

Infect, Attach or Bounce off?: The Independence of Mechanistic Reasoning and Canonical Understanding of Diffusion

Tamar Fuhrmann

May 25, 2023 Hong Kong University

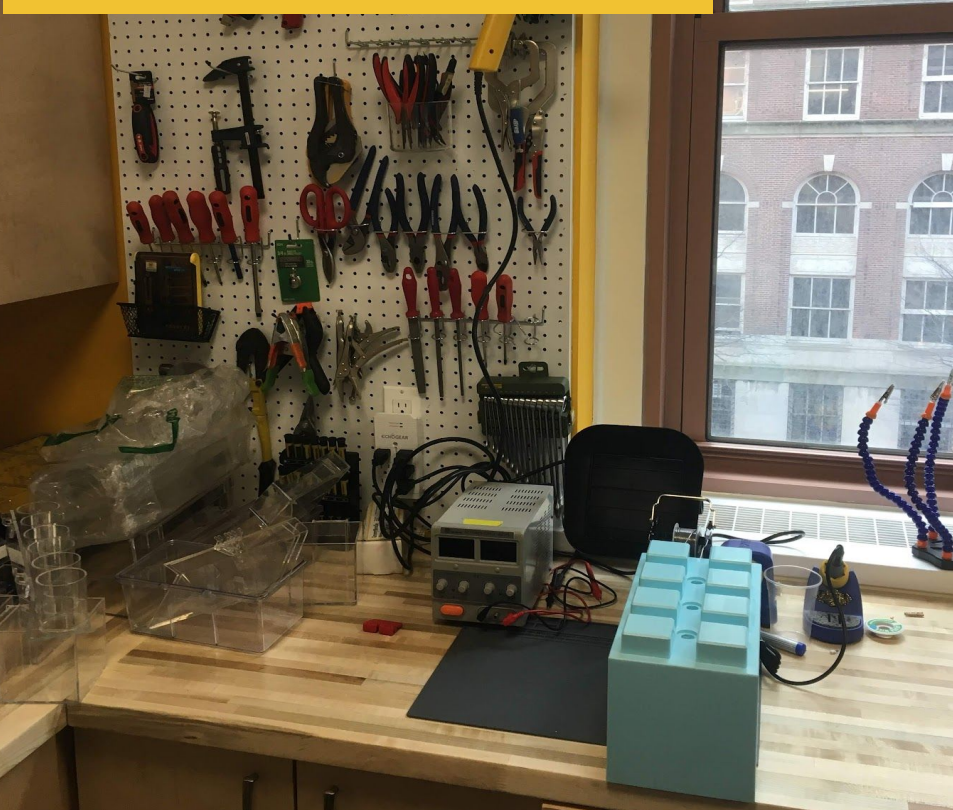
Teachers College, Columbia University



Transformative Learning
Technologies Lab

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Transformative Learning Technologies Lab



TC Columbia University
NYC



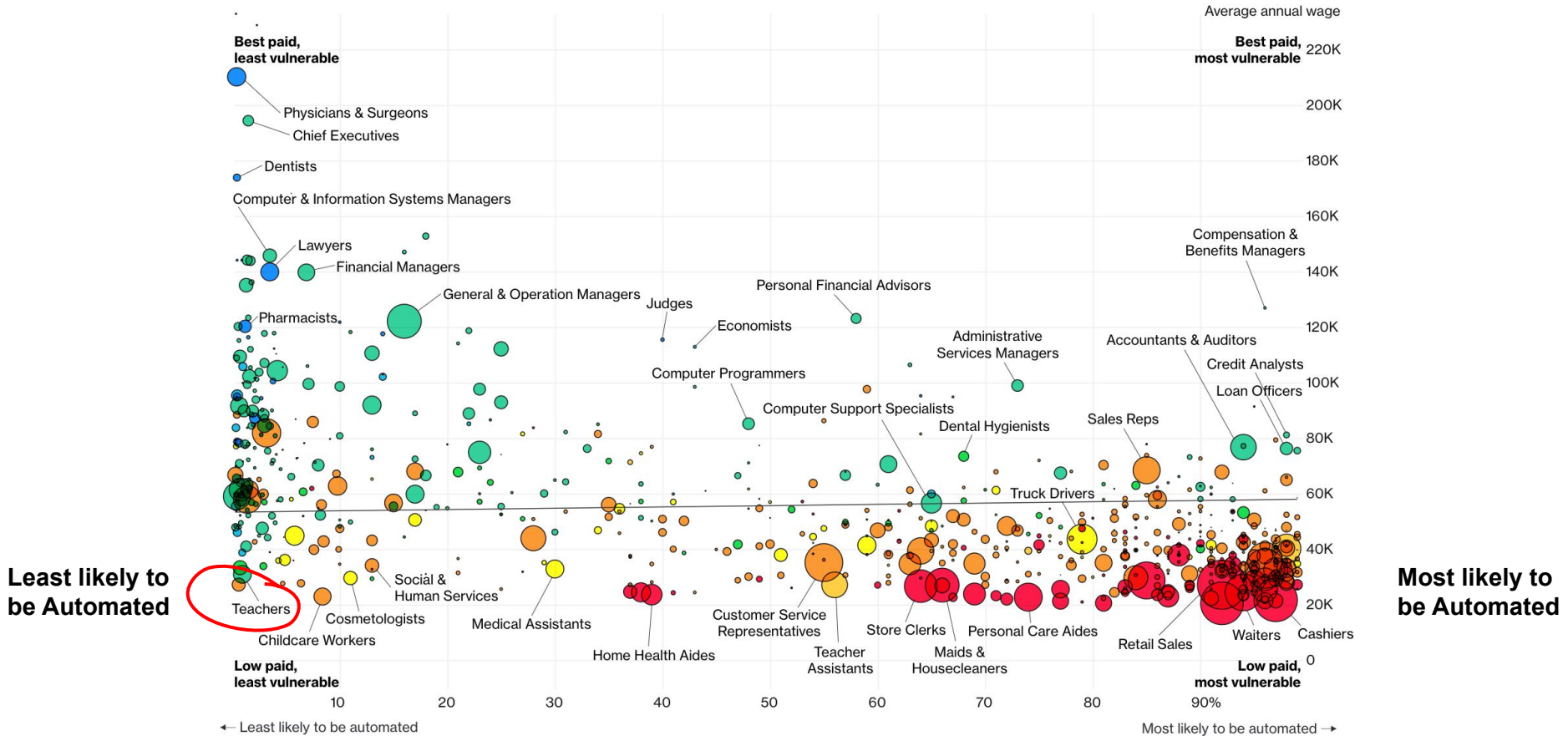
The Transformative Learning Technologies Lab

- Make school STEM similar to real science and engineering
 - Connect to student's interests
 - Solve real-world problems
- Combine vision with research and implementation of constructionist STEM activities in real school systems.
- *Radically change how children learn STEM*



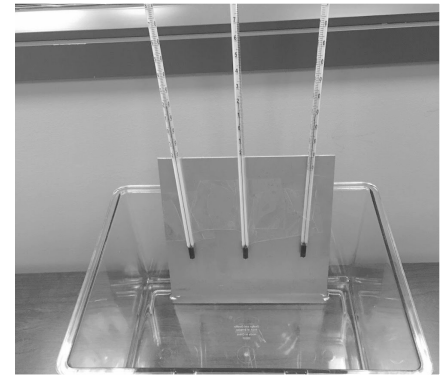
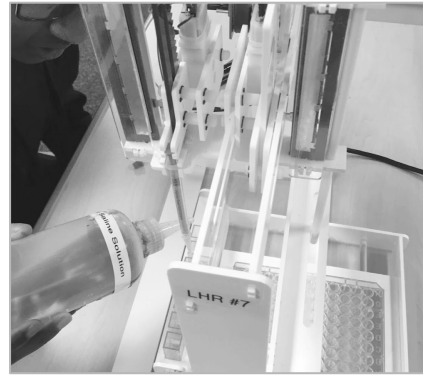
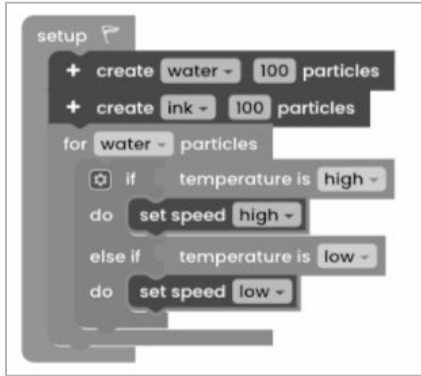
<https://tltlab.org/>

Workforce: will your Job be automated tomorrow?

