The Process of Science

How Do Scientists Think?

CERN HST 2023

Dave

Sean

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How Do Scientists Think?

Scientists Are Curious

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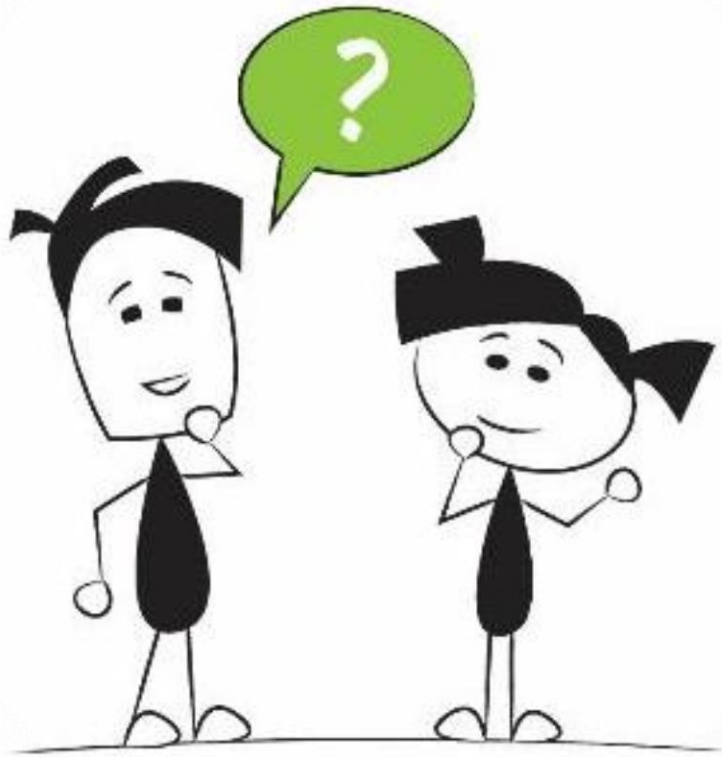
How Do Scientists Think?

Scientists Ask Questions



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How Do Scientists Think?

Scientists Build and Revise Models

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How Do Scientists Think?

Scientists Are Creative

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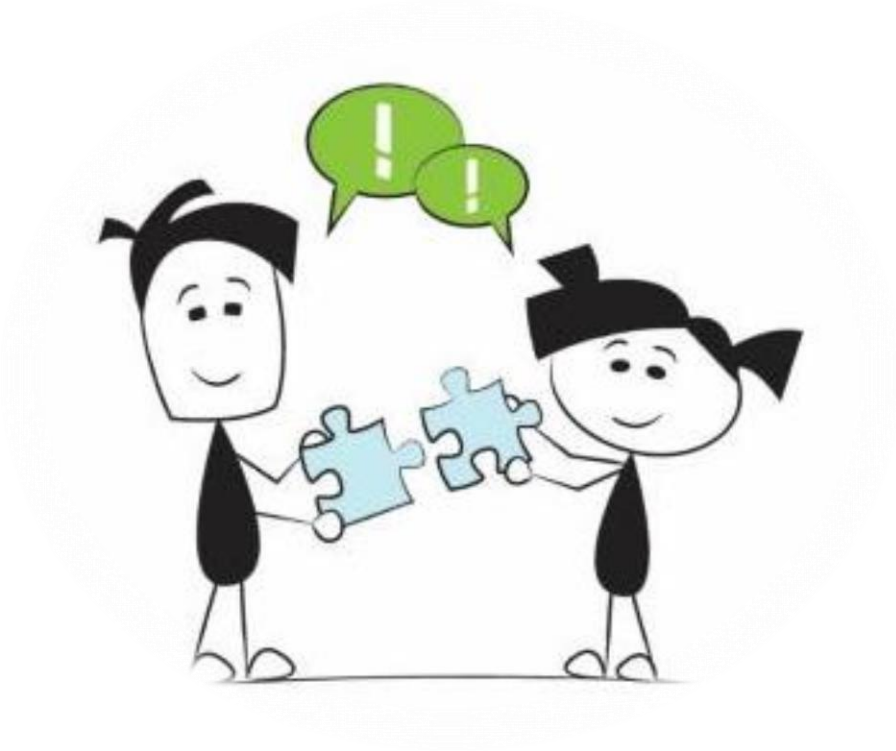
How Do Scientists Think?

Scientists Collaborate



How Do Scientists Think?

Scientists Look for Patterns

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Looking for patterns

- spin
- electric charge (Q)
- strangeness (S)
- mass
- date

spin 3/2

Q = -1

S = 0

mass: 1232 MeV

discovered: 1954

Finding patterns

spin 3/2
Q = -1
S = 0
mass: 1232 MeV
discovered: 1954

spin 3/2
Q = 0
S = 0
mass: 1231 MeV
discovered: 1954

spin 3/2
Q = +1
S = 0
mass: 1235 MeV
discovered: 1954

spin 3/2
Q = 0
S = -2
mass: 1532 MeV
discovered: 1962

spin 3/2
Q = +2
S = 0
mass: 1231 MeV
discovered: 1954

spin 3/2
Q = +1
S = -1
mass: 1383 MeV
discovered: 1960

spin 3/2
Q = -1
S = -1
mass: 1387 MeV
discovered: 1960

spin 3/2
Q = 0
S = -1
mass: 1384 MeV
discovered: 1960

spin 3/2
Q = -1
S = -2
mass: 1535 MeV
discovered: 1962

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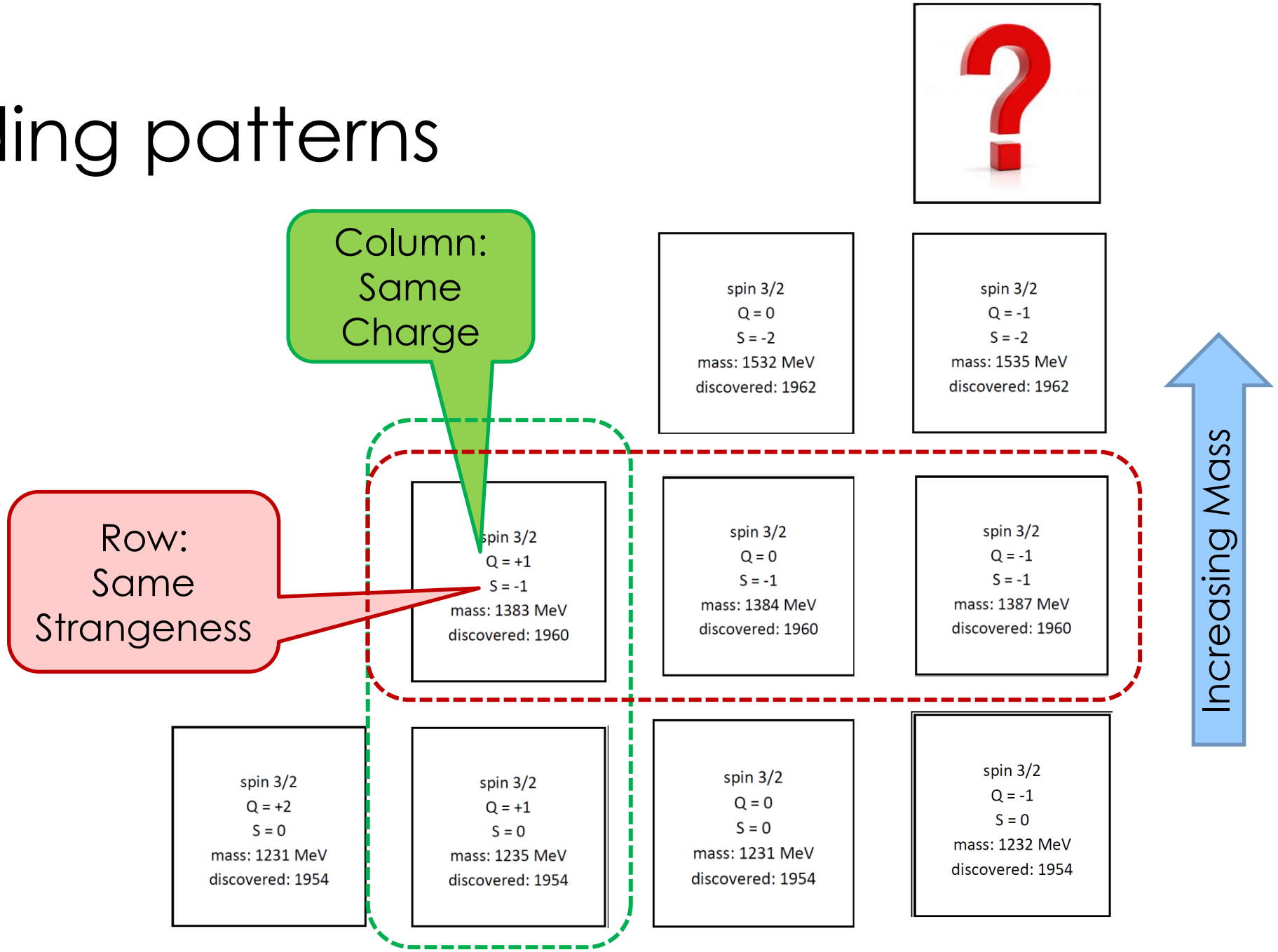
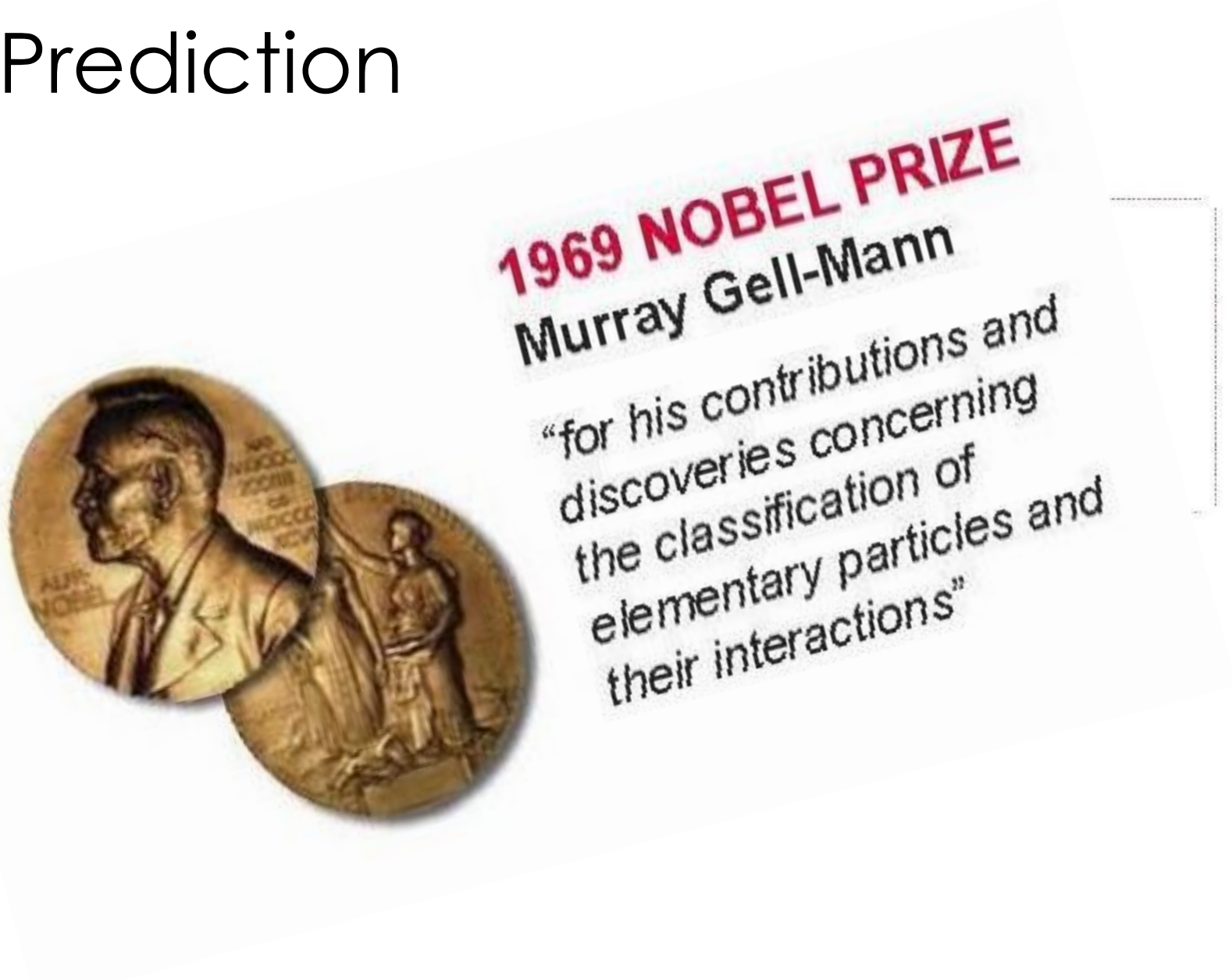
Finding patterns



Particle Prediction

- spin 3/2
- cha
- strar
- mass



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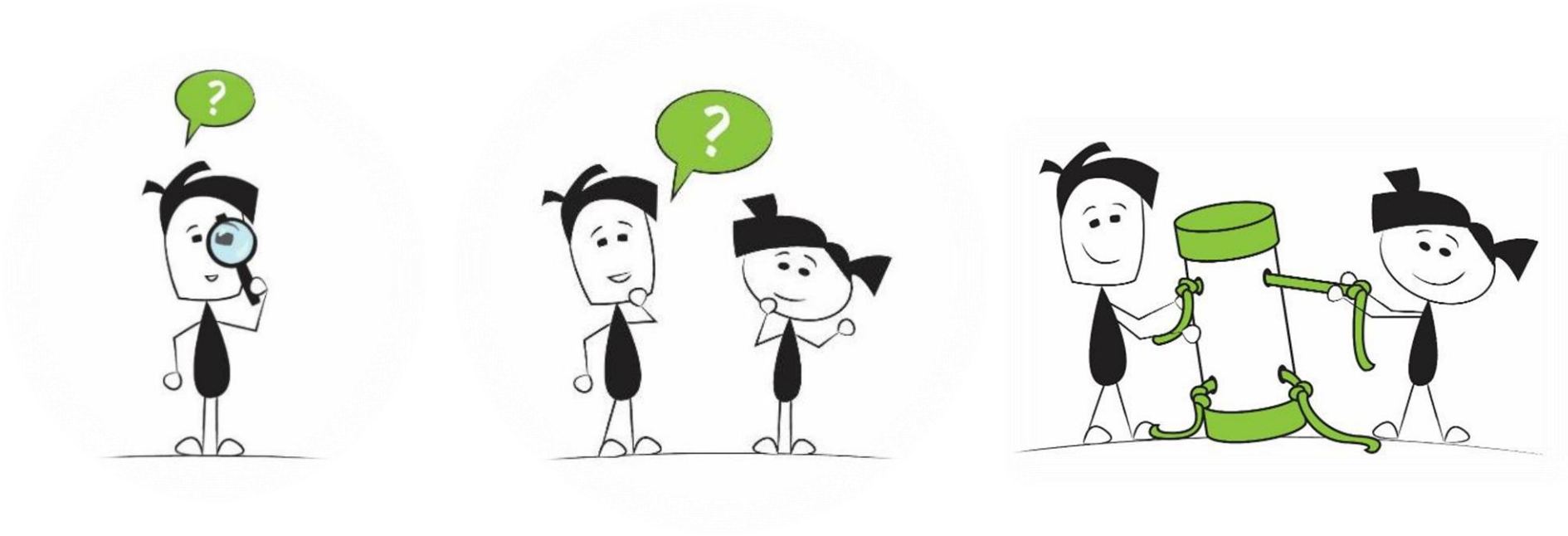
Thinking Like A Scientist



Let's work together to build and revise our model for a simple question.

