Is it possible to teach modern physics in primary school?

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Sara Mattiello
Matteo Leone

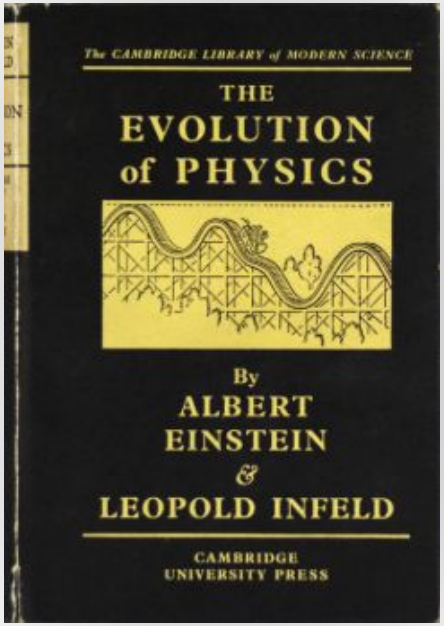
an introduction

To begin with...

Society vs. Scientists

School and Science

Science for all

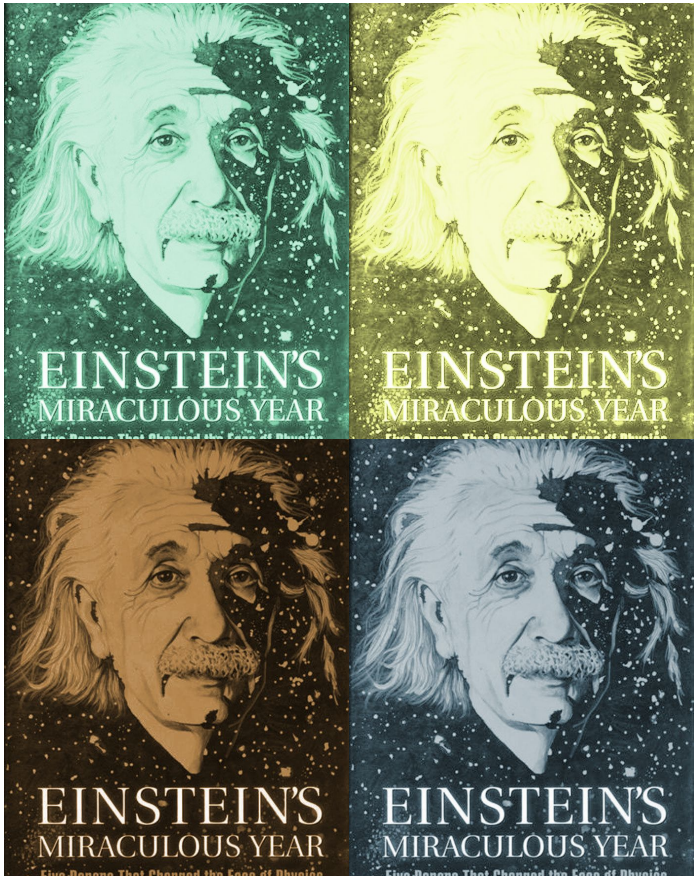


The evolution of Physics

Modern Physics and us (...›100 years after)

1905

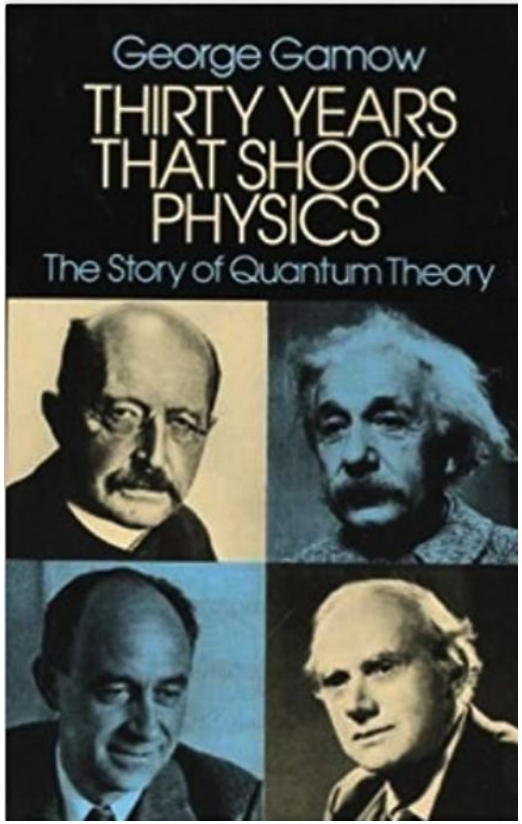
Fundamental works on relativity and quantum mechanics published by Albert Einstein



Modern Physics and us (...›100 years after)

1900-1930

Starting from Planck, up to Dirac and Fermi, many scientists contributed to shock the foundations of Classical Physics

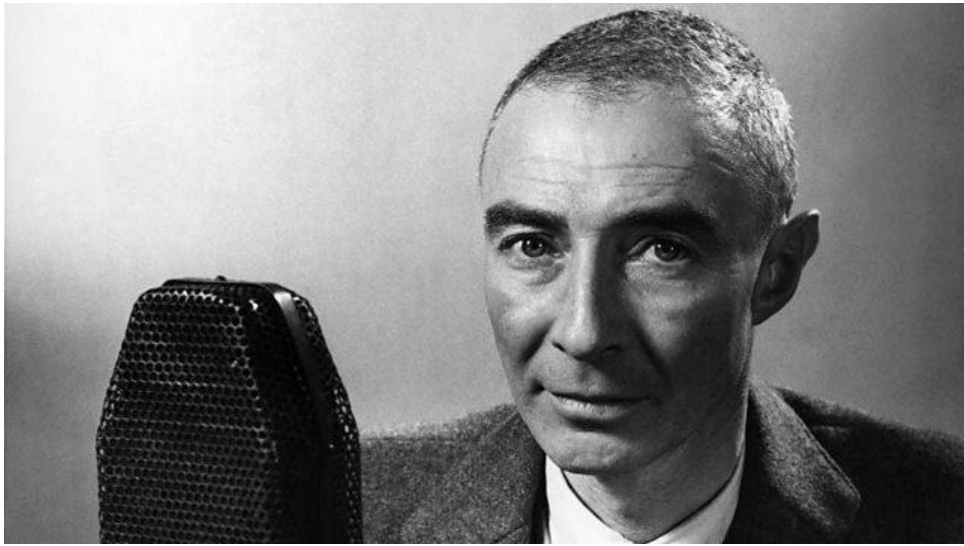


An increasing gap

- During the XX century the gap between common people and science increased.
- Relativity and Quantum Mechanics, the great revolutions in the paradigm of physics, are counterintuitive

An increasing gap

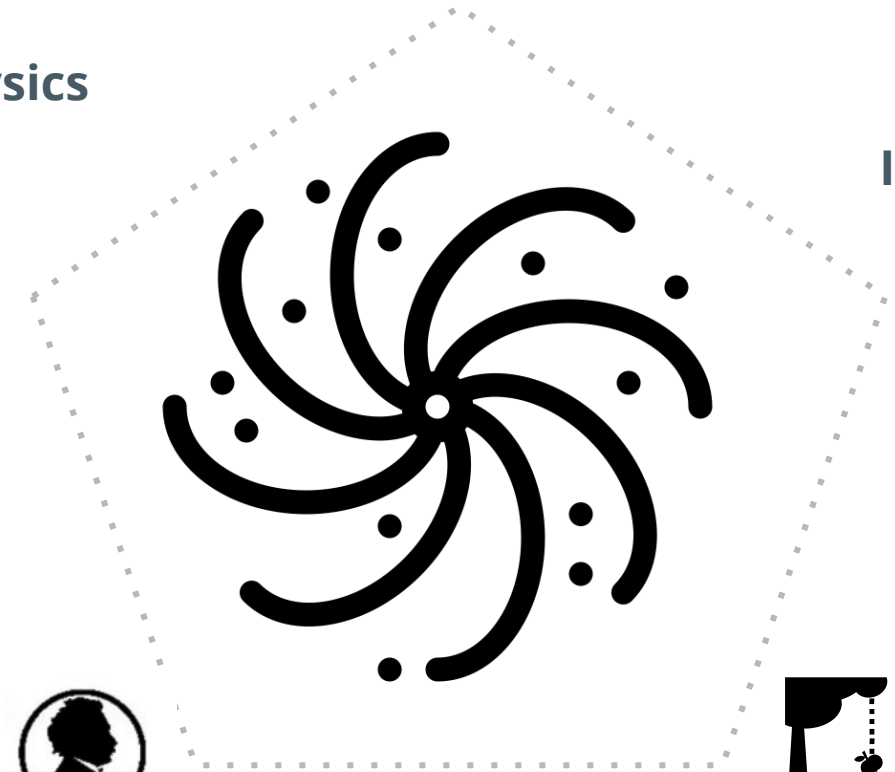
“Within a lifetime what we learned at school has been rendered inadequate by new discoveries and new inventions; the ways that we learn in childhood are only very meagerly adequate to the issues that we must meet in maturity”



Science and the Common Understanding (J.R. Oppenheimer, 1953)

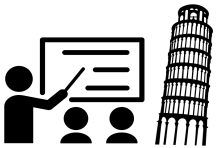
Where do we go from here...?

