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

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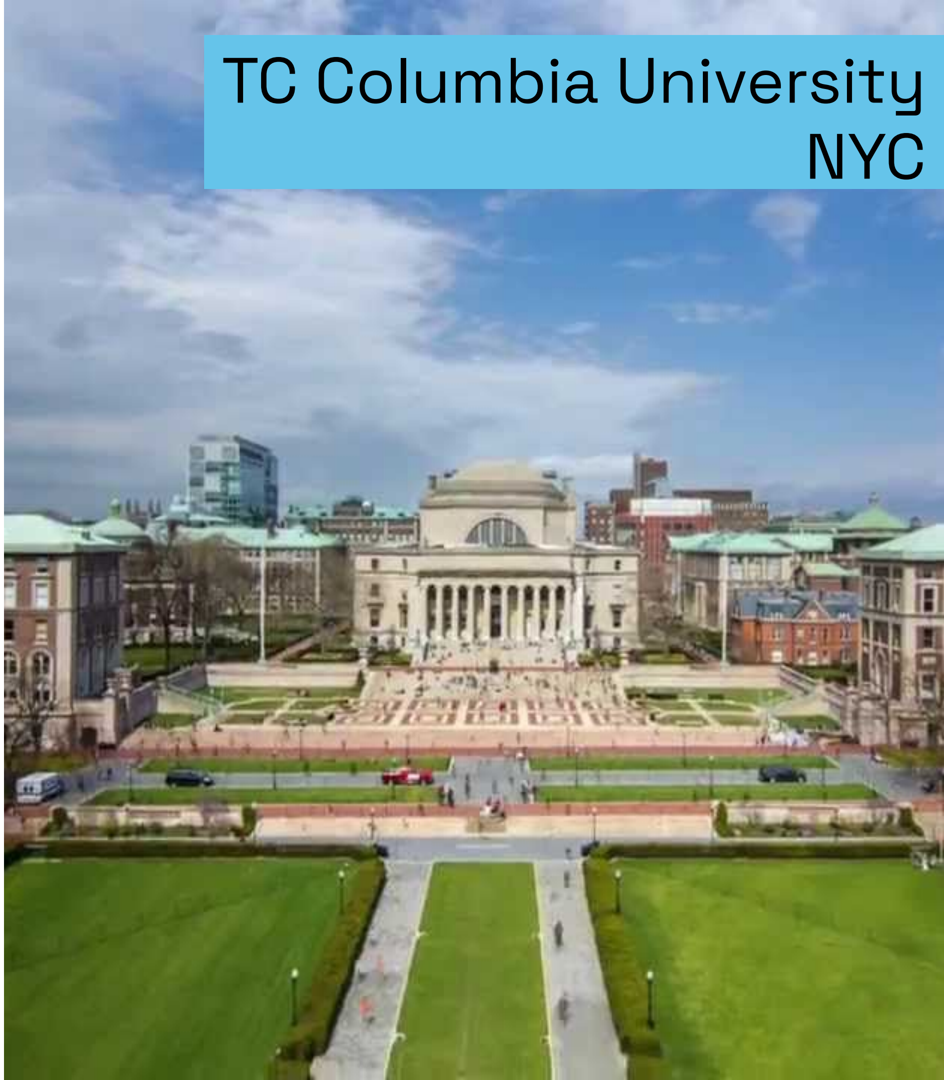
Teachers College, Columbia University

Transformative Learning Technologies Lab

TEACHERS COLLEGE COLUMBIA UNIVERSITY


Transformative
Learning
Technologies Lab


TC Columbia University
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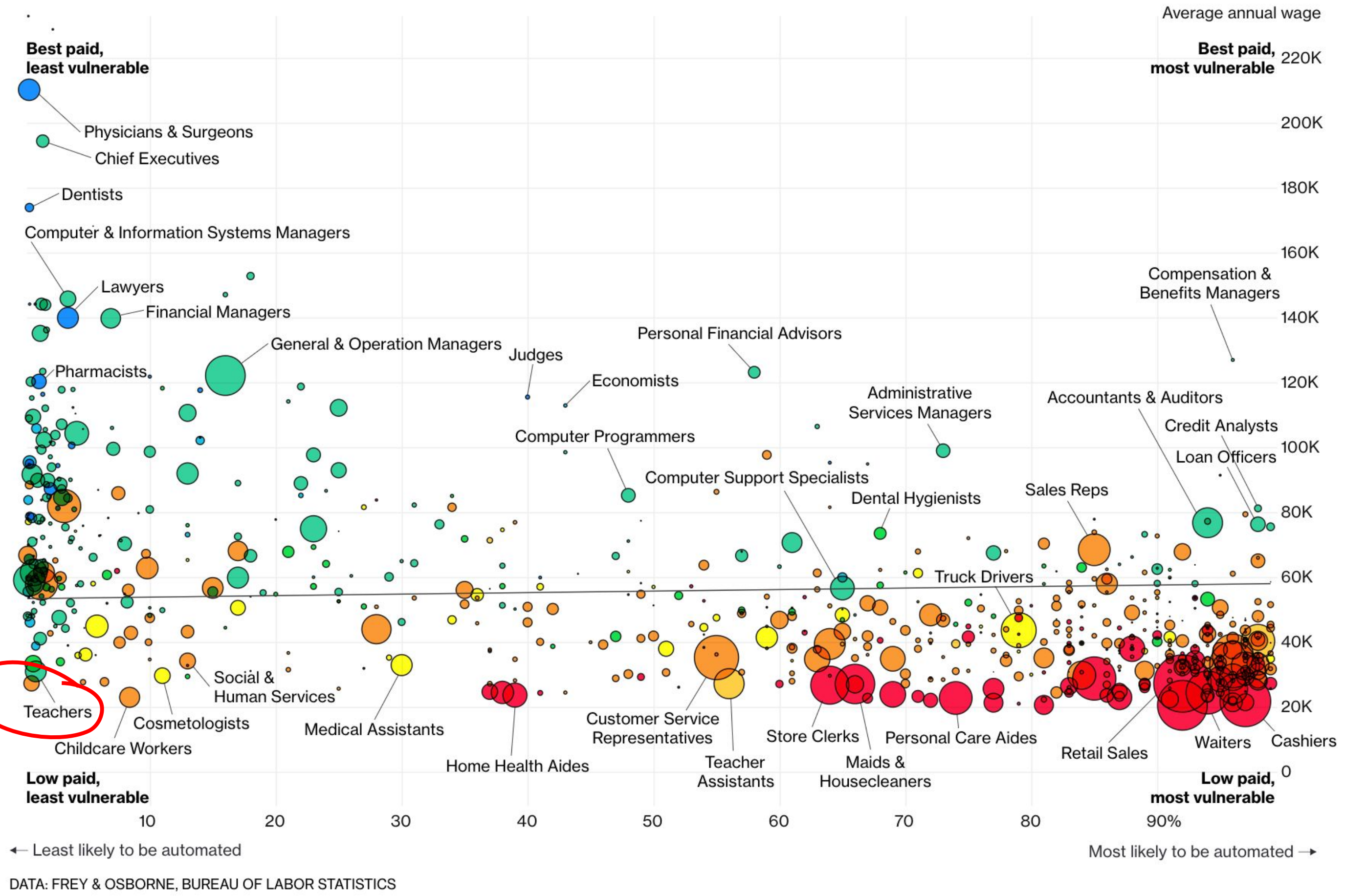
The Transformative Learning Technologies Lab

- 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?

