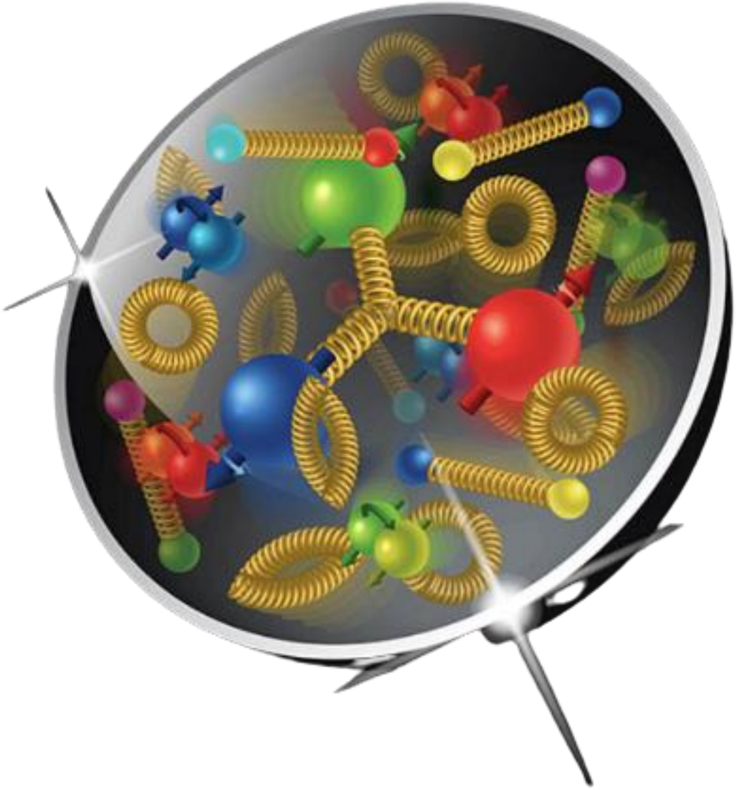
Magritte, 1928

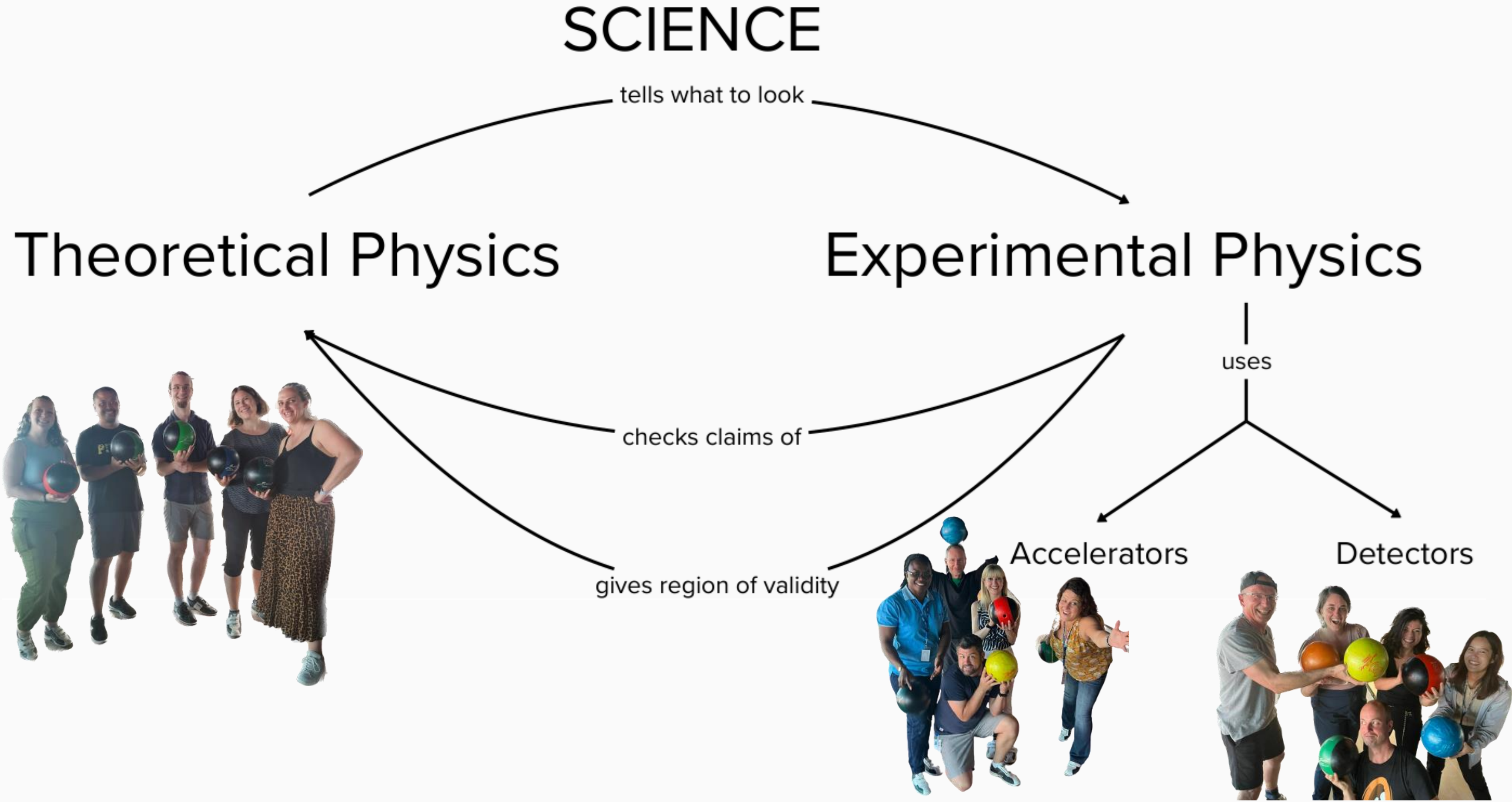
Ceci n'est pas un proton



Is this a proton?

…what is a particle?

$$\langle \Psi(y)\overline{\Psi}(x)\rangle = \int D\overline{\Psi}\, D\Psi\, A_{\mu}\, \Psi(y)\overline{\Psi}(x)\, e^{S_0}\left(1+S_I+\frac{1}{2!}S_I^2+\frac{1}{3!}S_I^3+\ldots\right)$$


SCIENCE
tells what to look
Theoretical Physics
Experimental Physics
uses
checks claims of
gives region of validity
Accelerators
Detectors

Curricula Time

Physics syllabus content overview

A. Space, time and motion	B. The particulate nature of matter	C. Wave behaviour	D. Fields	E. Nuclear and quantum physics
A.1 Kinematics • A.2 Forces and momentum • A.3 Work, energy and power • A.4 Rigid body mechanics ••• A.5 Galilean and special relativity ••	B.1 Thermal energy transfers • B.2 Greenhouse effect • B.3 Gas laws • B.4 Thermodynamics ••• B.5 Current and circuits •	C.1 Simple harmonic motion •• C.2 Wave model • C.3 Wave phenomena •• C.4 Standing waves and resonance • C.5 Doppler effect ••	D.1 Gravitational fields •• D.2 Electric and magnetic fields •• D.3 Motion in electromagnetic fields • D.4 Induction •••	E.1 Structure of the atom •• E.2 Quantum physics ••• E.3 Radioactive decay •• E.4 Fission • E.5 Fusion and stars •

Curricula Time - New Zealand - NCEA

Level 3

3 Examples of phenomena, concepts, or principles of Modern Physics include:

- the Bohr model of the hydrogen atom: the photon; the quantisation of energy; discrete atomic energy levels; electron transition between energy levels; ionisation; atomic line spectra, the electron volt
- the photoelectric effect
- wave-particle duality
- qualitative description of the effects of the strong interaction and Coulombic repulsion, binding energy and mass deficit; conservation of mass-energy for nuclear reactions
- qualitative treatment of special and general relativity
- qualitative treatment of quarks and leptons.