Plan of the Talk

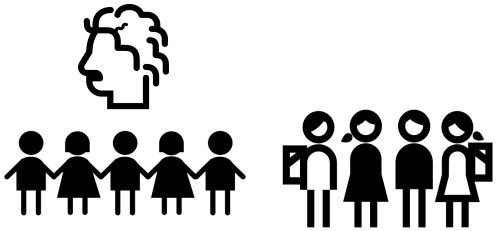


Future Prospects

Teaching Physics in Italy



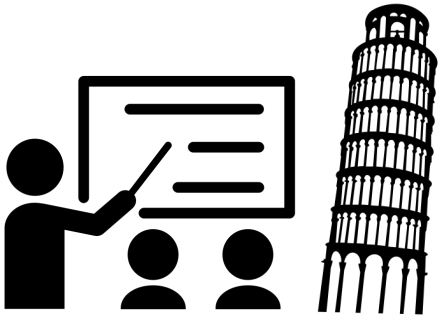
Interventions

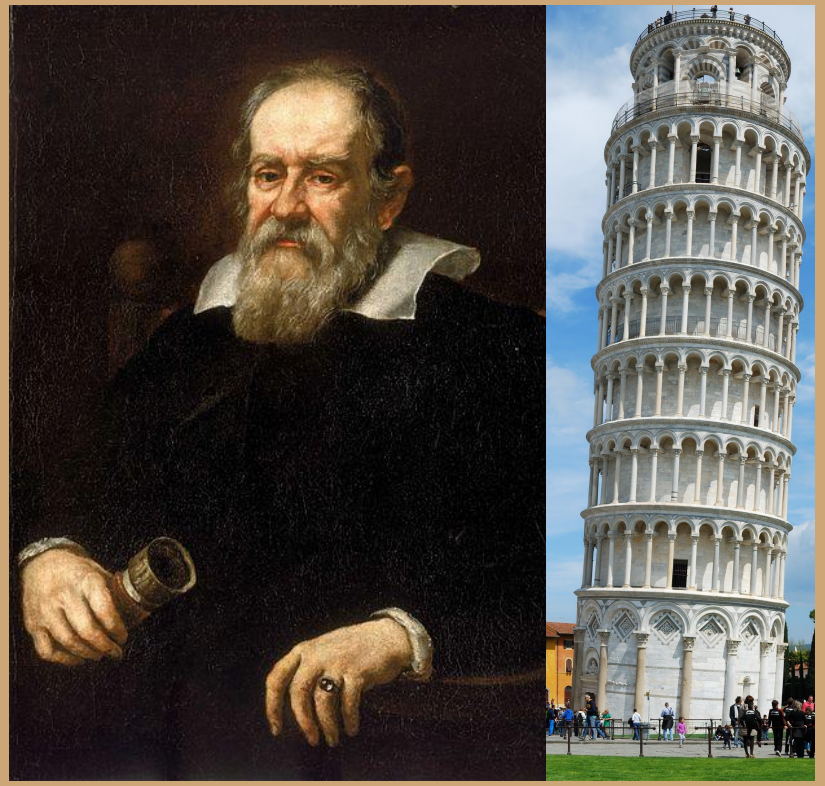


The Einstein First Project

Teaching Gravity

What we learn at school: Physics in Italian Education System

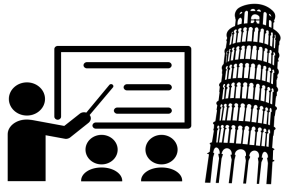




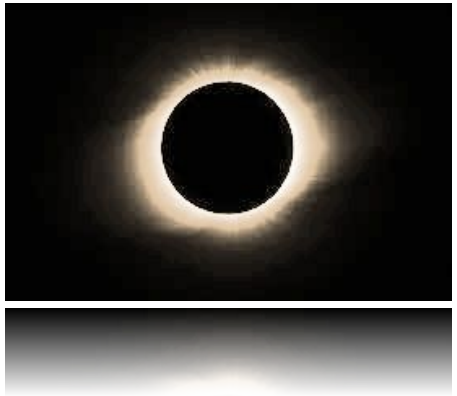
Physics in Primary School

Some Learning Objectives

- Identify the concepts of forces, movement
- Build in *an elementary way* the concept of energy
- Models of state transitions (time variation of the temperature)

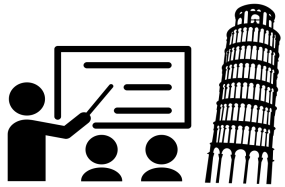


Physics in Lower Secondary School

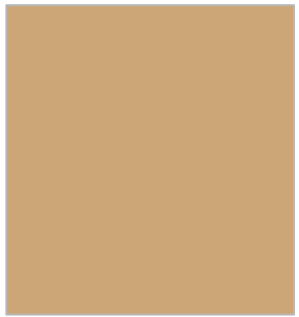


Some Learning Objectives

- Use and find quantitative relations between physical concepts (e.g. velocity, force…)
- Use of the concept of energy as a conserved quantity
- Three dimensional models of the Earth motion, understanding eclipses



Physics in Upper Secondary School



Professional Institute

- 1 or 2 years

Technical Institute

- 1 or 2 years

Lyceum

- 3 or 5 years

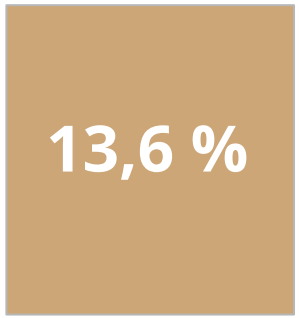
Classical: mechanics, thermodynamics, electromagnetism

Classical and Modern Physics

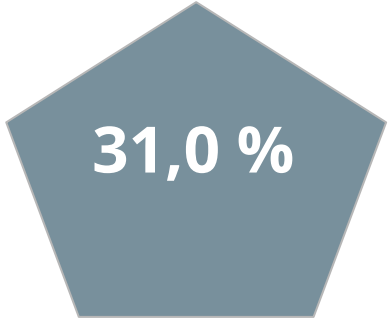
Physics in Upper Secondary School

Before 1905

1905-Today



Professional Institute



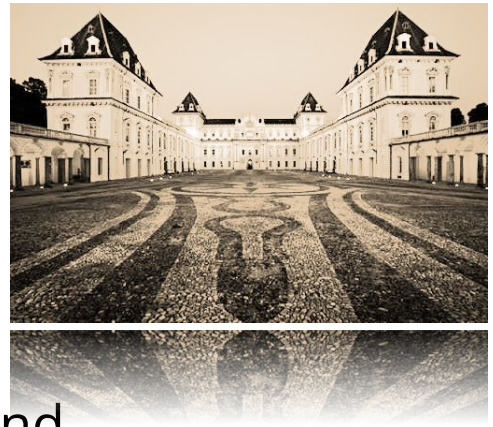
Technical Institute

Lyceum

More than 40% of the students will simply ignore the existence of Modern Physics

Chance to learn modern physics!

