When learning physics mirrors doing physics

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We all observed this


Dirt

Observe

Looks like chocolate…

Observe

Hypothesize

When eat, will taste like chocolate


Observe
Hypothesize
Predict
Test

They are all skilled in:

Trying and failing

Testing ideas experimentally

Persevering

Working together

And they are doing all this because they are motivated – they have the “Need to know”.

Why don’t they do it in our classrooms?

The problem is that traditional (and even reformed) teaching goes against much of what we are good at and much of what we know helps people learn:

The answers come before questions – no need to know

Grades without resubmission of work - no opportunity to try without being afraid to fail

Preset pace of the curriculum - punishment for learning at a pace different from expected

Grading on a curve - punishment for collaboration

Traditional problems on MC tests - punishment for needing reasoning tools other than mathematics

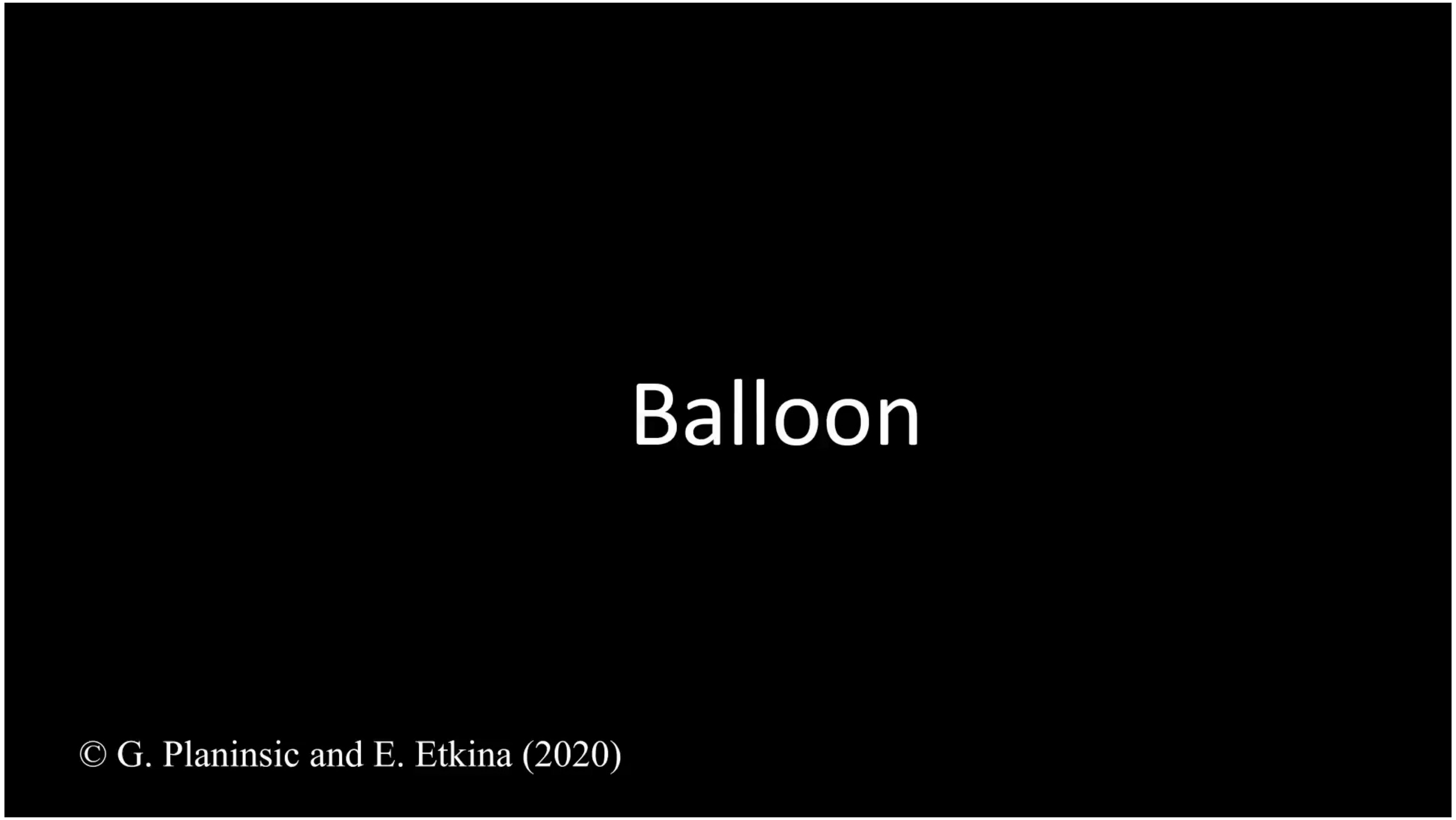
For women all these issues are exacerbated due to their tendency to blame themselves and often an “impostor syndrome” (which results in the absence of the learning community)

And there is more

We teach physics as religion

While we do it as science

Solution? We could start with something that everyone experienced but rarely questioned. Where does this loud sound come from?



Students work in groups. They propose explanations that we call crazy ideas.

The first explanation that they come up with is air!

How can we test that?

It looks like the “air” hypothesis is confirmed. But to make sure…

Hmmm…. It loos like it is not air? Then what? Oh! Rubber!
If this is the rubber that makes the loud sound…

It looks like we have to admit that both are important. How can we test that?

That was easy, what about a more difficult idea?

- Imagine that your students learned KMT. They know that air consists of molecules.
- Imagine that your students learned electricity, magnetism, and electromagnetic induction. They know about conductors and dielectrics, they are familiar with ionization.
- Imagine that they learned wave optics and they know the electromagnetic wave model of light.
- For them at this point light behaves as a wave of alternating electric and magnetic fields.