Curricula Time: European School

Fundamental Particles and Forces	Electrons, neutrons, protons	**Describe** the charge and mass and dimensions of these particles and how they contribute to the structure of the atom		A deeper discussion could be engaged with motivated students. CERN's "Particle Adventure" website and others like it can be used to explore
	Fundamental forces that cause	**State** that there are only a few		

Particles and the structure of matter

Random motion and forces between particles of matter

Temperature as a

Momentum of photons

$$p_{photon} = \frac{h}{\lambda}$$

The Compton Effect

students a powerful basis

life. Building on their kno

Wave-particle duality	Heisenberg's Uncertainty Principle $$\Delta x\,\Delta p \geq \frac{h}{4\,\pi}$$ $$\Delta E\,\Delta t \geq \frac{h}{4\,\pi}$$ Stochastic behaviour of quantum objects with particular reference to: • Interference patterns of photons and electrons • tunnel effect • the wave function description of quantum objects. Quantum objects to be considered: photons and electrons.	**Discuss** the consequences of the Uncertainty Principle in terms of measurement and information about the state of a system. **Explain** the interference pattern observed when (laser) light or electrons pass through a double slit based on the stochastic nature of quantum objects. **Derive** using a mathematical argument the claim that the momentum and position of a quantum object cannot both be exactly known simultaneously.		Double-slit experiments: The following three (historical) double-slit experiments allow for revisiting both photons and electrons as quantum objects: • Young's Experiment (1800): (Laser-)light of high intensity, major support for the wave theory of light; • Taylor's Experiment (1909): Light of low intensity; the original source "Interference Frings with feeble light" can be read with high school students; • Jönsson's Experiment (1960): Interference of electrons; the experiment can be understood using computer simulations or the experimental data from Jönsson's original publication. The single slit experiment can be used as an analogy to demonstrate the relationship between variables in Heisenberg's Uncertainty Principle.

celerators for probing matter,
e structure of nuclear particles,
rd Model, exchange model of
the Higgs Boson

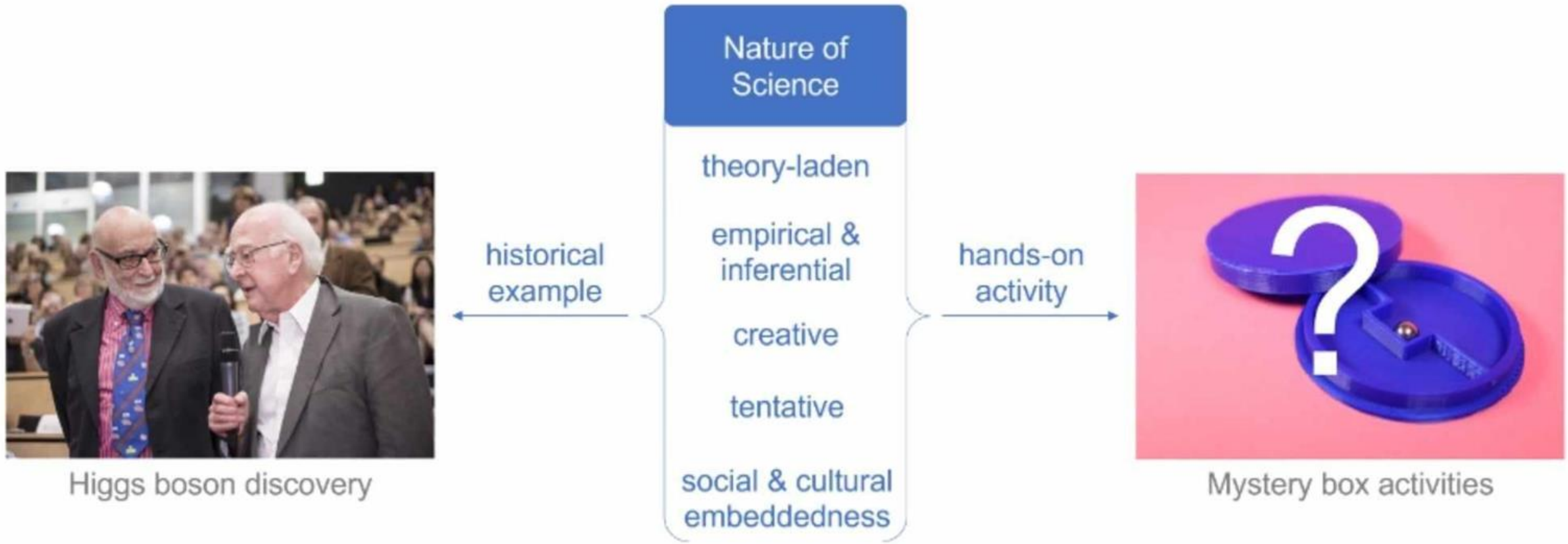
of how the numbers of
nd protons determine the
the nuclei they form

ars and other exotic examples
in nature could be researched

Quantum objects
ect is the photon.
ll aspects of light
uantum object. In
uilds on a prior
of an interaction
rough discussion
istoric double-slit
ll as their major
erties include: Quantization, Stochastic behaviour,
e application of quantum ideas to develop a quantum
to explain the structure of the periodic table mark the