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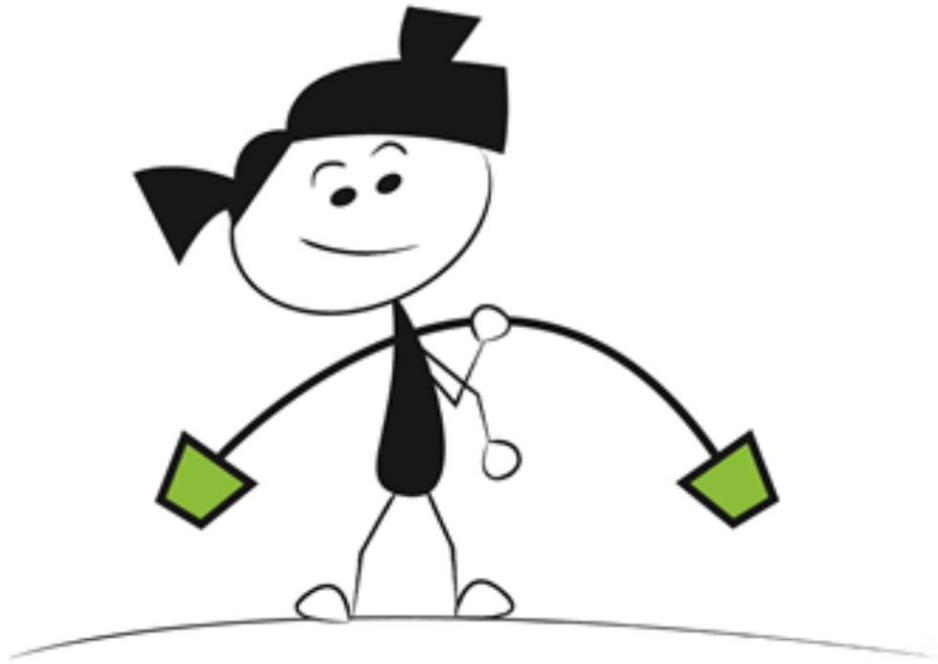
Why does this rod bend?



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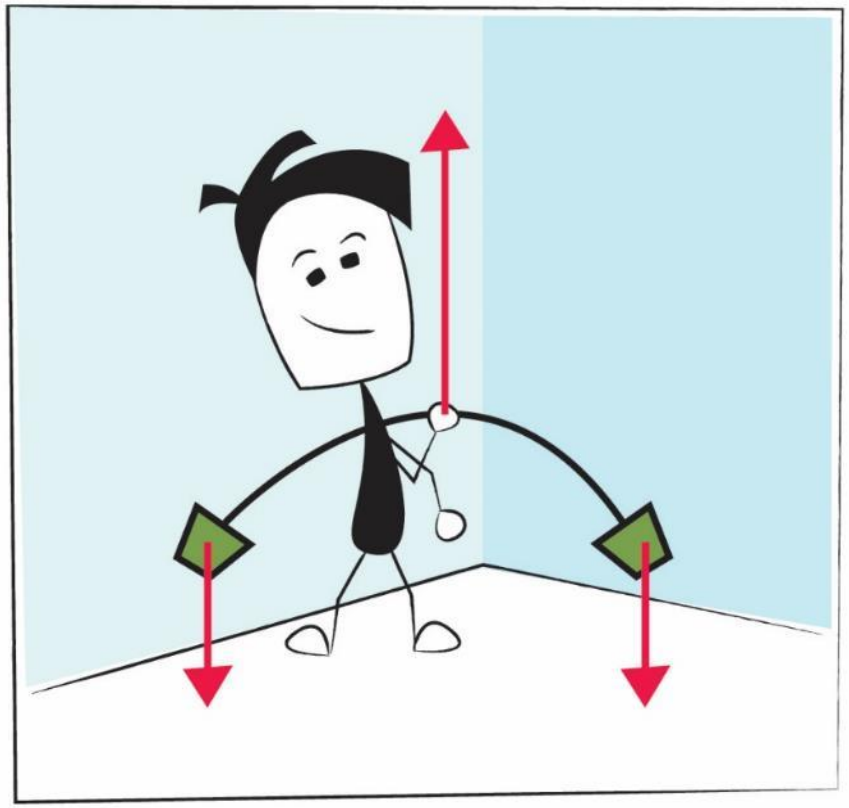
One force pulls down another pushes up



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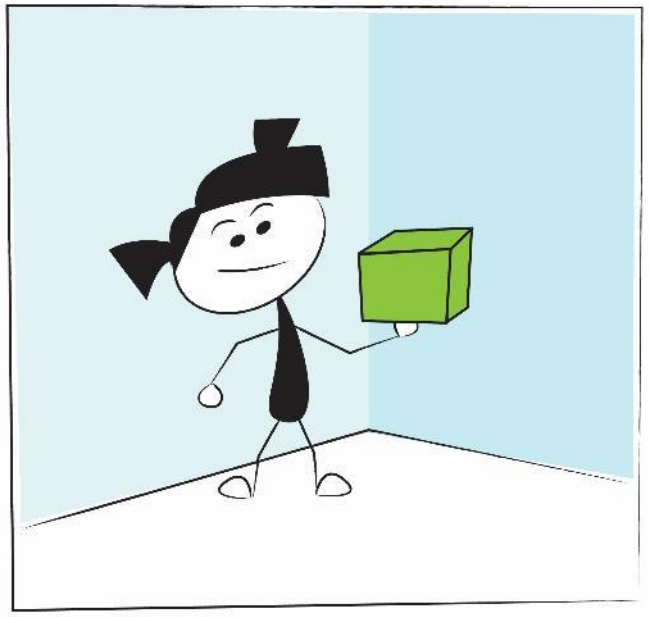
Force Model

Why do objects feel heavy?



Why do objects fall?

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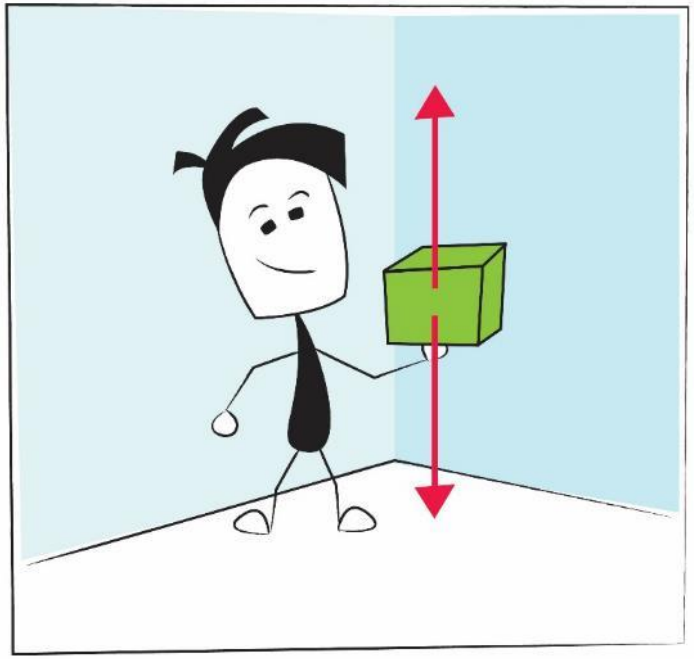
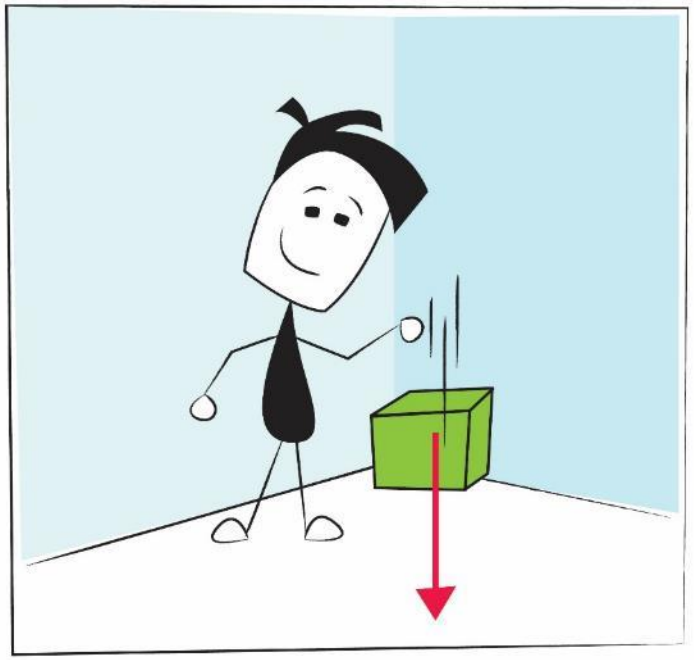
Force Model

Why do objects feel heavy?



You push up to oppose the force of gravity

Why do objects fall?



The force of gravity pulls them down

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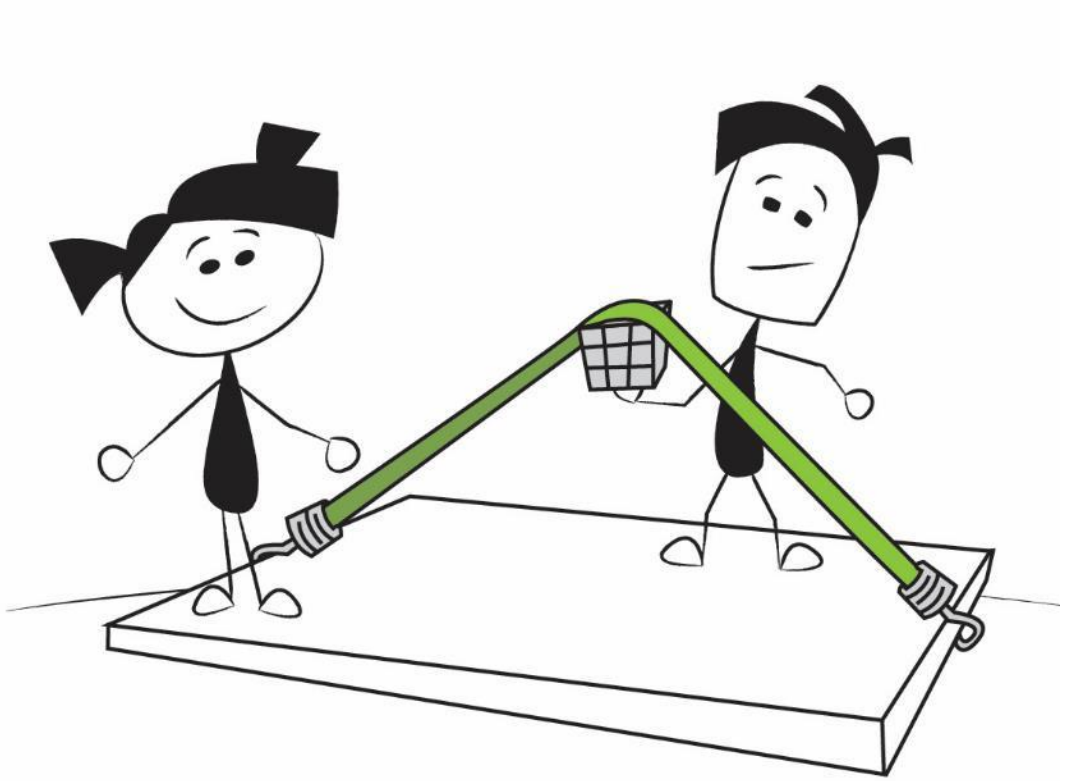
Force Model of Gravity

Gravity is like an Invisible Bungee Cord



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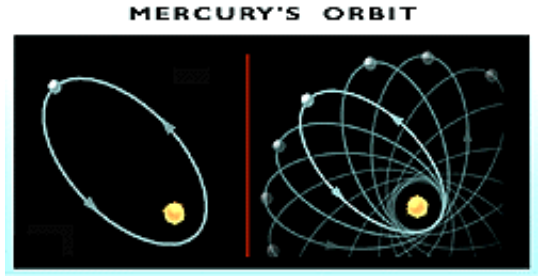
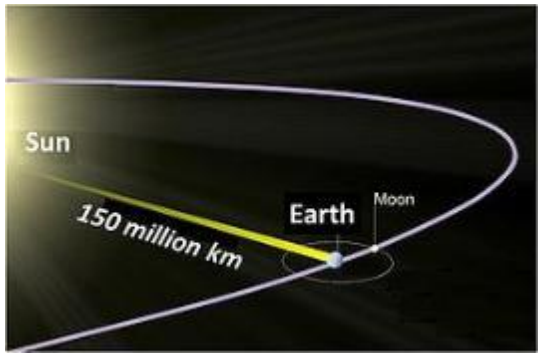
*"That gravity should be innate, inherent, and essential to matter so that one body may act upon another, at a distance through vacuum, without the mediation of anything else…**is to me so great an absurdity**, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it."*

- ***Isaac Newton***

Newtonian gravity works…right?