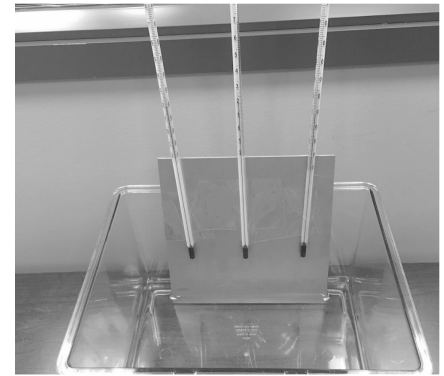
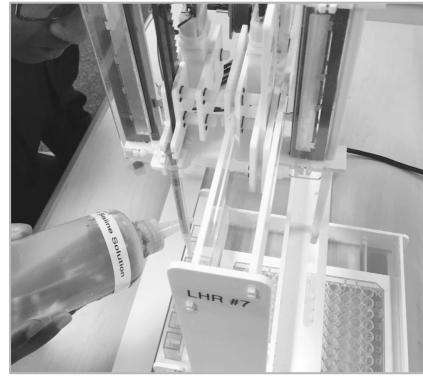
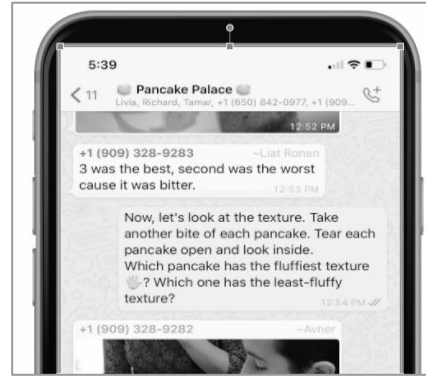
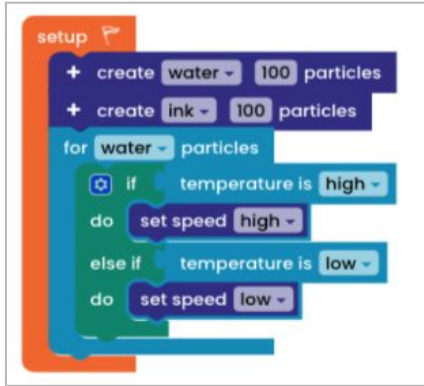


**How to teach STEM for a world
that doesn't exist (yet)?**

STEM curriculum & research



STEM curriculum & research



MoDa: How computational modeling can be made a sustainable practice across middle school classrooms through design and research?



Agenda

1. Project Vision & Design
2. Research
3. Try out MoDa

Project Vision & Design

Project Goals and team

- 3 years NSF Drk-12
- Investigate how **computational modeling** can be a sustainable practice across middle school classrooms through design and research.

PI Team



Tamar Fuhrmann
Columbia University



Aditi Wagh
MIT



Paulo Blikstein
Columbia University



Michelle Wilkerson
UC Berkeley

Project Team



Adelmo Eloy
Columbia University



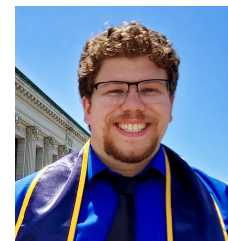
Leah Rosenbaum
Columbia University



Engin Bumbacher
HEP Vaud (SWI)



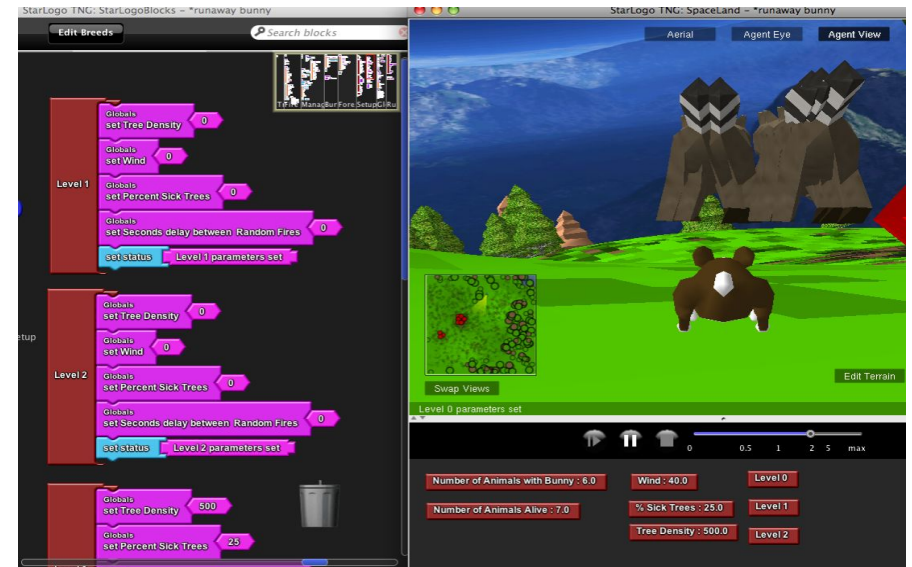
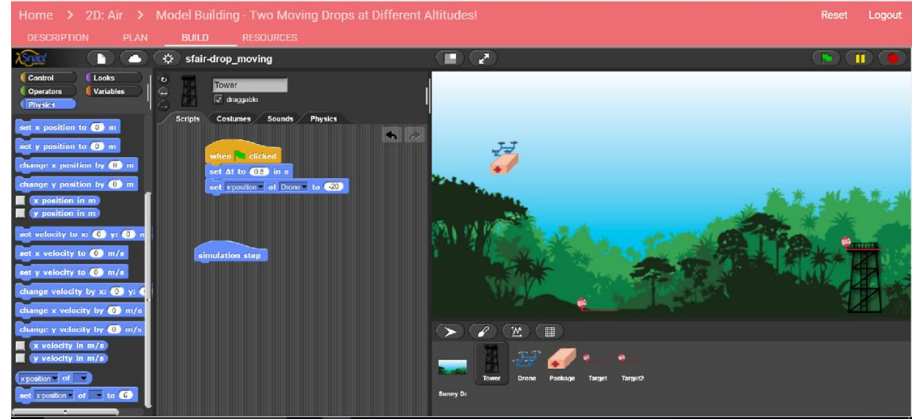
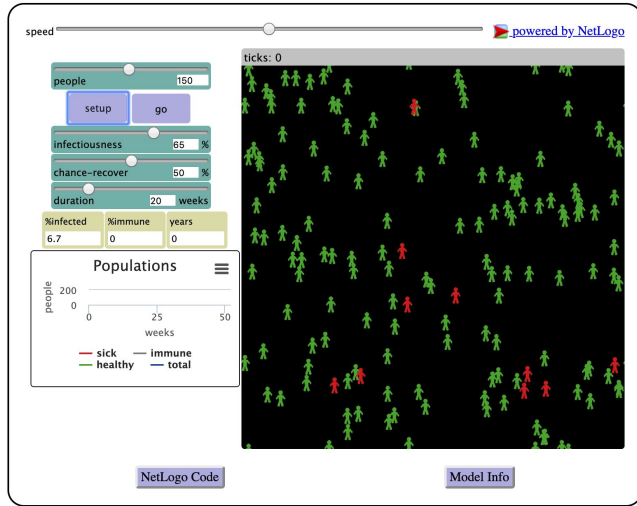
Nathan Rabinovitch
Columbia University



Brendan Henrique
UC Berkeley



Motivation: Computer modeling



- Scientific Modeling is powerful, but also difficult to enact in classrooms.
- Models are used in class to confirm theory and explore canonical ideas, but less as an inquiry tool for alternative ideas.