The implications of Quantum Nonlocality for determinism and causality	**Reason** based on evidence that the measurement of a property of a quantum object has non-local implications and consequences for the classical understanding of cause-and-effect.		One suitable (historic) context to discuss the implications of non-locality on our understanding of physics is the paradox formulated by Einstein, Podolski and Rosen; this context also provides the opportunity to discuss aspects of the nature of science and bridge into modern physics. Einstein-Podolski-Rosen experiment. Quantum entanglement.
The Correspondence Principle	**Discuss** the transition from lower numbers of quantum objects to higher numbers of quantum objects (i.e. the crossing into macroscopic physics).		Teachers should research text and resources for student reference and encourage reading and learning.

In essence it boils down to Nature of science



One take-home message; Empathy

Students’ lack of exposure

Imagine a 14 years old getting their mind blown by conservation of momentum

Use of lingo

Gauging pre-knowledge

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$$
$$\frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu -$$
$$M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H -$$
$$\frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2\phi^+\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\frac{2M^2}{g^2} +$$
$$\frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu -$$
$$W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu -$$
$$W^-_\nu\partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu\partial_\nu W^-_\mu -$$

Kepler II : There is a force from the Sun to the planet

Assume the motion is circular, Newton II: $F_{SP} = mr\,\omega^2 = m\frac{4\pi^2 r}{T^2}$