Now they observe the following experiment:

The first idea that the students usually propose is that UV light ionizes air and ionized air is a conductor. That is why the electroscope discharges. If this is correct, then UV light should discharge positively charged electroscope as well.

It looks like it is not a good explanation. Maybe UV light kicks electrons out of the zinc plate? Then the neutral electroscope should become positively charged when UV light shines on it.

Why didn't the electroscope get charged? What do we know about the structure of metals? Oh, maybe it does get charged but the electrons come back to the positively charged electroscope… How can we test that?

If our reasoning is correct, the electroscope should be charged positively. How can we test this?

The Investigative Science Learning Environment (ISLE) approach

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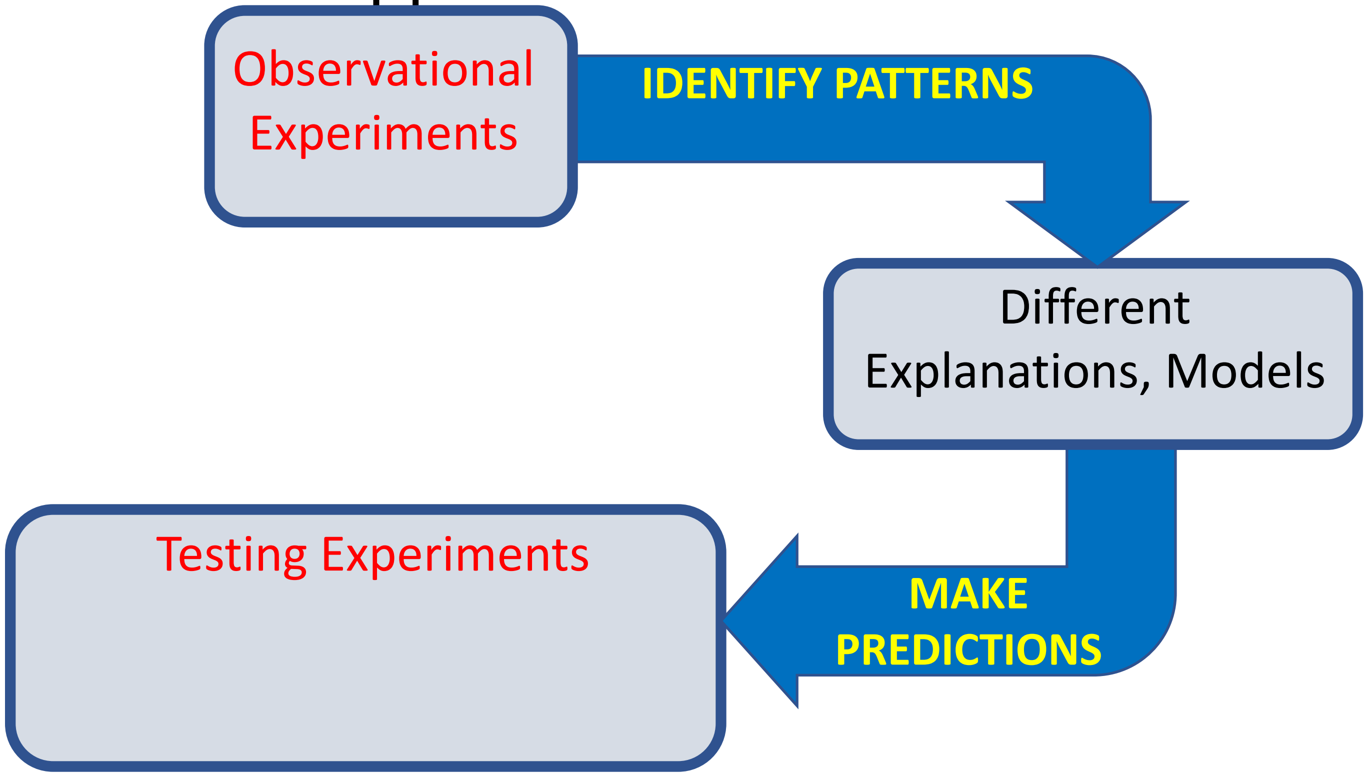
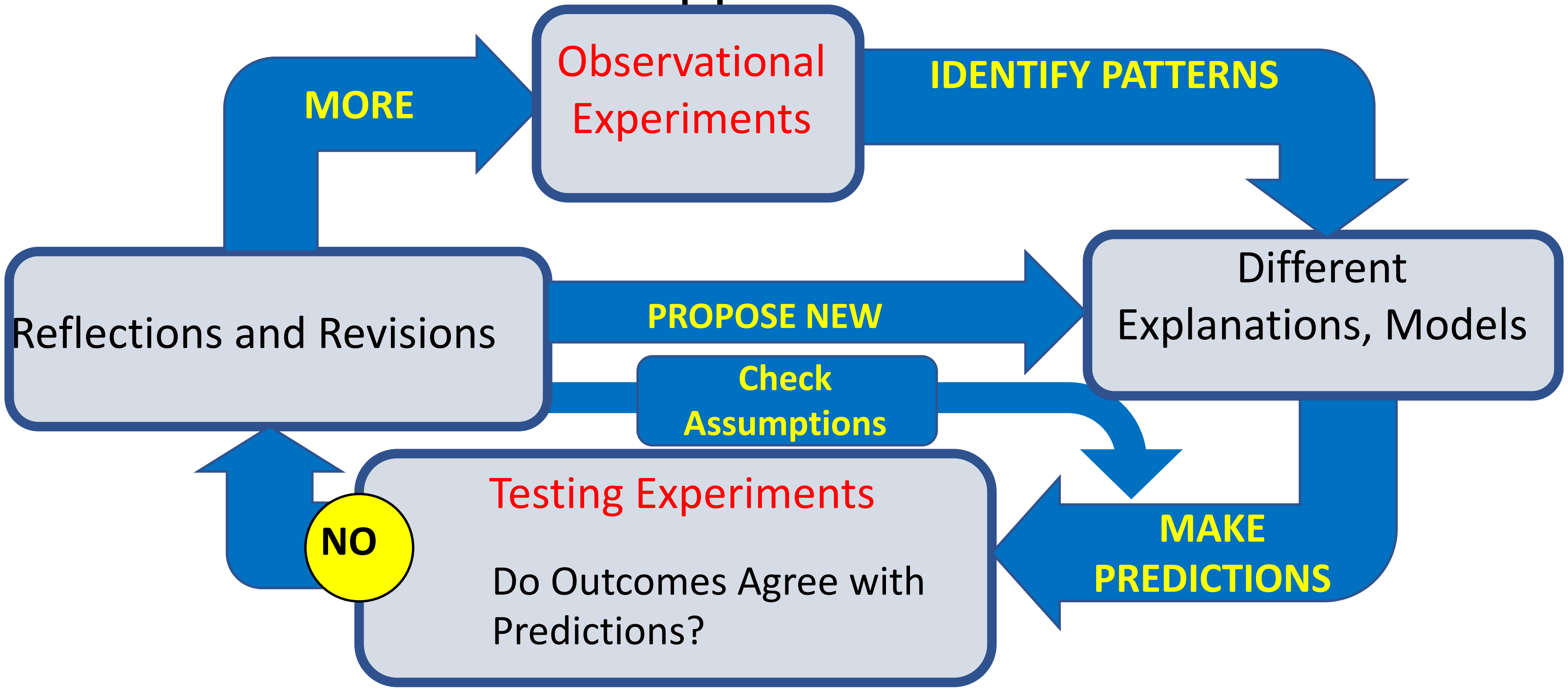