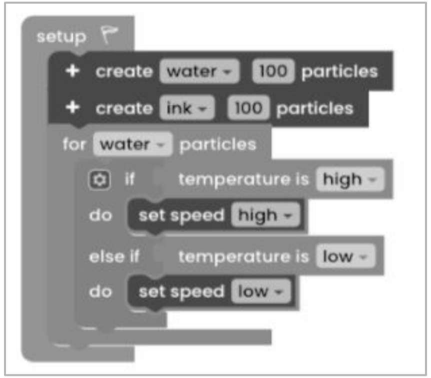
Least likely to be Automated

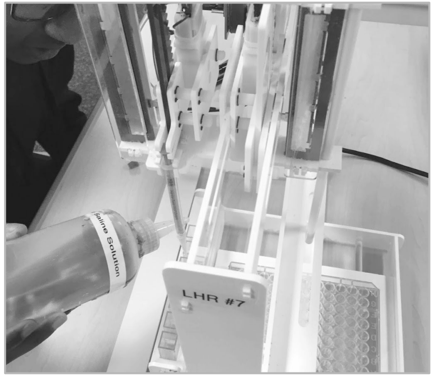


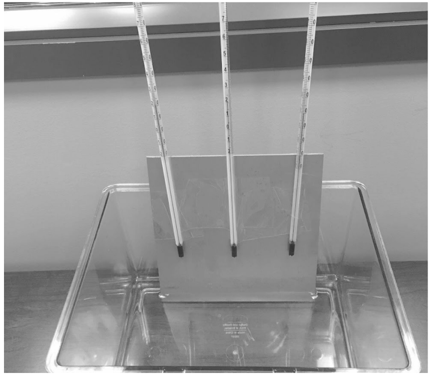
Most likely to be Automated

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

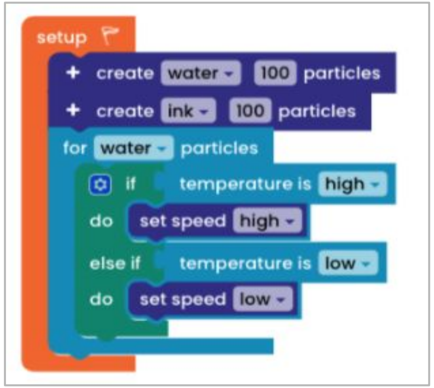
STEM curriculum & research

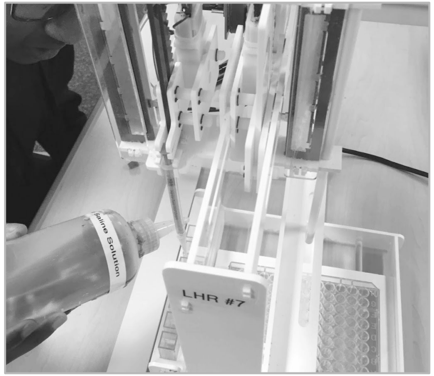


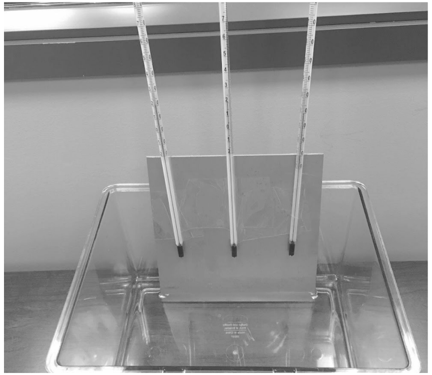




STEM curriculum & research







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)

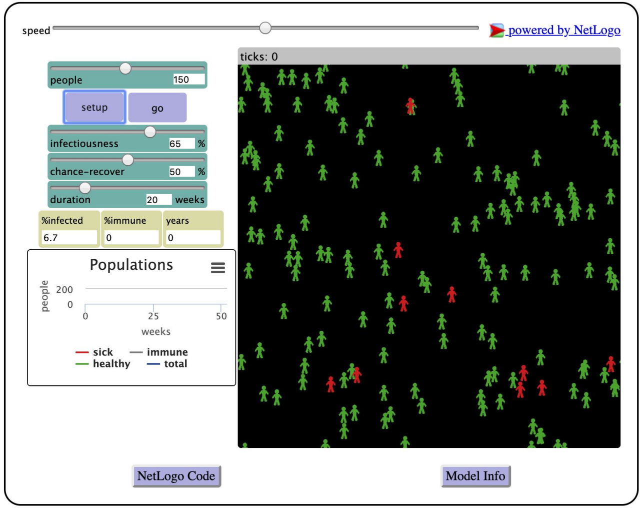
Nathan Rabinovitch
Columbia University

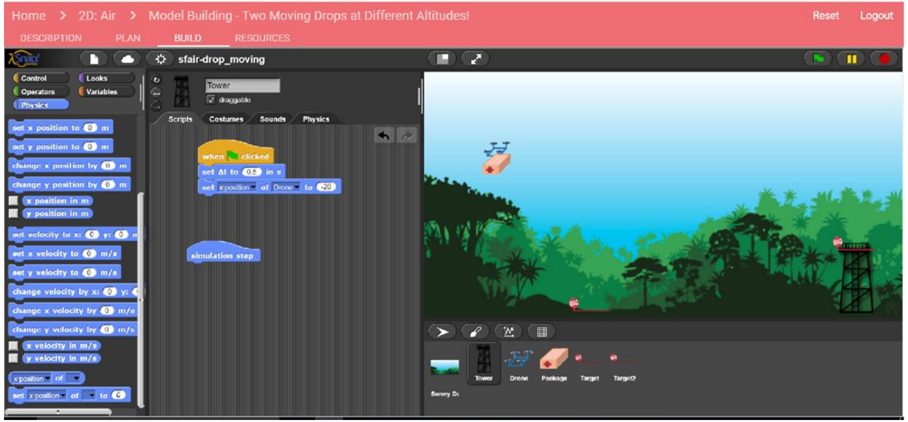
Brendan Henrique
UC Berkeley

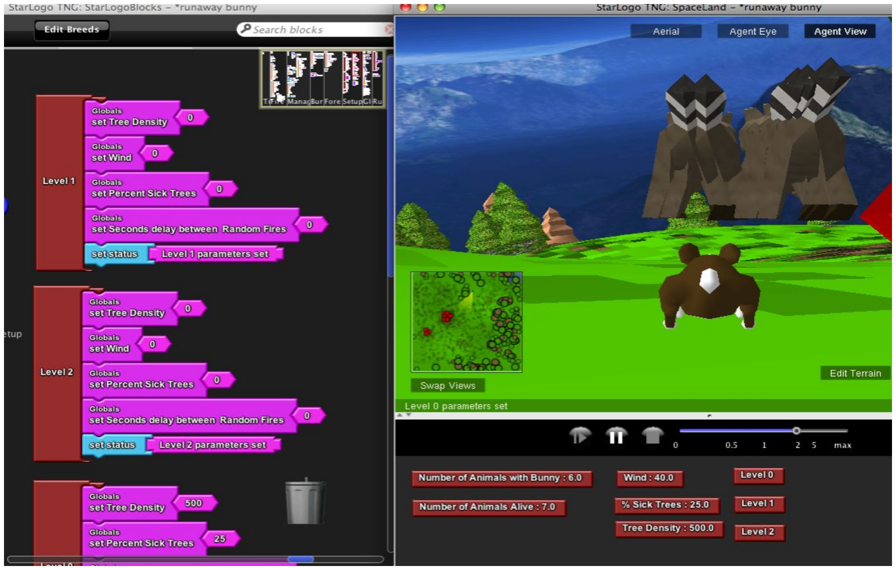
MIT | SCHELLER TEACHER EDUCATION PROGRAM education arcade

NSF Berkeley Graduate School of Education

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

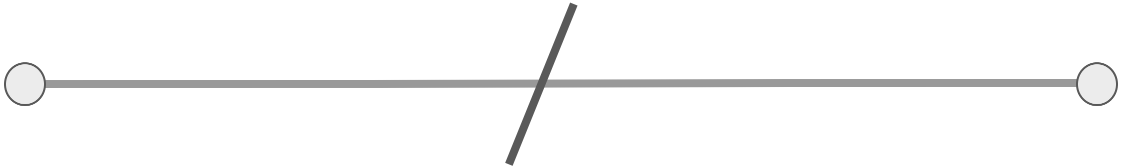
- Programmable modeling environment

↓

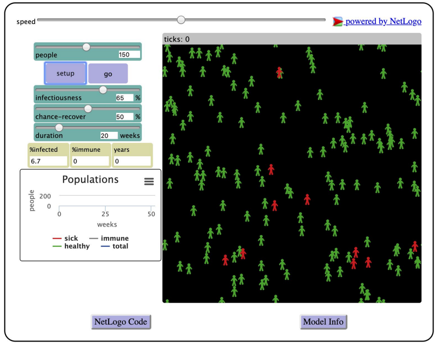
- Challenging for novices
- Requires too much time for students to learn to program
- Hard to use as part of science class