Kepler II : there is a constant of a Sun C_S : $\frac{r^3}{T^2} = C_N$

$$\frac{r}{T^2} = \frac{C_N}{r^2}$$

$$F_{SP} = 4\pi^2 C_N \frac{m}{r^2}$$

Newton III the same force exist $F_{PS} = 4\pi^2 C_N \frac{M}{r^2}$

Let be $4\pi^2 C_N = \gamma M$

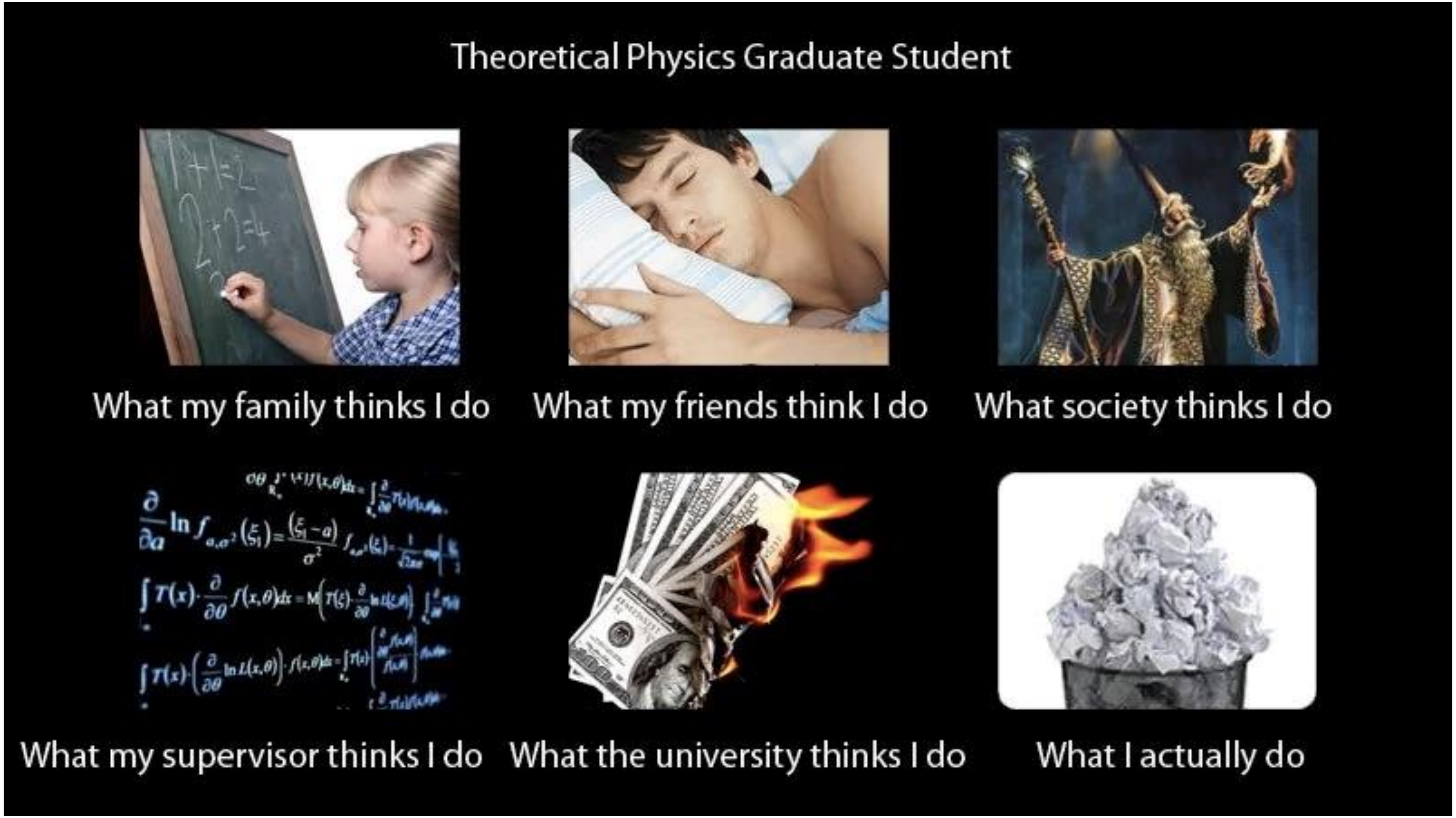
$$F_{SP} = \gamma\frac{m\cdot M}{r^2}$$

The same happens between any two objects: $F_{gr} = \gamma\frac{m\cdot M}{r^2}$

where γ universal constant

$$\frac{ig}{2}\frac{m^\lambda_d}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 -$$
$$\frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- -$$
$$\partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y -$$
$$\partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ -$$
$$\partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] +$$
$$\frac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] +$$
$$igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$$

Kids have preconception about Theoretical Physics



Kids have preconception about Theoretical Physics

Resources

https://www.worldscientific.com/doi/epdf/10.1142/S2661339522500196

https://www.symmetrymagazine.org/

The Mystery of Dark Matter – Perimeter Institute

Making Models: Wooden Blocks – Perimeter Institute

Beyond the Atom: Remodelling Particle Particles – Perimeter Institute

Everyday Einstein: GPS & Relativity – Perimeter Institute

Fields – Perimeter Institute

The Process of Science – Perimeter Institute

The Challenge of Quantum Reality – Perimeter Institute

Beyond Bohr: A Quantum Approach to the Atom – Perimeter Institute

The Expanding Universe – Perimeter Institute

Black Holes – Perimeter Institute

Mystery box S’Cool lab

Higgs in a box

Nine black box activities for optics

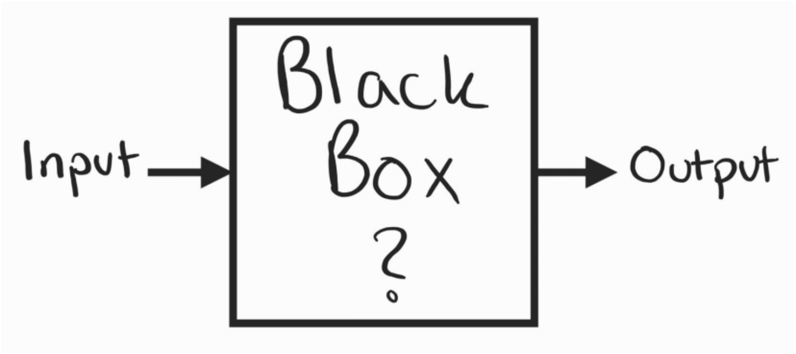
https://edu.rsc.org/resources/black-box/1275.article