The Investigative Science Learning Environment (ISLE) approach



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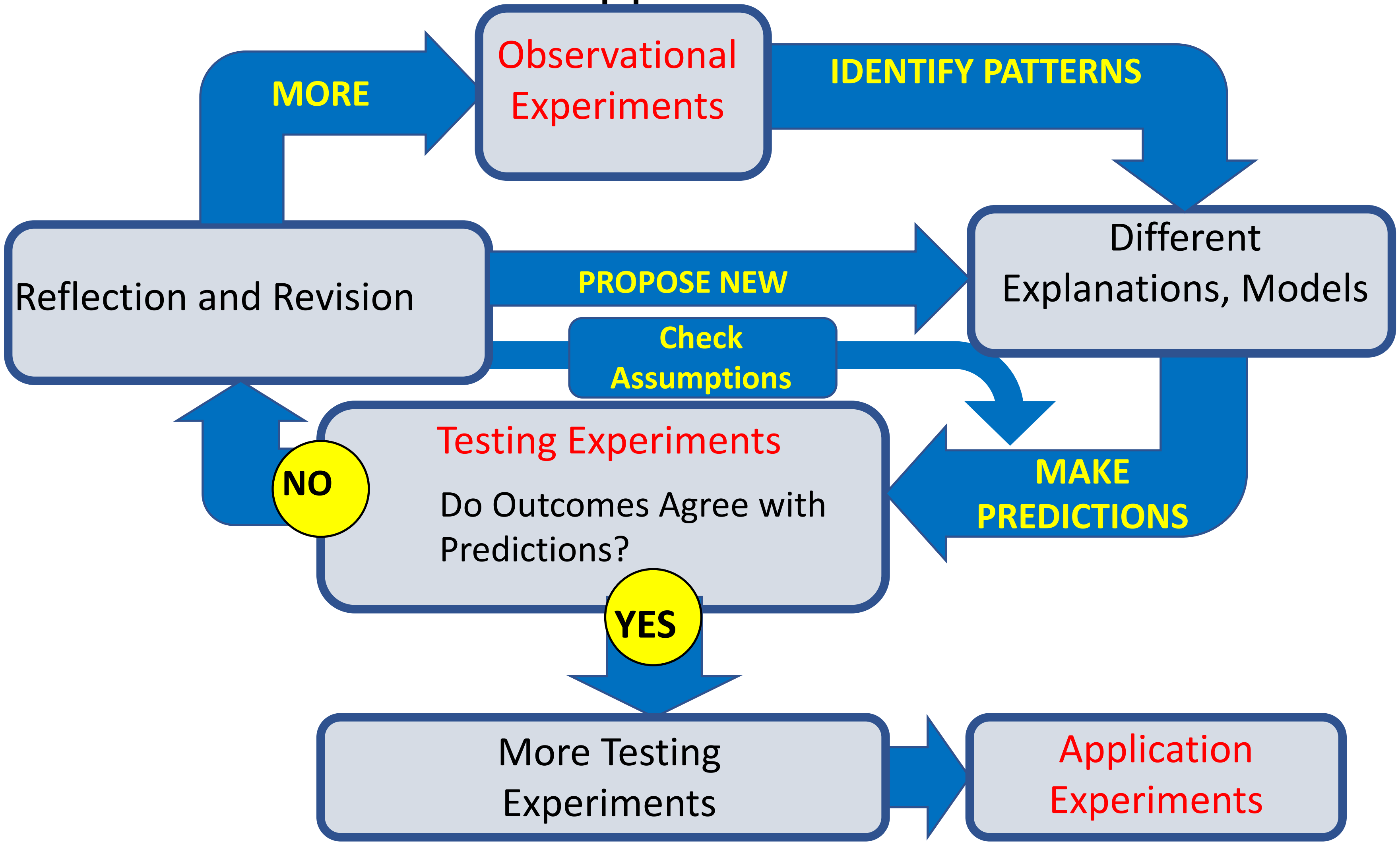