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

  ; move water based on termperature 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
```

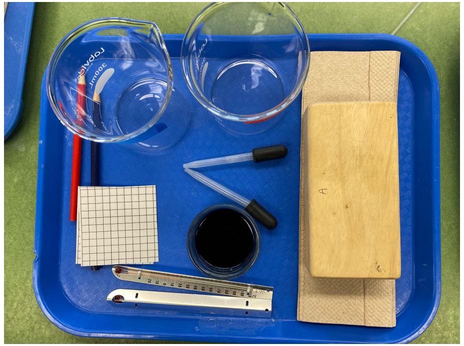
Motivation: Current Computer modeling status



Computer Modeling



Data/Experiment



Students use models disconnected from experiments & data

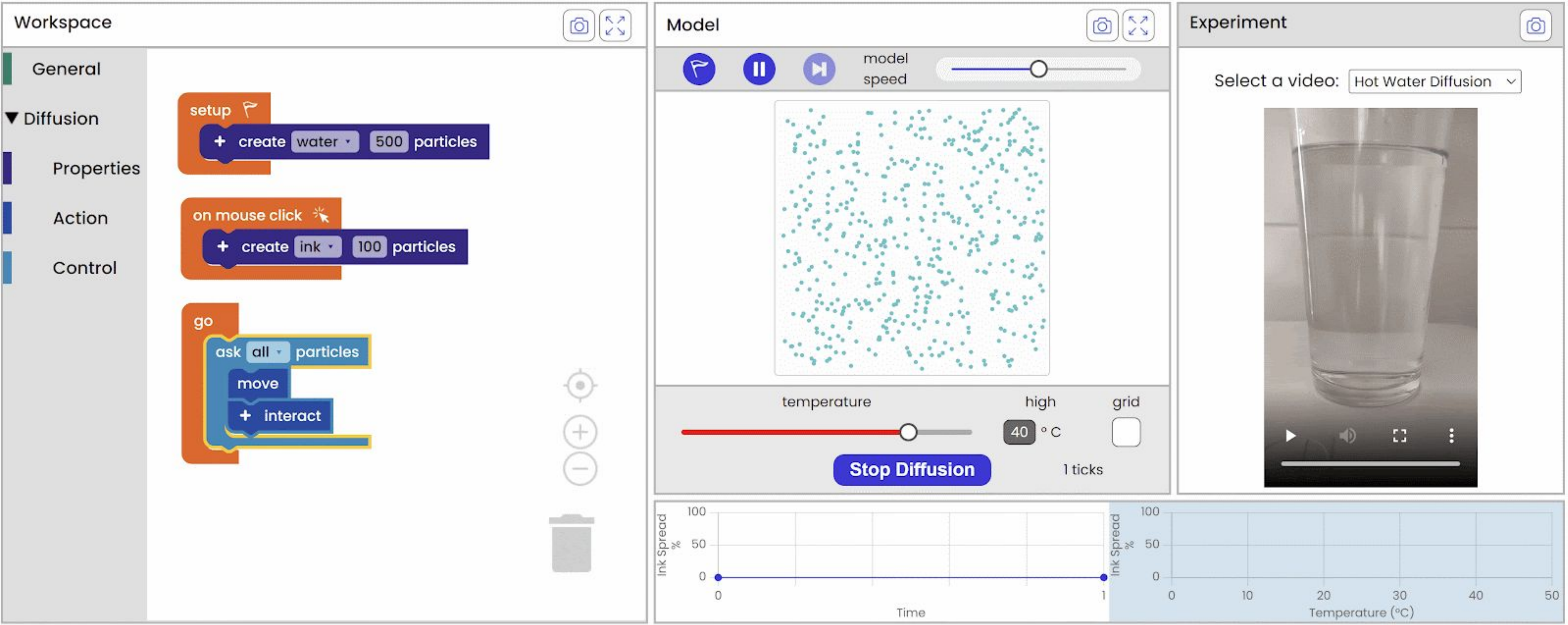
Theoretical background

- 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



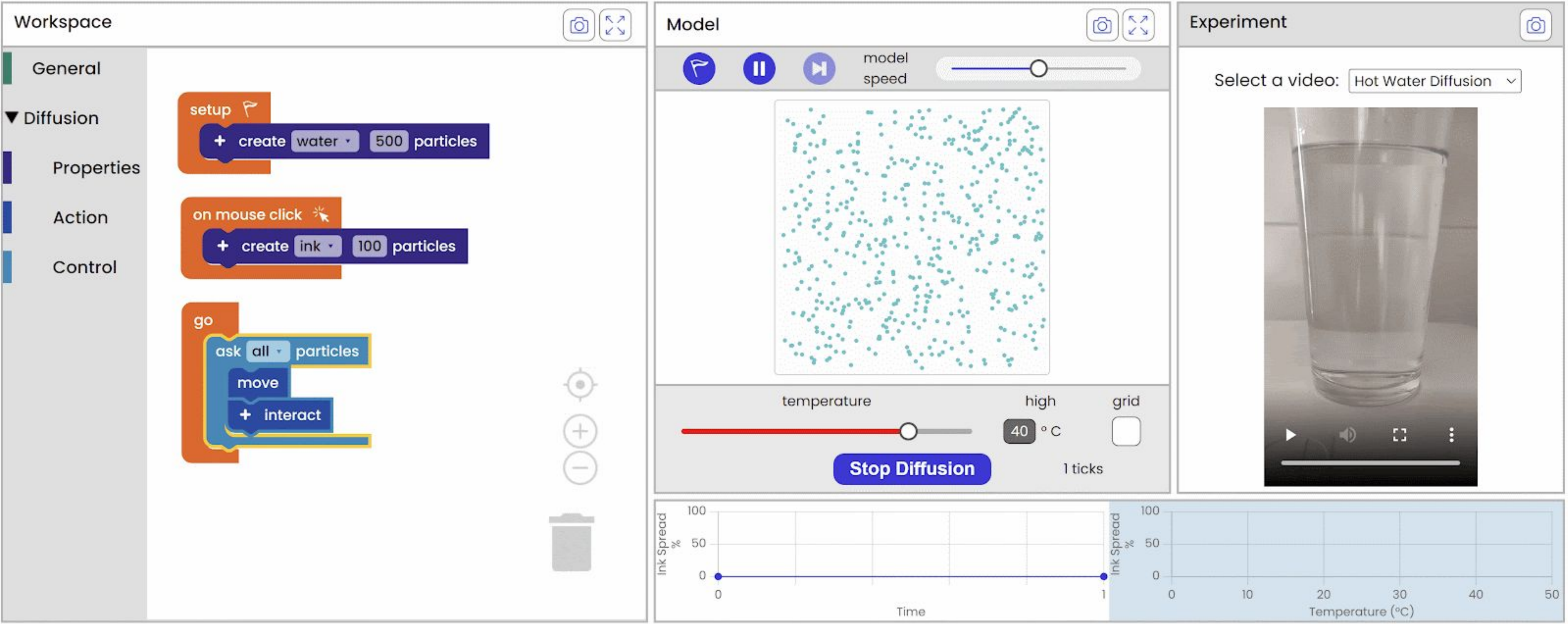
https://moda.education

MoDa web-based tool to integrate Modeling & Data

Coding Workspace

Simulation Workspace

Real-world Data



https://moda.education

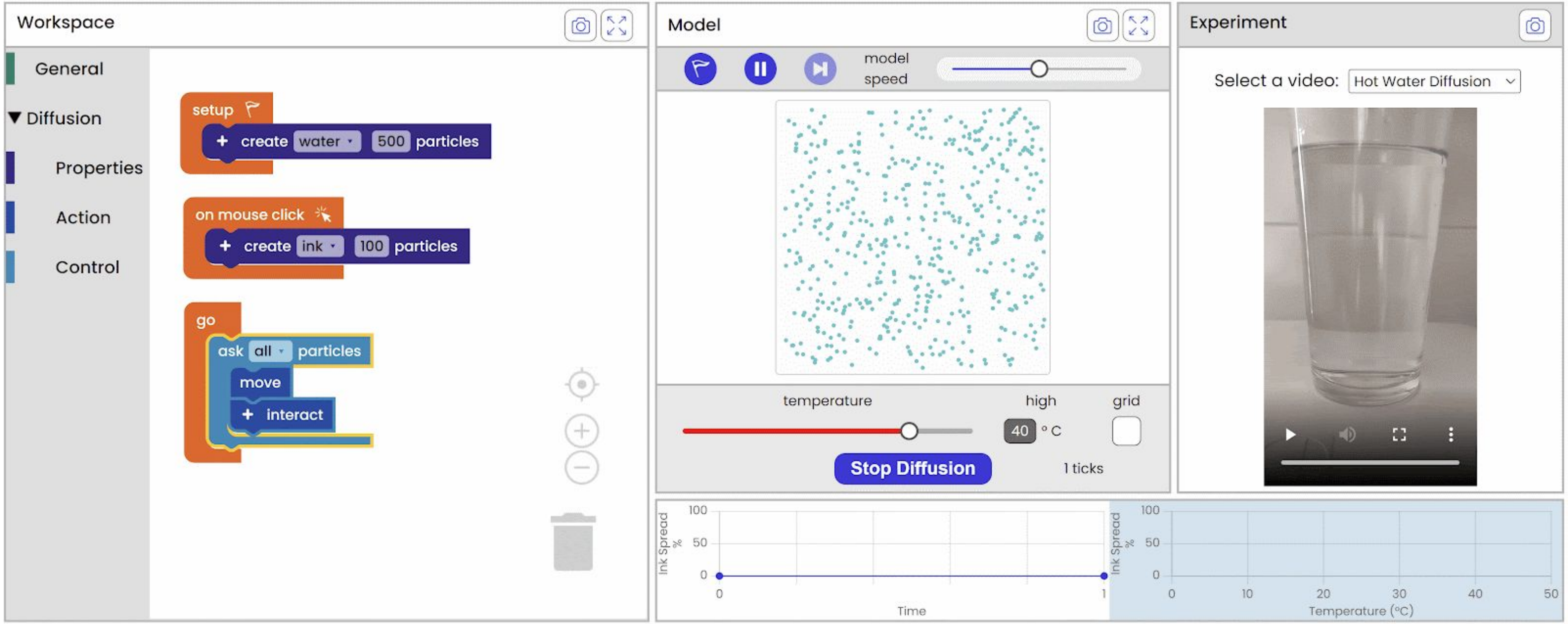
Data Visualization

MoDa design principles

https://moda.education

1. Block-based, Domain-specific modeling

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



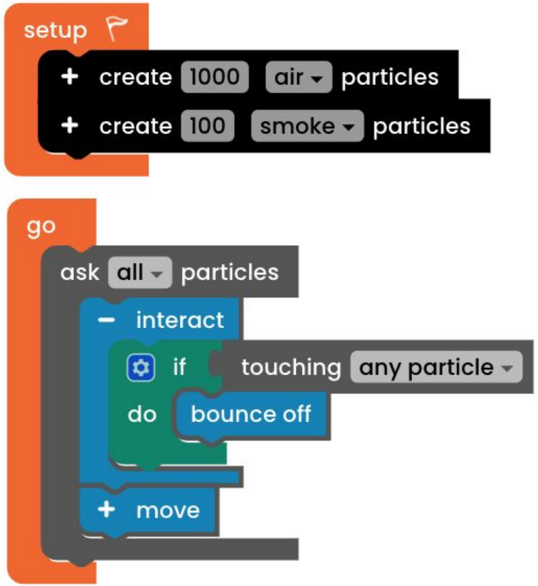
2. “Unpacking” blocks to move from simple to complex models

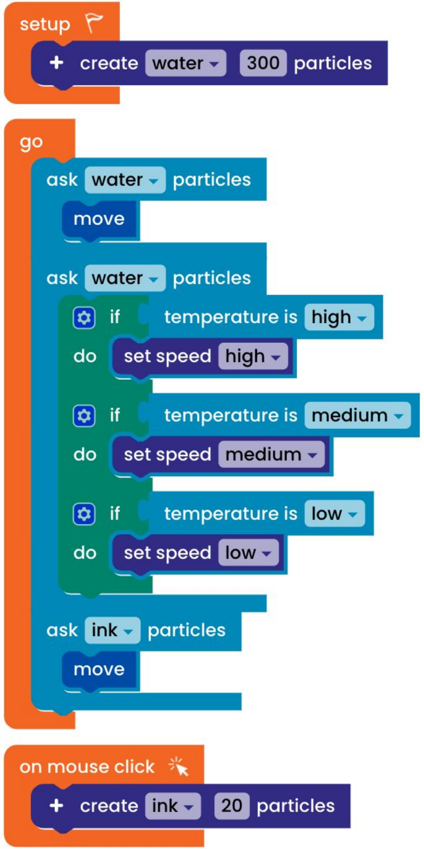