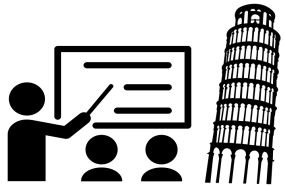
Modern Physics in Higher Education



Some Observations

- If we exclude students who graduate in Physics and Mathematics, *Relativity and Quantum Mechanics are not part of the curricula*

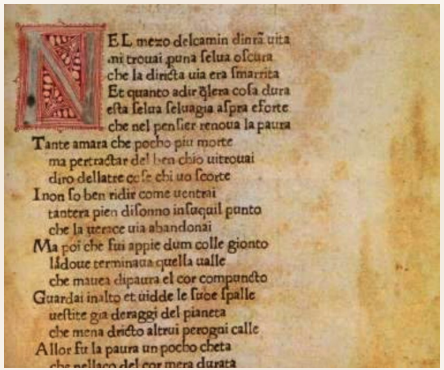
- For instance, this is true in Engineering Schools: there could be no compulsory modern physics courses in the curricula



In the beginning...

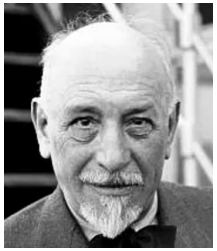
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *JS. NEWTON, Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.



Today...

?



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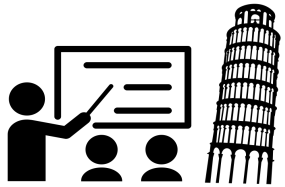
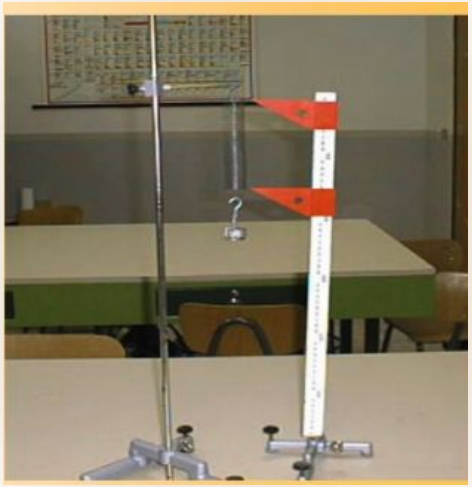
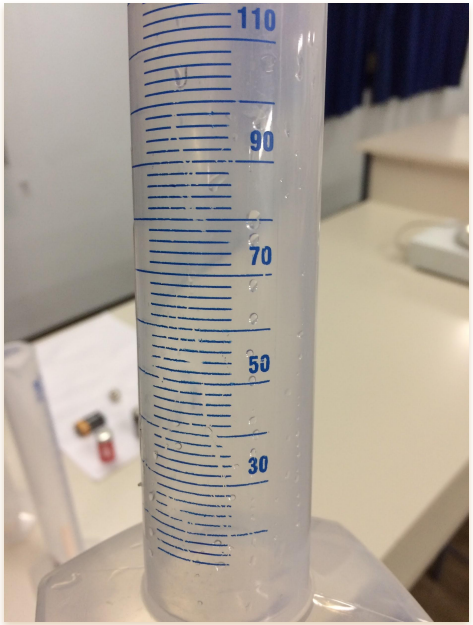
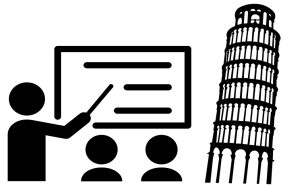


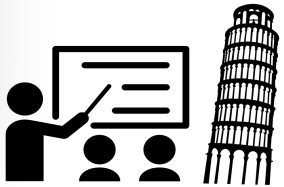
Good practices of school Physics...







...vs Contemporary Physics



Some Self-Evident Facts

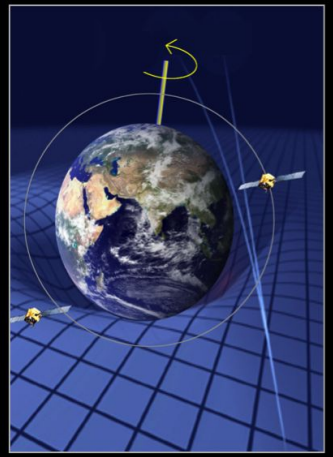
- **Relativity and Quantum Mechanics, the great revolutions in the paradigm of physics, are out of the curricula except for their general outlines, in the final years of some secondary schools**

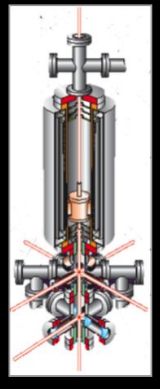
- **The great majority of students are completely unaware of the physical principles on which are based not only the recent discoveries but also their technological devices, such as, for instance, mobile phones and tablets or game consoles**

GPS: relativity in everyday life

Relatività e GPS

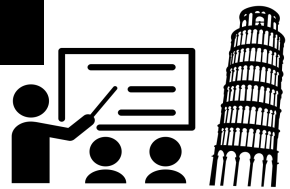
Effetto netto relativistico: l'orologio in orbita è più veloce di quello a Terra di 38600 ns al giorno che corrispondono a 11,58 Km





Trascurando gli effetti relativistici il GPS "non funzionerebbe!"

Solo gli orologi atomici hanno la stabilità e precisione necessarie per il GPS



Fisica e Wii

E’ dotato di un accelerometro in grado di misurare l’accelerazione lungo 3 assi con un range di ± 3g. Inoltre, è dotato di un sensore ottico in grado di determinare la posizione e l’orientamento del dispositivo.

The Einstein First Project

https://www.einsteinianphysics.com

The Einstein First Project

Einstein First

The Einstein First Project

- Aims at teaching the basic ideas of modern physics from an early age, i.e. starting from primary school
- Prevent conceptual conflicts between Classical and Modern Physics

Einstein First

The Einstein First Project

- The basic ideas of modern physics are explained by an extensive use of models and analogies
- Role plays are very powerful ways to introduce concepts

Einstein First

The Einstein First Project

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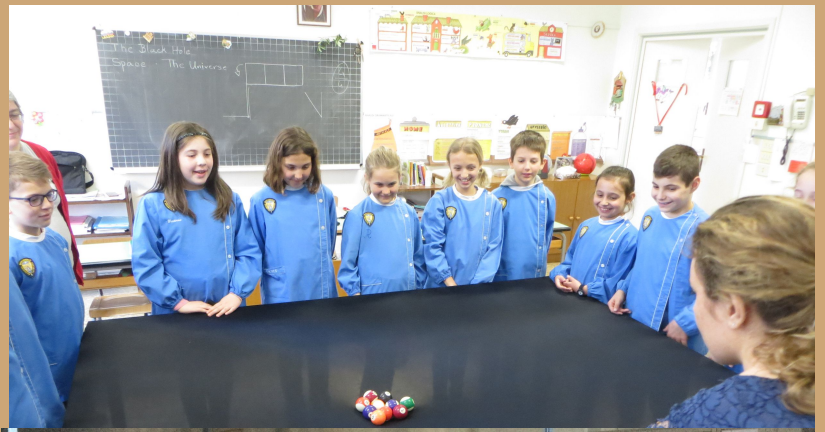
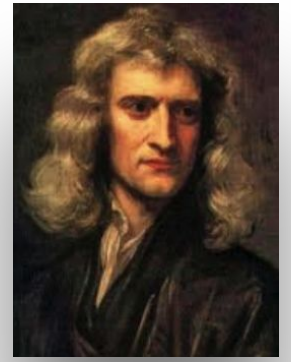
!!!

This new approach does not suggest to completely abandon the paradigm of classical physics, because it is important to understand many phenomena; rather it is suggested that classical physics can be introduced after learning the language and basic concepts of modern physics.