Motivation: Current Computer modeling status

- Programmable modeling environment



- Challenging for novices
- Requires too much time for students to learn to program
- Hard to use as part of science class

```
to go
; set sea level based on temperature rise
set sea-level (-13 + (temp-rise * 3.6))

; move water based on temperature rise
ask waters [
  set heading 0
  setxy -16.5 -16.5
  set size 40 + (temp-rise * 70)
]

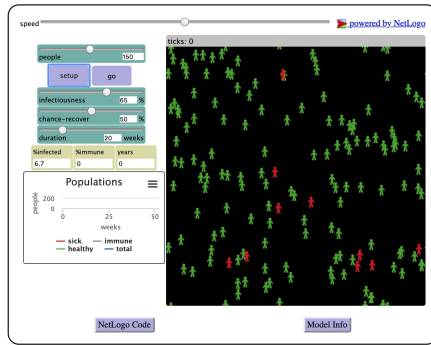
; set output to the sea level rise
set rise-in-feet (temp-rise * 8)
output-type rise-in-feet output-type " feet sea level rise"
output-print ""

end
```


Motivation: Current Computer modeling status



Computer Modeling



Data/Experiment



Students use models disconnected from experiments & data

Theoretical background

- Domain-specific agent-based modeling (e.g., Kahn, 2007; Saba et al., 2021; Wilkerson, Wagh & Wilensky, 2015)
- Integrating data and modeling (Blikstein et al., 2012; 2014; Fuhrmann et al., 2018; Gouvea & Wagh, 2017)
- Extended engagement in modeling and data (e.g., Lehrer & Schauble, 2012; Manz, 2015; Schwarz et al., 2009)

MoDa web-based tool to integrate Modeling & Data

The image displays the MoDa web-based tool interface, which is divided into three main panels: Workspace, Model, and Experiment.

Workspace: This panel contains a Scratch-style block palette on the left with categories: General, Diffusion, Properties, Action, and Control. The main workspace shows a script with the following blocks:

- setup** block containing a **create water 500 particles** block.
- on mouse click** block containing a **create ink 100 particles** block.
- go** block containing:
 - ask all particles** block
 - move** block
 - + interact** block

Below the workspace are zoom and pan controls (a target icon, a plus sign, a minus sign, and a trash can icon).

Model: This panel features a simulation window with a grid of particles. Above the window are controls for **model speed** (play, pause, and a slider) and **temperature** (a slider set to 40 °C, with a 'high' label and a 'grid' checkbox). A **Stop Diffusion** button is located below the temperature controls. At the bottom of the model panel are two graphs: **Ink Spread %** vs **Time** (showing a flat line at 0%) and **Ink Spread %** vs **Temperature (°C)** (showing a flat line at 0%).

Experiment: This panel allows users to **Select a video** from a dropdown menu (currently showing 'Hot Water Diffusion'). Below the menu is a video player showing a glass of water with a white substance being poured into it. The video player includes standard playback controls (play, volume, full screen, and a menu icon).

MoDa web-based tool to integrate Modeling & Data

Coding Workspace

Workspace

General

Diffusion

Properties

Action

Control

The coding workspace shows a Scratch-style script editor. It contains three main blocks: a 'setup' block with a 'create water' block set to 500 particles; an 'on mouse click' block with a 'create ink' block set to 100 particles; and a 'go' block containing 'ask all particles', 'move', and '+ interact' blocks. A trash icon is visible at the bottom right of the workspace.

Simulation Workspace

Model

model speed

The simulation workspace displays a 2D grid of particles. The 'model speed' slider is at the top right. Below the grid, there is a 'temperature' slider set to 40 °C, a 'grid' checkbox, and a '1 ticks' label. A blue 'Stop Diffusion' button is at the bottom. At the bottom of the workspace, there are two graphs: 'Ink Spread %' vs 'Time' and 'Ink Spread %' vs 'Temperature (°C)'. The 'Time' graph shows a single data point at (0,0) and (1,0). The 'Temperature' graph shows a single data point at (40,0).

Real-world Data

Experiment

Select a video: Hot Water Diffusion

The real-world data section shows a video player with a dropdown menu set to 'Hot Water Diffusion'. The video shows a glass of water with a vertical line of ink being added, illustrating the diffusion process. The video player has standard controls like play, volume, and full screen.

MoDa design principles

<https://moda.education>

1. Block-based, Domain-specific modeling

The workspace shows a sidebar with categories: General, Diffusion, Properties, Action, and Control. The Diffusion category is expanded, showing a 'setup' block containing a 'create water' block with '500 particles' and an 'on mouse click' block containing a 'create link' block with '100 particles'. Below these is a 'go' block containing an 'ask all particles' block, a 'move' block, and an 'interact' block. A trash icon is visible at the bottom right of the workspace.

2. “Unpacking” blocks to move from simple to complex models

3. Linking data & modeling: to validate models with real world data

The Model panel features a 'model speed' slider, a central visualization of a diffusion model with blue particles on a grid, a 'temperature' slider set to '40 °C', a 'grid' checkbox, and a 'Stop Diffusion' button. Below the visualization are two graphs: 'Ink Spread %' vs 'Time' and 'Ink Spread %' vs 'Temperature (°C)'. The Experiment panel shows a video player with a dropdown menu set to 'Hot Water Diffusion' and a video of a glass of water.

4. Thematically linked units center around diffusion

5. Co-designed with teachers
6. Teachers' dashboard

Domain-specific modeling to make modeling accessible to students

```
setup
+ create 1000 air particles
+ create 100 smoke particles

go
ask all particles
- interact
  if touching any particle
  do bounce off
+ move
```

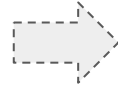
```
setup
+ create water 300 particles

go
ask water particles
  move
ask water particles
  if temperature is high
  do set speed high
  if temperature is medium
  do set speed medium
  if temperature is low
  do set speed low
ask ink particles
  move

on mouse click
+ create ink 20 particles
```

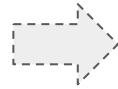
“Unpacking” to move from simple to progressively complex models

```
setup  
+ create 100 water particles
```



```
setup  
- create 100 water particles  
  set speed initial temperature  
  set position random  
  set heading random  
  set mass medium  
  set color cyan  
  set size medium
```

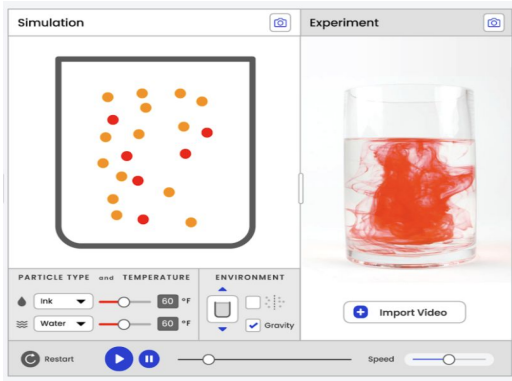
```
on mouse click  
  ask water particles  
  move  
  + interact
```



