PhET Interactive Simulations

Successes and Challenges in Scaling Innovation and Impact

Kathy Perkins

Director, PhET Interactive Simulations
University of Colorado Boulder

Presented to the Board on Science Education, PreK-12 STEM Education Innovations Study Committee, 12/07/2023

FOUNDED IN 2002 BY CARL WIEMAN:

2001 Nobel Prize in Physics

PhET (**P**hysics **E**ducation **T**echnology)

Launched with Funding From:
NSF Distinguished Teaching Scholar ($300K)
Nobel Prize Award (~$300K)
Kavli Foundation (~$500K)

PhET has received multiple NSF grants for ***new*** research and development, including:

NSF (2001) Distinguished Teaching Scholar
NSF CCLI (2008) College Physics & Chemistry
NSF DRK12 (2010) Middle School Science
NSF TUES (2012) College Chemistry
NSF DRK12 (2015) Accessibility
NSF DRK12 (2015) Middle School Math
NSF DRK12 (2016) Sound and Sonification

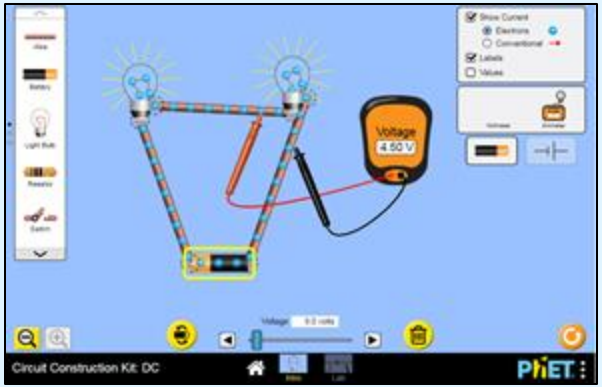
GOAL:
TO MAKE STEM LEARNING MORE...

- ☑ **ENGAGING** Interact and discover key ideas
- ☑ **RELEVANT** Connect to everyday life
- ☑ **ACCESSIBLE** Intuitive & understandable
- ☑ **EFFECTIVE** Develop conceptual understanding
- ☑ **PERSONAL** Elevate student agency and voice

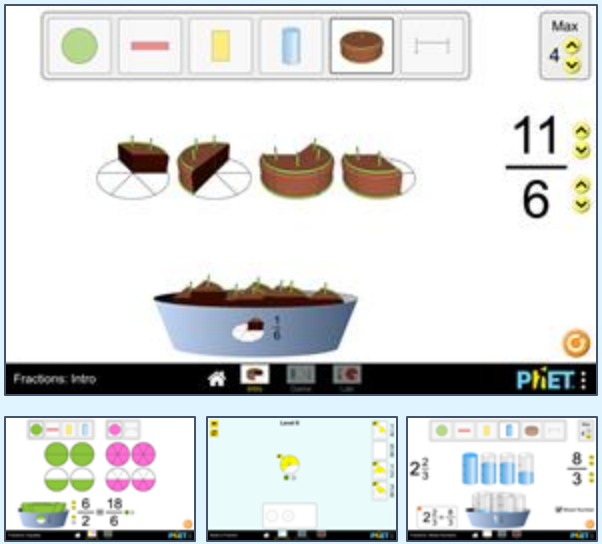
Make **learning STEM** more like **doing STEM**

…THROUGH POWERFUL PEDAGOGICAL TOOLS.

Used 1.4+ billion times!



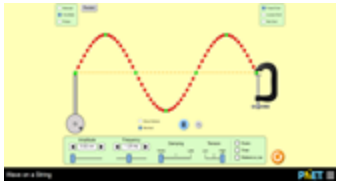
Circuit Construction Kit
Grade 3 - College
12M uses/yr



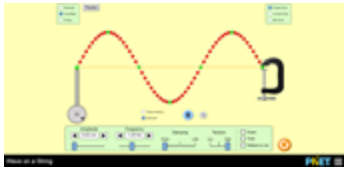
Fractions Suite
Grade 1 - 5
3M uses/yr

BY FOCUSING ON…

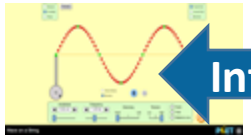
Product Development



Research



Classroom



Integration

Teacher

Student ⟷ Student

Teacher Professional Development (2021+)

TODAY
(21 years later) …

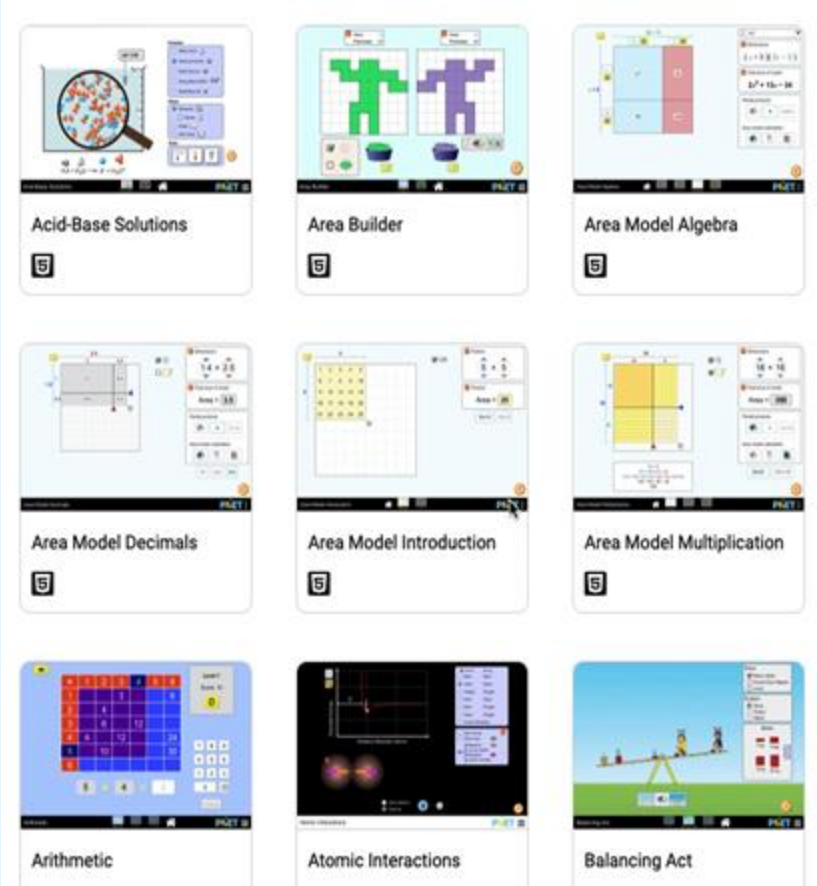
Total Investment:
~$39M total
~$11.5M by NSF (to PhET)