Newton, in Principle

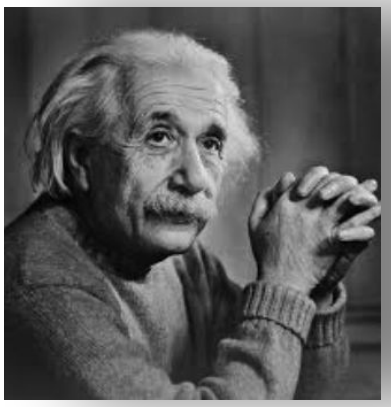


Issues in Teaching Newtonian Gravity



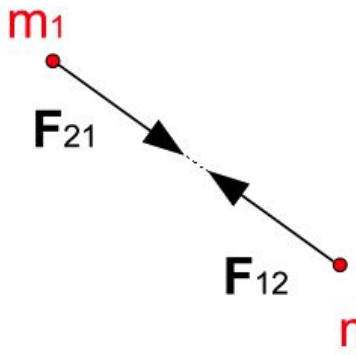
Mass tell gravity how much force to exert; force tells mass how to move

Spacetime tells matter how to move, matter tells spacetime how to curve



Issues in Teaching Newtonian Gravity

- According to Newton's law of gravity all bodies having a mass attract each other, and this force is proportional to the product of the masses, and inversely proportional to the square of their distance. Newton's gravity force is, hence, **an action at distance between bodies.**



$$\mathbf{F}_{21} = G\frac{m_1 m_2}{r_{12}^2}\hat{\mathbf{r}}_{12}$$

Issues in Teaching Newtonian Gravity

- Gravity need air to act, magnetism and gravity are connected and also electrostatic and gravity (Bar et al. 1997)

- Gravity is a force pulling things to the ground, rather than to the centre of the Earth; gravity does not act on objects at rest; there is no gravity underground, because gravity need air to act (Palmer 2001)

Issues in Teaching Newtonian Gravity

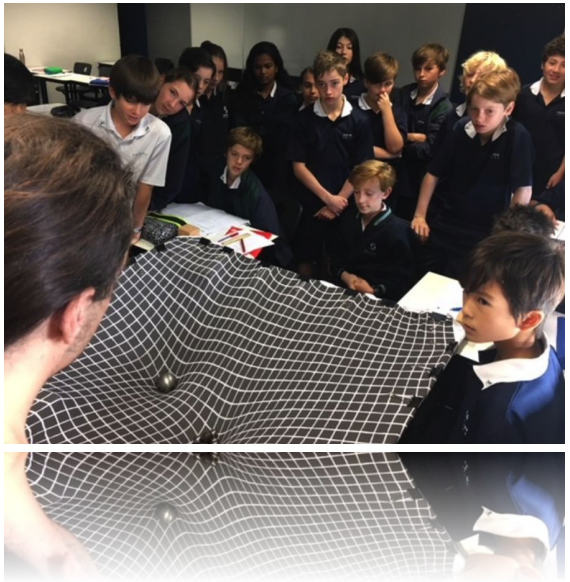
- Gravitational force is symmetric, but the Earth does not follow to the apple!

- Students look at the Earth as a privileged place, with its own laws: there is an Aristotelean division between the heavens and the Earth (Vosniadou 1994, Baldy 2005)

- Universal attraction between bodies contradict everyday experience (Posner 1992)

Newtonian gravity is not intuitive!

Analogies and hands-on activities



- In teaching science to young children, there should be great emphasis on giving students suitable representations and on developing appropriate language (Tytler 2010)

- The use of model and analogies could prove very useful (Duit 1991, Venville 1996)

Probably, explaining Newtonian action at distance is more difficult to depict gravity as a deformation of spacetime, according to Einsteinian view!

The spacetime simulator

The spacetime simulator

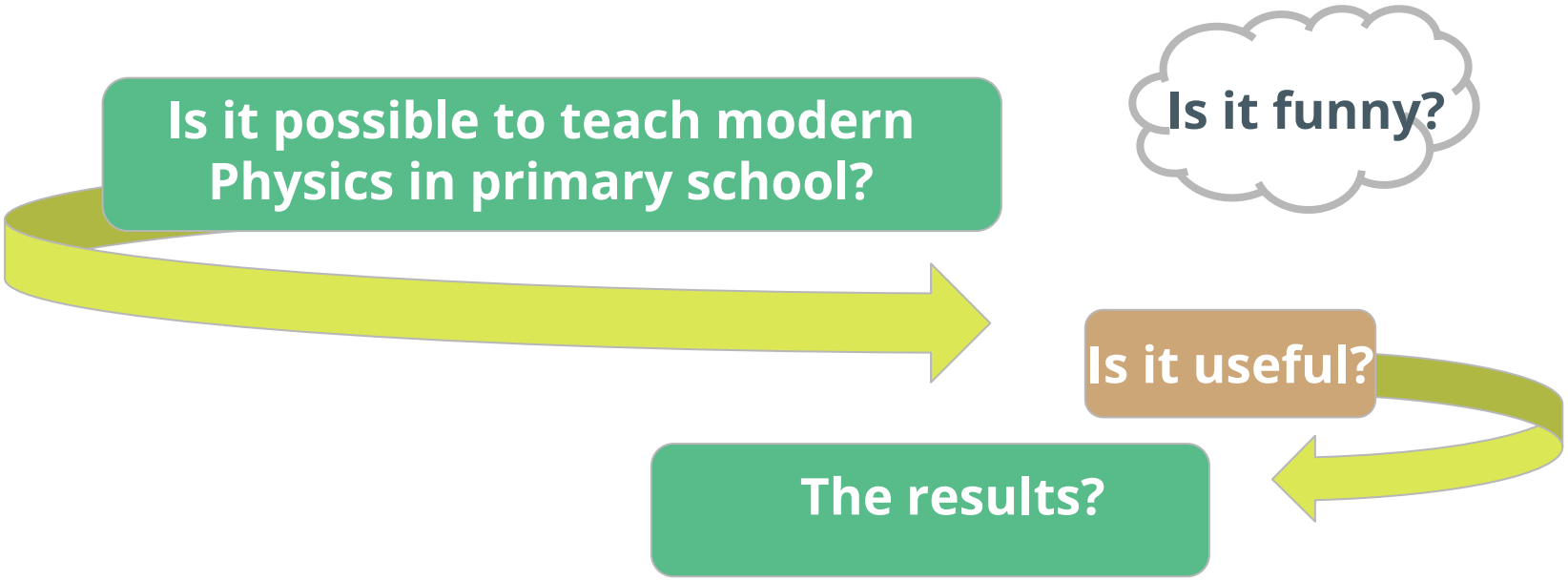
- The lycra sheet empty of bodies is the analogue of vacuum spacetime
- The presence of a single body deforms the sheet: then, a nearby object experiences an attractive force as a result of the deformation. This is the analogue of what happens around masses, in spacetime
- Both the universality of the attraction (each balls deforms the surface around it) and the symmetry in the interaction (the surface between two balls is deformed by both of them) are reproduced

The analogy is not perfect, of course, but it is useful!

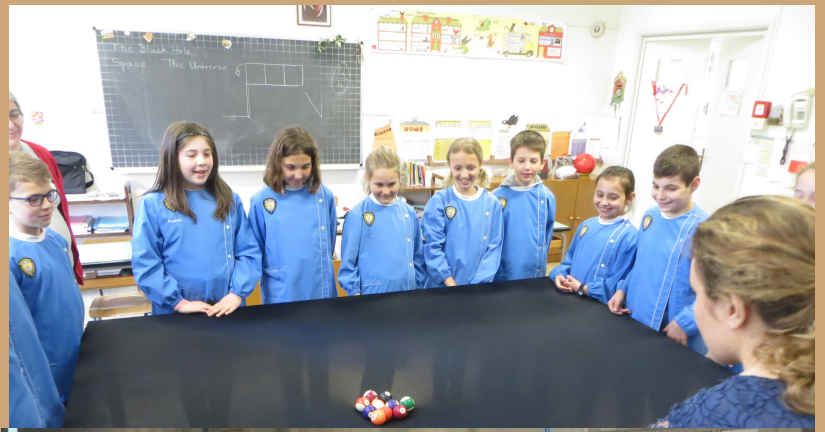
The spacetime simulator

The lycra sheet allows to explain the meaning of action at distance: the two balls interact without being in contact. If students can reason well, their ability of understanding complex concepts increases (She & Liao 2010)

Research Questions



The Interventions



2018-2019 Interventions in Turin

Collaboration with the Departments

- Physics
- Philosophy and Education Science

First year of Upper Secondary School

Prof. Matteo Leone Dr. Marta Rinaudo

Sara Mattiello

Last year of Primary School

Primary School Intervention

Primary School Intervention

The context

- 2 primary schools in Torino
- 3 terminal classes
- About 60 students involved (10-11 y.o.)
- 15 hours per class
- No pre-knowledges (but one class already studied light and astronomy)

Research work done by Sara Mattiello for her Master's Degree Thesis.

