Investigating Complementary Computational and Empirical Activities for Students Learning Diffusion

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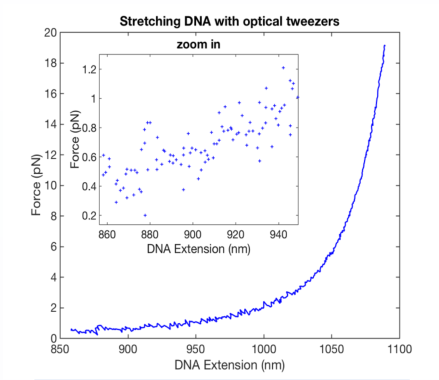
Introduction

Recently, efforts have been made to integrate computational exercises into introductory physics courses, but there is limited work regarding how these activities can complement traditional empirical labs. In this research, we study how physical microscope labs can complement computational modeling activities for students studying diffusion.

Designing Experiments

Applying to Biology



Computation

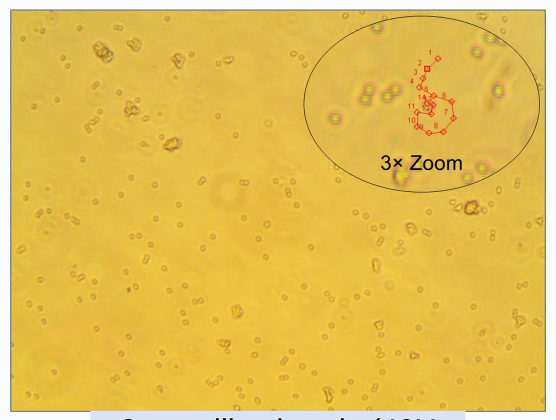
LB 273: Introductory Physics 1 for the Life Sciences

- Fall 2017 semester, 4 sections, 2 instructors, $N = 156$ students
- Studio physics model focusing on the topic of **diffusion**

Investigating Diffusion with Microscopes

In the Fall 2017 semester, we developed an empirical microscope lab for students to investigate the random motion of microbead solutions.

Microscope with attached camera



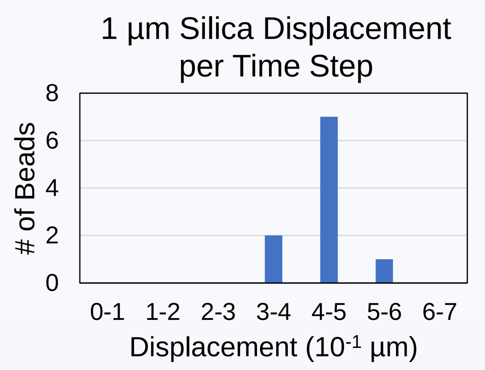
2 µm silica beads (40X magnification) in DI water

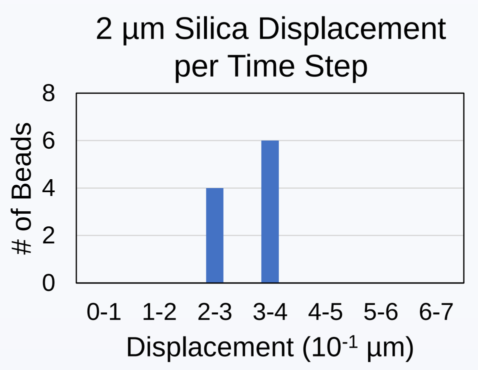
Students designed experiments to validate their hypotheses relating the motion of beads to…

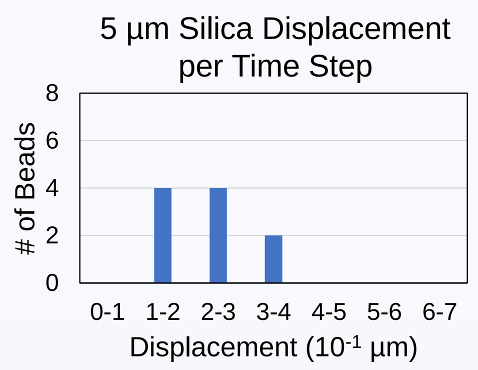
- Bead size (1, 2, 5 µm diameters)
- Bead material (silica or polystyrene)
- Solvent (DI water or 25% glycerol)
- Temperature, concentration, barriers, or other interesting ideas

Example Experimental Data

Displacement of differently sized beads was measured using Tracker software, and from this data, one can draw conclusions about momentum conservation and collisions.



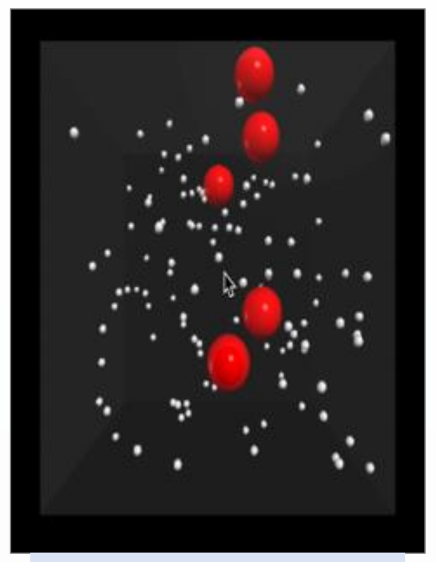




From this data, students may conclude that larger beads experience smaller displacements while undergoing diffusion.