Etkina and Van Heuvelen, 2001, 2007; Etkina, 2015, Etkina et al., 2019

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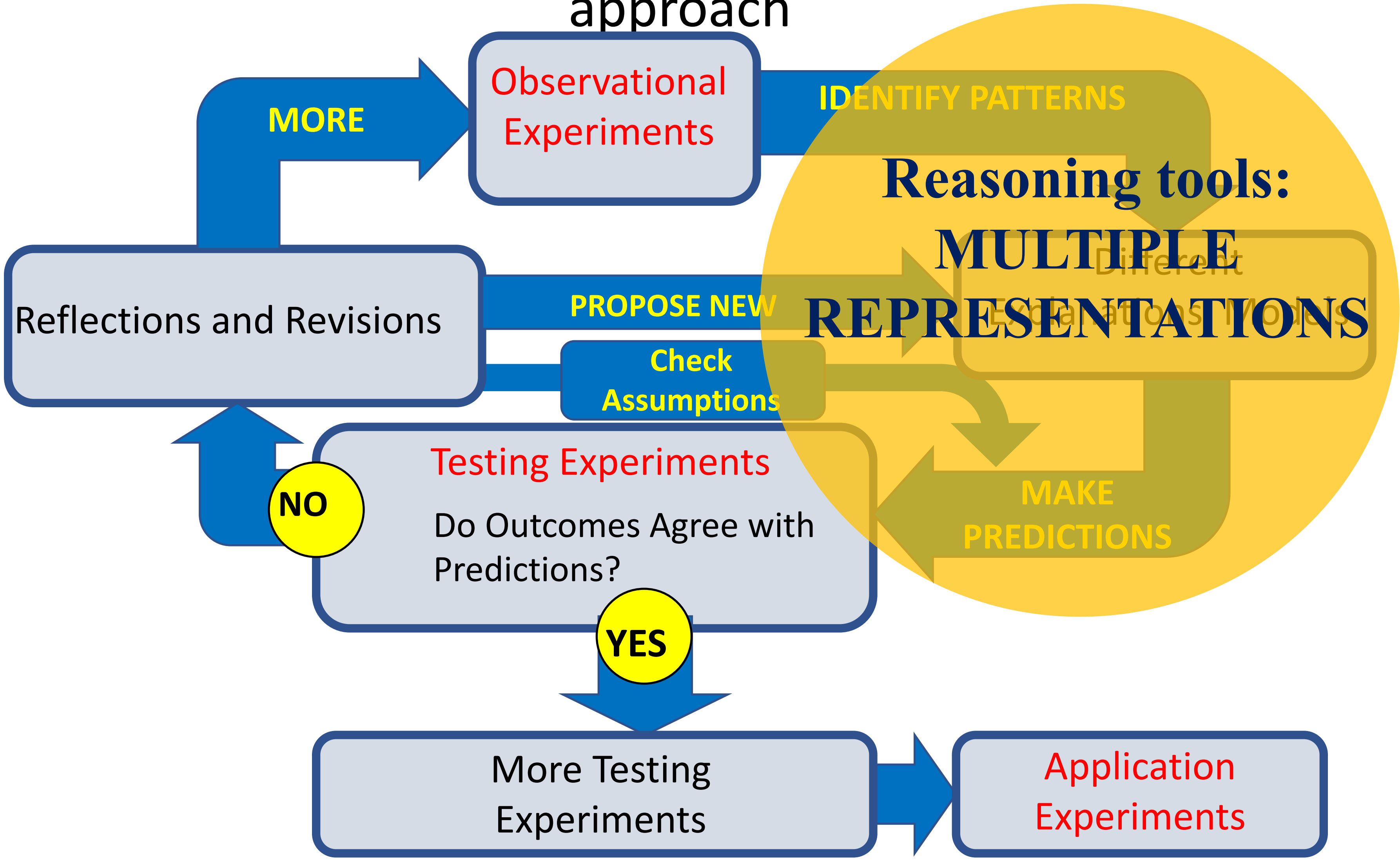