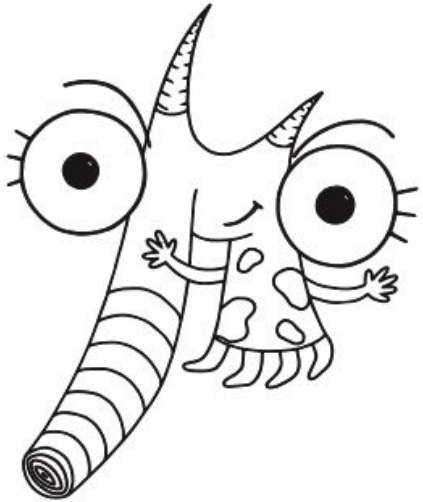
Primary School Intervention

The methodology

- Laboratory experiments (hands on)
- Thought experiments and cognitive conflict
- Role of language: the scientific terminology is introduced only when the teacher feels that students have understood the relevant concepts
- Narrative frame and historical context

Narrative Framework and Historical Context

Muon Enigma: a letter from the school principal, stating that a muon was seen around the school. But this is impossible, so the children were asked to solve this enigma.



Muon

Data
Muon life time: 0,00005 seconds
Muon speed: 200000 km/s
Muon lives in the atmosphere, 20 km upon the Earth surface
How can we find it on the ground?

Narrative Framework and Historical Context

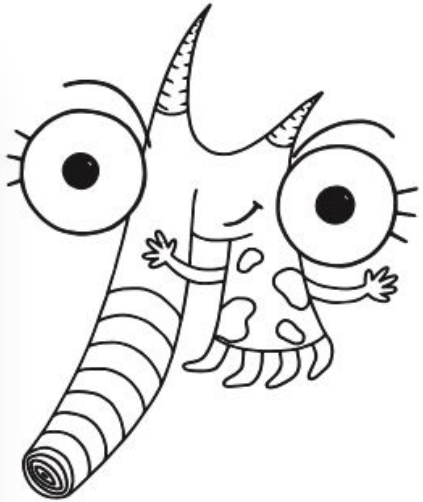
Attenzione!!!

Avvistamento muone nei pressi della scuola

I giorni scorsi una particella che di solito vive nell'atmosfera (l'atmosfera si trova a **20 km** di distanza dal suolo terrestre), il muone, è stata avvistata nei pressi della scuola Buon Consiglio. Tutti gli esperti concordano sul fatto che la vita dei muoni è di al massimo **0,00005 secondi** e questo, data la sua velocità (che è di **200.000 km/s**), gli consente di percorrere al massimo **10.000 metri**.

Tale avvistamento ha già provocato sconcerto e stupore tra gli abitanti del quartiere e la notizia è arrivata sino agli scienziati che stanno analizzando il caso senza successo.

Per questo, mi rivolgo a tutti voi studenti di quinta perché possiate aiutare la comunità a risolvere questo mistero. Il muone ha disobbedito a tutte le leggi della fisica che noi conosciamo, perciò, come è riuscito ad arrivare fino a noi?



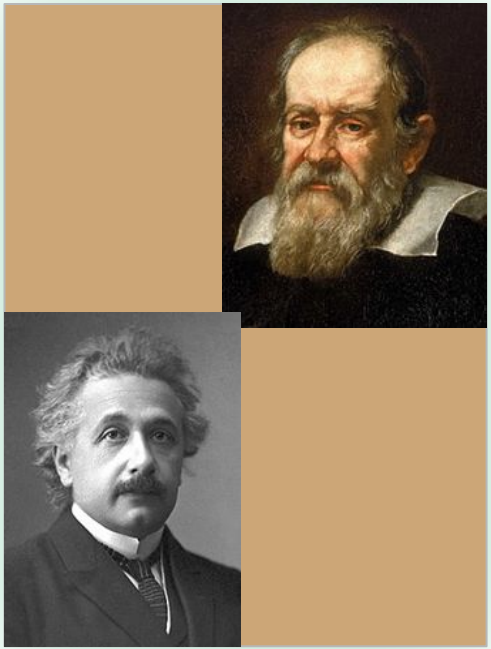
Muon

Narrative Framework and Historical Context

The life and works of Galileo and Einstein

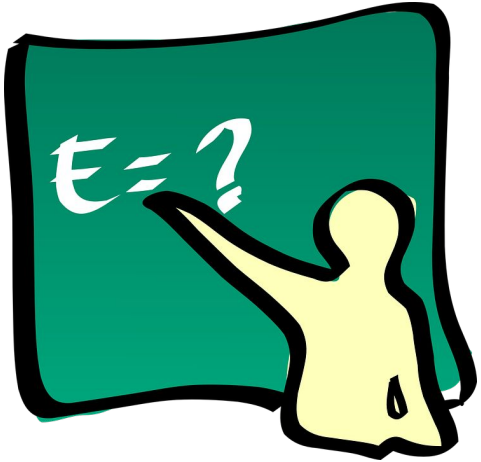
The historical context helps to understand the idea of science as a continuous interaction between scientists and the world around them.

- Dialogue Concerning the Two Chief World Systems
- “Il Gran Naviglio”



Conceptual Nuclei

During the intervention we focused on these basic concepts:



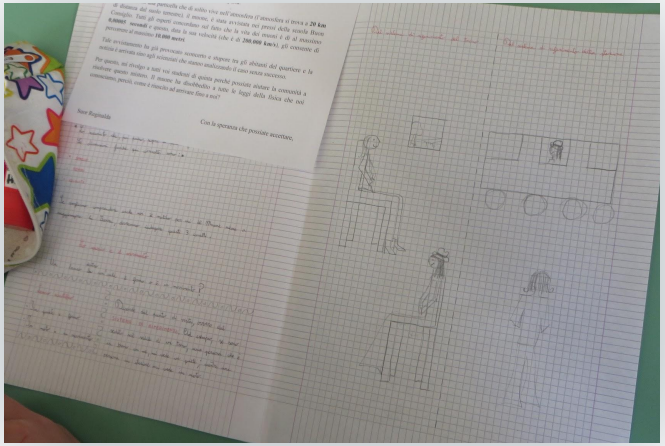
- **Galilean Relativity:** reference frame and uniform rectilinear motion
- **Speed of light:** speed of light in different reference frames and meaning of the light year
- **Gravity:** space-time deformations and geometry

Galilean Relativity

Motion, rest and velocity-addition

Thought experiment and cognitive conflict

If I am sitting on a train moving with a given velocity, am I moving or am I at rest?

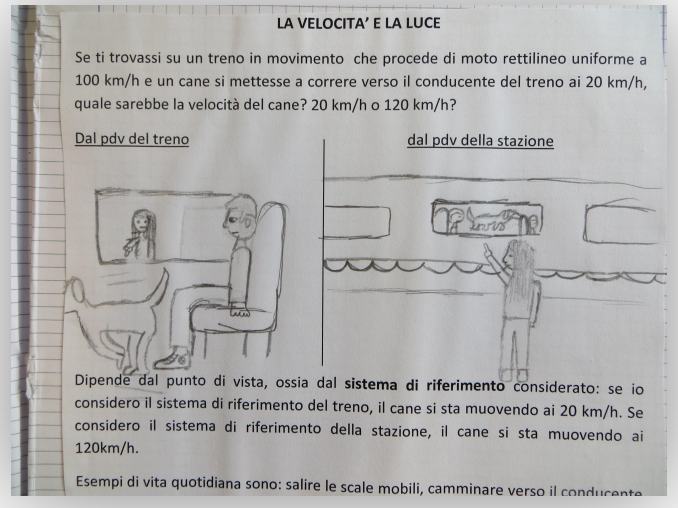


"Both of them are right, since we have two viewpoints: if someone is at the platform or outside the train, he would see you moving, because the train is moving. On the other hand, according to your viewpoint, you are at rest, hence you are not moving"

Galilean Relativity

Motion, rest and velocity-addition

Thought experiment and cognitive conflict



LA VELOCITA' E LA LUCE

Se ti trovassi su un treno in movimento che procede di moto rettilineo uniforme a 100 km/h e un cane si mettesse a correre verso il conducente del treno ai 20 km/h, quale sarebbe la velocità del cane? 20 km/h o 120 km/h?