4. Thematically linked units center around diffusion

5. Co-designed with teachers

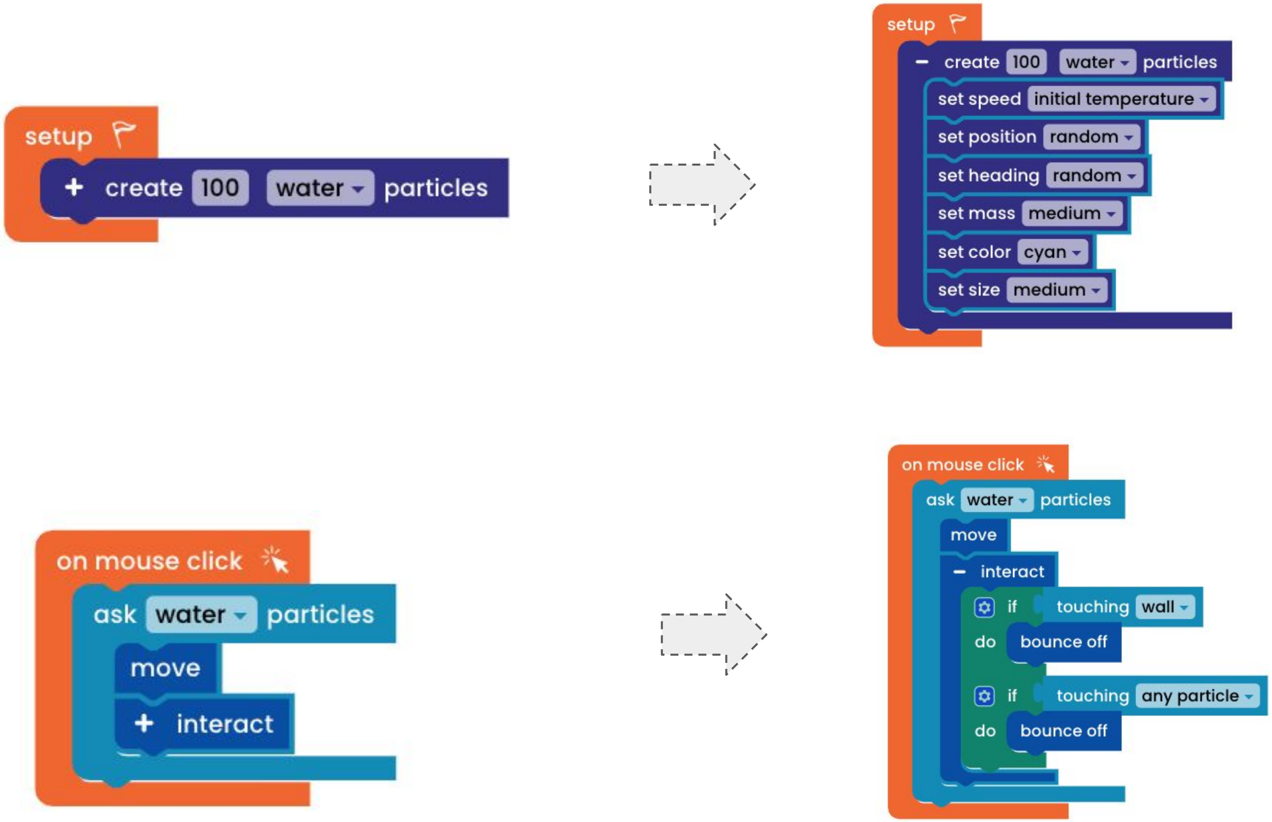
6. Teachers’ dashboard

Domain-specific modeling to make modeling accessible to students



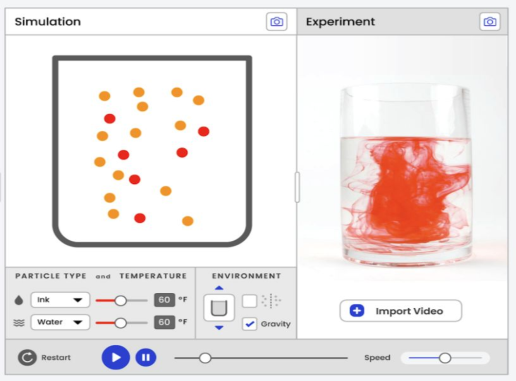


“Unpacking” to move from simple to progressively complex models

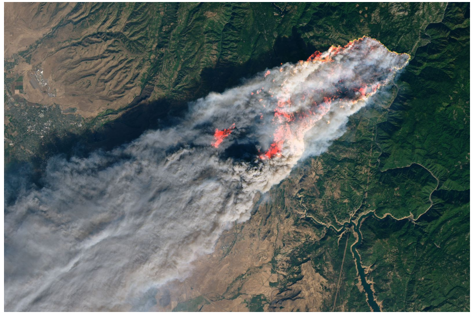


Linking data & modeling

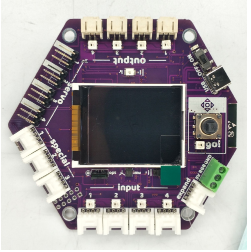
Experiments: Ink spread

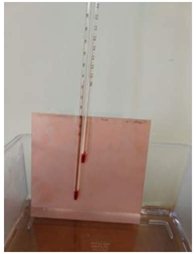


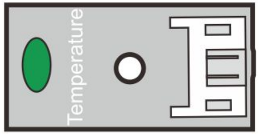
Public Data: Smoke spread

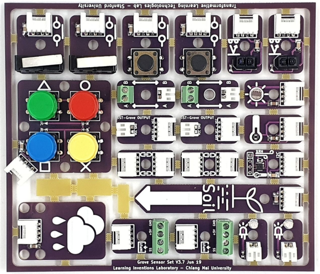


Sensor Data: Conduction



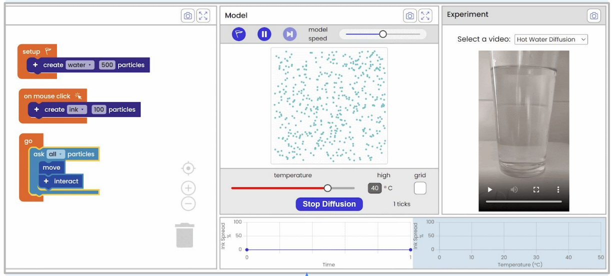




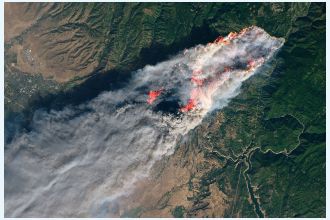


Thematically linked units

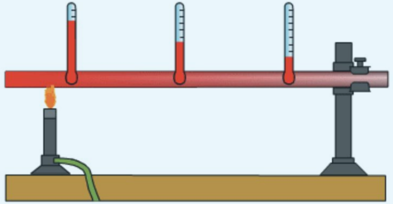
Unit 1: How does ink spread in hot and cold water?

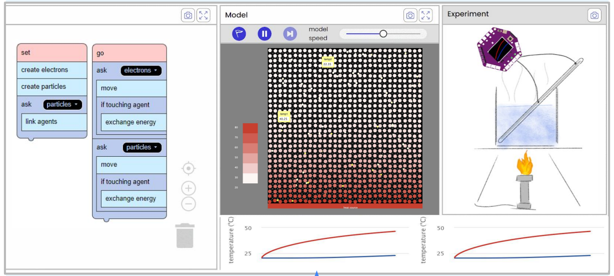


Unit 2: How does wildfire smoke spread?



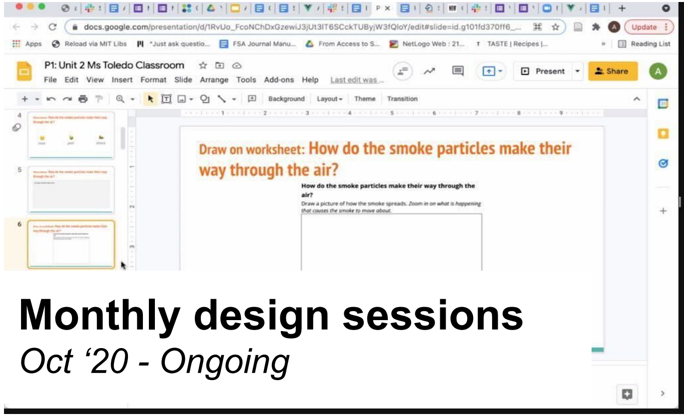
Unit 3: How do things get hot?