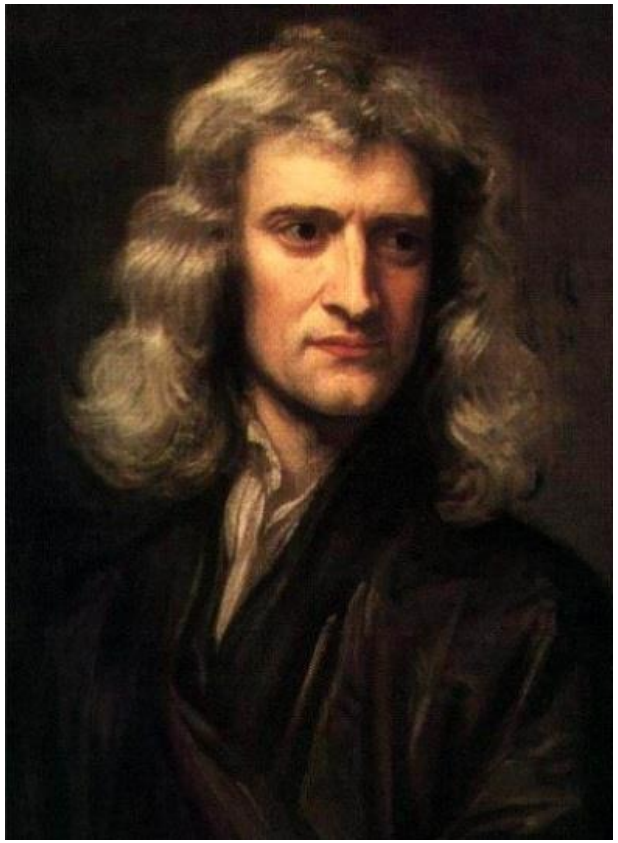
Observations (1859)
Force model predicts the wrong orbits



Theory (1905)
Force model violates speed of light limit

Newton: Gravity is a force

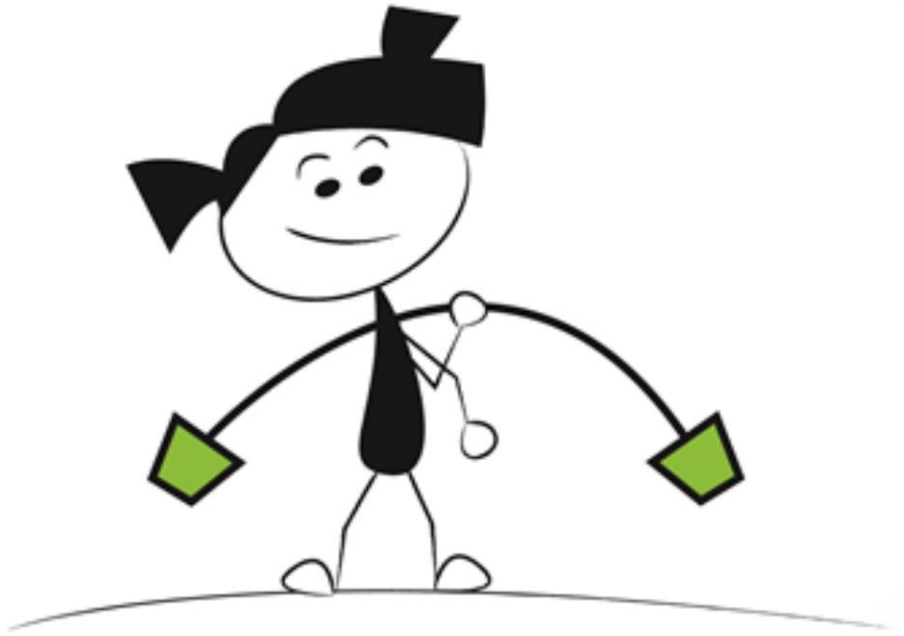
FEELS RIGHT, but doesn't survive experimental tests



so….

something is ***wrong*** with our force model for GRAVITY

How else can I make this rod bend?



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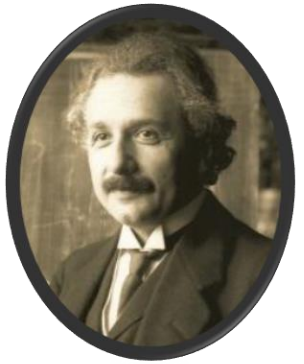
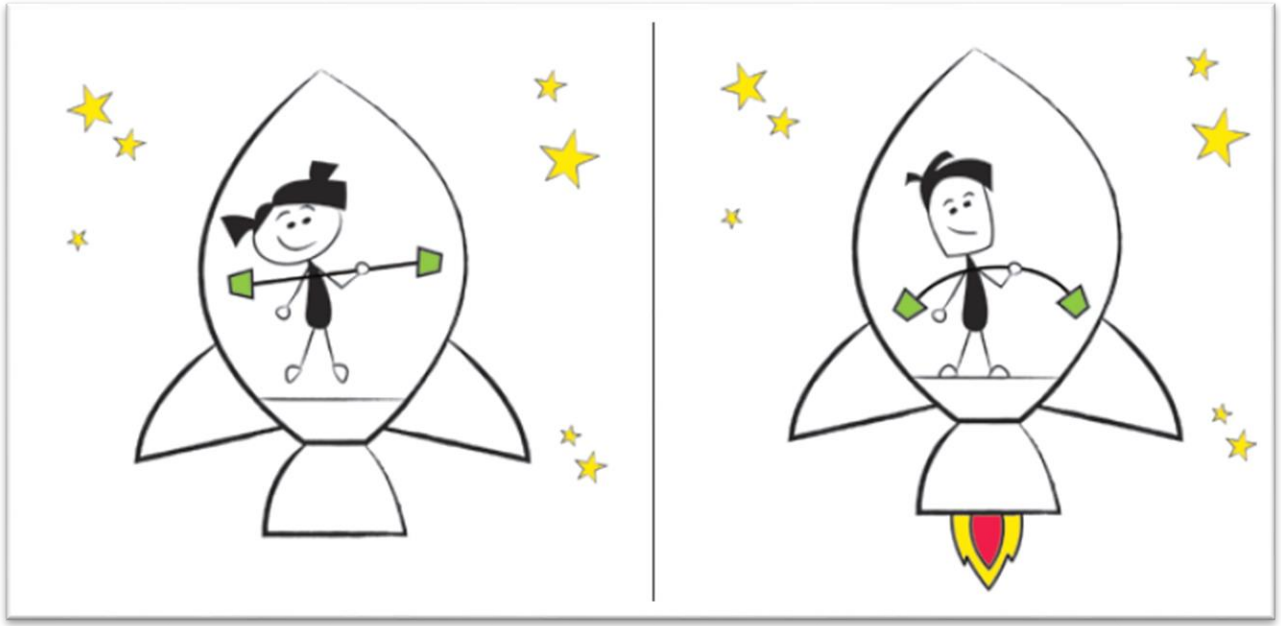
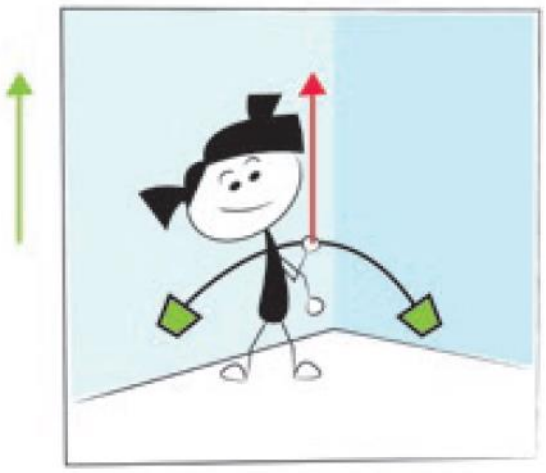
Acceleration Model



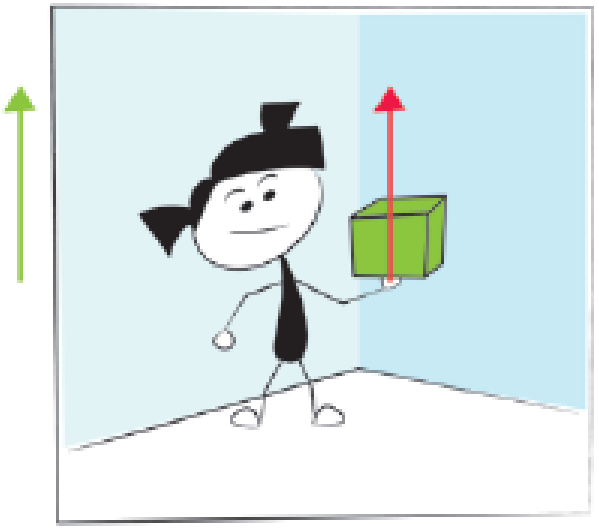


Acceleration Model

Bendy Rod



Weight



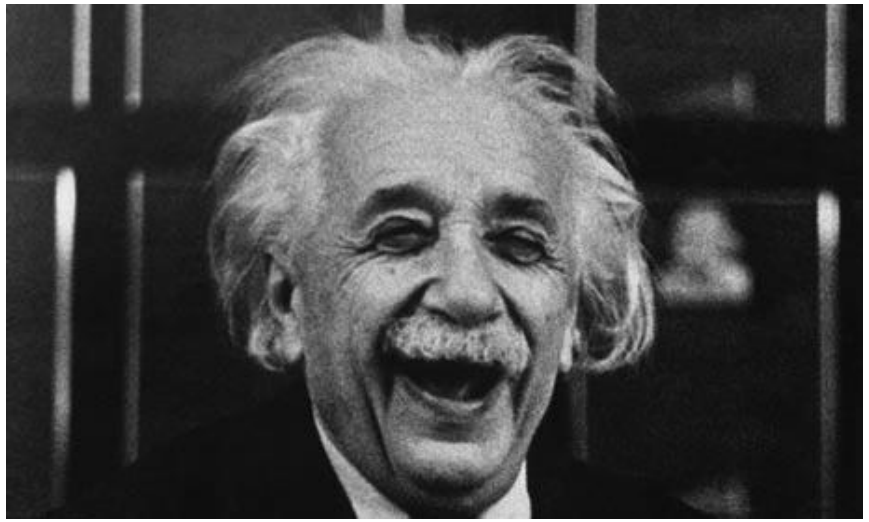
Freefall

Acceleration Model of Gravity

Acceleration in one direction is identical to a force in the other direction!
-Einstein's "happiest thought"

Gravity isn't a force pulling us down.

We are accelerating UP!



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The BIG Question

How can the ground be *accelerating* up without *moving* up?

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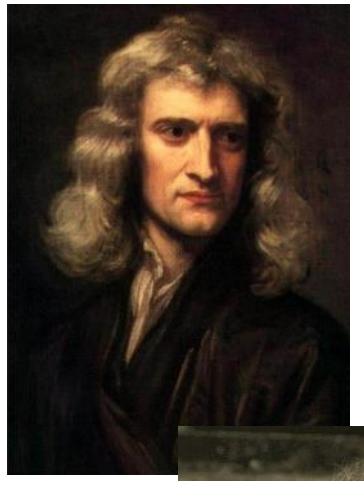
Two Models

Newton: Gravity is a force

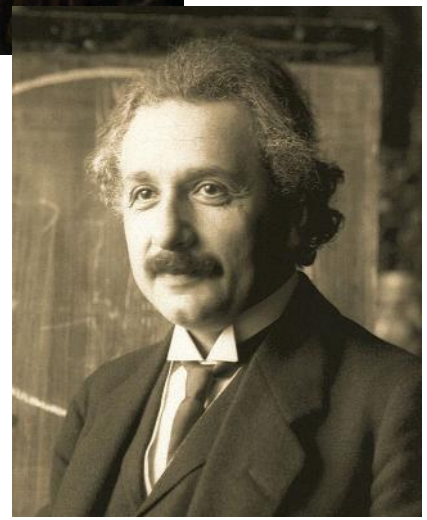
FEELS RIGHT, but doesn't survive experimental tests.



Einstein: Acceleration Model

FEELS WEIRD but could work...

... But earth isn't expanding!



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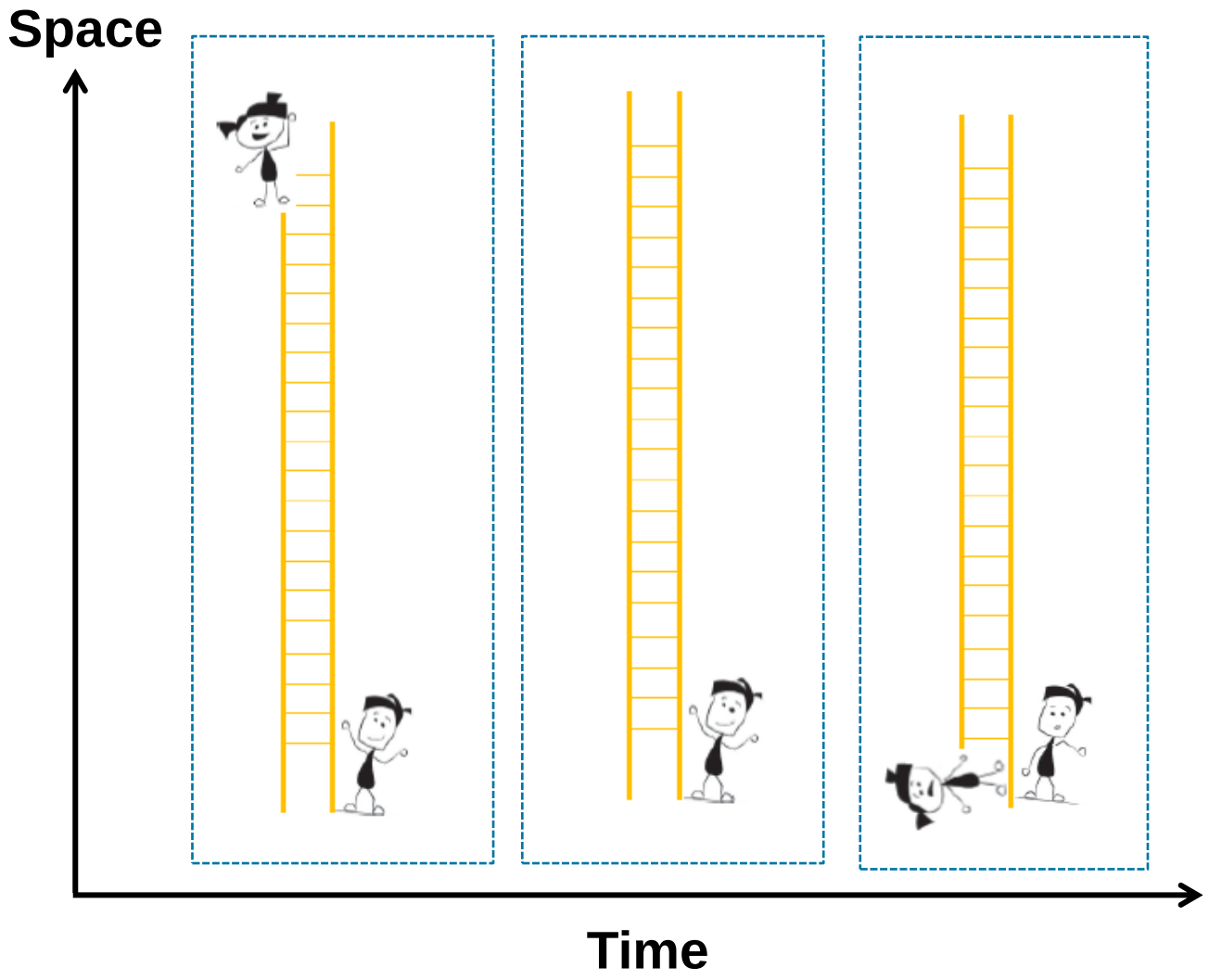
Force Model: Falling Off a Ladder



Where will Alice be in the middle frame?