Current Annual Budget:
$4M/year

Core team of 35 staff

https://phet.colorado.edu

169 simulations (108 in HTML5)



PhET'S IMPACT AND GROWTH

IMPACT OF PhET SIMULATIONS

Transform classroom instruction

- support transition from teacher-centered ➔ student-centered
- more inquiry, discourse, student agency

Increase student achievement in disciplinary core ideas

- deeper conceptual learning
- higher learning gains

Develop STEM practices

- actively engage students in the NGSS practices
- make learning STEM more like doing STEM

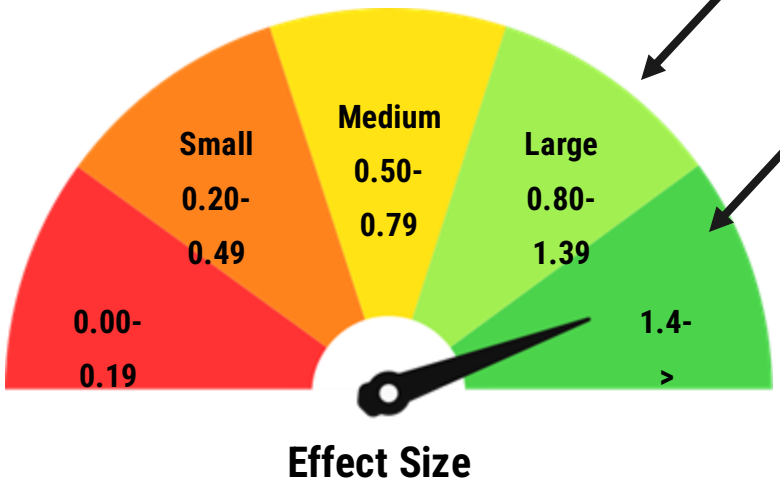
Improve student attitudes about science

Close the learning gap

- ensure equity, especially for marginalized students

Supporting slides at end of slide deck

PhET simulations… result in significantly **higher learning gains** than traditional instruction.



Effect Size

Meta-analyses

Antonio & Castro, 2023

- 15 quasi-experimental studies (87% with PhET sims)
- Effect sizes up to g = 1.26
- Effect size weighted average of g = 0.941

Rutten et al., 2012

- 17 quasi-experimental studies (some with PhET sims)
- Effect sizes up to d = 1.54.

Literature Review

Banda & Nzabahimana, 2021

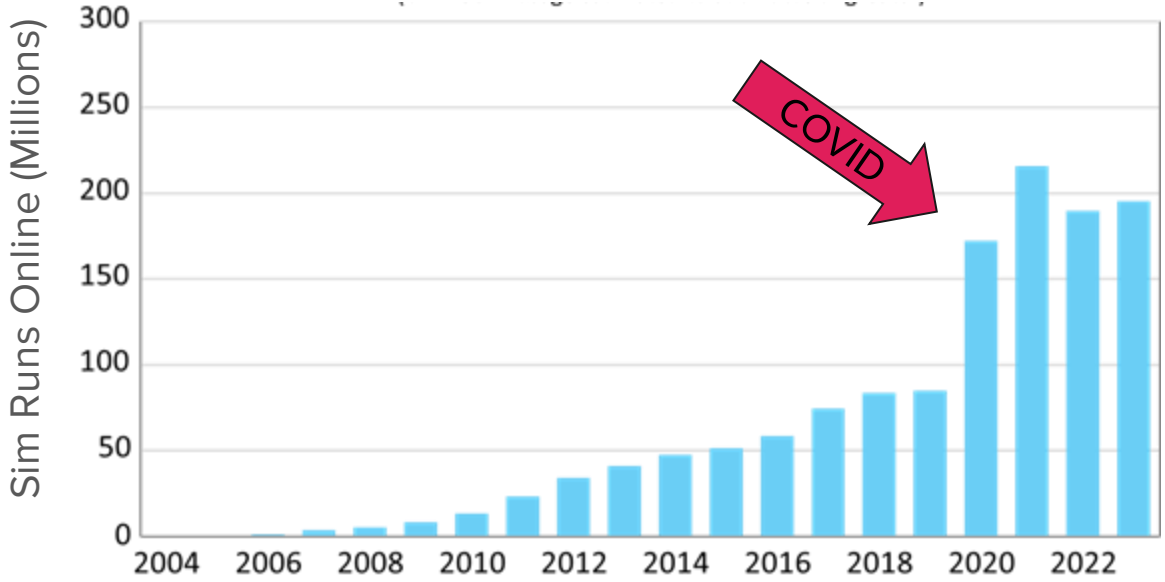
- 31 quasi-experimental studies (all with PhET sims)
- Up to 37% higher normalized gains than control

USE OF PHET SIMULATIONS

1.4 billion sims
delivered globally
in 120 languages

~50% of usage in USA

Usage: Sim Runs Online per Year



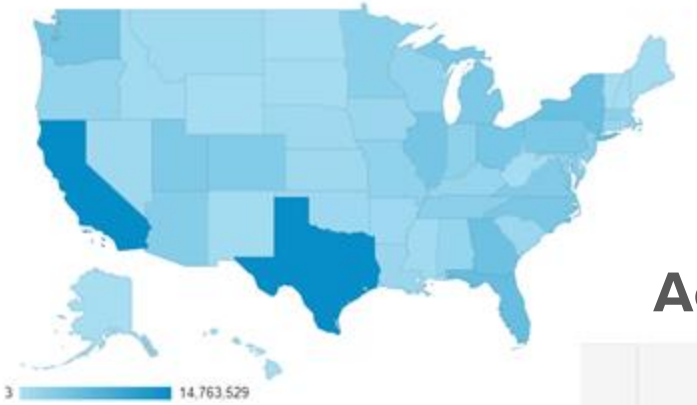
*(Use Oct-Dec 2023 estimated;
2023-24 school year showing 10% use growth)