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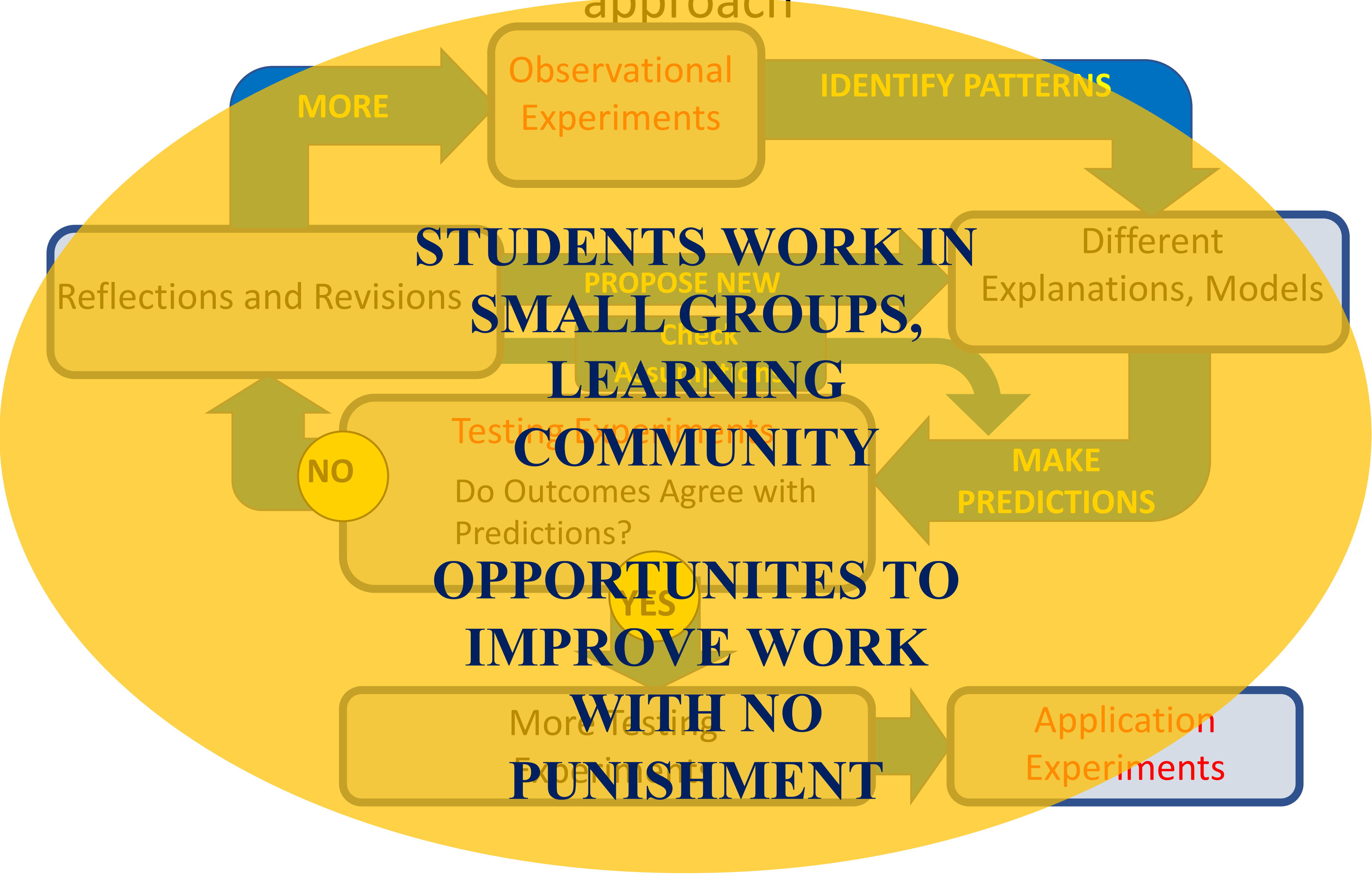


The ISLE approach– an intentional approach to curriculum design

Based on: "the medium is the message" - If we want students to learn the process of physics they have to be engaged in that process.

Intentionalities of ISLE

Based on: Theories of human motivation: People will only learn if they enjoy it (c.f. Flow), see the value in their personal lives, experience learning as an opportunity for mental and spiritual growth.

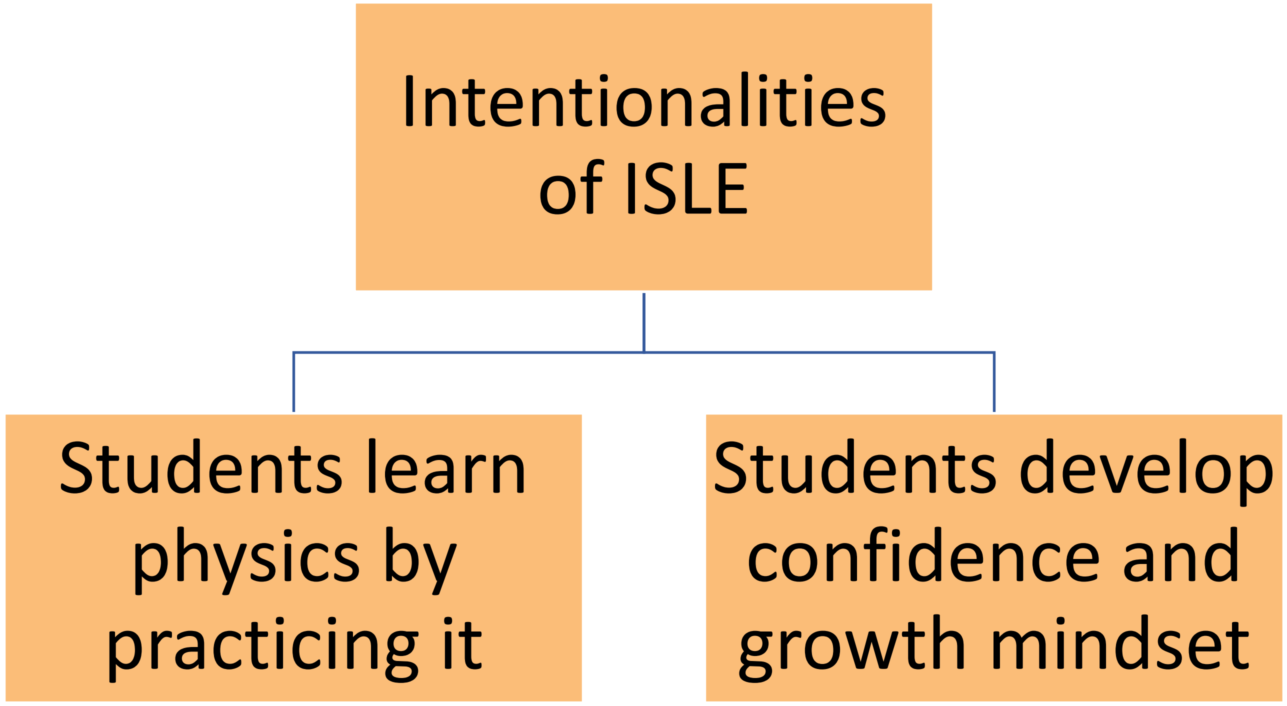
What and how students learn

How students feel about learning physics

Intentionality: the product of knowledge cannot and should not be separated from the means by which it came to be known.