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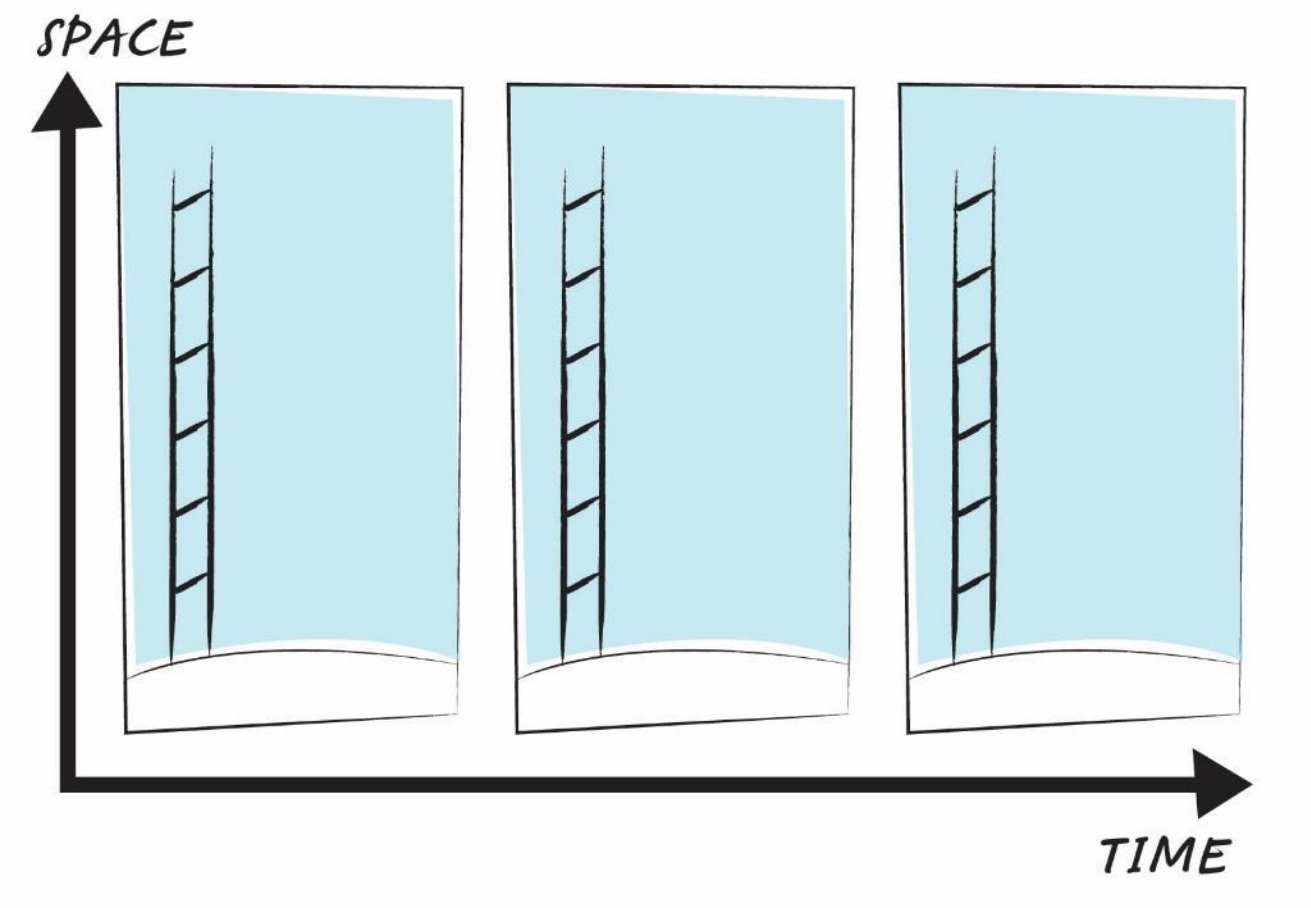
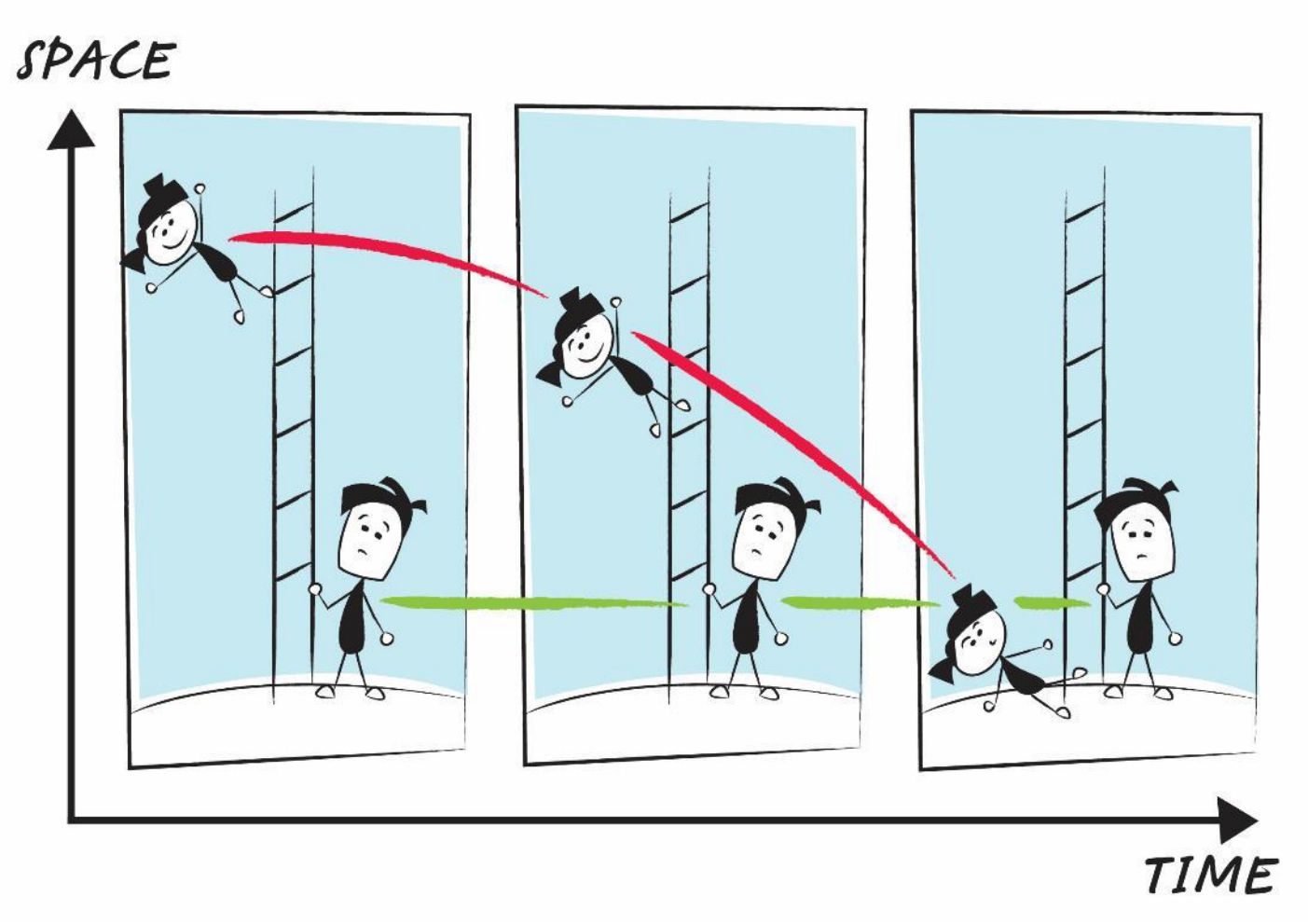
Spacetime Diagram



Plot the lines for Alice and Bob on a whiteboard.

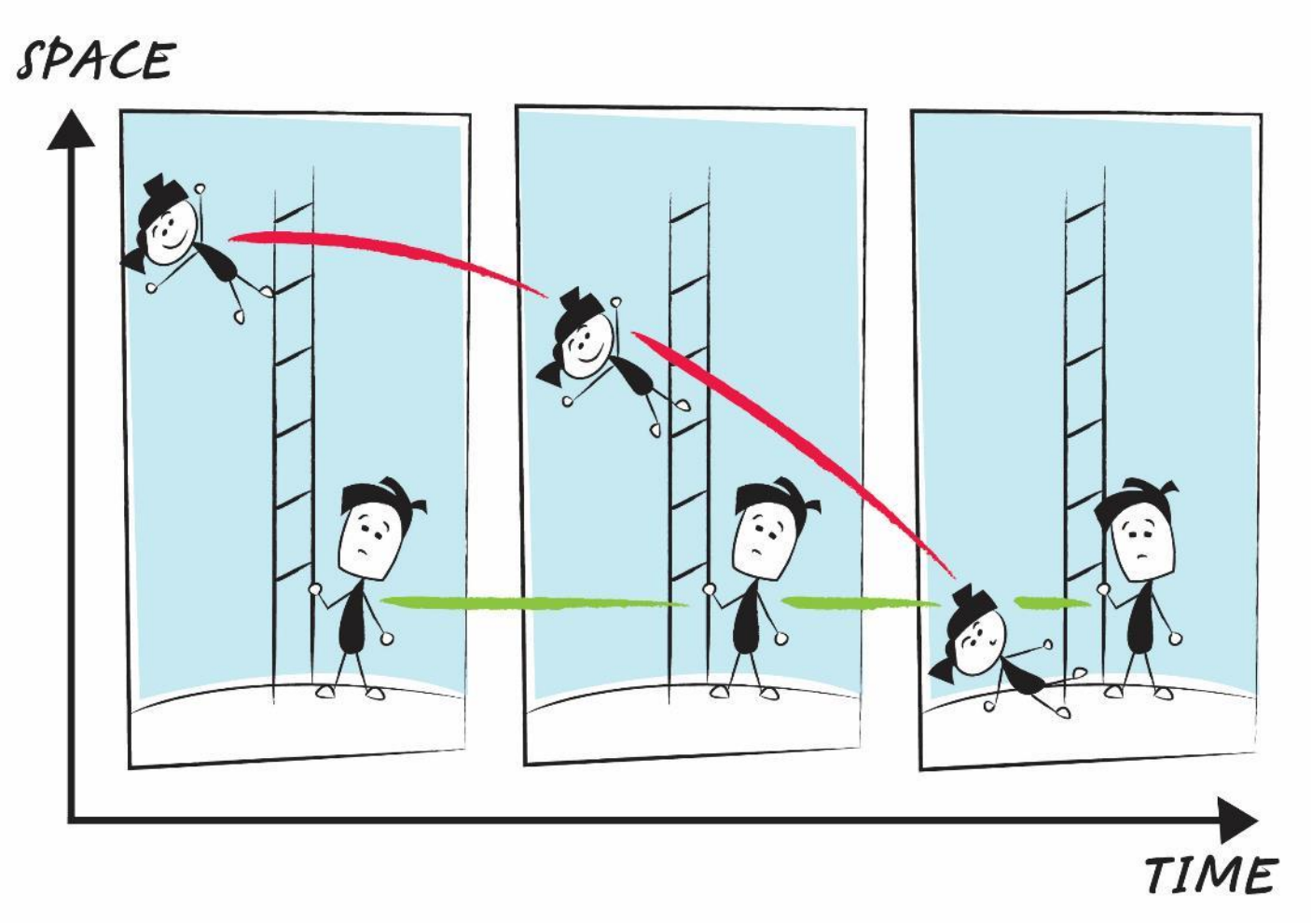
Spacetime Diagram



Curved lines on a spacetime diagram mean the object accelerated.

Now trace the lines using one continuous piece of tape for each.

Spacetime Diagram

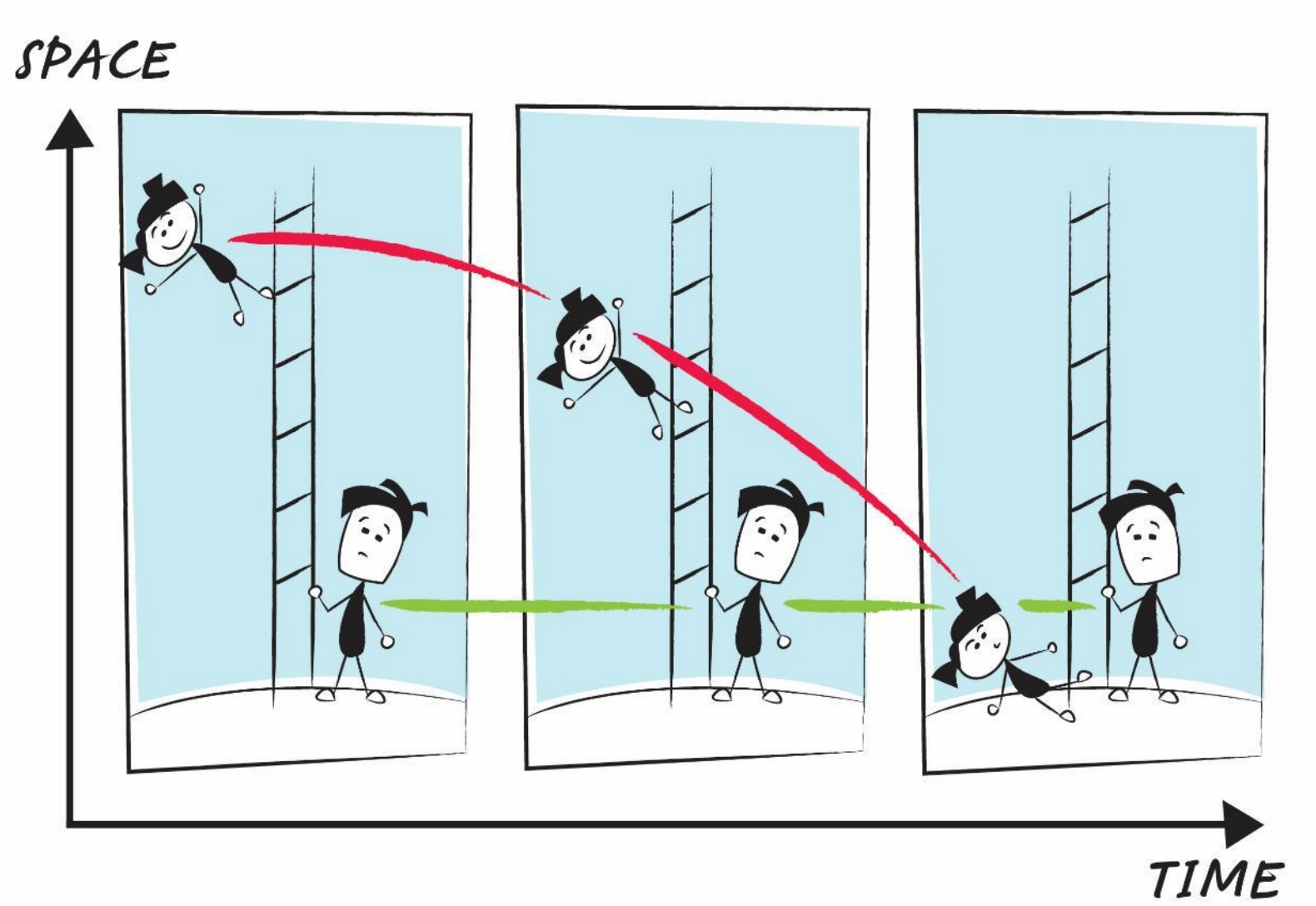


Describe the tape for Alice (accelerating) and Bob (not accelerating).