USE OF PHET SIMULATIONS

Around the world (USA ~50%)

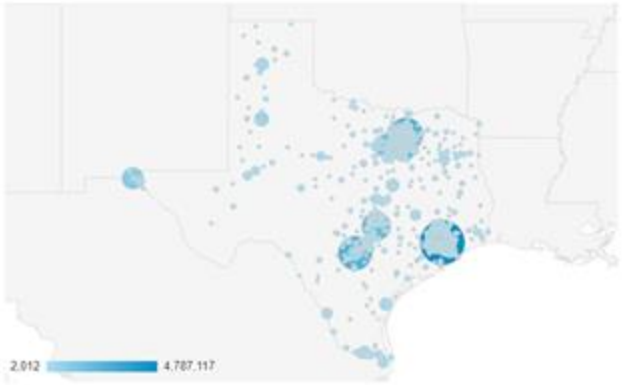
US excluded

Across the USA



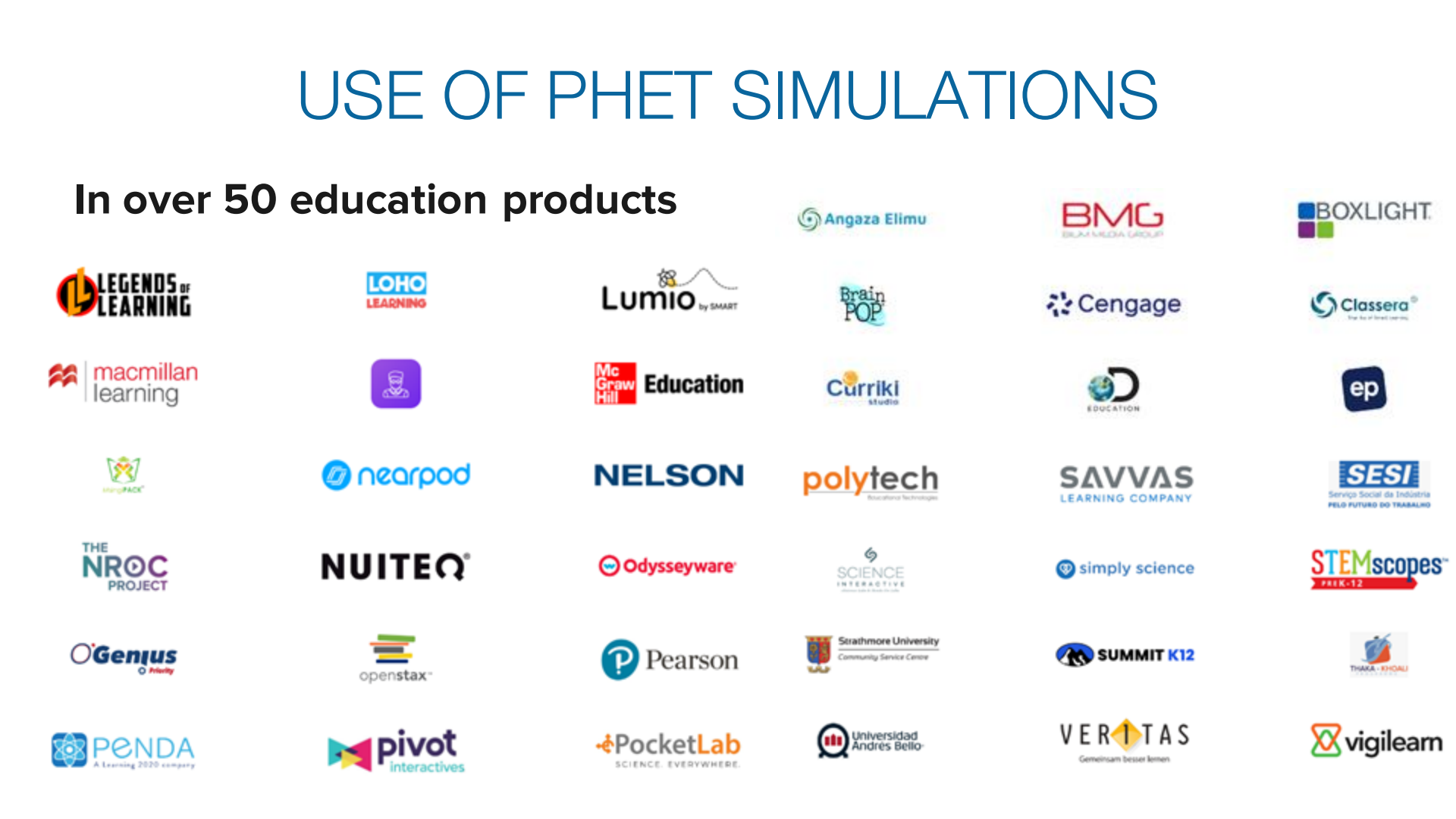
Over 600 towns in Texas

Across each State

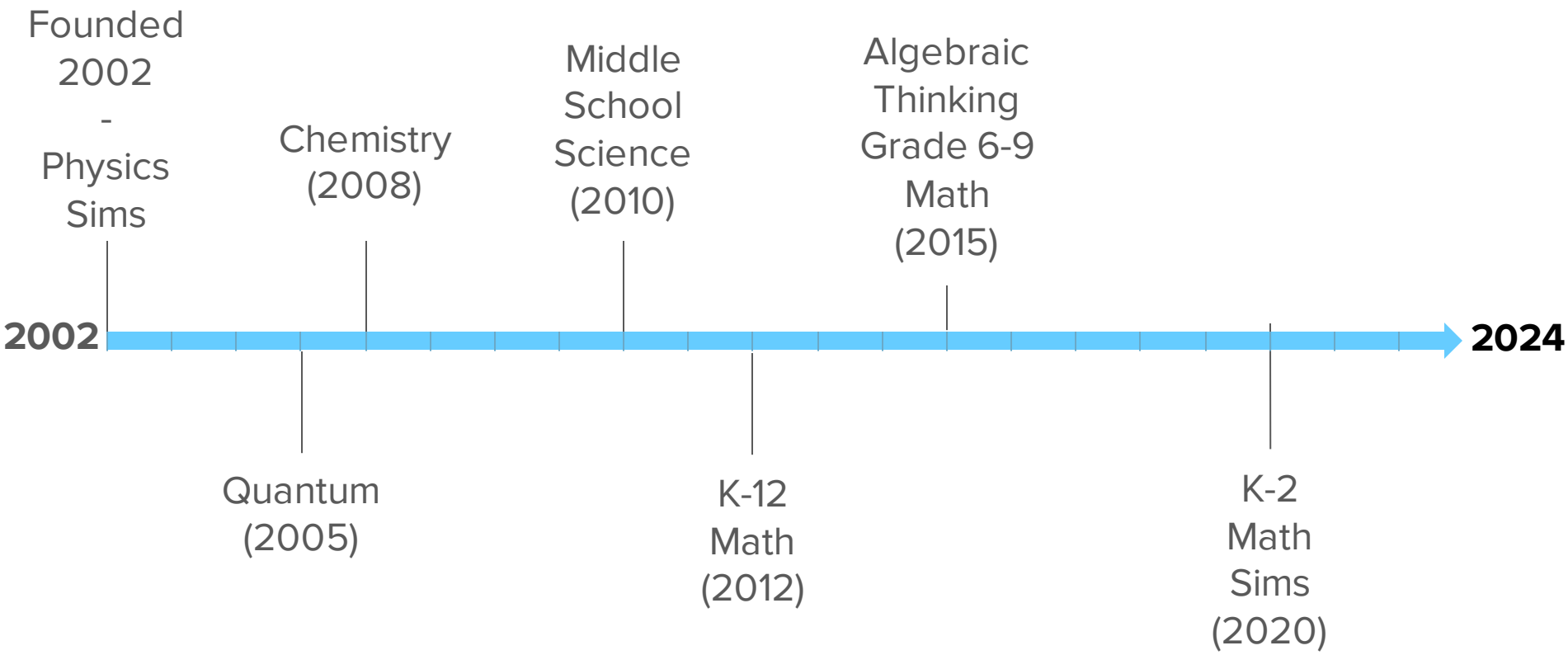


USE OF PHET SIMULATIONS

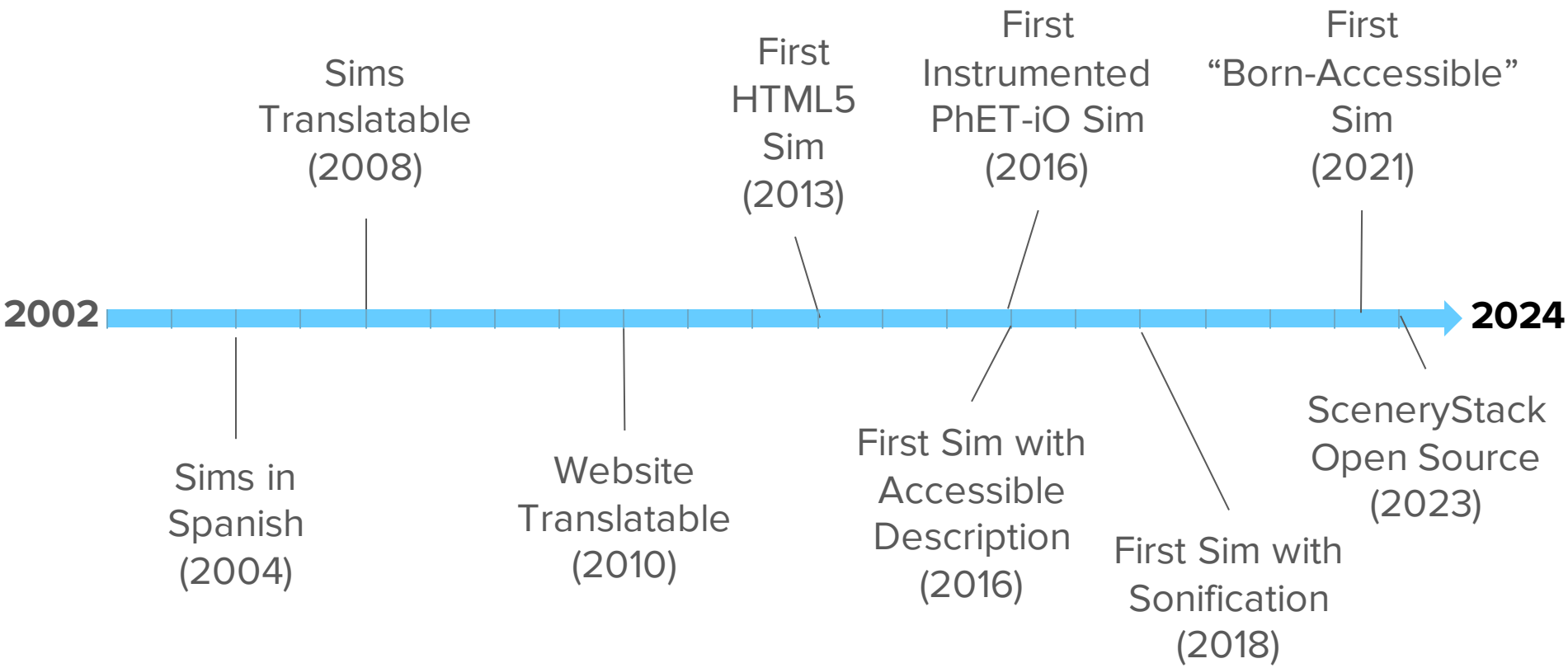
In over 50 education products



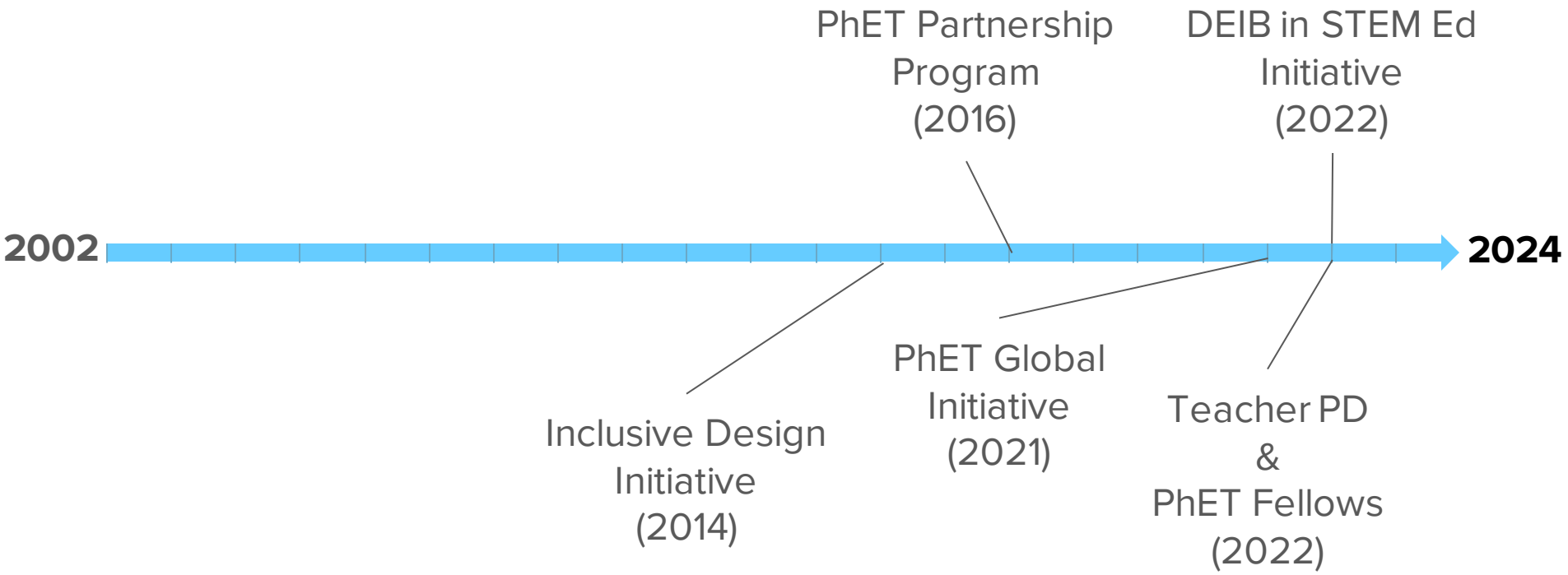