Macmillan and Garrison, A Logical Theory of Teaching: Erotetics and Intentionality, 1988.

The ISLE approach– an intentional approach to curriculum design



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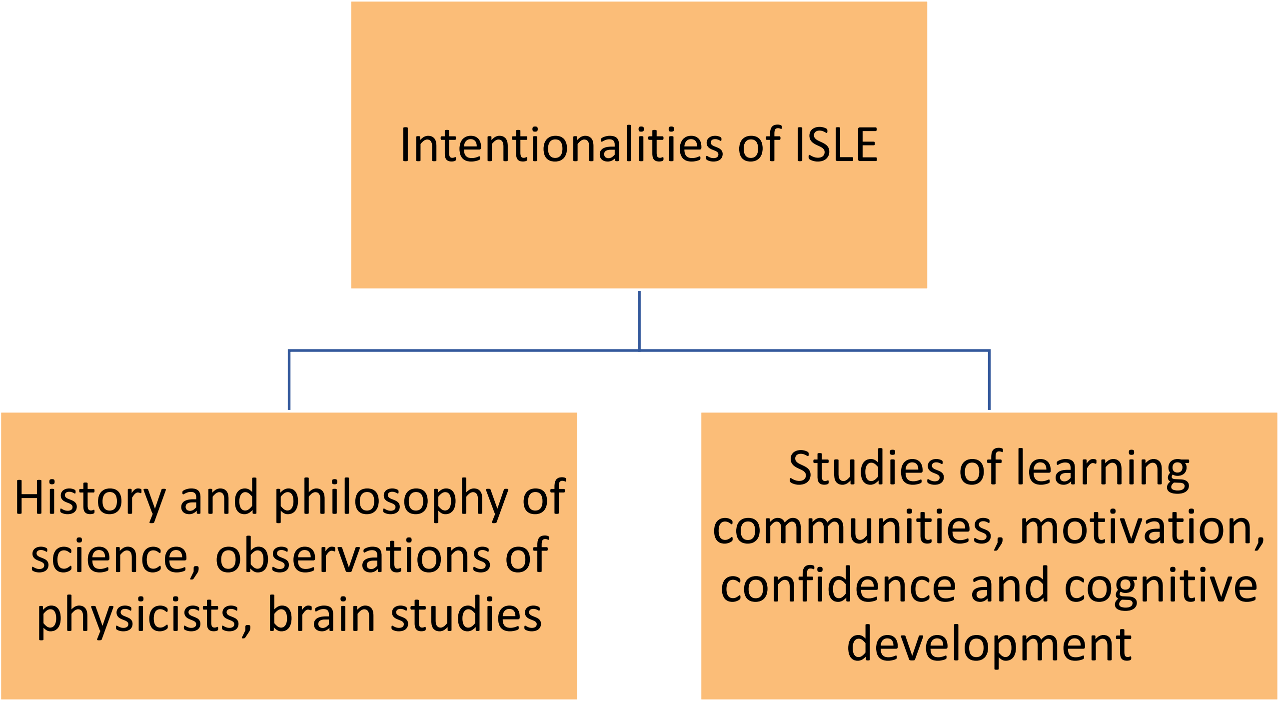
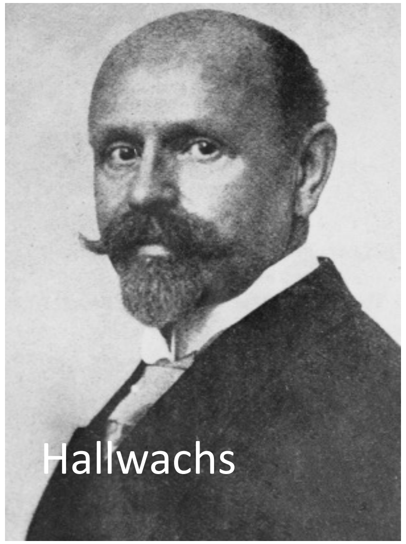
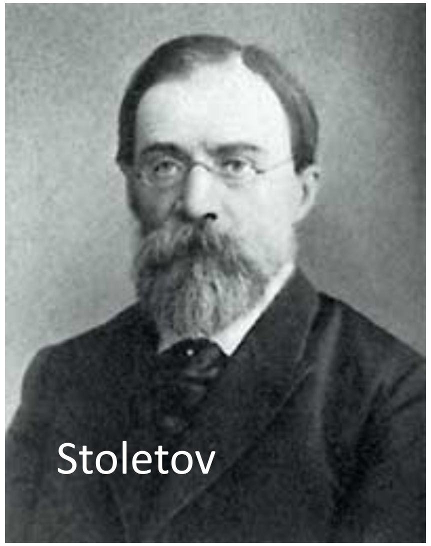


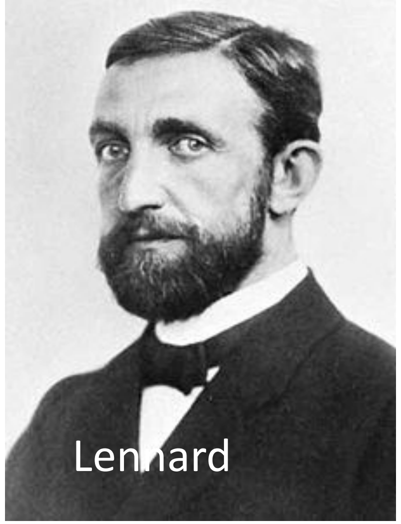
History of science: Photoelectric effect

