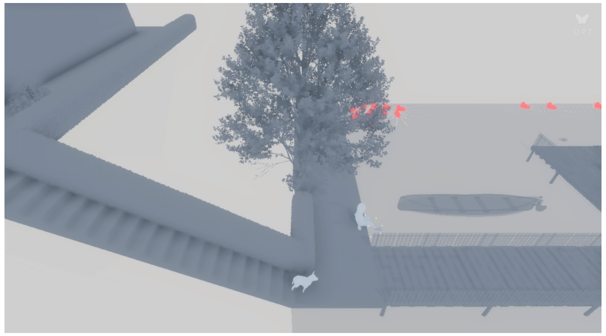
| No. Learners who asked | Questions asked M (SD) · median · range | Time with the agent M (SD) · median · range |
|---|---|---|
| 14 | **9.29 (9.27)** Mdn 6 · 2–36 | **77.64 s (86.05)** Mdn 41 · 10–295 |

**RQ3** Among learners with AI agent questioning:
how is their choice enacted, and does that relate to learning gains?

## Where and for how long?




Path Area 1



Path Area 2


Path Area 3

| No. Learners who asked | Questions asked M (SD) · median · range | Time with the agent M (SD) · median · range |
|---|---|---|
| **20** | **12.50 (13.72)**<br>Mdn 7 · 2–56 | **160.40 s (222.71)**<br>Mdn 54 · 8–795 |

**RQ3** **Most questioning happened where there were no instructional props.**

## So what?

| Exploration area | Learners who asked | Questions asked M (SD) · median · range | Time with the agent M (SD) · median · range |
|---|---|---|---|
| **Hidden Systems** *Instruction props* | **12** | **6.33 (3.06)** Mdn 6 · 2–12 | **86.75 s (63.30)** Mdn 74 · 22–237 |
| **Exhibit Areas** *instructional props* | **14** | **9.29 (9.27)** Mdn 6 · 2–36 | **77.64 s (86.05)** Mdn 41 · 10–295 |
| **Path Areas** *no instructional props* | **20** | **12.50 (13.72)** Mdn 7 · 2–56 | **160.40 s (222.71)** Mdn 54 · 8–795 |

**No significant correlations** between learning gains and either the number of questions or the time spent asking and reading answers in any of the three areas.

## We varied Step 1. We did not vary or support Steps 2 and 3.

### Step 1
**Opportunity to decide**

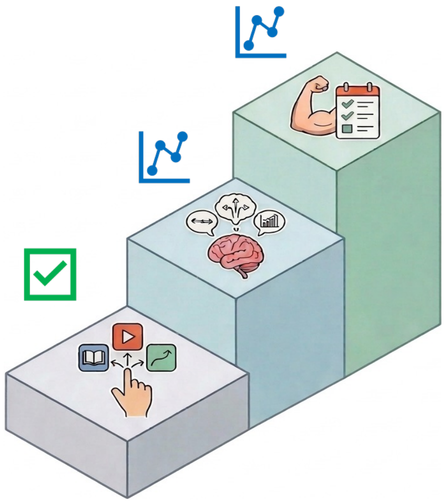
**Manipulated**:
- Parameter control on/off
- AI agent on/off

### Step 2
**Capacity to decide**

Not scaffolded.
No support for evaluating alternatives before making choices.

### Step 3
**Capacity to enact**

Not scaffolded.
No progress tracking, planning, or volitional support.



**Because each step is necessary but not sufficient for the next, a manipulation confined to the first step (choices) cannot be expected to foster learner agency on its own.**

The absence of main effects is not evidence that agency is unimportant. It is evidence that what our conditions distributed was **choice**, not **agency**.

Taub (2020) · Brod (2026)

# DESIGNING TECHNOLOGY-ENHANCED LEARNING FOR AGENCY

Three priorities for simulation-based and AI-supported instruction

01

## CONTROL

**Match choice to the task**

Give learners room to explore when control serves the conceptual work.

02

## TIMING

**Offer AI when a need emerges**

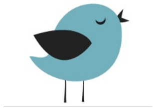
Introduce support after a question, conflict, or impasse becomes visible.

03

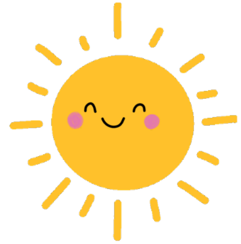
## INQUIRY

**Support the full inquiry cycle**

Prompt learners to predict, test, compare, and revise, not simply choose.



# Thank you!



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## Questions

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