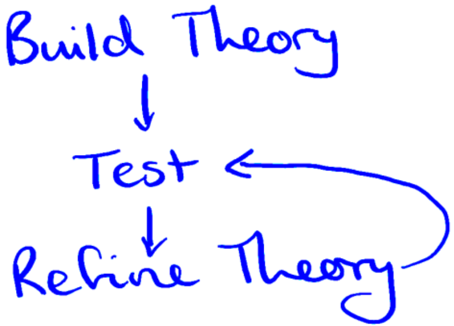
https://iopscience.iop.org/article/10.1088/1361-6552/aa62eb

https://iopscience.iop.org/article/10.1088/0031-9120/48/4/477

Things you can try: Nature of Science and Black Boxes

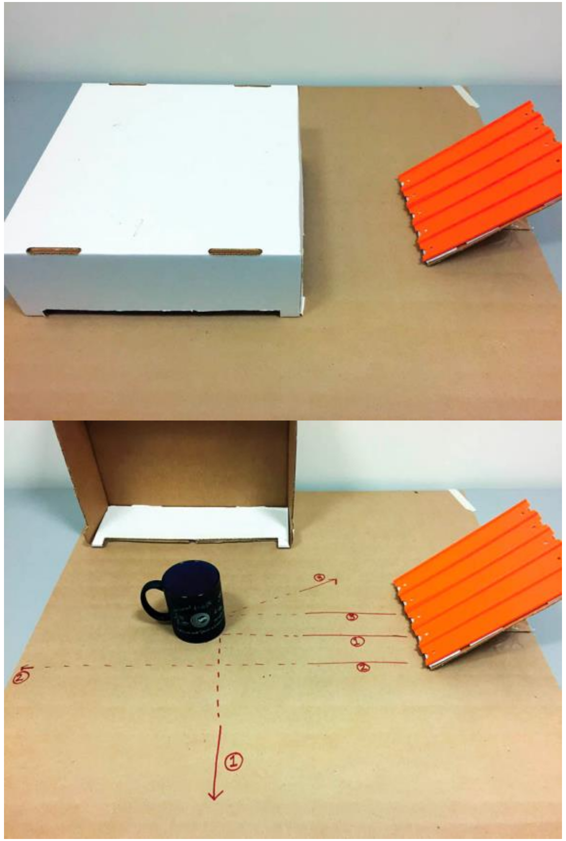
In real life scientists spend a lot of time working in the dark, trying to piece together data collected from various sources - [Royal Society of Chemistry]

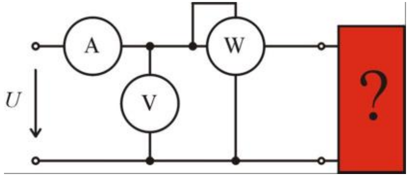


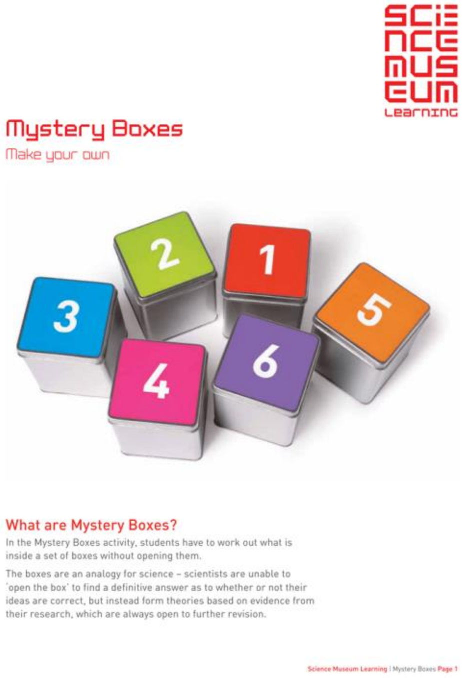


All images of resource from Perimeter institute: the Black Box

Things you can try: Nature of Science and Black Boxes other examples






SCIENCE MUSEUM LEARNING

Mystery Boxes

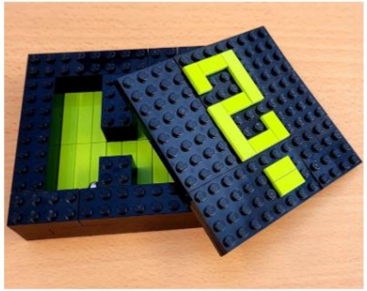
Make your own

What are Mystery Boxes?