Accidental observation



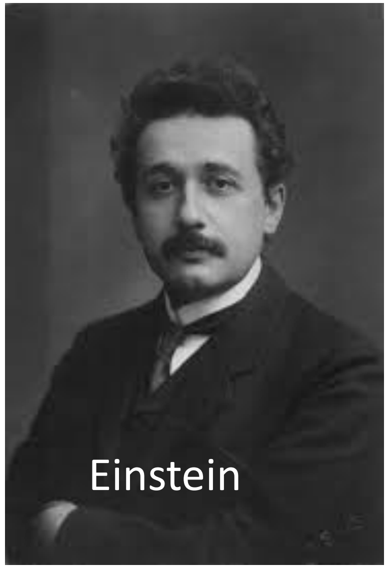
Qualitative observational experiments



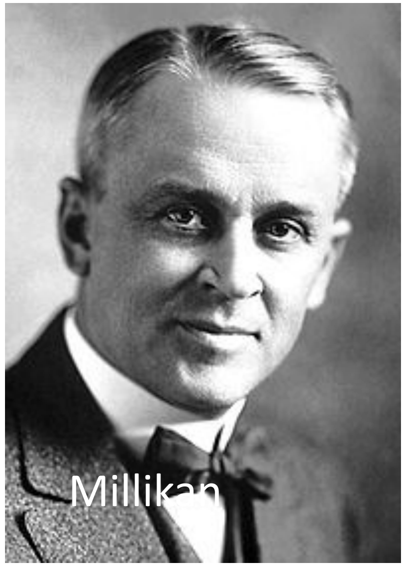


Quantitative observational experiments and explanations

Assumption



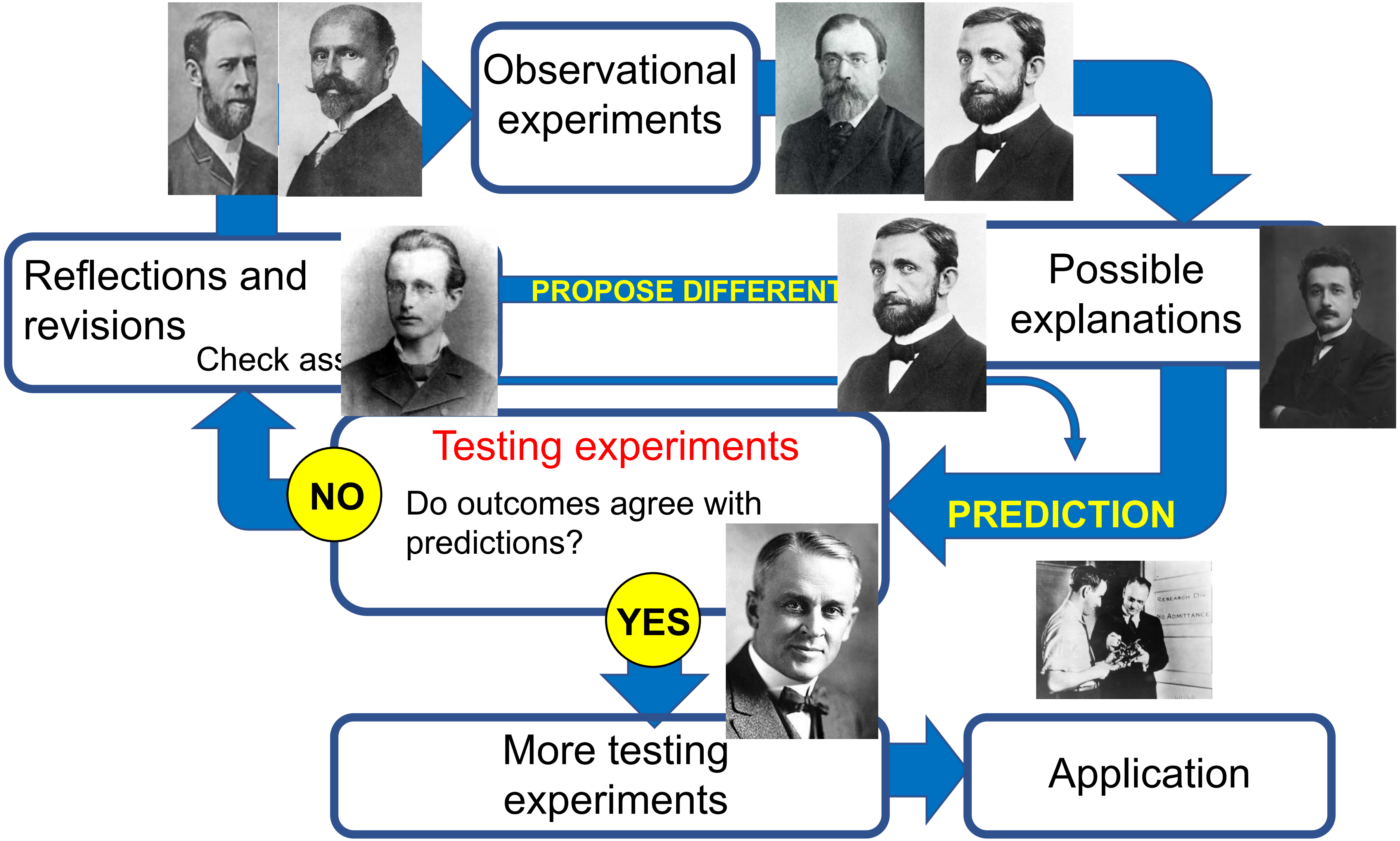
Explanation



Testing
experiment,
prediction,
outcome

Application (photomultiplier tube)

Investigative Science Learning Environment - ISLE



Cognitive science

Learning is a social process (Bielaczyc & Collins, Learning communities in classrooms: A reconceptualization of educational practice, 1999).