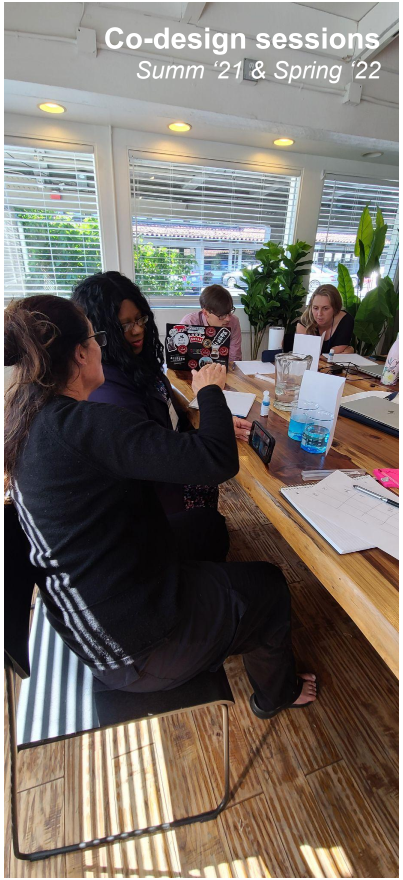


Diffusion: Movement from high to low concentration/temperature

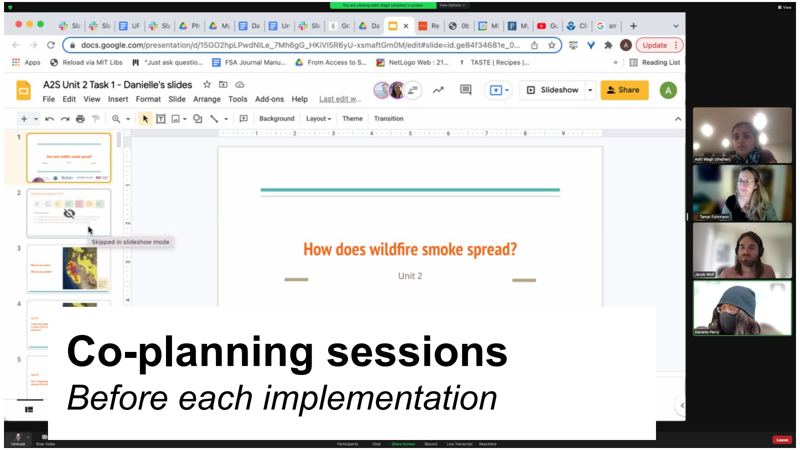
Co-design with teachers



Monthly design sessions
Oct '20 - Ongoing



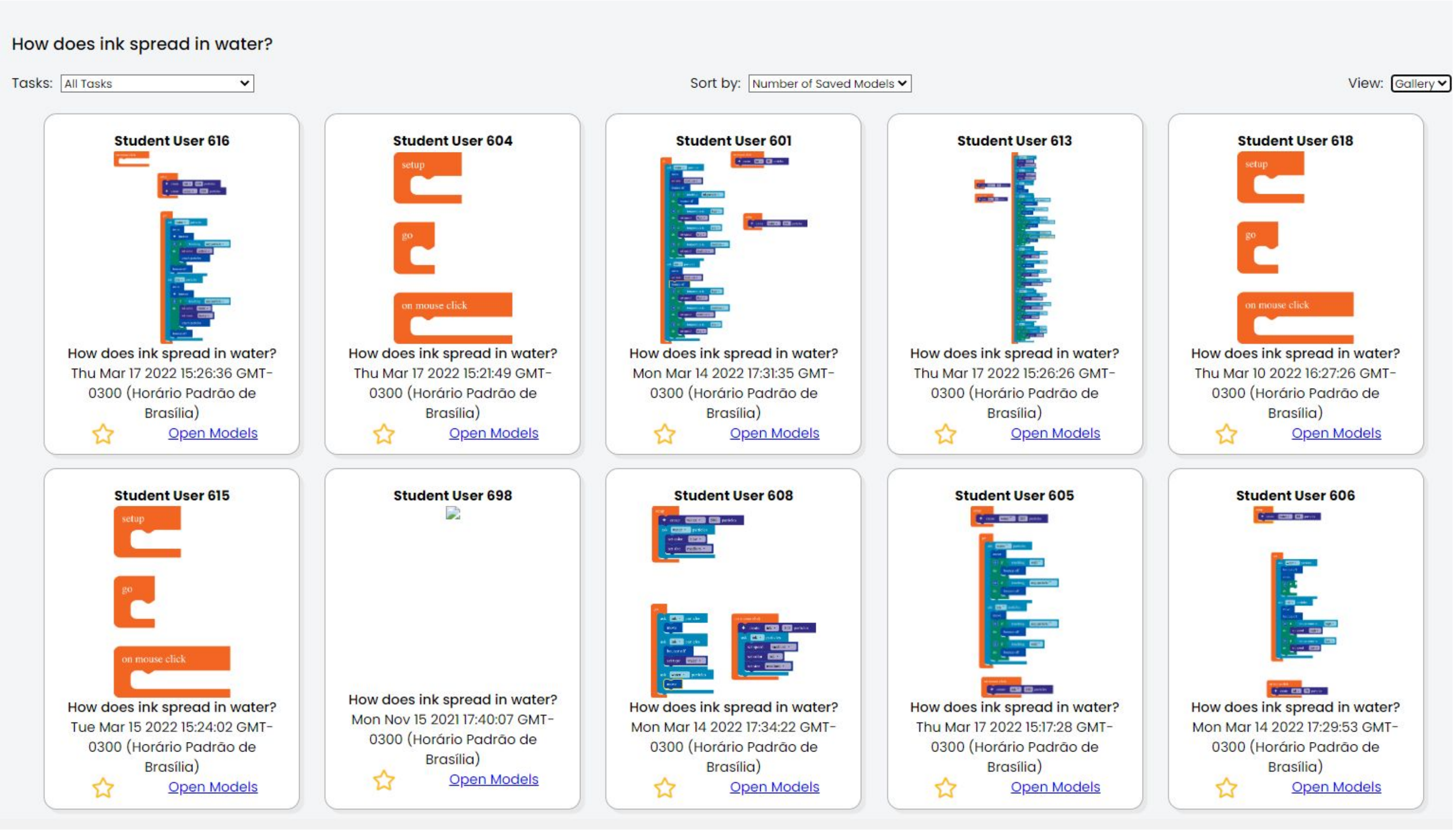
Co-design sessions
Summ '21 & Spring '22



Co-planning sessions
Before each implementation

Co-design sessions
Summ '21 & Spring '22

Teacher dashboard



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

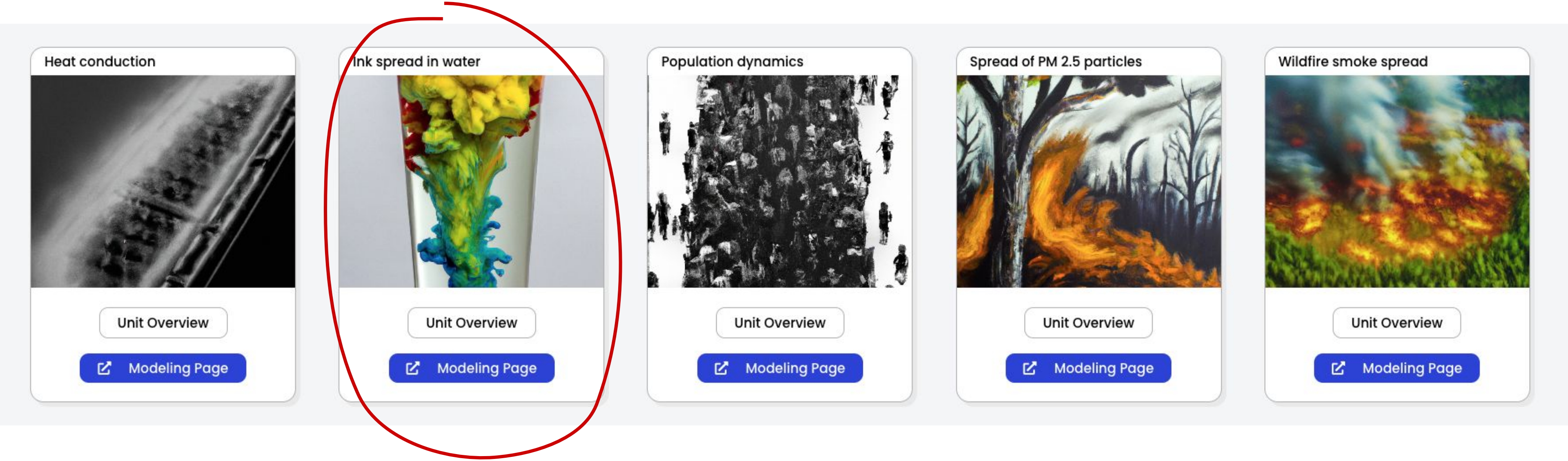
Wagh, A., Fuhrmann, T., Eloy, A., Wolf, J., Bumbacher, E., Blikstein, P., & Wilkerson, M. (2022). **Strategies towards Designing for Sustained Engagement in Computational Modeling in Science Classrooms**. Poster to appear in Proceedings of the 2022 Annual Meeting of the International Society for the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

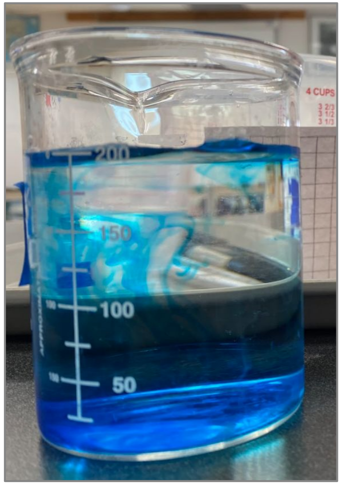