PHET CONTENT EXPANSION



PHET TECHNOLOGY ADVANCEMENT



PHET INITIATIVES AND PROGRAM EXPANSION



MISSION-DRIVEN BUSINESS MODEL

DIRECT-TO-CONSUMER

FREE PHET WEBSITE

+ donations from individual users

LOW-COST PHET APP

Download on the App Store | GET IT ON Google Play

$0.99 purchase

BUSINESS-TO-BUSINESS

BASIC PARTNERSHIP

PhET INTERACTIVE SIMULATIONS

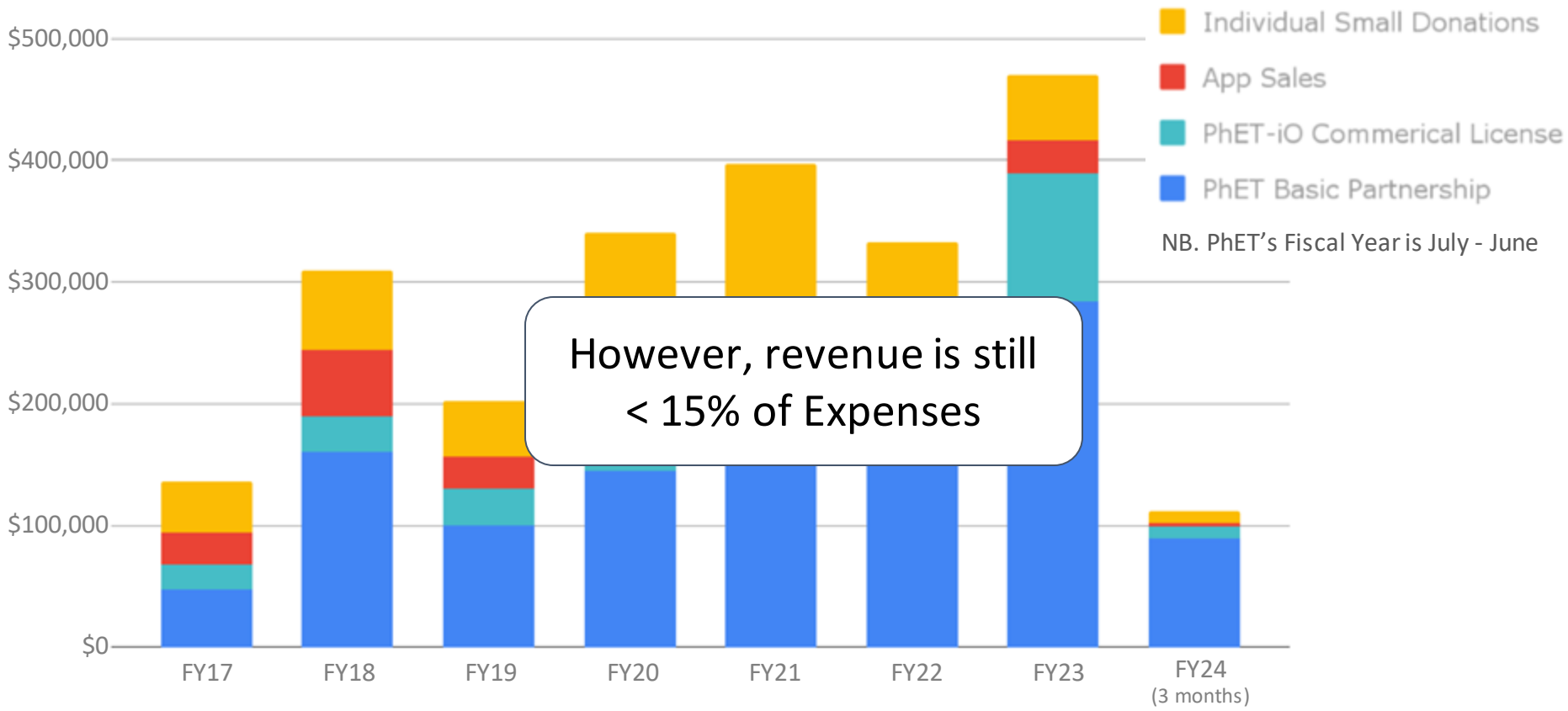
$10,000/year

EMERGING PRODUCT

PhETio INTERACTIVE SIMULATIONS WITH INTEROPERABLE FEATURES

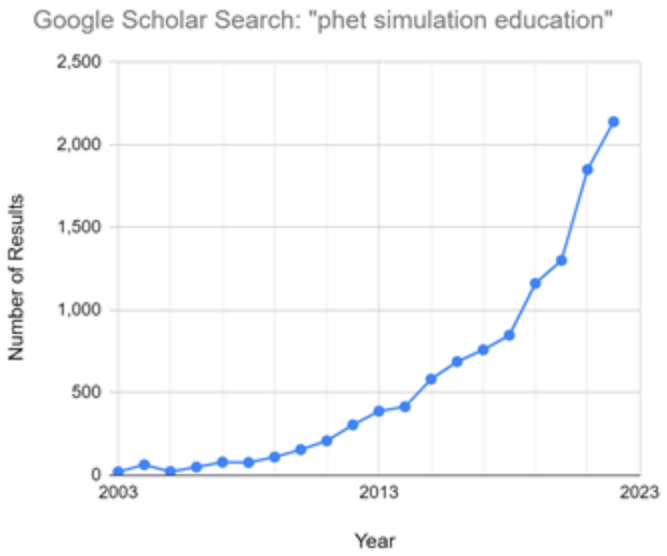
per-student licensing, revenue share or usage-based

REVENUE GROWTH SINCE 2017



RESEARCH AND IMPACT STORIES

Studies of PhET sims document positive impact (13,200 Google Scholar Results)