Dal pdv del treno

dal pdv della stazione

Dipende dal punto di vista, ossia dal **sistema di riferimento** considerato: se io considero il sistema di riferimento del treno, il cane si sta muovendo ai 20 km/h. Se considero il sistema di riferimento della stazione, il cane si sta muovendo ai 120km/h.

Esempi di vita quotidiana sono: salire le scale mobili, camminare verso il conducente

You are on a train moving at 200 km/h and your dog is running at 30 km/h. What is your dog's velocity?

"If someone is on board with you, he would see you moving at 30 km/h, while someone outside the train would see you at 230 km/h. In fact, if I am on train, with an eye patch, I would not know to be moving at 200 km/h"

Galilean Relativity

Motion, rest and velocity-addition

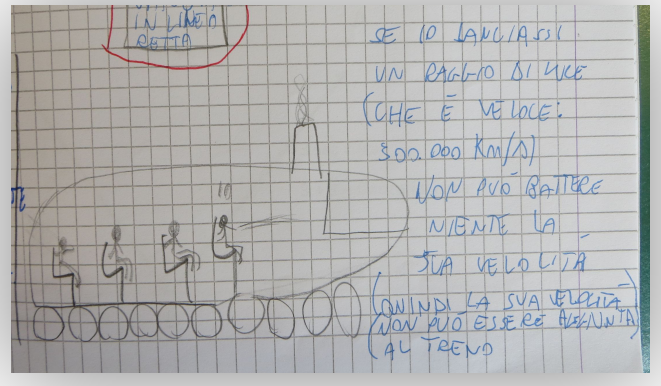
What are the necessary conditions for a body to remain at rest, while it is on a moving trolley?

Rectilinear motion

Constant Velocity

Speed of Light

Thought experiment and cognitive conflict



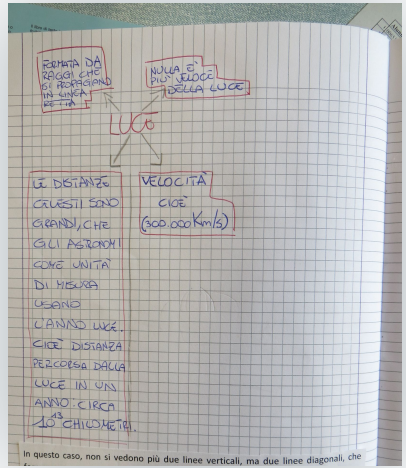
If a light ray is sent from a moving train, what would be the speed of light?

"Nothing can exceed the speed of light! So the speed of light cannot be added to the speed of the train!"

Speed of Light

Reflections on the light year

What does it mean if we say that a star is 325 light years apart from us?

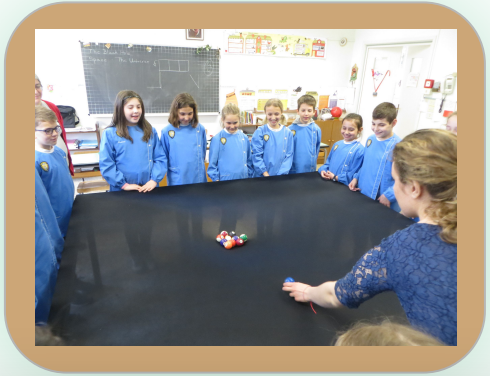


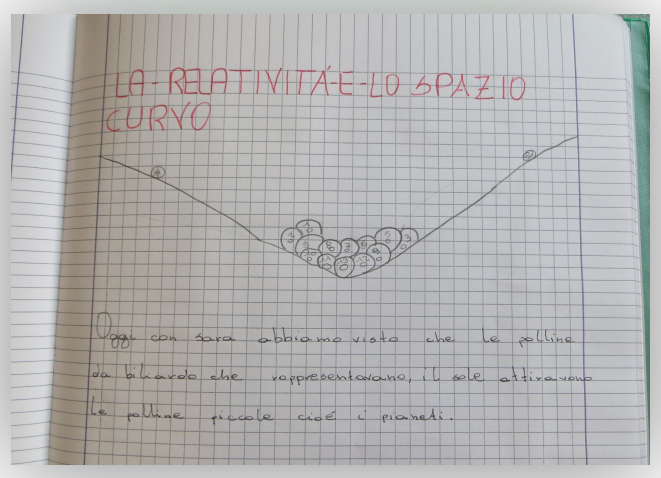
"It is very difficult to understand, because, teacher, you say it is in the past but we see it in the present! "

Gravity

Gravity as space-time deformation

Laboratory activity: the space-time simulator and the motion of the planets

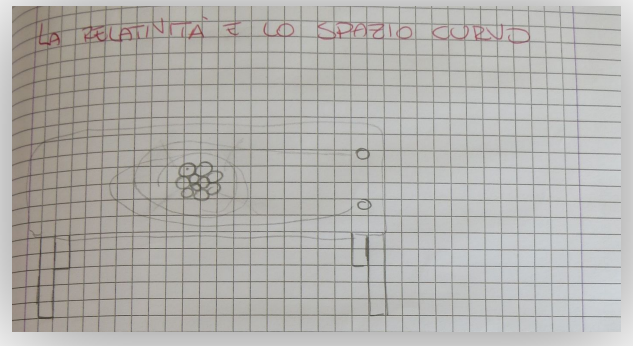




Gravity

Straight lines and triangles

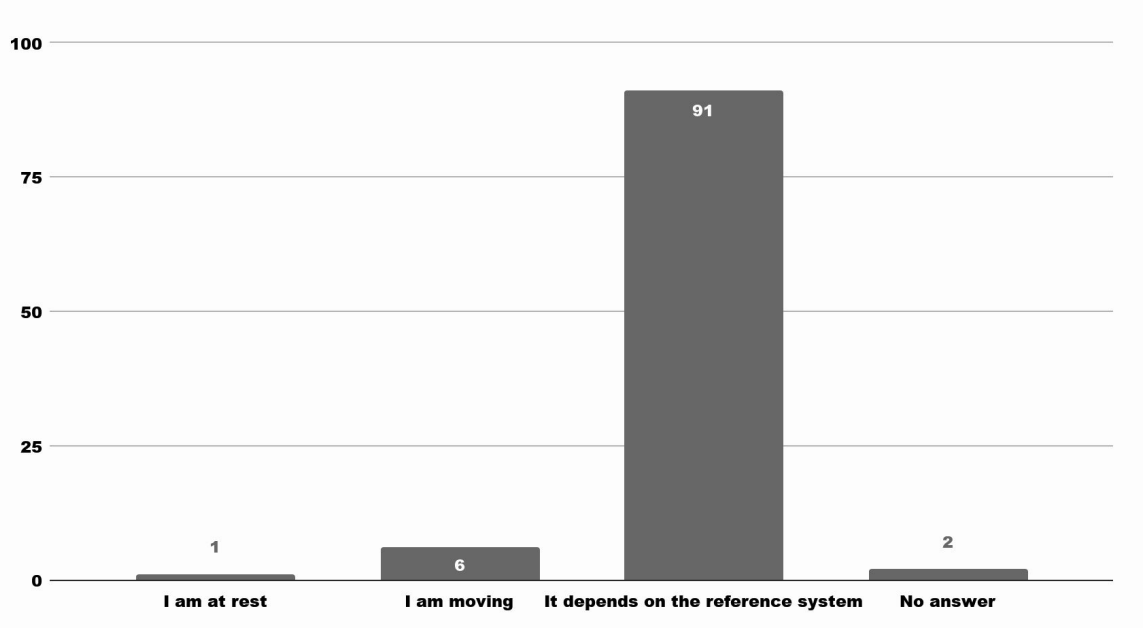
Laboratory activity: sum of the internal angles for triangles on balloons; “straight” lines on the space-time simulator