Crinkled tape means the object accelerated.

Flat tape means the object did not accelerate.

Spacetime Diagram



According to Einstein, there is NO FORCE acting on Alice so she should not accelerate.

Bob is the one who should accelerate because of the normal force acting on him.

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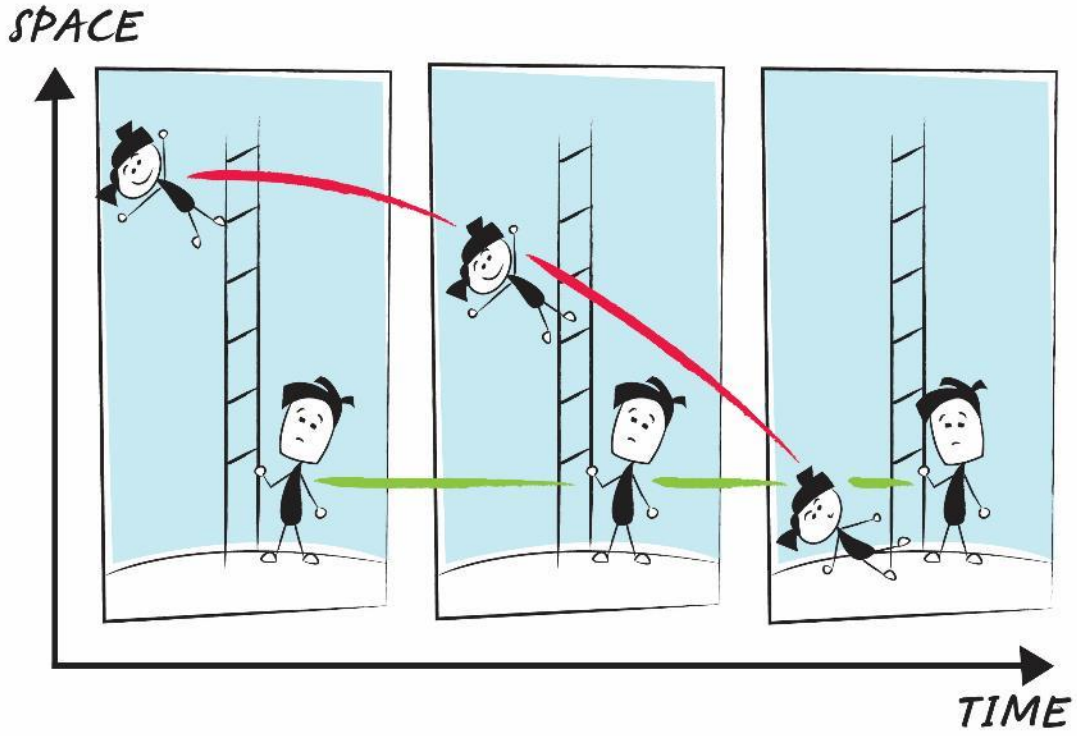
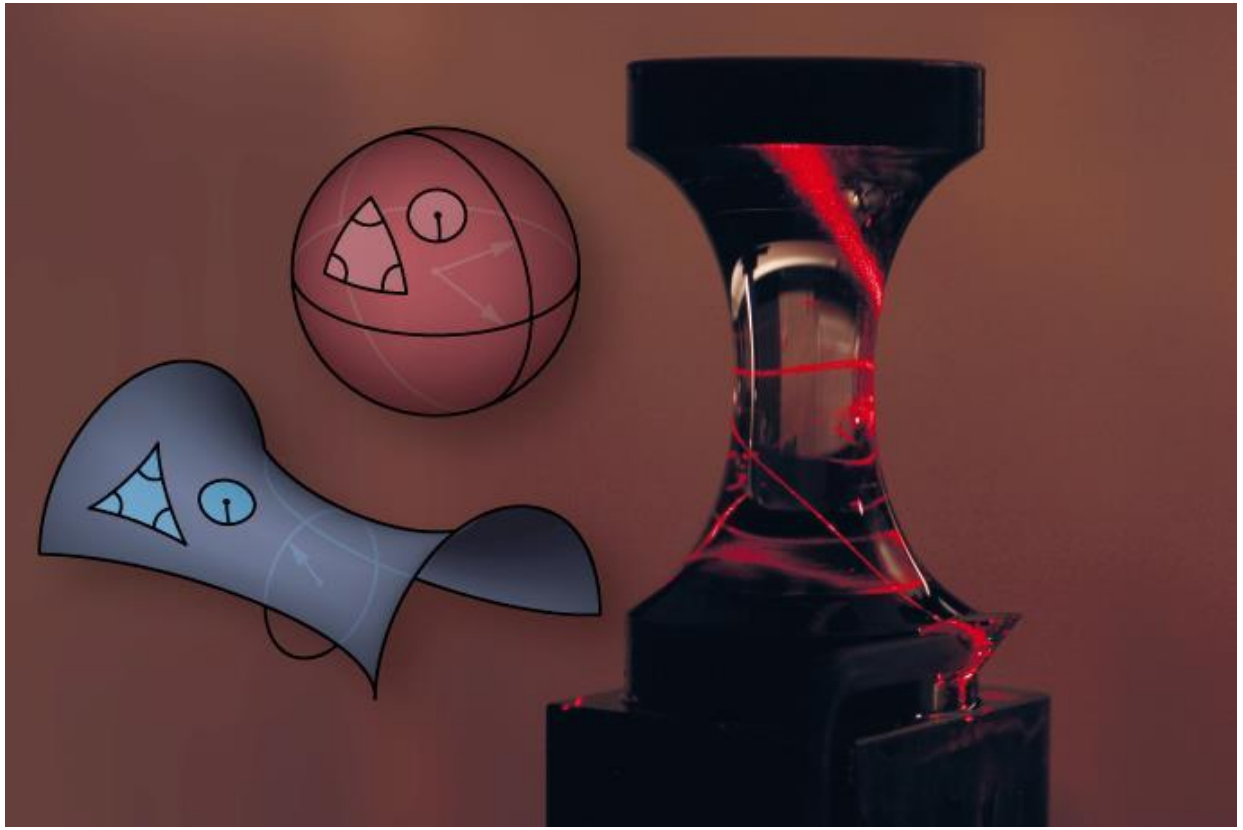
How can Alice fall without accelerating?



How can Bob accelerate while stationary?

Einstein's Solution: Spacetime is not flat!



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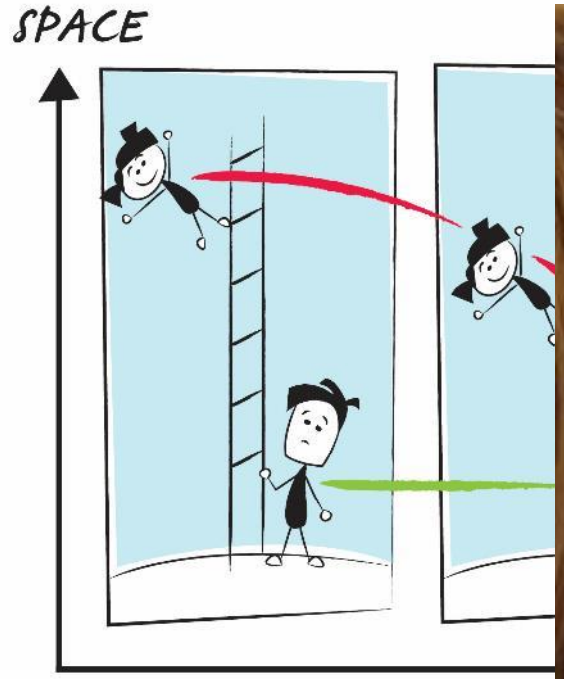
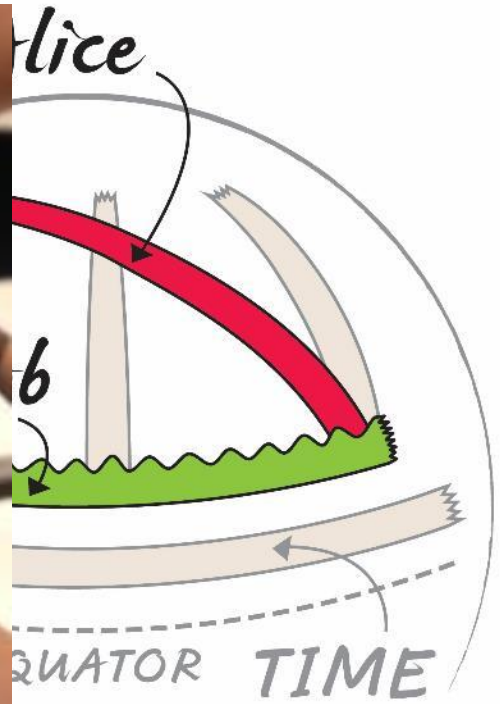
“Draw” the plots for Alice and Bob using tape on the balloon.





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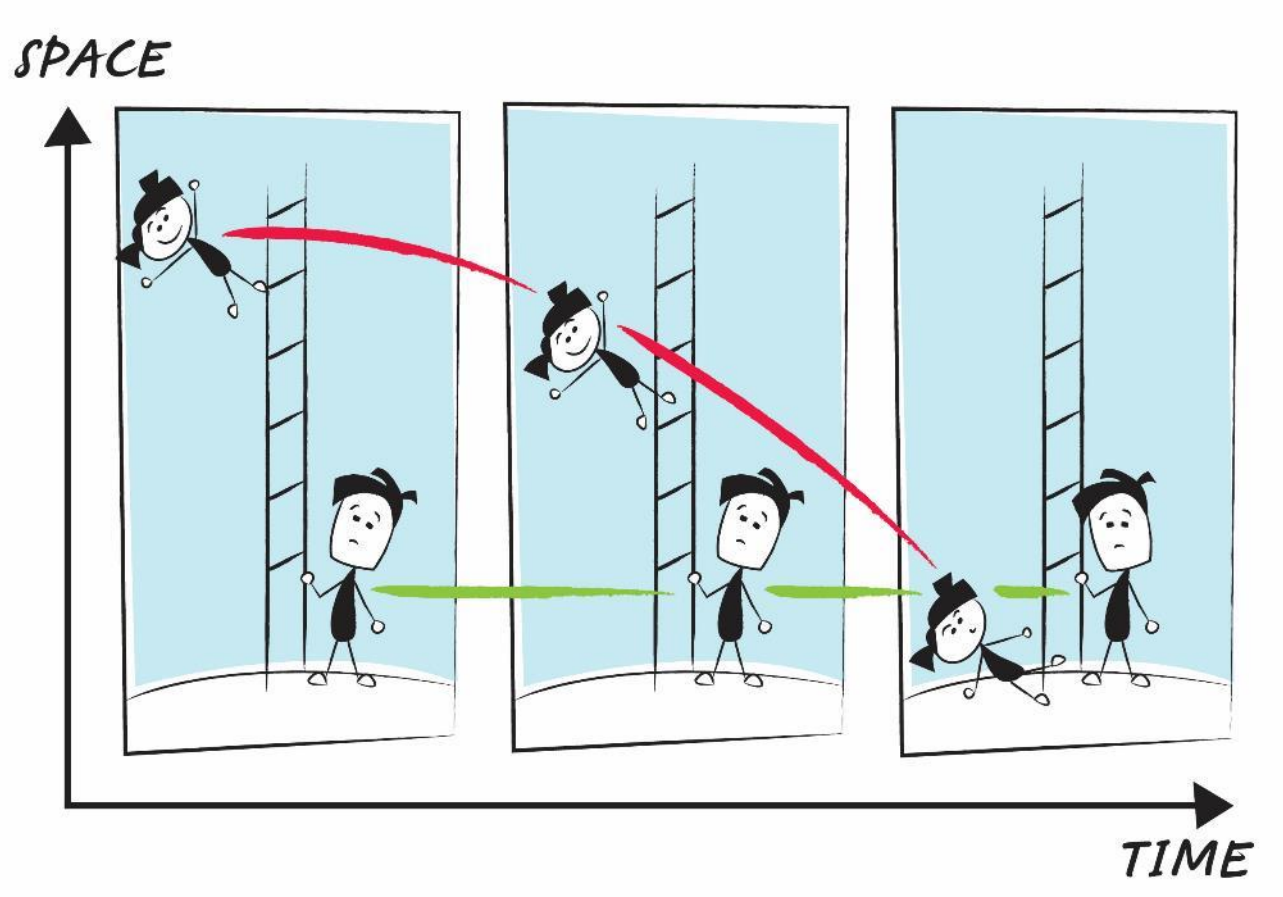
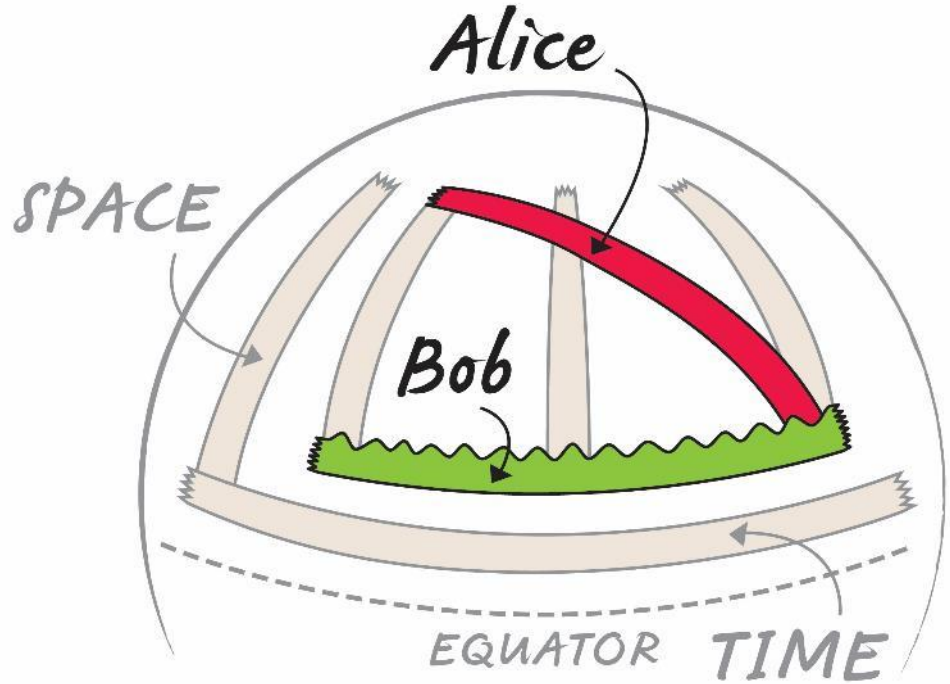
Curved Spacetime