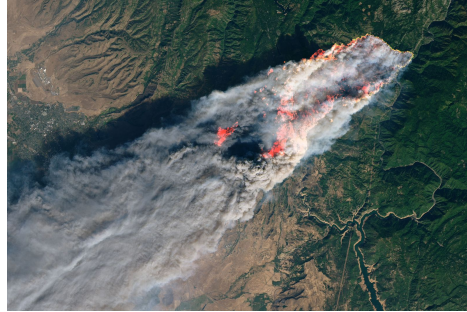
```
on mouse click  
  ask water particles  
  move  
  - interact  
    if touching wall  
    do bounce off  
    if touching any particle  
    do bounce off
```

Linking data & modeling

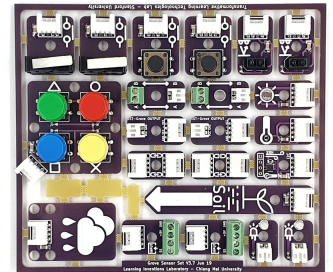
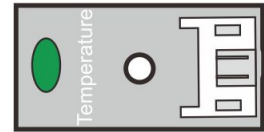
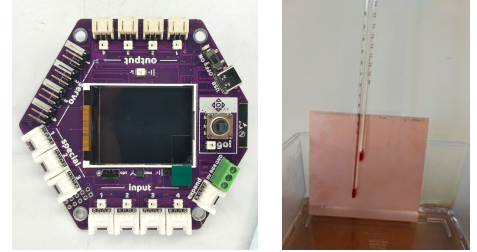
Experiments: Ink spread



Public Data: Smoke spread

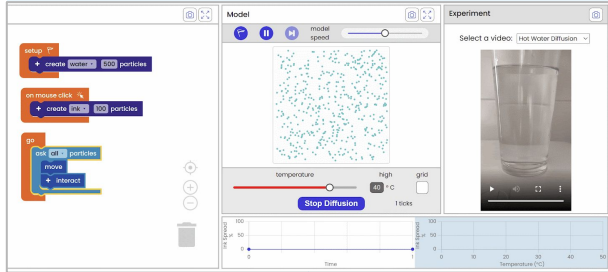


Sensor Data: Conduction

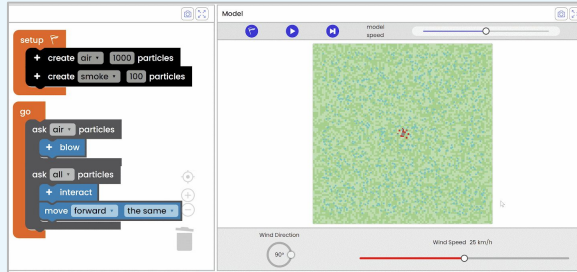
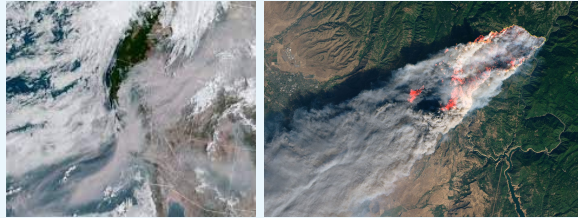


Thematically linked units

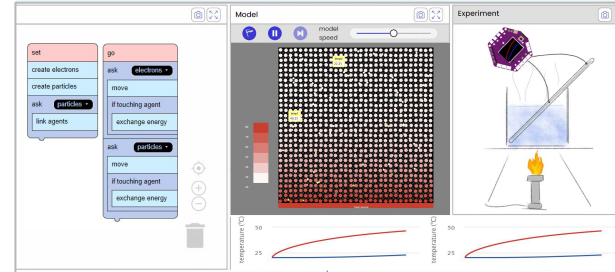
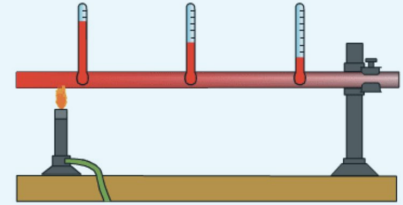
Unit 1: How does ink spread in hot and cold water?



Unit 2: How does wildfire smoke spread?

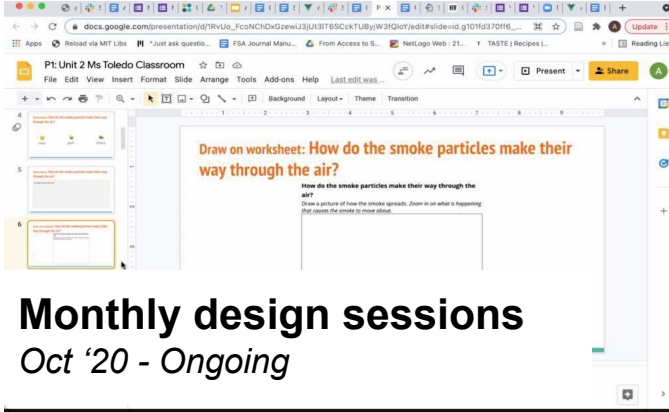


Unit 3: How do things get hot?

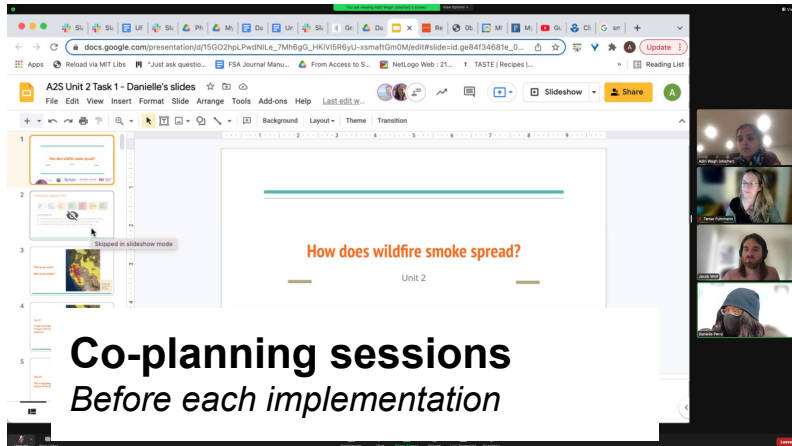


Diffusion: Movement from high to low concentration/temperature

Co-design with teachers



Monthly design sessions
Oct '20 - Ongoing



Co-planning sessions
Before each implementation



Teacher dashboard


How does ink spread in water?

Tasks:

Sort by:

View:

Student User 616



How does ink spread in water?
Thu Mar 17 2022 15:26:36 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)


Student User 604



How does ink spread in water?
Thu Mar 17 2022 15:21:49 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)


Student User 601



How does ink spread in water?
Mon Mar 14 2022 17:31:35 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)


Student User 613



How does ink spread in water?
Thu Mar 17 2022 15:26:26 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)

Student User 618



How does ink spread in water?
Thu Mar 10 2022 16:27:26 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)


Student User 615



How does ink spread in water?
Tue Mar 15 2022 15:24:02 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)

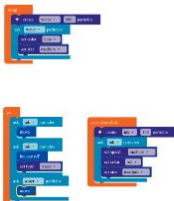
Student User 698



How does ink spread in water?
Mon Nov 15 2021 17:40:07 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)


Student User 608



How does ink spread in water?
Mon Mar 14 2022 17:34:22 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)


Student User 605



How does ink spread in water?
Thu Mar 17 2022 15:17:28 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)

Student User 606



How does ink spread in water?
Mon Mar 14 2022 17:29:53 GMT-0300 (Horário Padrão de Brasília)

★ [Open Models](#)

Project Research

Publications

1 journal manuscripts
submitted

2 journal manuscripts in
preparation

17 conference papers

Impact:

Teachers: 6

Co-design & PD sessions: 70
hours

Students: 400

Fuhrmann, T., et al...**Unpacking the Relationship between Students' Mechanistic Reasoning and Conceptual Understanding when Designing Computational Models with Data** (Submitted Science Education)

How Can Computational Modeling Help Students Shift Their Ideas Towards Scientifically Accurate Explanations? (ISLS 2023)

Fuhrmann, T., Rosenbaum, L., Eloy, A., Wagh, A., Wolf, J., Blikstein, P., Wilkerson, M., (2023). **Right but Wrong: The Independence of Mechanistic Reasoning and Canonical Understanding in Studying Diffusion.** NARST, Chicago, USA.