In the Mystery Boxes activity, students have to work out what is inside a set of boxes without opening them.

The boxes are an analogy for science – scientists are unable to 'open the box' to find a definitive answer as to whether or not their ideas are correct, but instead form theories based on evidence from their research, which are always open to further revision.

Science Museum Learning | Mystery Boxes Page 1

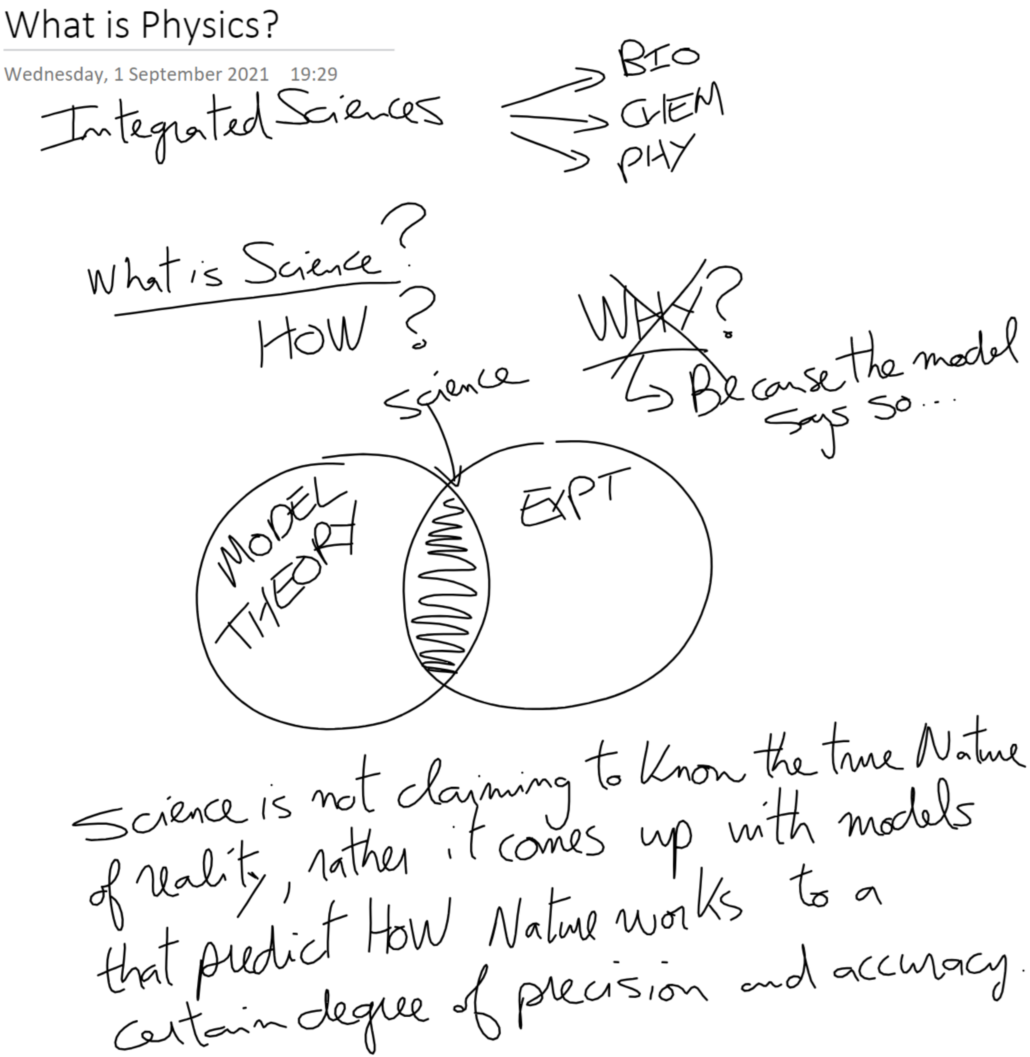


Things you can try: Epistemolo-what?

Epistemology

Not to be confused with Epidemiology.

Observation inseparable from Theory



How to bring the idea of Higgs field to our classrooms?

Idea: David J. Miller
[A quasi-political Explanation of the Higgs Boson; for Mr Waldegrave, UK Science Minister 1993.]

How to bring the idea of Higgs field to our classrooms?

Merci bien!

Questions?

except …. what is a particle?