Galilean Relativity

Post Intervention Questionnaire

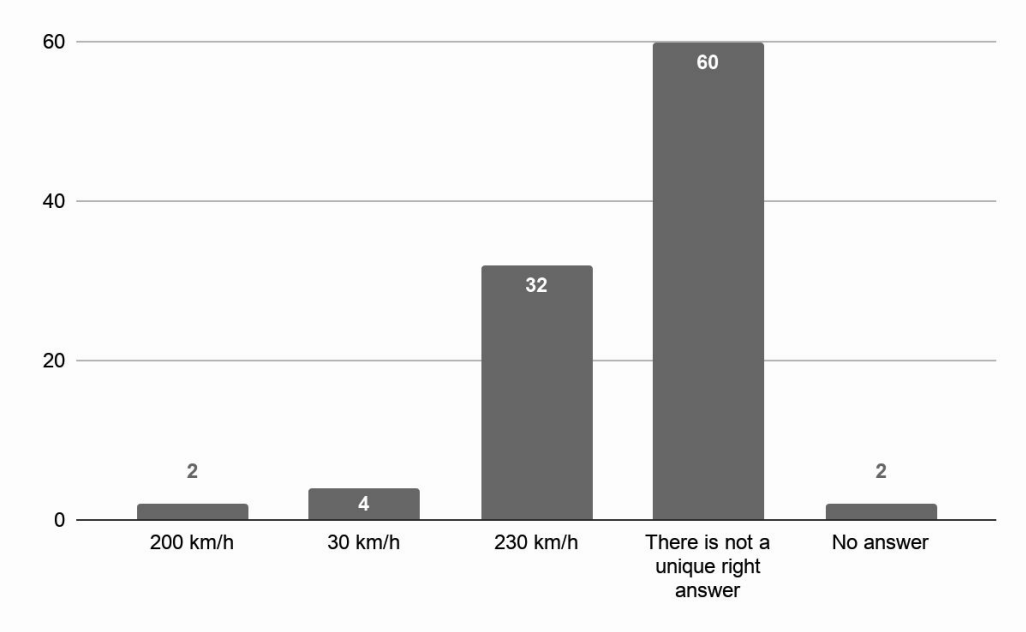
If I am sitting on a train moving with a given speed, am I moving or am I at rest?



Galilean Relativity

Post Intervention Questionnaire

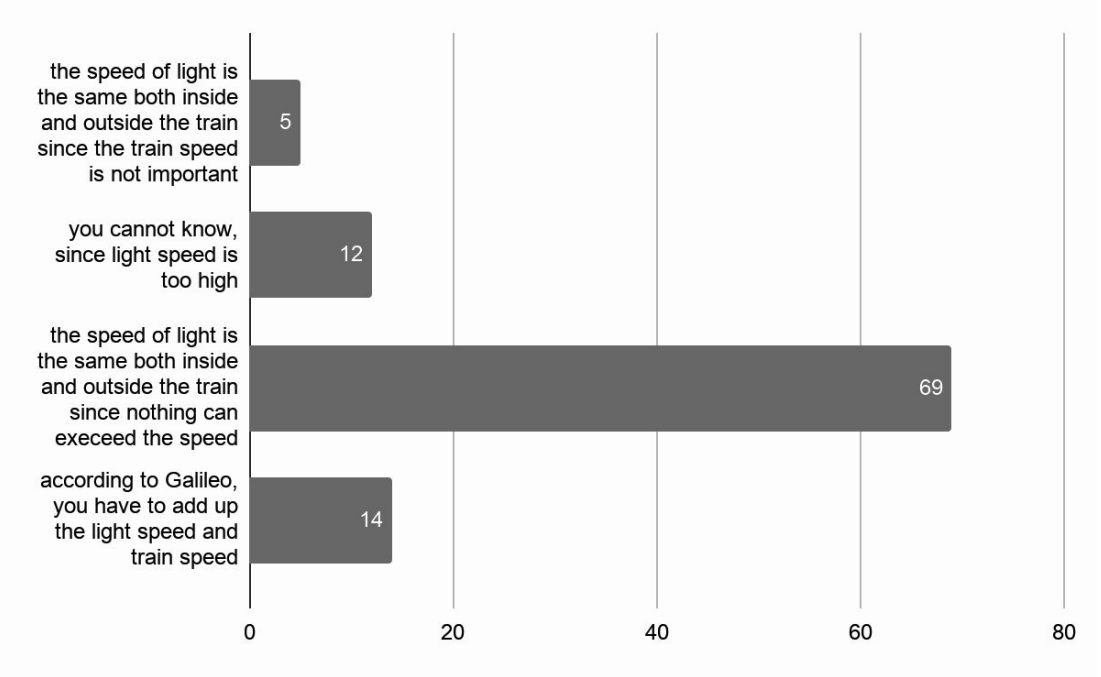
You are on a train moving at 200 km/h and your dog is running at 30 km/h. What is your dog's speed?



Speed of Light

Post Intervention Questionnaire

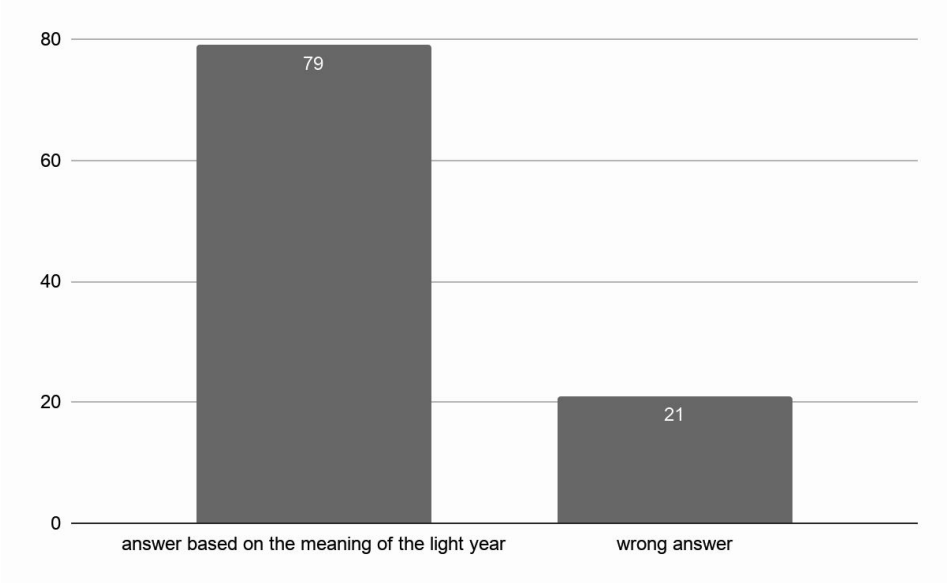
You are on a train moving at 200 km/h. If you turn on a light, what is the light speed according to an observer at rest outside the train?



Speed of Light

Post Intervention Questionnaire

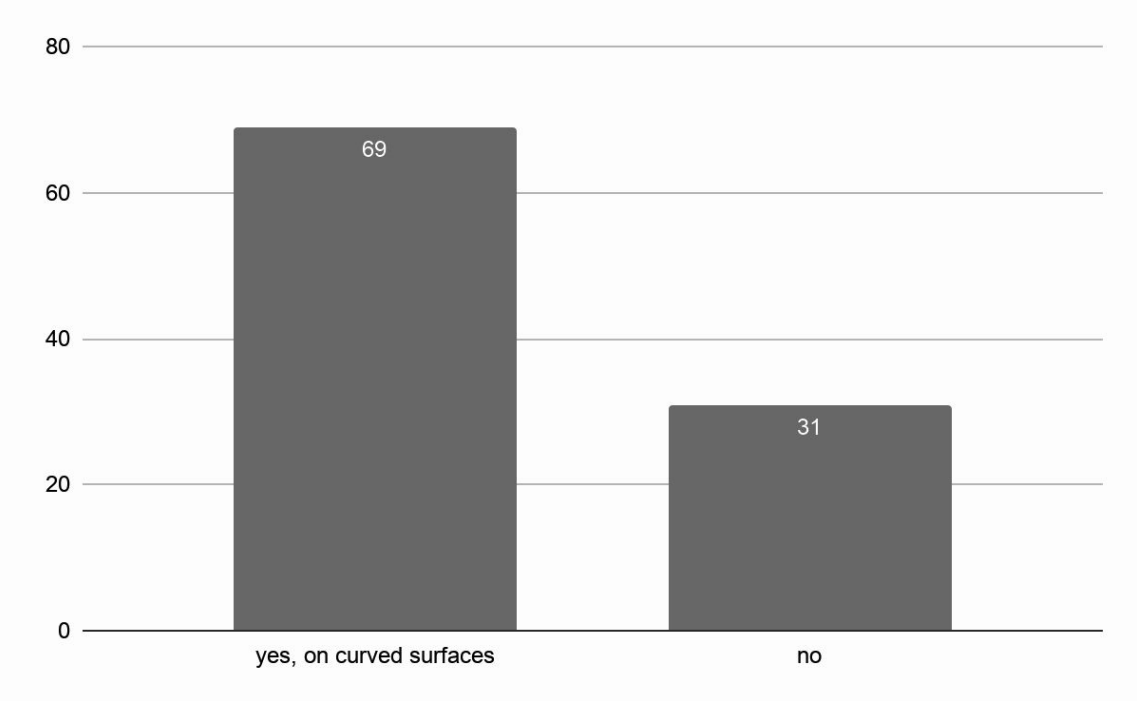
In a summer night you look at the Polar Star, which is 325 light years away and you say “What is happening now on the star?”. According to you, how would Einstein comment on your statement?