Eloy, A., Wolf, J., Wagh, A., Fuhrmann, T., Bumbacher, E., Wilkerson, M. H., & Blikstein, P. (2022). **A2S: Designing an integrated platform for computational modeling & data analysis for sustained investigations in science classrooms**. Interactive Workshop to appear in Proceedings of the 2022 Annual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

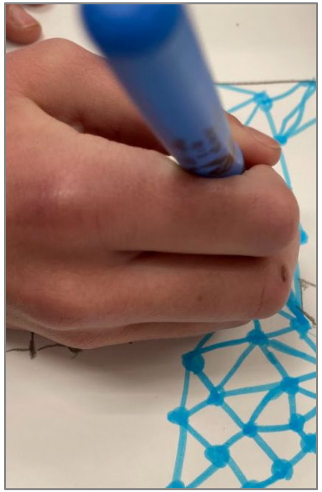
Moda units

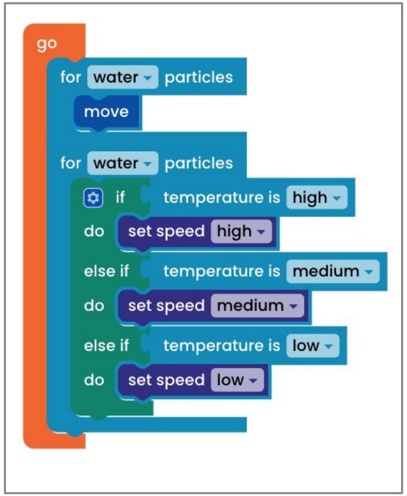
How does ink spread in hot and cold water?



Methods: Data source







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 *spread evenly*
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**	
Idea	*Example Responses*	*Idea*	*Example Responses*
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

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

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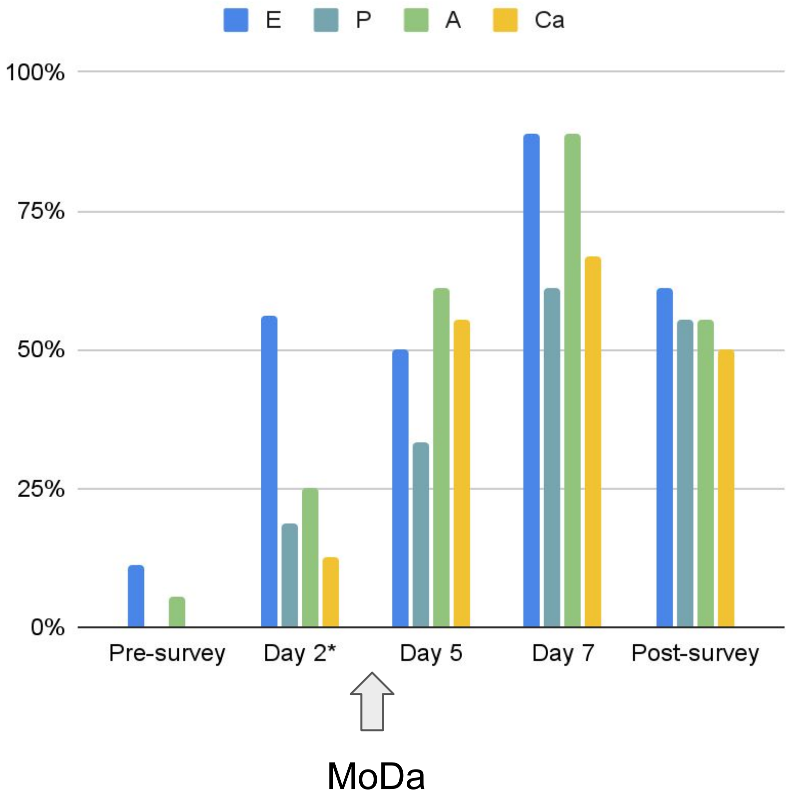
Findings: Shifts in mechanistic reasoning

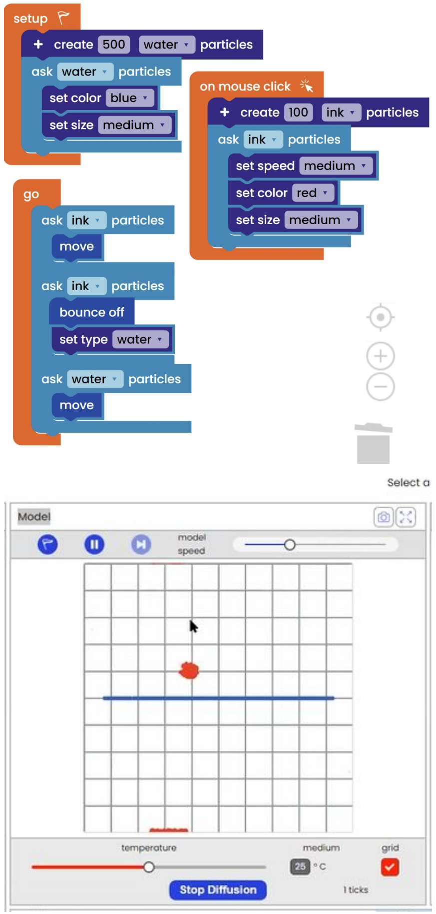
The percentage of explanations that included MR components



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."