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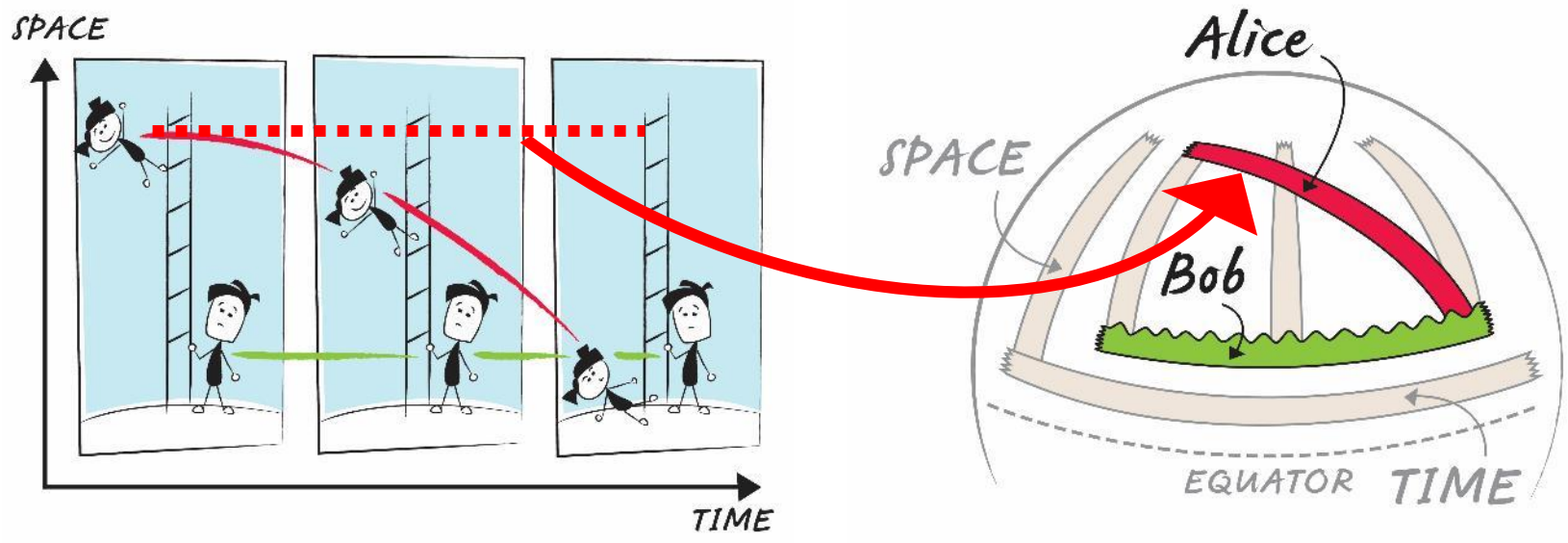
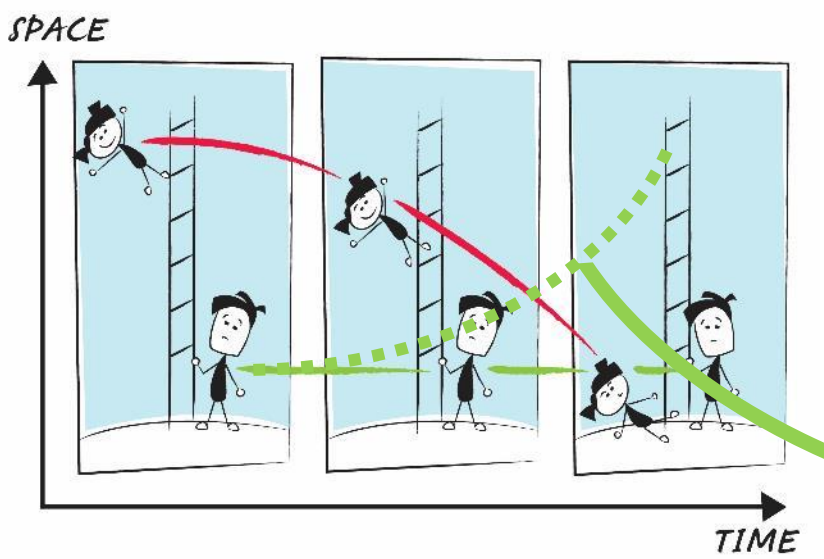
Alice's path *stays straight* (no force, no acceleration)

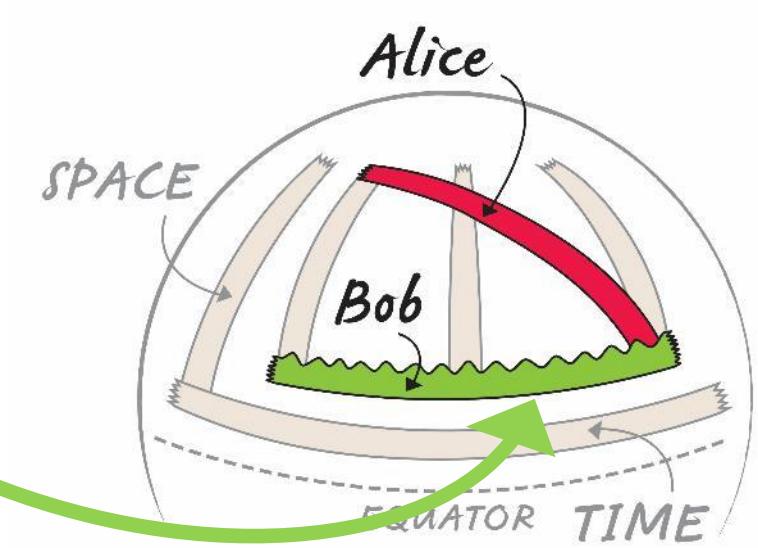
…and yet she is *falling* from the top of the ladder to the bottom!



Bob's path *curves up* (he feels upward force and acceleration)

…and yet he is not *moving* up!





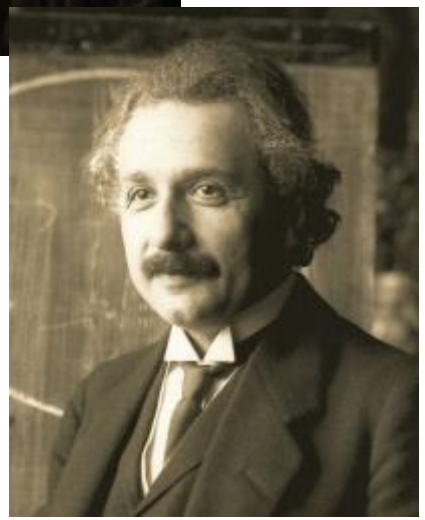
Two Models

Newton: Gravity is a force

FEELS RIGHT, but doesn't survive experimental tests

Einstein: Spacetime is curved

FEELS WEIRD but explains what we see (so far)



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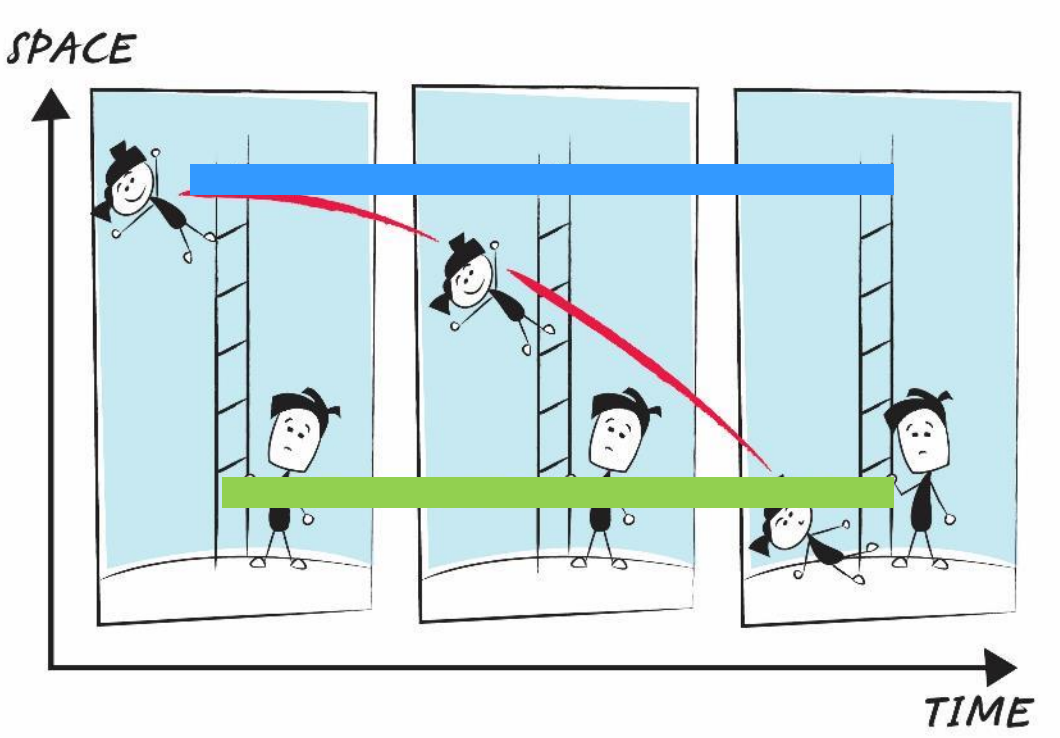
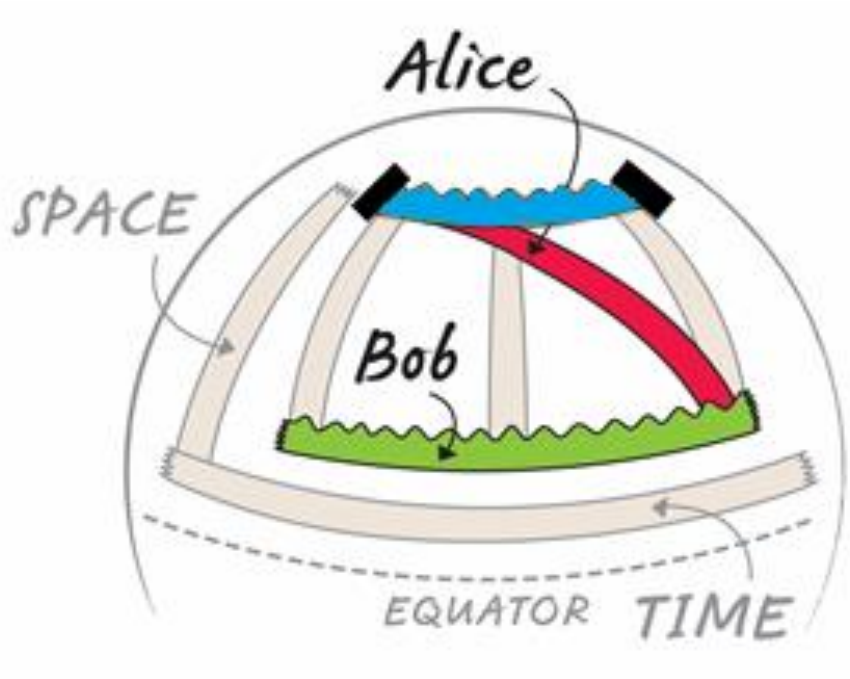
Models cannot be proven ***right***, only ***wrong***
Curved spacetime predicts time dilation





GPS confirms that time dilation is ***REAL!***

Time dilation proves the force model is ***WRONG***

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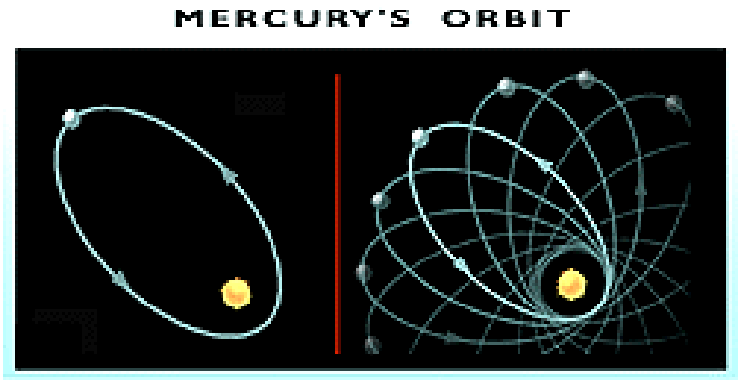
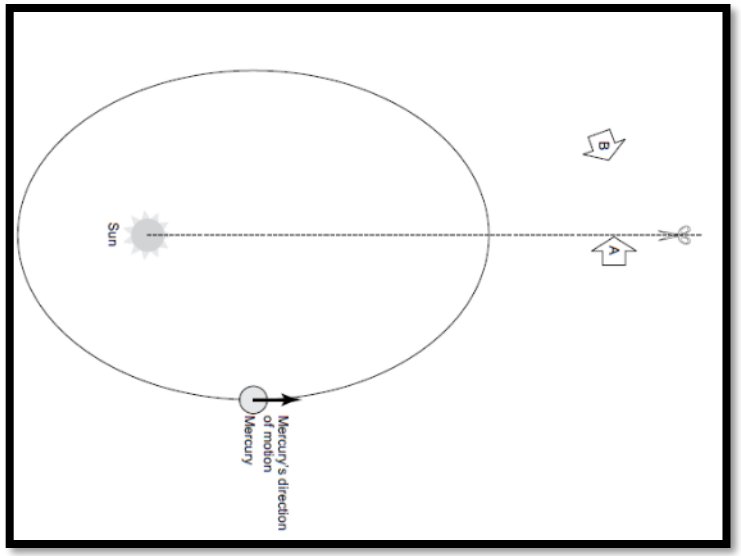
Relativity predicts exact precession