Gravity

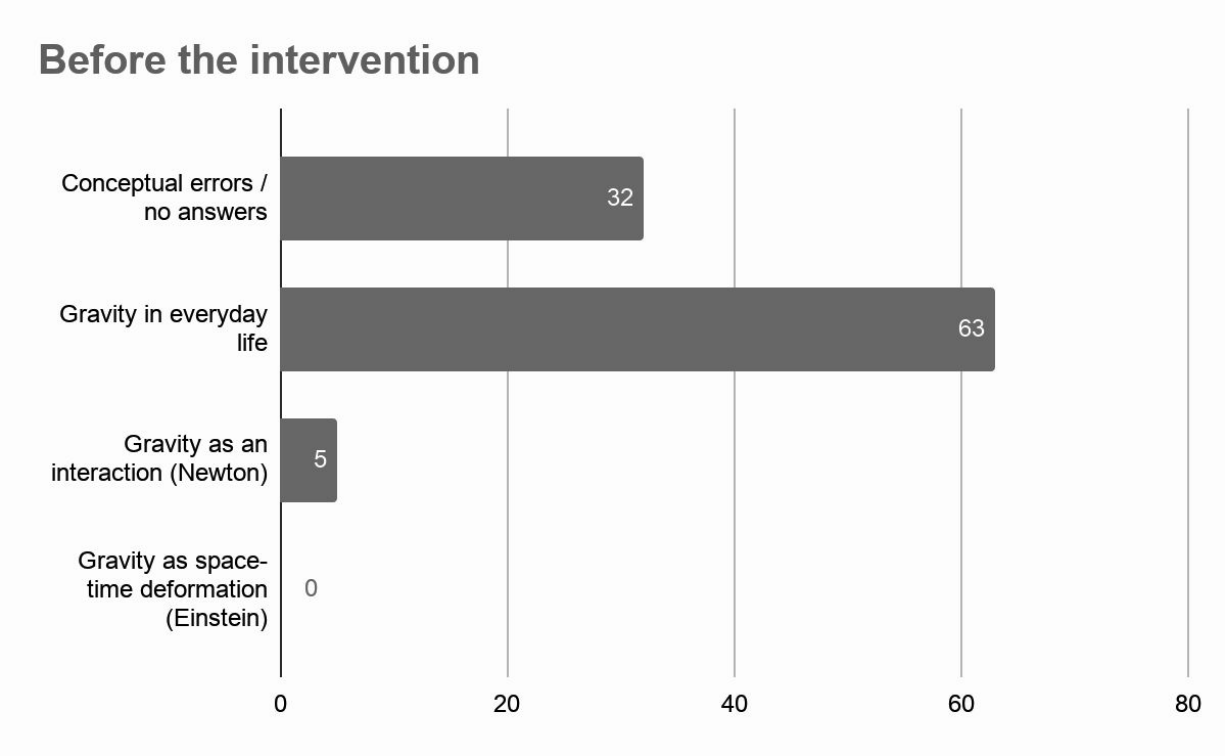
Post Intervention Questionnaire

Can parallel lines meet?



Gravity

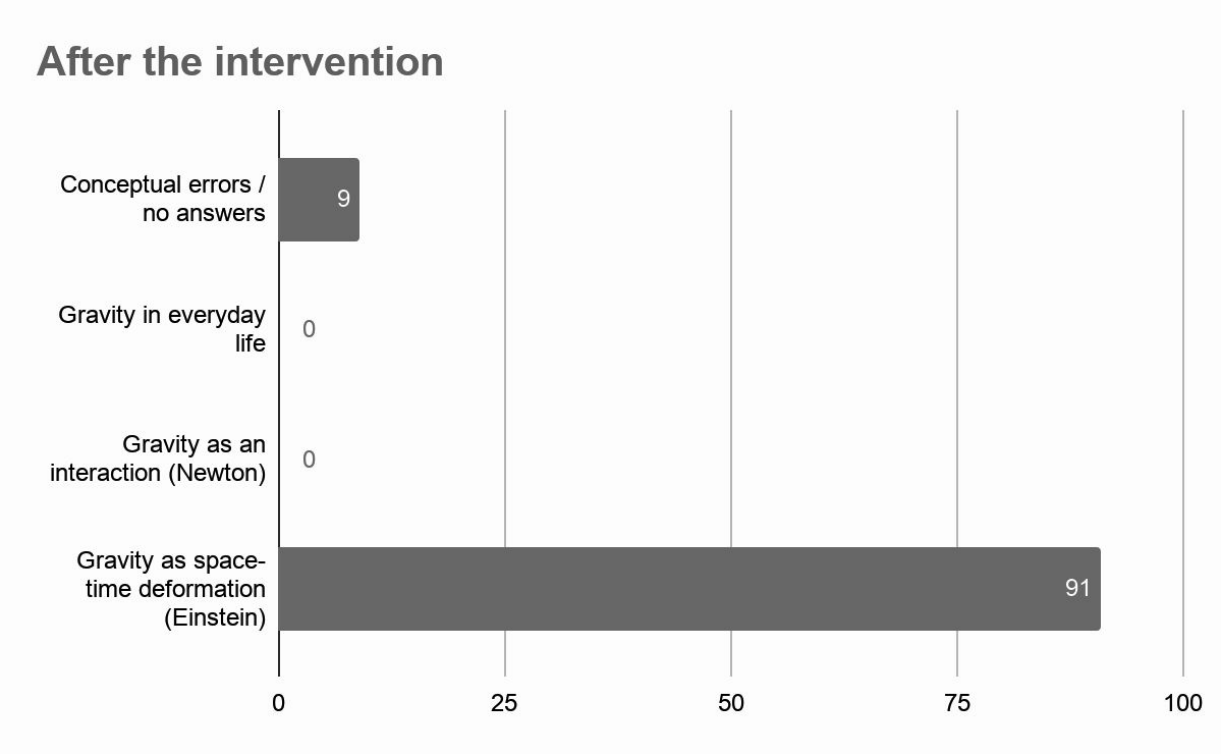
What is gravity? Understanding of gravity



Gravity

Post Intervention Questionnaire

What is gravity? Understanding of gravity



Conclusions and Future Prospects

Teaching Modern Physics

Conclusions and Future Prospects

- Better understanding of the concept of space (basic properties of curved surfaces)
- Role of the Reference Frame
- Velocity addition law
- Relativity of simultaneity
- Gravity as space-time deformation

Einsteinian concept of gravity is more intuitive than Newtonian one: deformation vs. action at distance

Conclusions and Future Prospects

- **Attitude and motivation**

"I have understood that it is important looking at the World from different viewpoints and the Universe is not regular, there are body with different masses and time flows differently on the Earth and in space"

- **Historical context**

"Now I know that Galileo went on secretly writing about science [...] and that Einstein looked at the World from different viewpoints "

" I know that to make important discovery it is necessary to question everything"

Conclusions and Future Prospects

- Further interventions
  - Agreement with a School for a continuous experimentation
  - Application for funding
- Introducing Quantum Ideas
- Teachers' Formation Program
- Collaborations...?

THANKS FOR YOUR ATTENTION….!