Investigating Diffusion with Computation

The empirical microscope lab complemented a previous computational modeling activity where students simulated diffusive motion in Python.



Simulation of solute (red) particles in solvent (white)

Tracers depicting motion of solute (red) particles in solution with invisible solvent particles

Research Questions

1. How do students perceive the realistic or idealistic nature of empirical labs and computational modeling?
2. What are the affordances and constraints of learning diffusion with the microscope lab versus the computational activity?

Pre/Post-lab and Final Exam Questions

We gathered data from students' responses to the microscope pre/post-lab questions and final exam questions.

Pre-lab: What might look similar or different between the microscope and computational activities?

Post-lab: Compare and contrast the motion of the beads in your microscope videos to the motion of the particles in the simulation.

Final exam questions: Describe one advantage and one limitation of modeling diffusion with a computational activity and observing diffusion with a physical lab activity.

Codebook for Analyzing Responses

Code	Sub-code	Indicators	Example Response
Realistic or Idealistic	Realistic	Real, reality, actual, fake	"I think the microscope will be different because computer generated things are different than real, physical things. In real life, they will stop moving by themselves, eventually."
	Idealistic	Ideal, theoretical, controlled, imperfect	"The computational activity had theoretical and ideal conditions while the microscope lab is not ideal."
	Assumptions	Other factors (accounted for or ignored)	"There will also be other natural factors that weren't seen in the computational model that we will see in the microscope experiment (i.e. gravity)."
Affordances of microscope	—	—	"The physical model is useful for having larger number of water/glycerol solvent molecules compared to the computational model."
Constraints of microscope	—	—	"Compared to the computational activity, I think there will be differences in the clarity of the beads. It will be harder to see the process when compared to the computational activity."
Affordances of computation	—	—	"The motion of the particles in the computational model are much more prominent and easier to see."
Constraints of computation	—	—	"We didn't account for all of the water molecules in the computational model, due to the computer's crashing threshold and having to decrease the number of molecules versus what is actually there."

Table 1: Simplified codebook for analyzing students responses to microscope pre/post-lab and final exam questions.

Analysis of Realistic/Idealistic Themes

We found that student responses discussing the realistic/idealistic nature of the activities commonly linked these ideas to physics concepts or experimental factors.

	Physics concepts			Experimental factors				
	Collisions	Gravity	Friction	Particles slowing	Number of particles	Error	Other outside factors	Particle mass, size, shape
Pre-lab	4	7	5	7	6	4	2	2
Post-lab	14	10	9	25	8	3	4	4
Total	18	17	14	32	14	7	6	6

Table 2: Counts of realistic/idealistic responses from microscope pre/post-lab related to physics concepts and experimental factors.

	Particles slowing	Collisions	Gravity	Friction	Number of particles	Error	Other outside factors	Particle mass, size, shape
Particles slowing	—	21	7	18	1	2	3	0
Collisions	21	—	2	14	0	0	0	2
Gravity	7	2	—	2	6	0	0	3
Friction	18	14	2	—	1	0	0	1
Number of particles	1	0	6	1	—	0	0	3
Error	2	0	0	0	0	—	2	0
Other outside factors	3	0	0	0	0	2	—	0
Particle mass, size, shape	0	2	3	1	3	0	0	—

Table 3: Code relations matrix depicting the relationships between concepts and factors discussed in pre/post-lab student responses.

Affordances and Constraints of Activities

Affordances and constraints of the differing in-class activities were identified from student responses to final exam questions. We further categorized the most prevalent affordances and constraints into **scientific practices** and **learning outcomes**. From this analysis, we infer how the complementary in-class activities affect students' scientific skillset and conceptual understanding.

		Computational Activity	Microscope Lab
Affordances	Practices	Easily manipulate variables Teaches physics concepts/theory Fast, easy, repeatable	Easily test variables Teaches experimental techniques
	Outcomes	Does not include external factors Microscopic representation Obtain numerical data Easy to observe 3D	Includes external factors Macroscopic representation Obtain numerical data and visual data Direct observation, hands-on, interactive
Constraints	Practices	Programming skill-dependent Limited by code Computational power, crashing threshold	Experimentally skill-dependent Time-consuming, difficult to perform Expensive equipment Experimental/human error
	Outcomes	Does not include external factors Difficult to observe	Includes external factors Difficult to observe or track Beads settle/slow down quickly 2D

Conclusions

After participating in complementary in-class activities, students gain a better understanding of the shortcomings and advantages of computation vs. experimentation. Furthermore, students justify their understanding of "realistic" or "idealistic" science from these activities.

Acknowledgements

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