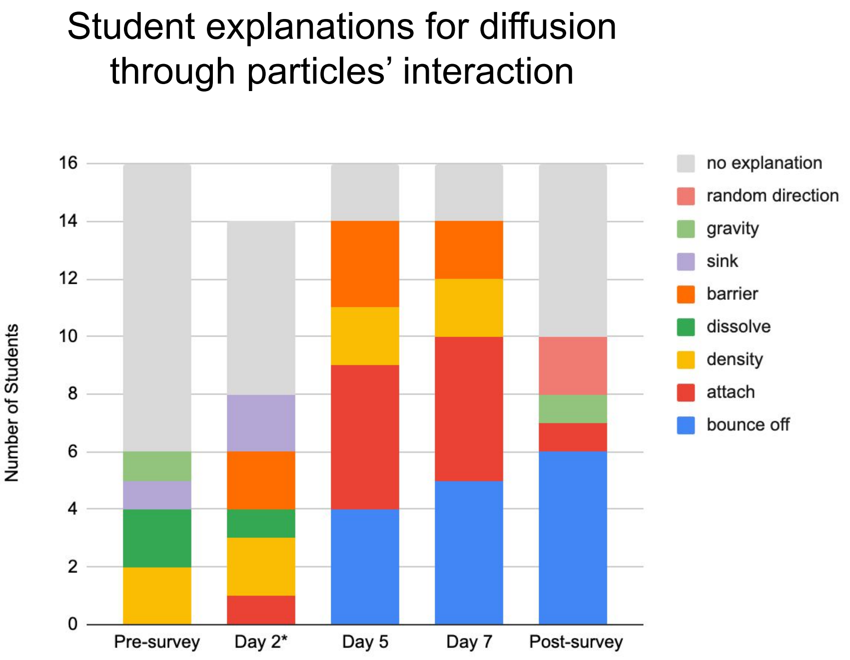
Findings

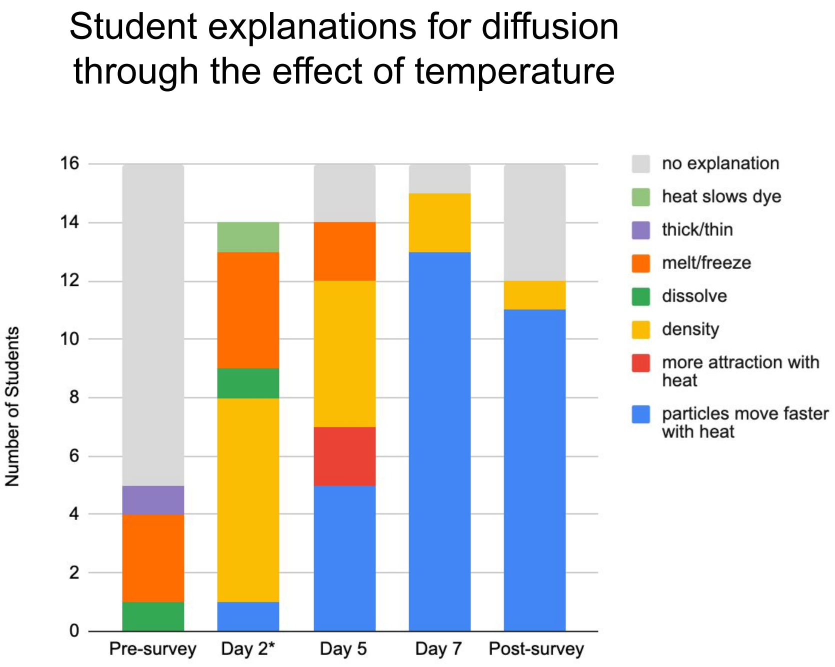
1. Modeling shifts students explanations from simple to sophisticated mechanistic reasoning

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

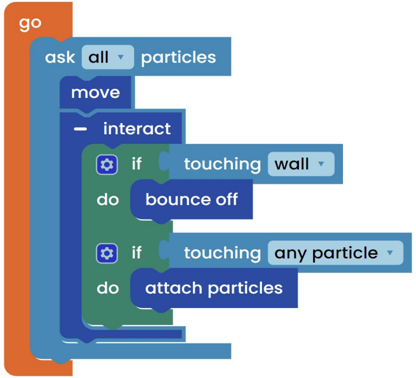
Findings: Shifts from non canonical to canonical



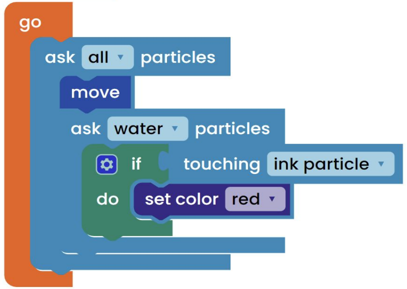


Findings: Students could translate their ideas into code in MoDa

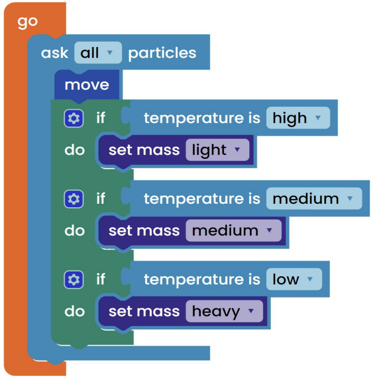
(1) "attached" model



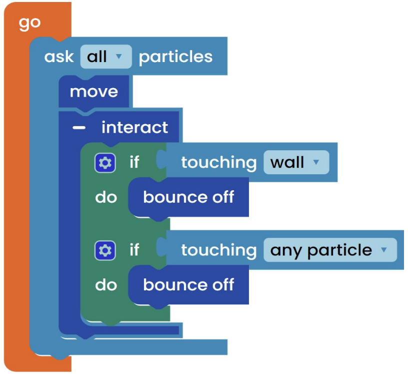
(2) "infect" model



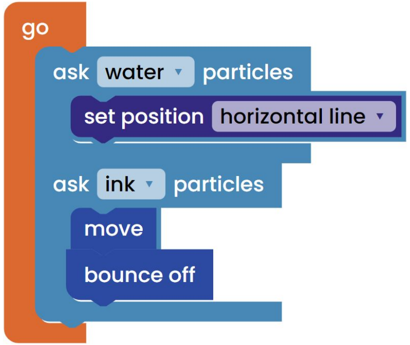
(3) "weights more" model



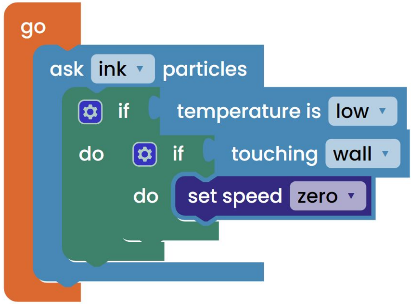
(7) "bounce off" model



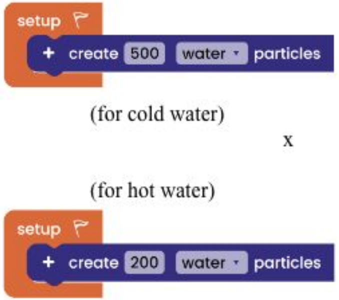
(4) "Barrier" model



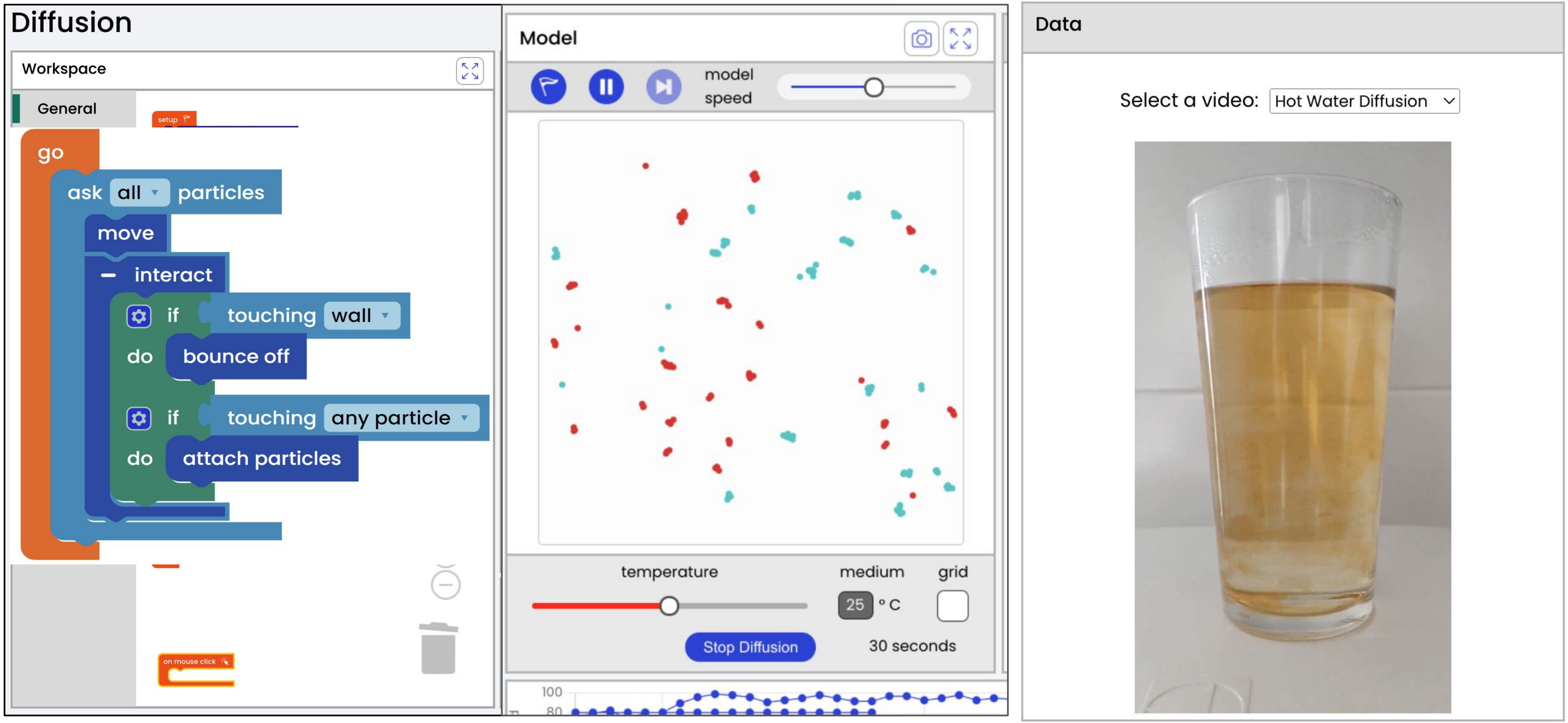
(5) "Sandwich" model



(6) "Dense" model



Findings: “Attached” model



Findings

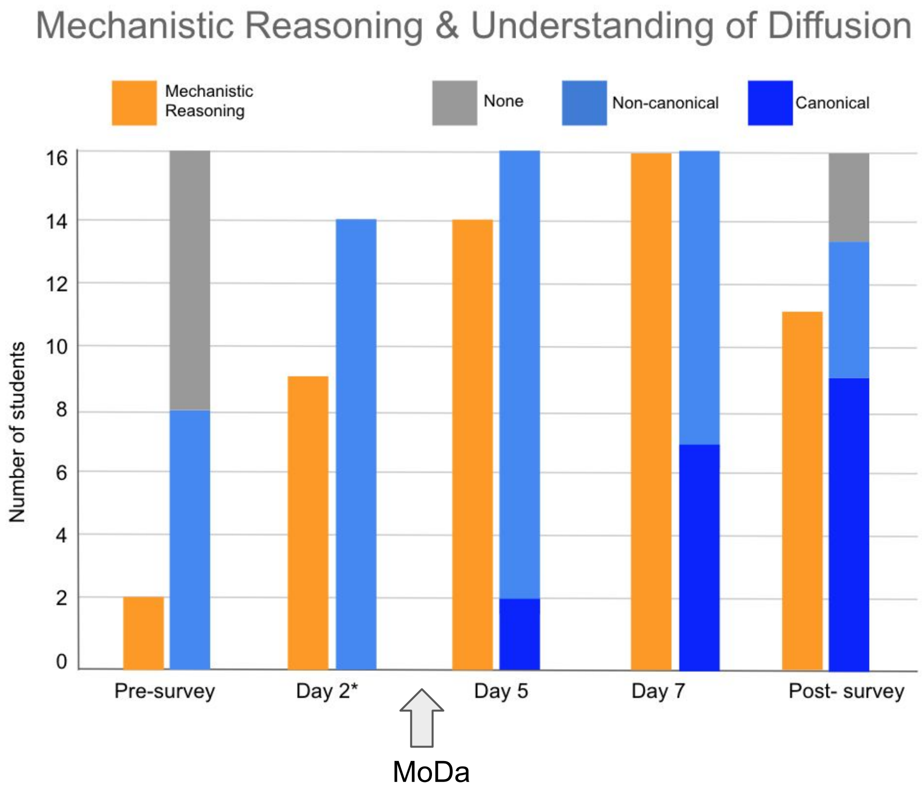
1. Modeling shifts students explanations from simple to sophisticated mechanistic reasoning