Wagh, A., Eloy, A., Fuhrmann, T., Rosenbaum, L., Blikstein, P., Wilkerson M. (2023). **What dimensions of a phenomenon do students notice through computational modeling and data analysis?: An investigation using MoDa.** NARST, Chicago, USA.

Wagh, A., Fuhrmann, T., Eloy, A., Bumbacher, E., Wilkerson, M. H., & Blikstein, P. (2022). **Lessons from co-designing with science teachers to support sustained computational modeling in middle school classrooms.** Roundtable paper presented at the 2022 Annual Meeting of the American Educational Research Association, San Diego, CA, USA.

Wagh, A., Fuhrmann, T., Bumbacher, E., Eloy, A., Wolf, J., Blikstein, P., & Wilkerson, M. H. (2022). **MoDa: Designing a tool to interweave computational modeling with real-world data analysis for science learning in middle school.** In Proceedings of Interaction Design and Children (IDC '22), June 27-30, 2022, Braga, Portugal. ACM, New York, NY, USA, 9 pages. doi: 10.1145/3501712.3529723

Wolf, J., Fuhrmann, T., Wagh, A., Eloy, A., Blikstein, P., & Wilkerson, M. H. (2022). **After the study ends: Developing heuristics to design for sustainable use of learning technologies in classrooms.** In Proceedings of Interaction Design and Children (IDC '22), June 27-30, 2022, Braga, Portugal. ACM, New York, NY, USA, 4 pages. doi: 10.1145/3501712.3529723

Wagh, A., Fuhrmann, T., Eloy, A., Wolf, J., Bumbacher, E., Blikstein, P., & Wilkerson, M. (2022). **Strategies towards Designing for Sustained Engagement in Computational Modeling in Science Classrooms.** Poster to appear in Proceedings of the 2022 Annual Meeting of the International Society for the Learning Sciences (ISLS 2022), Hiroshima, Japan.

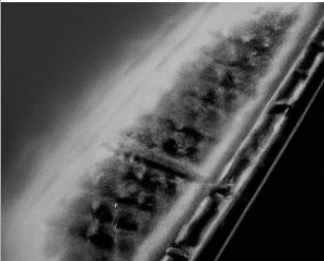
Fuhrmann, T., Wagh, A., Eloy, A., Wolf, J., Bumbacher, E., Wilkerson, M., & Blikstein, P. (2022). **Infect, Attach or Bounce off?: Linking Real Data and Computational Models to Make Sense of the Mechanisms of Diffusion.** Proceedings of the 2022 Annual Meeting of the International Society for the Learning Sciences (ISLS 2022), Hiroshima, Japan.

Eloy, A., Wolf, J., Wagh, A., Fuhrmann, T., Bumbacher, E., Wilkerson, M. H., & Blikstein, P. (2022). **A2S: Designing an integrated platform for computational modeling & data analysis for sustained investigations in science classrooms.** Interactive Workshop to appear in Proceedings of the 2022 Annual Meeting of the International Society for the Learning Sciences (ISLS 2022). ISLS: San Diego, CA.

Moda units

How does ink spread in hot and cold water?


Heat conduction



Unit Overview

[Modeling Page](#)


Ink spread in water



Unit Overview

[Modeling Page](#)


Population dynamics



Unit Overview

[Modeling Page](#)


Spread of PM 2.5 particles



Unit Overview

[Modeling Page](#)

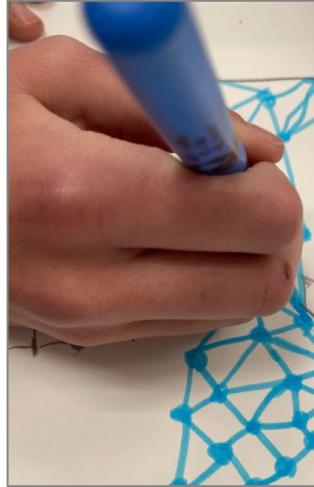
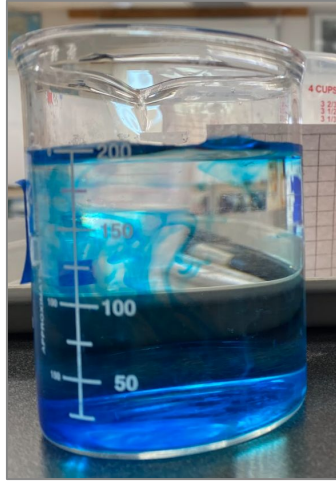
Wildfire smoke spread



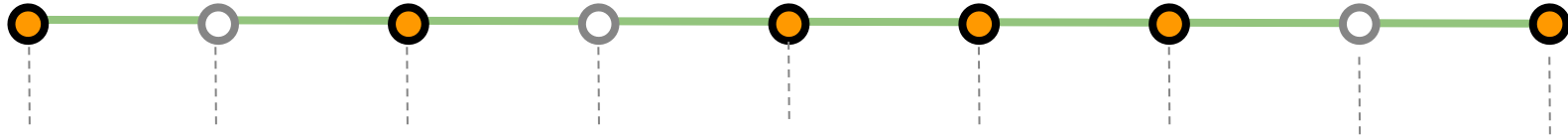
Unit Overview

[Modeling Page](#)

Methods: Data source



```
go
for water particles
  move
for water particles
  if temperature is high
    do set speed high
  else if temperature is medium
    do set speed medium
  else if temperature is low
    do set speed low
```



Pre-test;
Open-ended questions

Day 1:
Experiment

Day 2:
Individual model drawings

Day 3 +4:
MoDa:
Intro
+Challenges

Day 5:
Pair model drawing

Day 6:
Design MoDa models **Pair design video**

Day 7:
Model share-out

Day 8:
Discuss theory & validity

Post-test;
Open-ended questions

Research Questions

- In what ways do the designed activities support students in developing *mechanistic reasoning* and *canonical understandings* of diffusion?
- What is the *relationship* between students' mechanistic reasoning and their understanding of diffusion?