By way of comparison, Khan Academy has 17,500 results in the same period. Other well-known products are typically in the 100 - 2,500 citations range.

Stories of PhET's Impact around the world

THREATS AND LIMITATIONS TO SCALING AT PhET

EXISTENTIAL THREATS TO PhET

2008: Carl Wieman left CU Boulder and PhET leadership

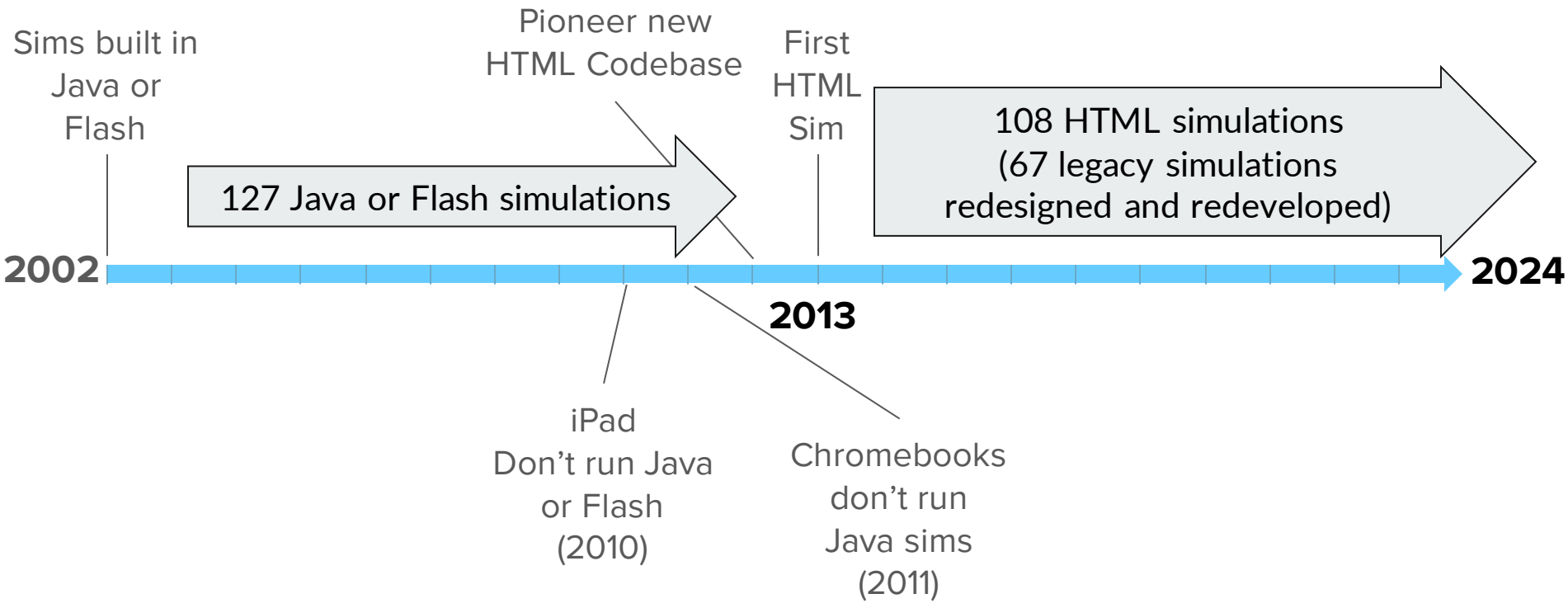
- Kathy Perkins stepped in as (co-)Director