Observations (1859)
Force model predicts the wrong orbits



Classroom Activity
Curved spacetime produces precession

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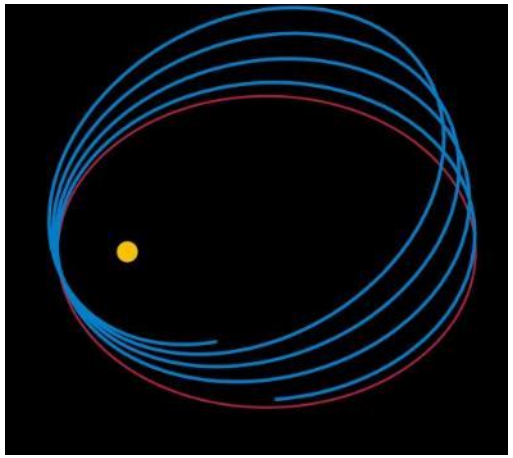
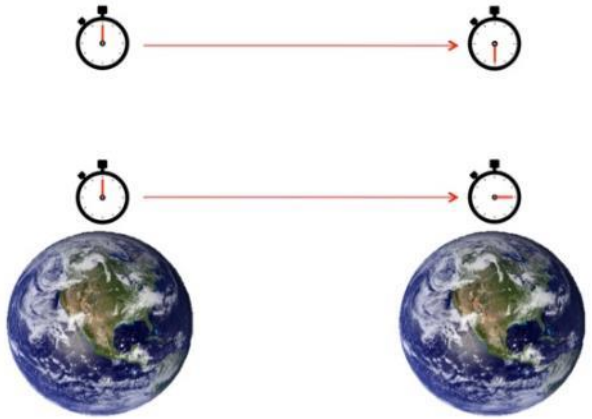
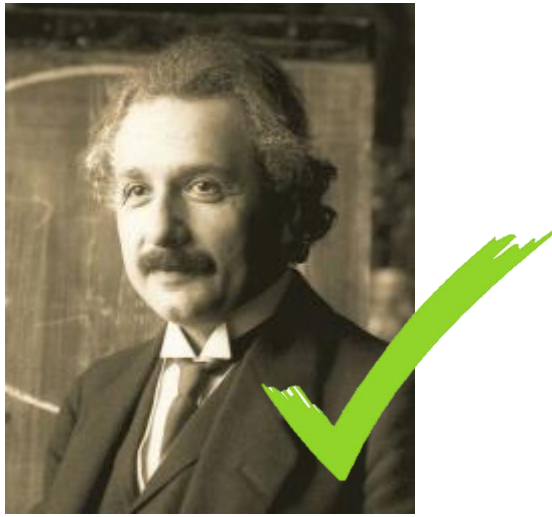
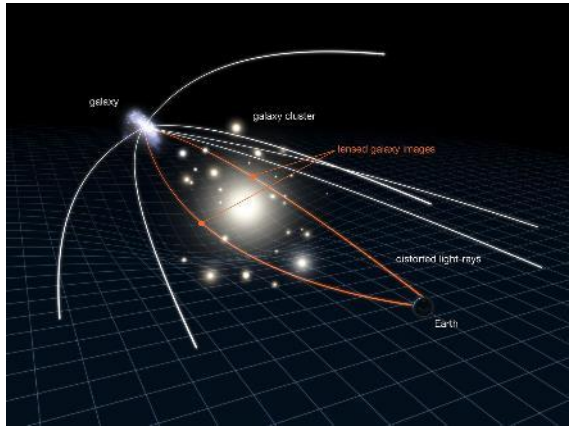


Mercury's Orbit

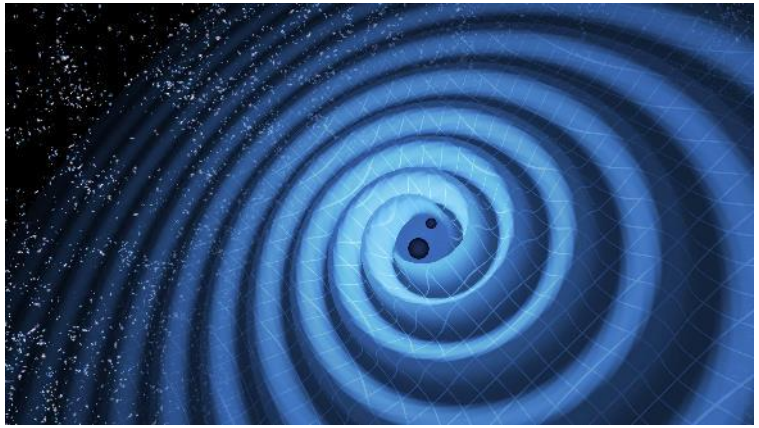


Time Dilation





Lensing



Gravitational Waves

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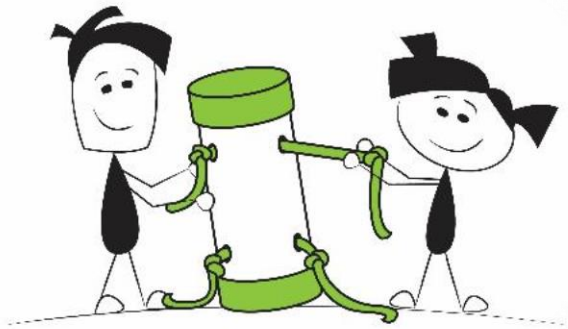
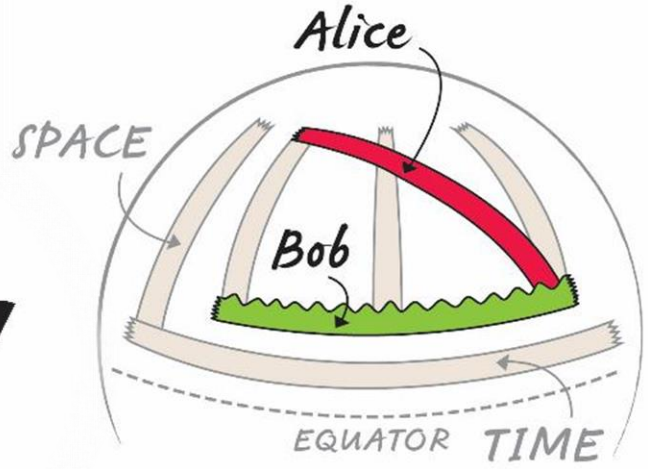
Science is a powerful way of thinking





Curiousity Creativity Collaboration

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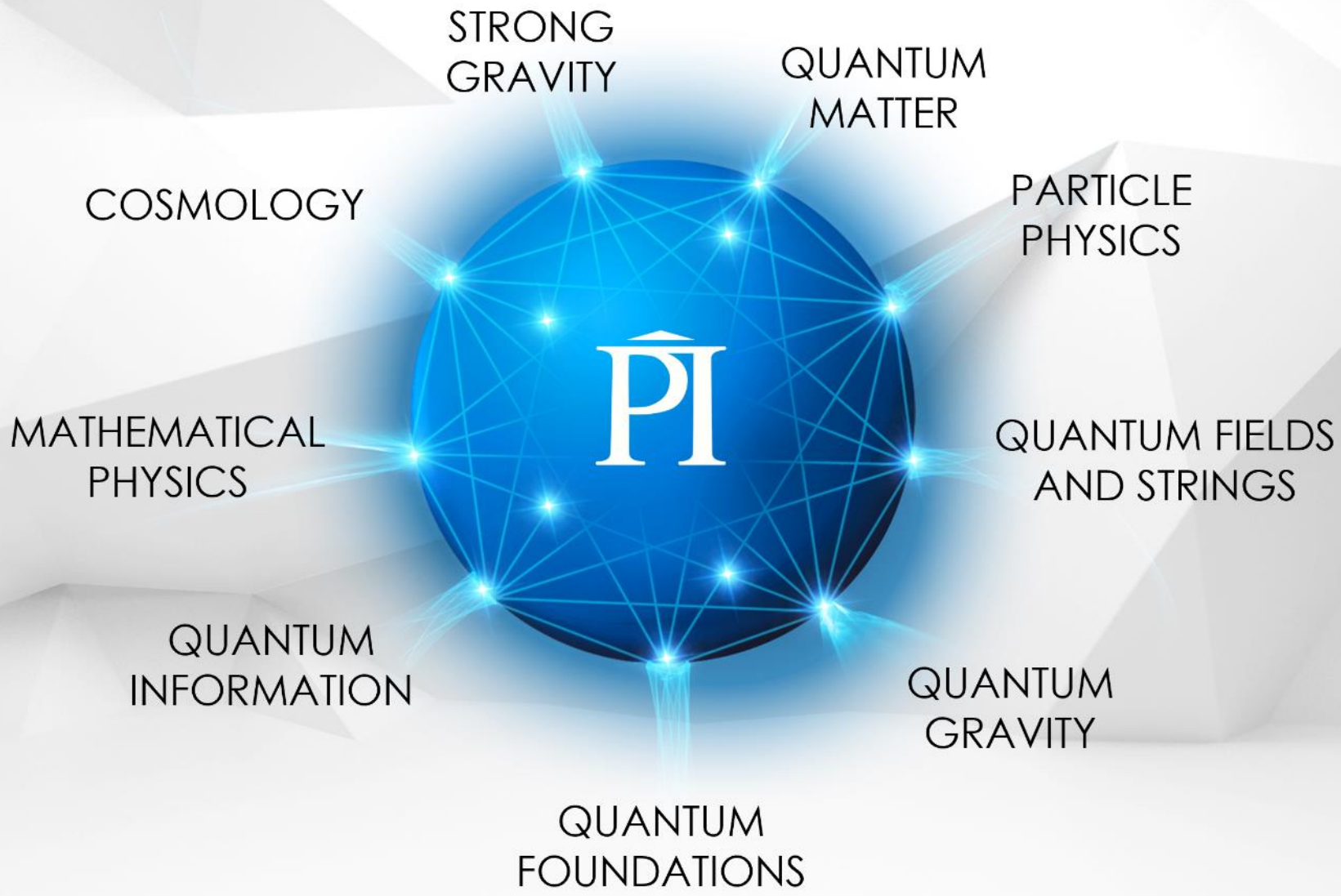
PERIMETER RESEARCH AREAS



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IN-CLASS RESOURCES

- Experienced teachers
- Perimeter researchers
- Pedagogy and teaching strategies

resources.perimeterinstitute.ca

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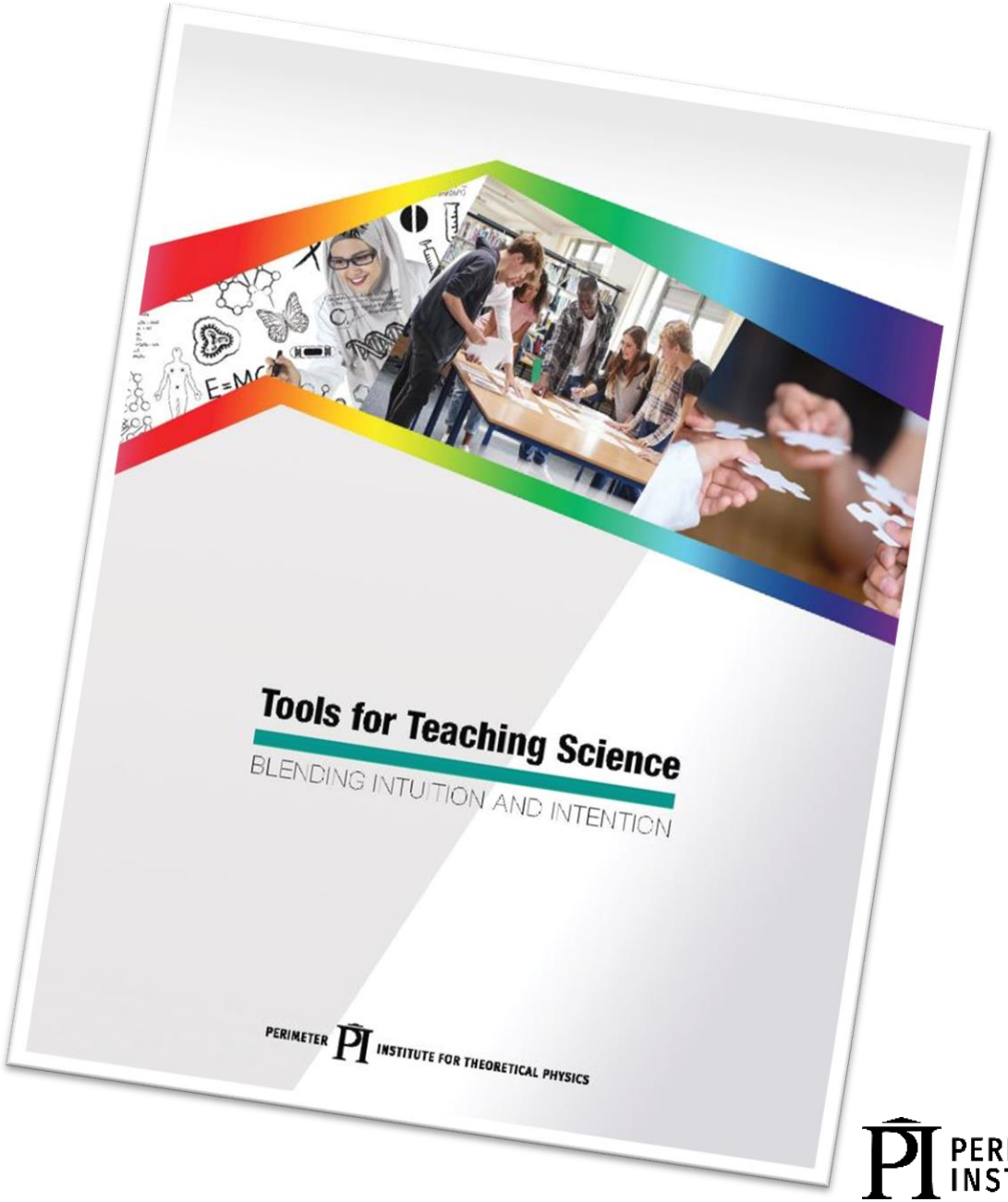
This session:

- Tools for your classrooms
- Teacher collaboration



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Tool	ACTIVATING	ESTABLISHING	DEEPENING	REFLECTING/ REVIEWING
Interleaving				
Jigsaw Activity ◈				
Know-Wonder-Learne				
Laboratory Investigati				
Medicine Wheel				
Muddy Cards ◈				
Multiple Representatic bar charts, free-body and calculations) ◈				
Peer Feedback/Peer E				
Peer Instruction				
Playing Games				
Predict, Explain, Obse				
Processing Feedback				
Ranking Tasks				
Reading for Understa				

Jigsaw Activity ◈

Description | By using dynamic group configurations within a class, you allow students to first interpret information and then share what they have learned with the intent of creating a coherent

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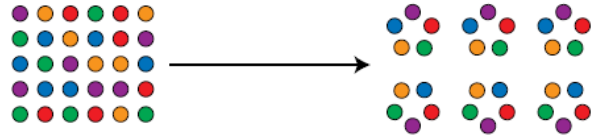
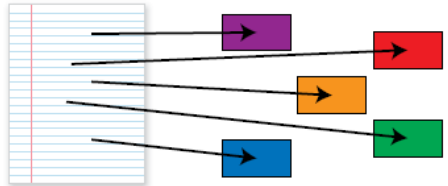
How to Run a Jigsaw Activity

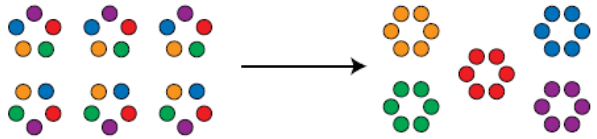
1. Arrange your class into home groups consisting of five or six students.