Methods: Data analysis

Rubric for MR about diffusion
(Adapted from Russ et al., 2008)

Code	Description	Micro-level Reasoning
Identifying Entities (IE)	Students mention the elements (entities) that play roles in producing diffusion.	Water molecules, color molecules, air molecules, particles, elements, atoms
Identifying Activities (IA)	Students describe actions and activities that caused diffusion.	Molecules spread apart, molecules <i>spread evenly</i>
Identify Properties of Entities (IP)	Students describe properties (adjectives) of the entities responsible for the target phenomenon.	Water molecules are little hard balls that bounce off everything, molecules move faster, molecules are bigger
Identifying Organization of Entities (IOE)	Students indicate how the entities are spatially organized and structured.	Dye molecules move between the water molecules, cold molecules are closer together, molecules move from high concentration to low concentration
Causality (Ca)	Students reason about the relationship between cause and effect, namely between temperature and movement.	The faster the water molecules move, the more they spread the ink

Rubric for canonical understanding of diffusion

Canonical		Non-canonical	
<i>Idea</i>	<i>Example Responses</i>	<i>Idea</i>	<i>Example Responses</i>
Particles interact by bouncing.	“when the ink and water particles collide, they bounce off of each other”	Other particle interaction	“Spreading throughout the water molecules and attaching to them as they go.” “water particles making a barrier”
Particles move faster with heat	“The hotter the water, the faster the water particles move.”	Other effect of temperature	“if the water was cold, it would be more solid in a way. [...] if the water is hot or warm, it flows better?” “cold [water] has a density, hot has air bubbles”

Each data source was coded separately to assess students’ MR and understanding of diffusion

Students: n=16

Findings

1. Modeling shifts students explanations from simple to sophisticated mechanistic reasoning

2. Comparing model with Data shifts students' explanations from non-canonical to canonical

3. Students' MR and their understanding of a scientific phenomenon developed independently

Findings

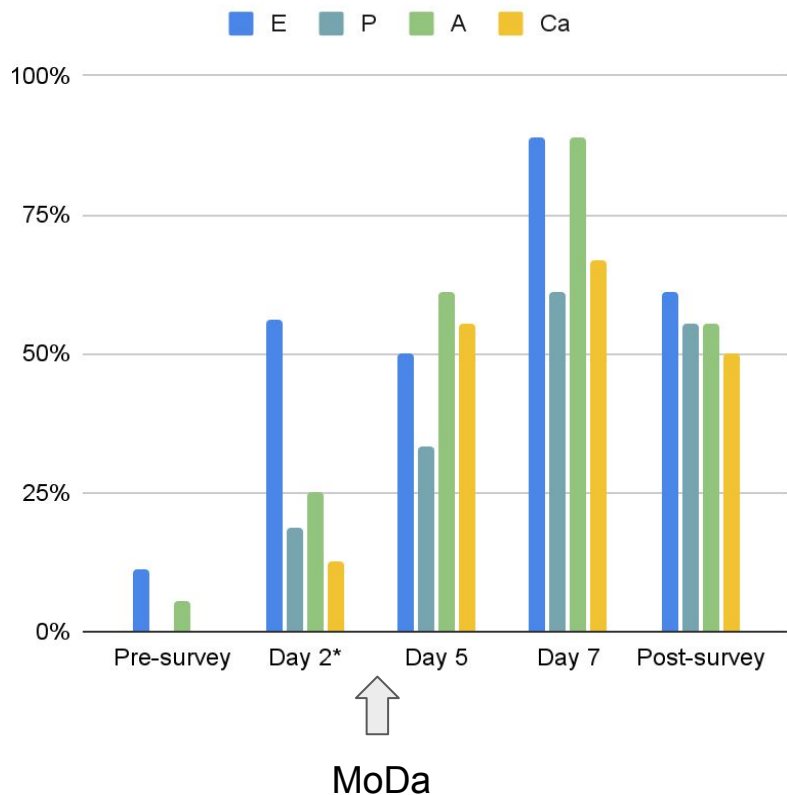
1. Modeling shifts students explanations from simple to sophisticated mechanistic reasoning

2. Comparing model with Data shifts students' explanations from non-canonical to canonical

3. Students' MR and their understanding of a scientific phenomenon developed independently

Findings: Shifts in mechanistic reasoning

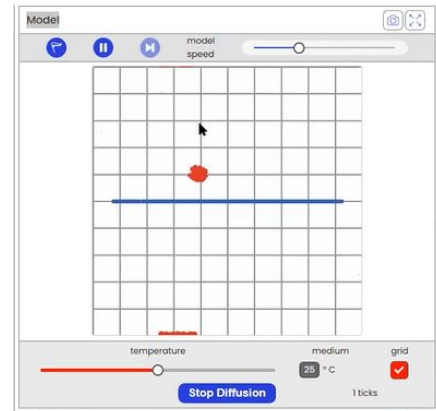
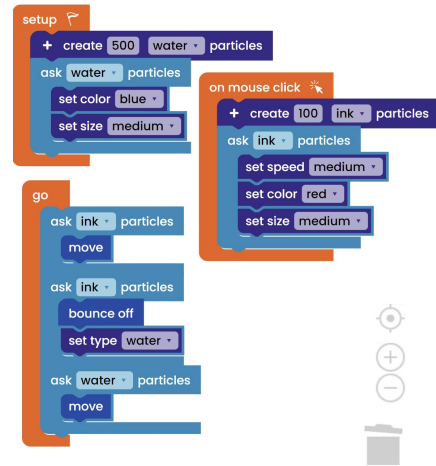
The percentage of explanations that included MR components



MR	Pre-survey	Day 2	Day 5	Day 7	Post-survey
E	11%	56%	50%	89%	61%
P	0%	19%	33%	61%	56%
A	6%	25%	61%	89%	56%
Ca	0%	13%	56%	67%	50%

Findings: Shifts in mechanistic reasoning

Pre-test:
“I imagine it spreads through the water maybe because of gravity.”



Post test:
“The **ink particles bounce off** of the **water particles**, when the water is warm the **particles move faster** so the ink particles move through the water faster. When the water is cold The water **particles move slower** so when the ink particles bounce off of them they move slower.”

Findings

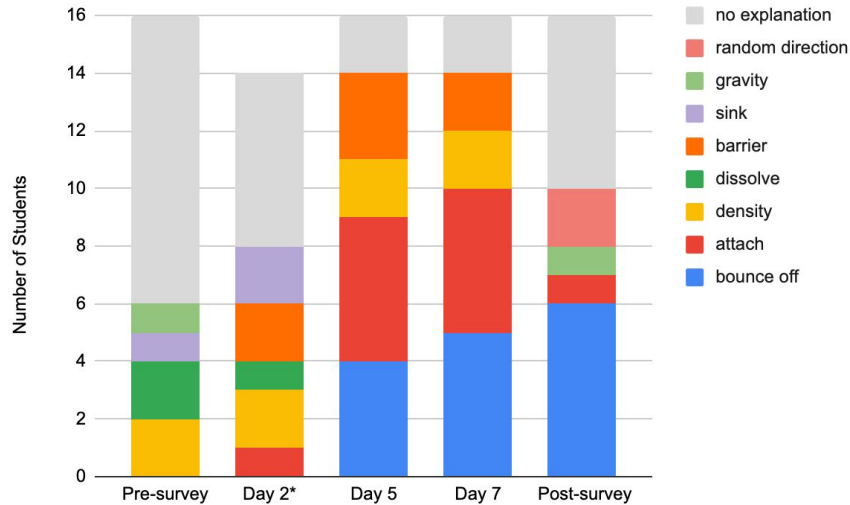
1. Modeling shifts students explanations from simple to sophisticated mechanistic reasoning