2010 & 2011: Disruptive technology changes in education

Ongoing: Soft funding ... no base funding

- Pieced together with

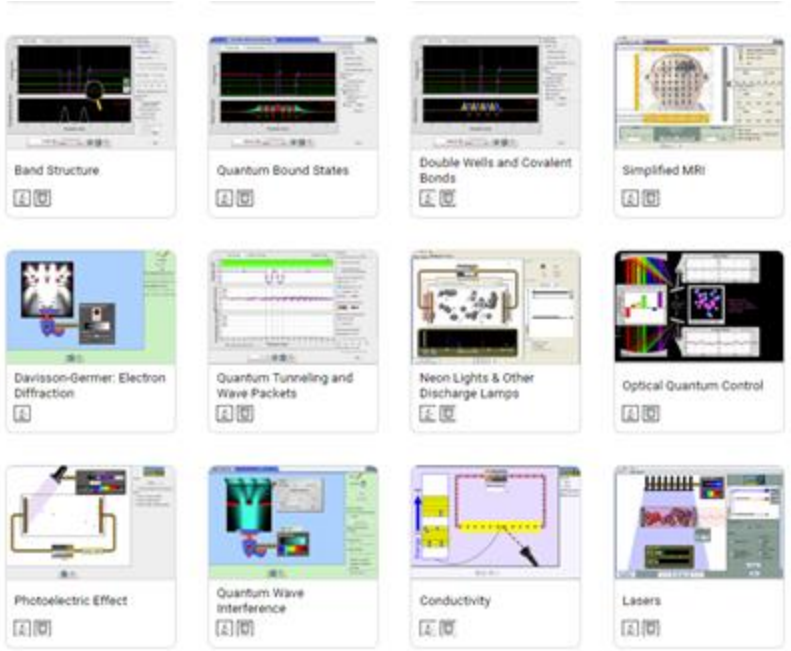
TECHNOLOGY CHANGE AND MAINTENANCE



TECHNOLOGY CHANGE AND MAINTENANCE

60 legacy PhET sims remain in Java and Flash, including many popular physics sims and 18 quantum sims (CHIPS Act)

Impact? loss of access & use
Why? lack of funding resources



LIMITATIONS TO SCALE

- Have not yet redesigned and redeveloped all the sims to HTML (~60 remaining).
- Could have much more content coverage.
- Unable to focus on professional development until 2021.
- Have not yet scaled the inclusive design features, even though we know the solutions.

RECOMMENDATIONS FOR THE PANEL

Challenge common assumptions:

1. There exists an effective business model for each evidence-based innovation in STEM Ed.

1. We need to fund *new* innovation, prioritizing *tomorrow's* challenges over *today's*.

1. Existing governmental educational frameworks are sufficient for supporting STEM teachers.

Assumption 1: There exists an effective business model for each evidence-based innovation in STEM Ed.

- PhET and many other Open Education Resources are not compatible with most business models and may significantly restrict access.
- PhET sims would not have been produced by the private sector–they are too expensive and require too much specialized knowledge.
- PhET's efforts to commercialize products and generate revenue have come at the resource opportunity cost of maintaining, refining, and broadening our existing resources.

Assumption 2: We need to fund *new* innovation, prioritizing *tomorrow's* challenges over *today's.*

- The research community has established many effective teaching practices and tools that have yet to be adopted/institutionalized.
- The priority must be what's happening in the classroom. PhET simulations foster innovation in teaching.
- With "continuing grant" funding to support incremental innovation starting 20 years ago, PhET would have been much further along now.

Assumption 3: Existing governmental education frameworks are sufficient for supporting STEM teachers.

- STEM teachers often lack access to deep STEM discipline-specific teacher PD through school districts and universities.
  - Lack of critical mass of STEM teachers per school/district
  - Need for high-specialized expertise to deliver PD

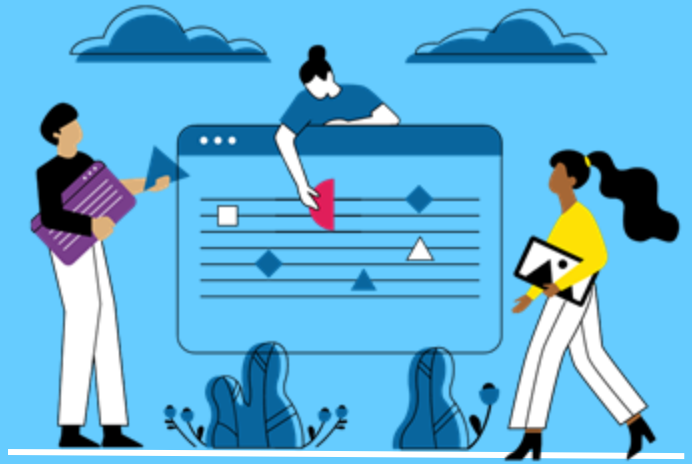
- The groups most capable of meeting this need are often least likely to be eligible for government funding (national or state)
  - STEM teacher professional societies
  - STEM projects (like PhET)
  - STEM teacher leaders (leveraging expertise)

Priority Recommendation

Provide **funding for sustaining and scaling** NSF-generated STEM education solutions, including providing teacher PD in the use of solutions.

Use a **continuing grant structure** to support the maintenance and scaling of evidence-based projects.

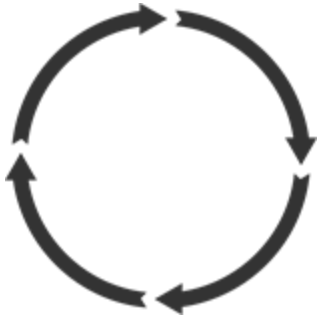
- NSF science directorates have long recognized the need for long-term funding through continuing grants.



THANK YOU!

SUPPLEMENTARY SLIDES

PhET simulations...
are developed with **research-based design** on learning.



PhET simulations follow a cycle of design, development, and testing that makes use of design research and discipline-based education research on common student prior knowledge, learning challenges, physical and cognitive differences, and motivation. *If we do not see expected outcomes in their use of the simulation, we do not publish it, and go back to design.*

Further Reading

Foundational design principles	Adams et al., 2008a	Adams et al., 2008b	Podolefsky et al., 2010
Inclusive features	Moore et al., 2015		
Role of play and exploration	Whitacre et al., 2018		

PhET simulations...
support teachers to **transition from teacher-centered to student-centered** instruction.

Teachers who make use of PhET simulations inherently see shifts in their classroom dynamics, including more student talk, inquiry, and agency.

Further Reading

Teacher facilitation & student agency	Atabas et al., 2020
Power of open play to center instruction on student ideas	Moore et al., 2013 Podolefsky et al., 2013

PhET simulations…
result in significantly **higher learning gains** than traditional instruction.