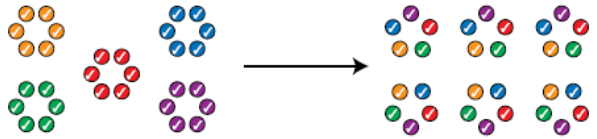
2. Divide your content into chunks of information. Separate it in the way that best suits your intention. Then, arrange your class into home groups, with the number of students matching the number of chunks of content.



3. Students "break out" from their home groups into expert groups, where they work together to master their chunk of information. The number of expert groups depends on how you chose to organize your information.



5. Once students have finished completing the assignments in their expert groups, they return to their home groups.

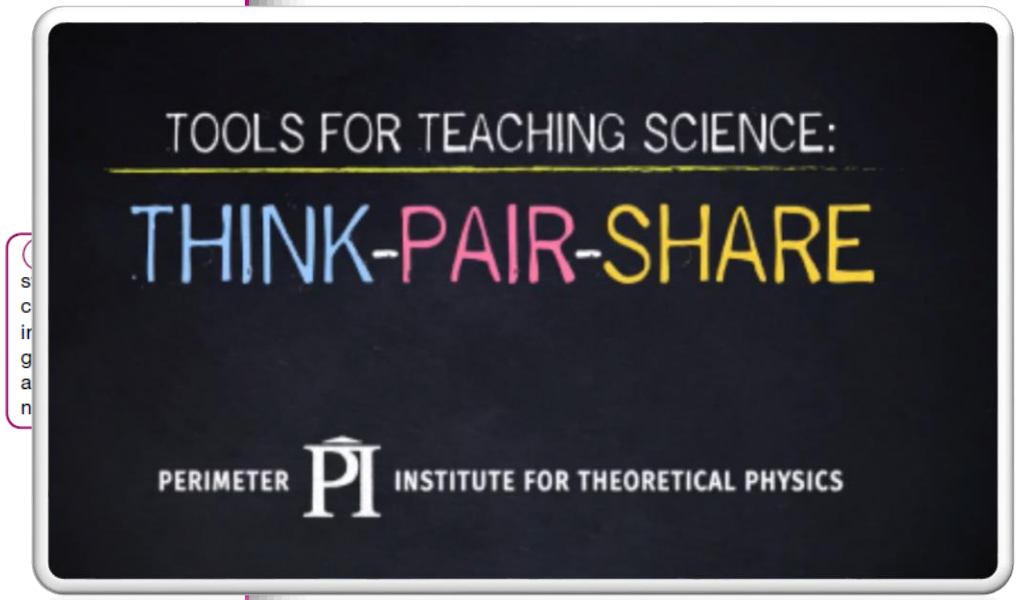


6. Members of the home group now update the other members by sharing their expertise.

about these partnerships.

! Jigsaw Activities can take a lot of preparatory work.

You will need to prepare and set up several stations. You also need to think about ways to group students. This isn't a last-minute activity, so give yourself time.



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Tool
Brainstorming
Building and Testing Models (mathematical and physical) ◈
Case Studies
Coding
Designing Games
Digital Simulations
Discussions (small group to full class)
Exit Tickets ◈
Field Trips/Field Studies
Fine Arts (e.g., dance, song, tableau, role playing, mural, poster making a video)
Gallery Walk
Graphic Organizers (e.g., Placemats, Anchor Charts, Mind Maps) ◈
Group Work ◈
Hands-on Activities (not Investigations)
Hook
Independent Work
Intentional Questioning ◈

Tool
Interleaving
Jigsaw Activity ◈
Know-Wonder-Learned (KWL) Chart ◈
Laboratory Investigation/Video Analysis ◈
Medicine Wheel
Muddy Cards ◈
Multiple Representations (e.g., situational diagrams, work-energy bar charts, free-body (force) diagrams, graph shapes, equations, and calculations) ◈
Peer Feedback/Peer Editing
Peer Instruction
Playing Games
Predict, Explain, Observe, Explain (PEOE) ◈
Processing Feedback/Self-evaluation
Ranking Tasks
Reading for Understanding
Research (open-ended and closed)
Rich Problems/Context-rich Problems ◈
Sharing Circle ◈

Tool
Intentional Retrieval
Interactive Demonstration/Discrepant Event
Interactive Lecture ◈
Interdisciplinary Projects/Project-based Learning
Snowball Activity
Socratic Questioning ◈
Sorting Tasks (open, closed, blended) ◈
Storytelling
Strong Writing/Qualitative Writing/Persuasive Writing
Student Voting (e.g., Pick a Side, Four Corners, Flippity Books, Thumbs Up/Thumbs Down) ◈
Team Problem Solving ◈
Think-Pair-Share (TPS)
Whiteboards (i.e., non-permanent surfaces)
Worksheets ◈

Teacher Programs

www.perimeterinstitute.ca/outreach/teachers

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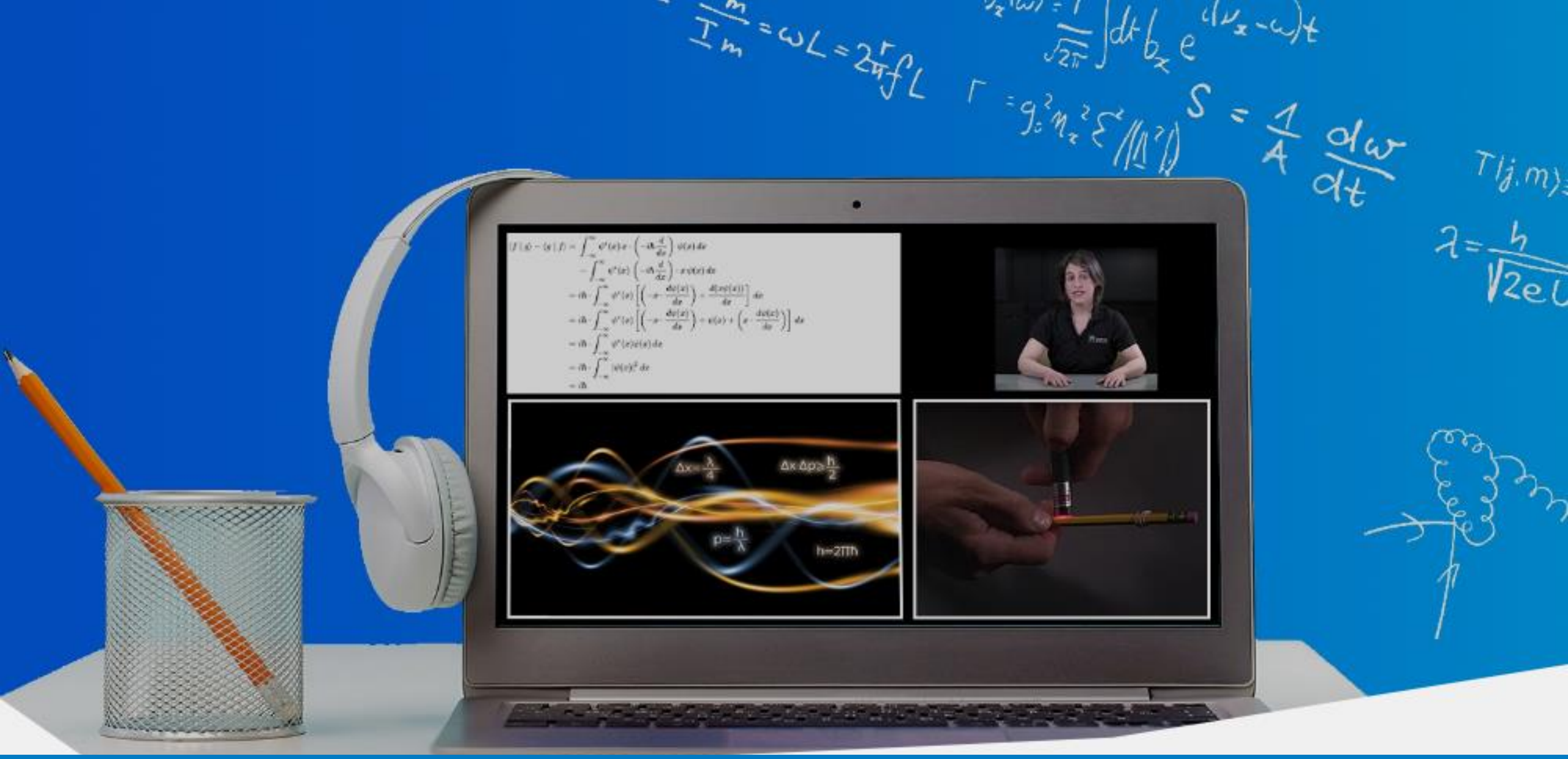
Perimeter Institute Teacher Courses

High School Student Programs

www.perimeterinstitute.ca/outreach/students

Go Physics!

1-day workshops
(online and in person)

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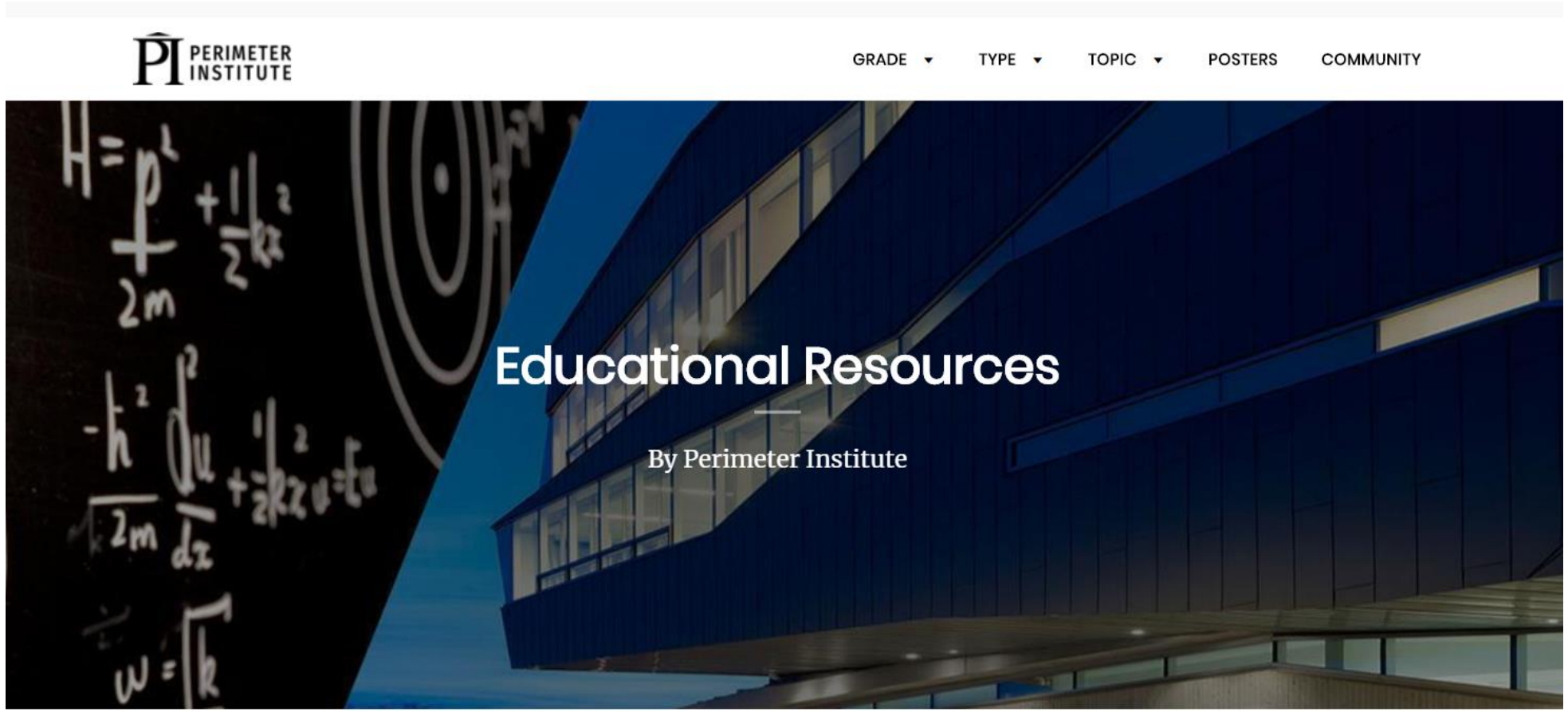

Free Educational Resources for Teachers

resources.perimeterinstitute.ca

Thank You!!

www.perimeterinstitute.ca

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