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

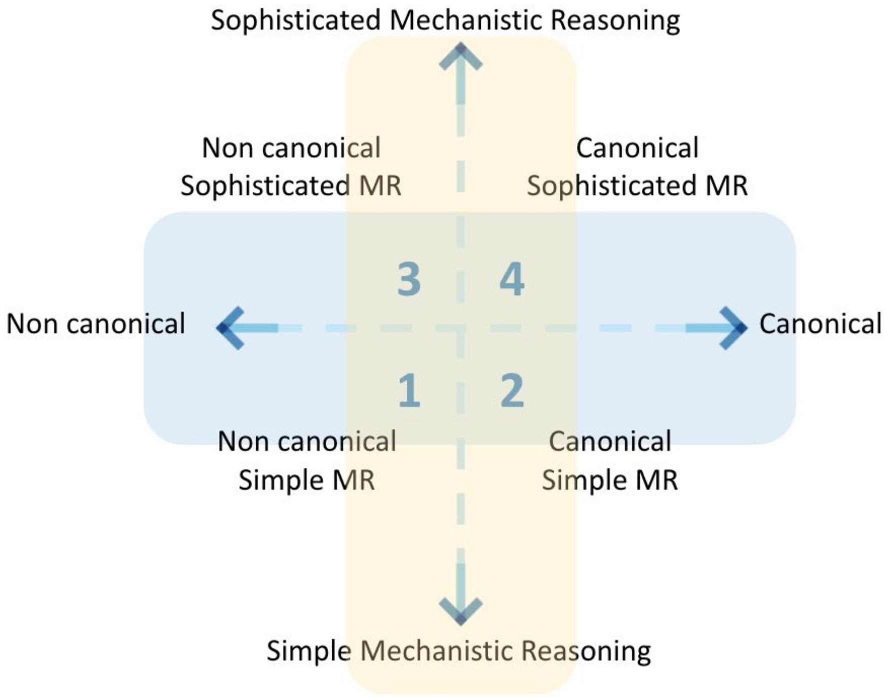
Findings: Use sophisticated MR with wrong ideas

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

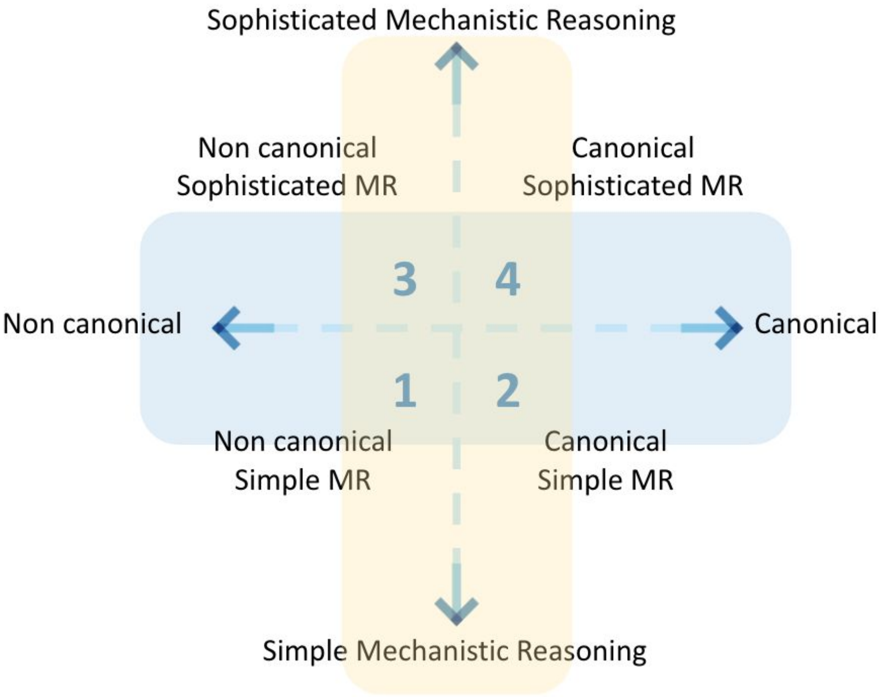


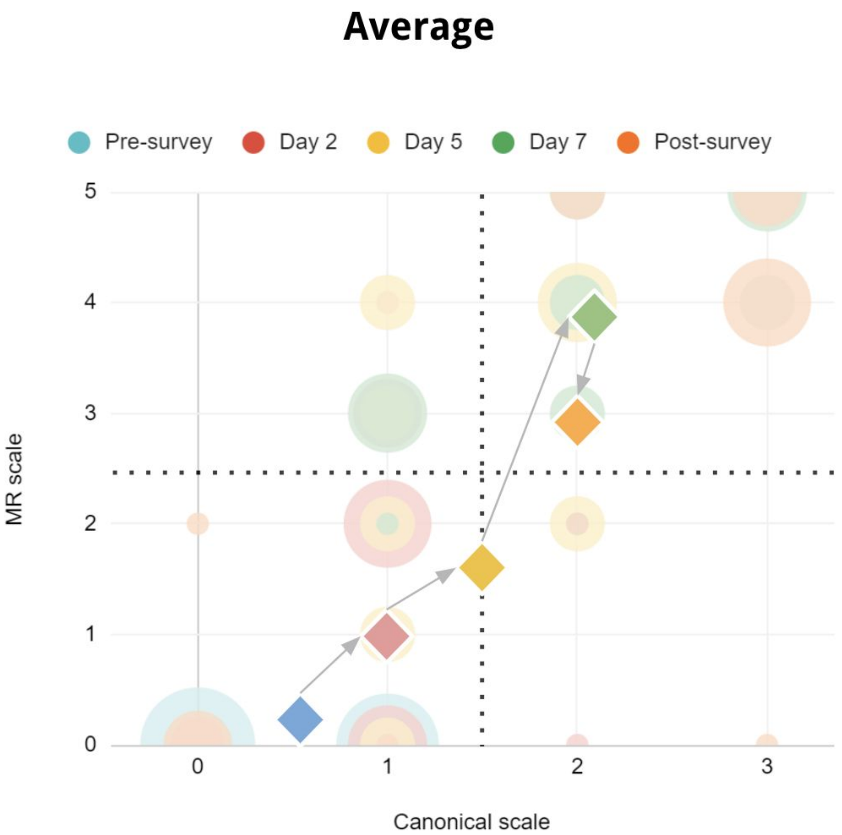
Summary

- **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.

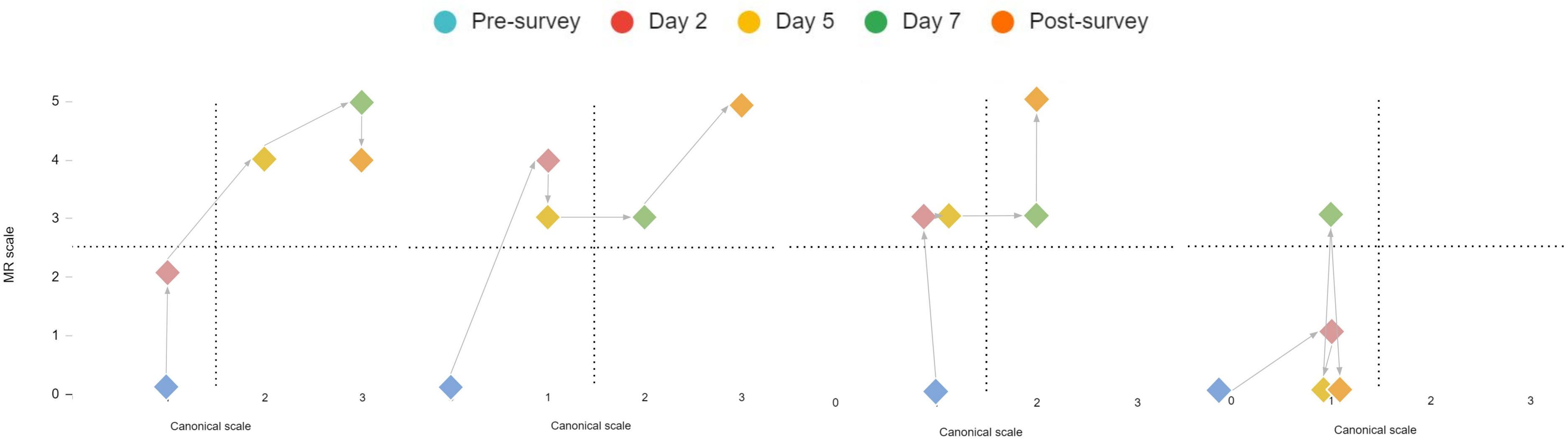


Summary


Sophisticated Mechanistic Reasoning
Non canonical
Sophisticated MR
Canonical
Sophisticated MR
3
4
Non canonical
Canonical
1
2
Non canonical
Simple MR
Canonical
Simple MR
Simple Mechanistic Reasoning


Average
Pre-survey
Day 2
Day 5
Day 7
Post-survey
MR scale
0
1
2
3
4
5
Canonical scale
0
1
2
3

Diverse trajectories



Student A

Student B

Student C

Student D


CENTURY
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

TLTL Transformative Learning Technologies Lab

TEACHERS COLLEGE
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Thanks!

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