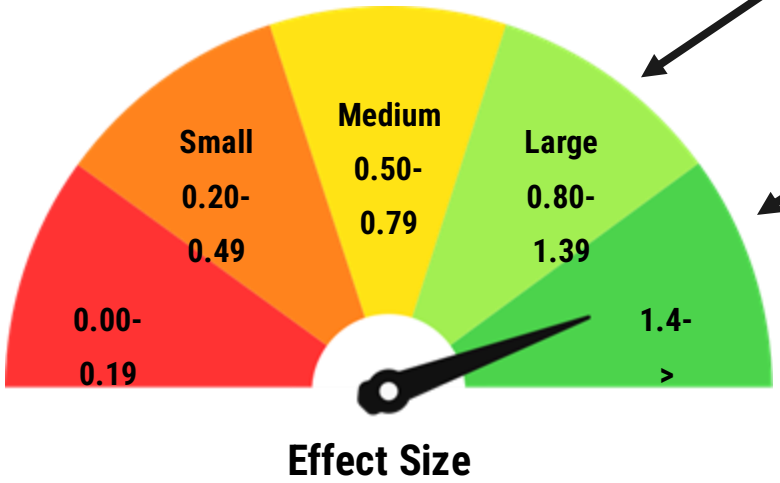
When teachers use PhET simulations paired with active learning, inquiry-based strategies, students learn substantially more than through traditional instruction. In many cases, using PhET simulations can be more effective than using physical equipment, especially when topics involve abstract concepts.

These findings generally hold true across

- Gender (males, females)
- Discipline (science, math)
- Socioeconomic contexts

PhET simulations…
result in significantly **higher learning gains** than traditional instruction.

Effect sizes represent the magnitude of difference in performance by students who received the intervention (use of interactive simulations) vs. those who received traditional instruction.



Effect Size

Meta-analyses

Antonio & Castro, 2023

- 15 quasi-experimental studies (87% with PhET sims)
- Effect sizes up to g = 1.26
- Effect size weighted average of g = 0.941

Rutten et al., 2012

- 17 quasi-experimental studies (some with PhET sims)
- Effect sizes up to d = 1.54.

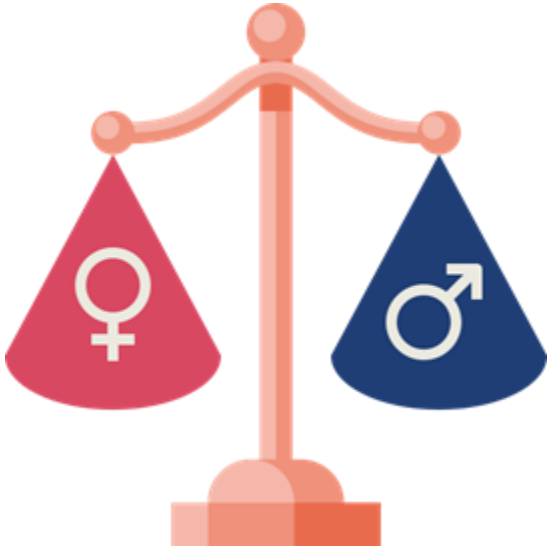
Literature Review

Banda & Nzabahimana, 2021

- 31 quasi-experimental studies (all with PhET sims)
- Up to 37% higher normalized gains than control

PhET simulations...
help **close the learning gap** between males and females.

PhET simulations do not discriminate against gender. Males and females demonstrate similar performance as a result of PhET-based teaching interventions.



Further Reading

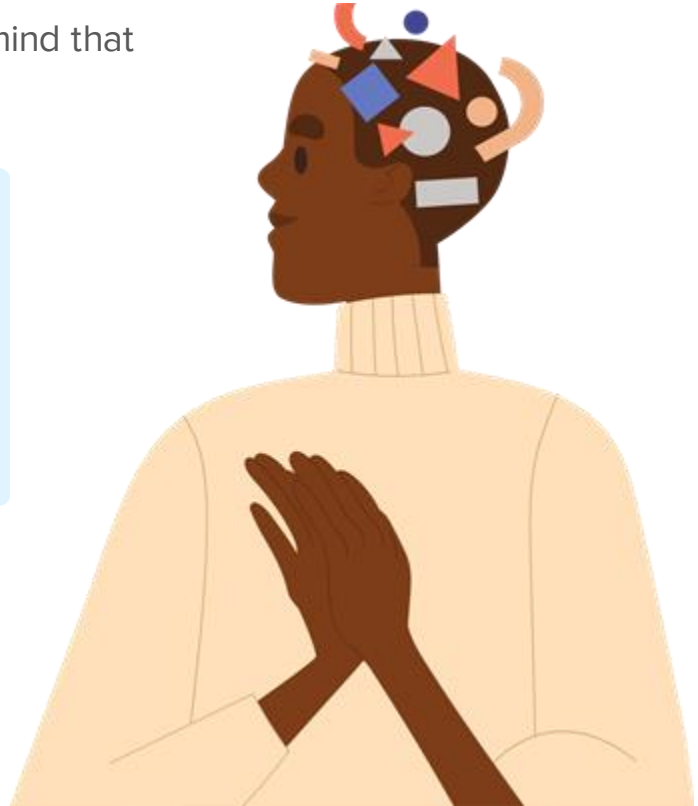
Physics	Pember & Achor, 2018
Chemistry	Ajijolajesu et al., 2019

PhET simulations...
support the development of STEM **process skills**.

The use of PhET simulations supports laboratory skills and habits of mind that are essential to success in STEM.

Further Reading

Lab Skills	Taibu et al., 2021
Coordinating Representations	Podolefsky et al., 2010
Science Communication	Rosero et al., 2022



PhET simulations…
improve students' attitudes about learning STEM.

Students in research studies involving PhET simulations often demonstrate high levels of engagement, and report increased motivation interest in learning about STEM in diverse contexts, including minority-serving institutions and community colleges.

Further Reading

USA	Salame & Samson, 2019 Salame & Makki, 2021 Taibu et al., 2021
Africa	Chumba et al., 2020 Ramnarain & Penn, 2021
Europe	Rutten et al., 2015
Latin America	Díaz-Pinzón, 2016