2. Comparing model with Data shifts students' explanations from non-canonical to canonical

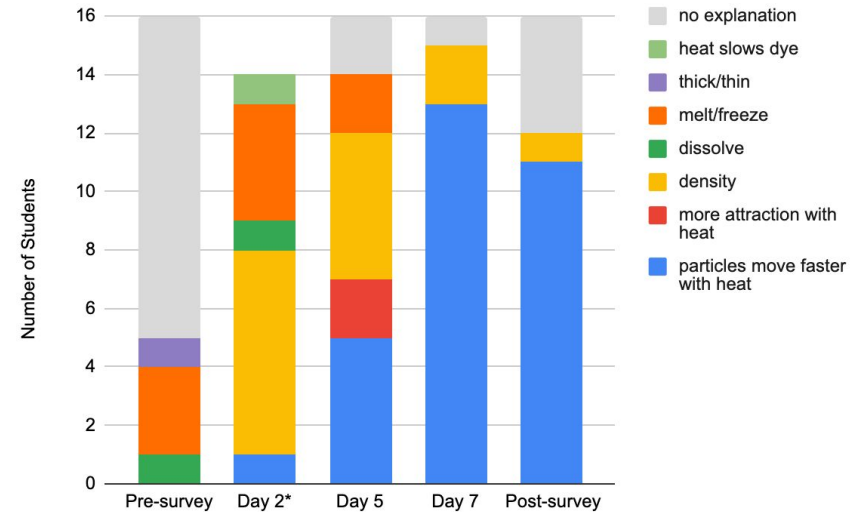
3. Students' MR and their understanding of a scientific phenomenon developed independently

Findings: Shifts from non canonical to canonical

Student explanations for diffusion through particles' interaction



Student explanations for diffusion through the effect of temperature



Findings: Students could translate their ideas into code in MoDa

(1) “attached” model

```
go
ask all particles
  move
  - interact
    if touching wall
    do bounce off
    if touching any particle
    do attach particles
```

(2) “infect” model

```
go
ask all particles
  move
  ask water particles
    if touching ink particle
    do set color red
```

(3) “weights more” model

```
go
ask all particles
  move
  if temperature is high
  do set mass light
  if temperature is medium
  do set mass medium
  if temperature is low
  do set mass heavy
```

(4) “Barrier” model

```
go
ask water particles
  set position horizontal line
ask ink particles
  move
  bounce off
```

(5) “Sandwich” model

```
go
ask ink particles
  if temperature is low
  do if touching wall
  do set speed zero
```

(6) “Dense” model

```
setup
+ create 500 water particles
  (for cold water)
x
  (for hot water)
setup
+ create 200 water particles
```

(7) “bounce off” model

```
go
ask all particles
  move
  - interact
    if touching wall
    do bounce off
    if touching any particle
    do bounce off
```


Findings: "Attached" model

Diffusion

Workspace

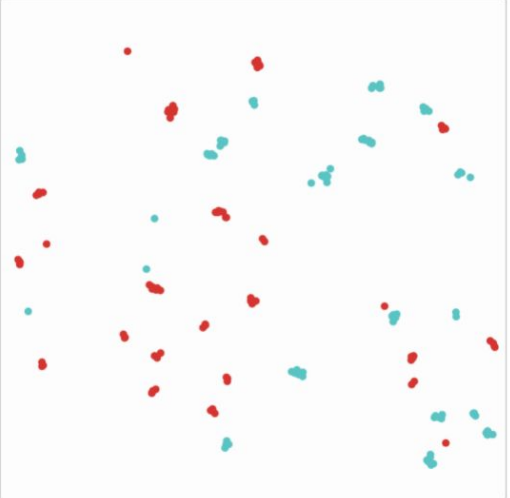
General

```
go
  ask all particles
  move
  - interact
    if touching wall
    do bounce off
    if touching any particle
    do attach particles
```

on mouse click

Model


model speed



temperature medium grid


25 °C

Stop Diffusion 30 seconds



Data

Select a video: Hot Water Diffusion



Findings

1. Modeling shifts students explanations from simple to sophisticated mechanistic reasoning

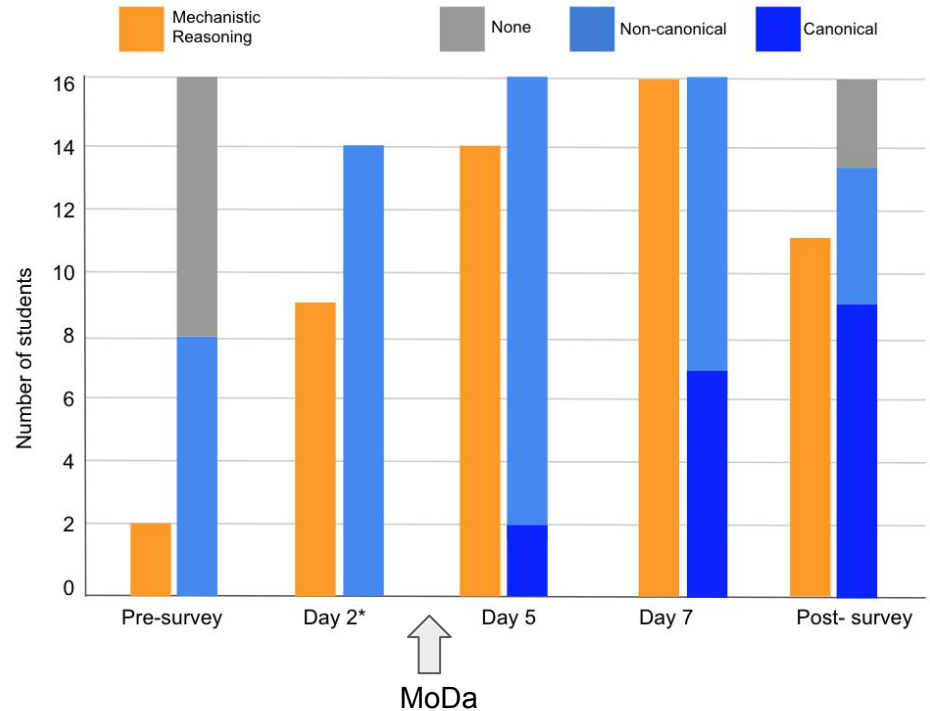
2. Comparing model with Data shifts students' explanations from non-canonical to canonical

3. Students' MR and their understanding of a scientific phenomenon developed independently

Findings: Use sophisticated MR with wrong ideas

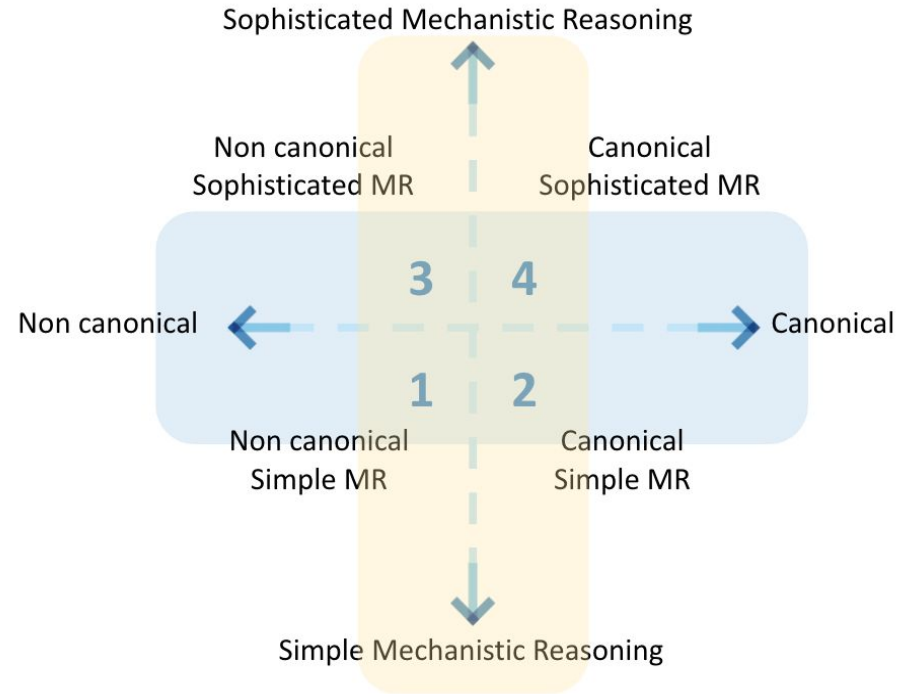
- Students' mechanistic reasoning and their understanding of a scientific phenomenon develop independently.
- Students use sophisticated mechanistic reasoning with wrong scientific ideas.

Mechanistic Reasoning & Understanding of Diffusion

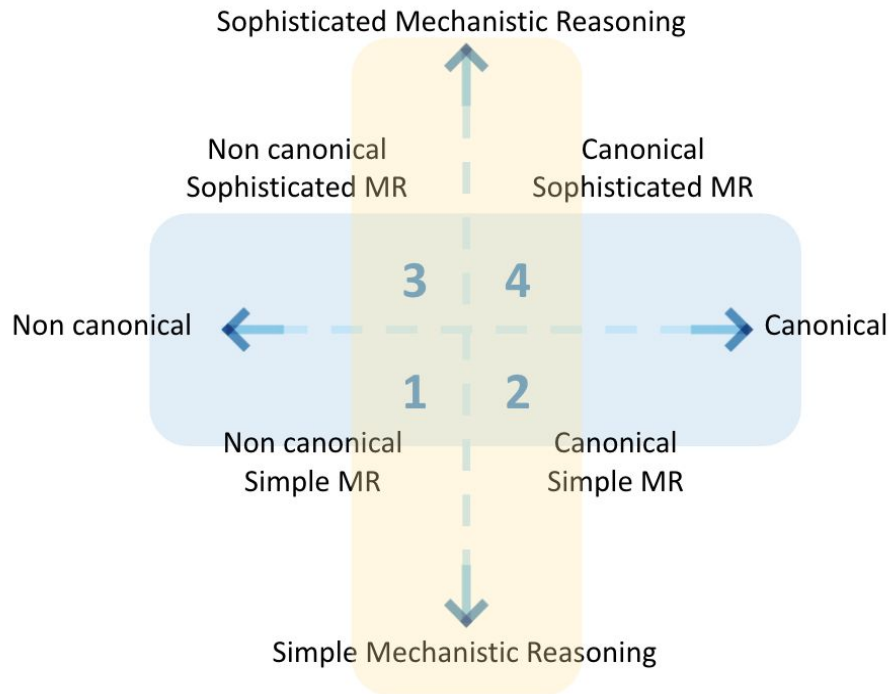


Summary

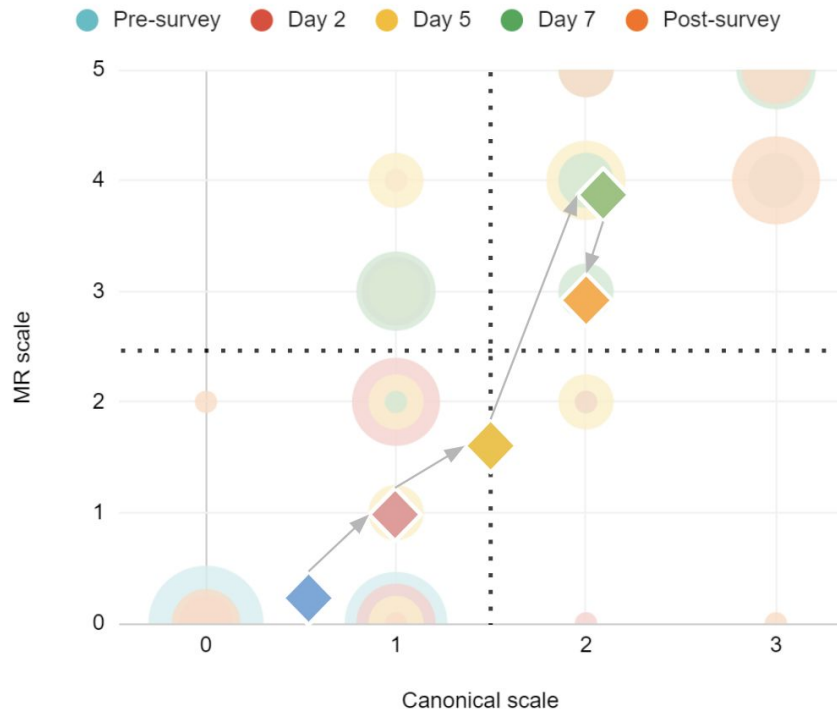
- **Modeling** shifted students' explanations from simple to sophisticated mechanistic reasoning.
 - Students explore theories to explain data.
 - Students use sophisticated MR with wrong scientific ideas.
- **Comparing model with Data** shifted students' explanations from non-canonical to canonical
 - Students testing their theories with data.
 - Students revise models to explain the data.



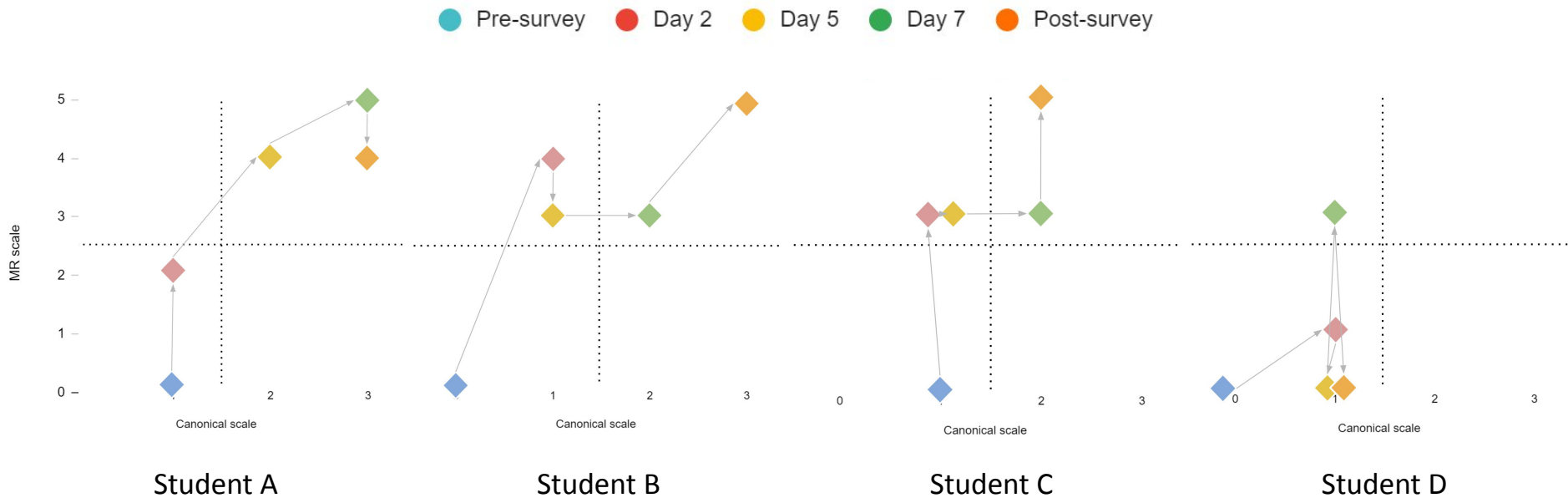
Summary



Average



Diverse trajectories





Kelly Miller

Santa Catalina School, Monterey - CA

Infect, Attach or Bounce off?: The Independence of Mechanistic Reasoning and Canonical Understanding of Diffusion

Tamar Fuhrmann

May 25, 2023 Hong Kong University

Teachers College, Columbia University



Transformative Learning
Technologies Lab

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Thanks!

- Teachers College, Columbia University
- Postdoc @Stanford
- Based @ California
- Husband +Three kids
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