Fixed or growth mindset determine how a person will learn and what choices they make in the process (Yeager & Dweck, Mindsets That Promote Resilience: When Students Believe That Personal Characteristics Can Be Developed, 2012).

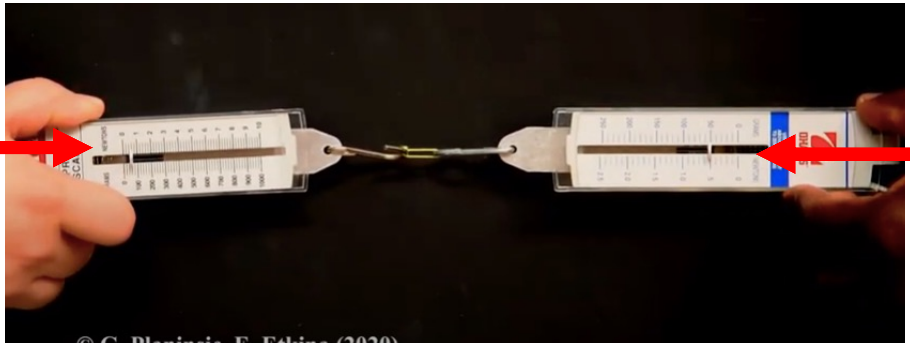
Perseverance is one of the major predictors of success in life (Hochanadel & Finamore, Fixed And Growth Mindset In Education And How Grit Helps Students Persist In The Face Of Adversity 2015).

ISLE process is a way of thinking about learning and teaching physics – we can apply it to any concept

Students conduct a series of experiments

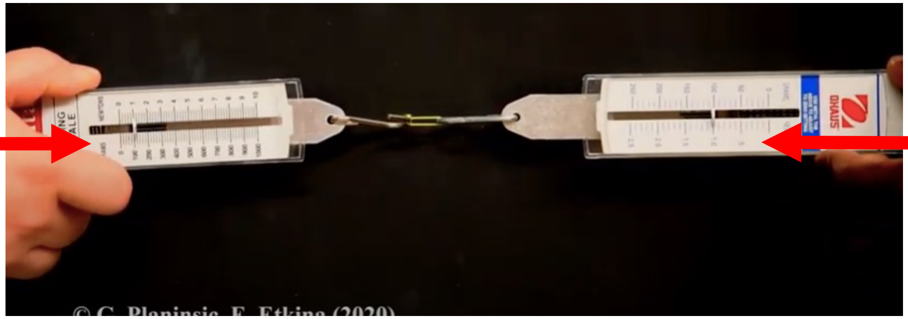
Scale 1 Scale 2

0.5 N



0.5 N

1.0 N



1.0 N

1.5 N

1.5 N

Etkina et al., 2019

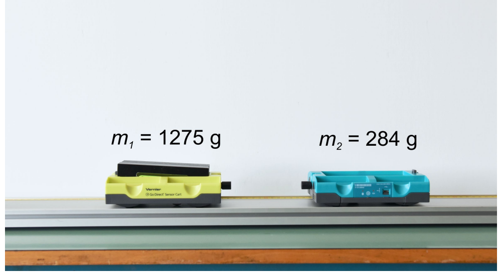
They use tools to analyze patterns

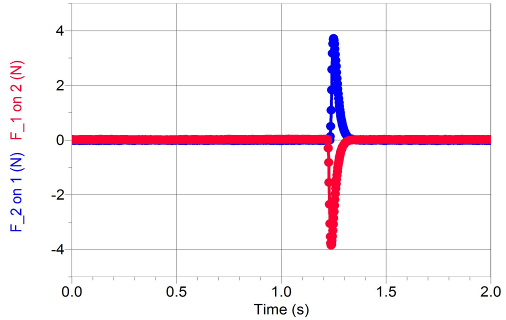
$F_{\text{scale 1 exerts on scale 2}}$ $F_{\text{scale 2 exerts on scale 1}}$

Explanation (hypothesis):
When ANY two objects interact with each other, they exert forces on each other that are the same in magnitude and opposite in direction.

While it sounds rather wild, how can we test it?

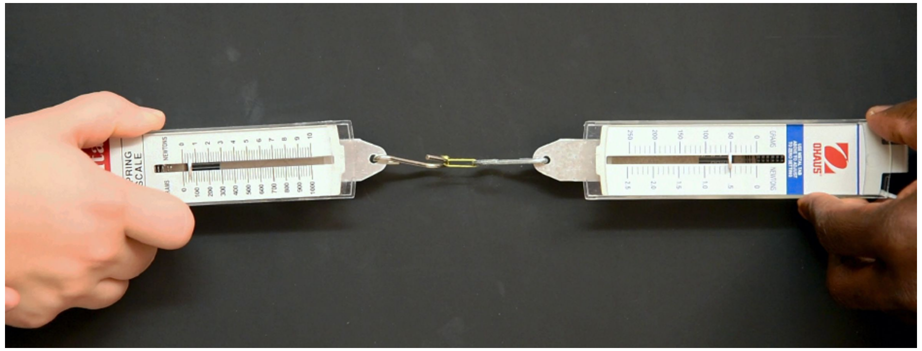
They design testing experiments

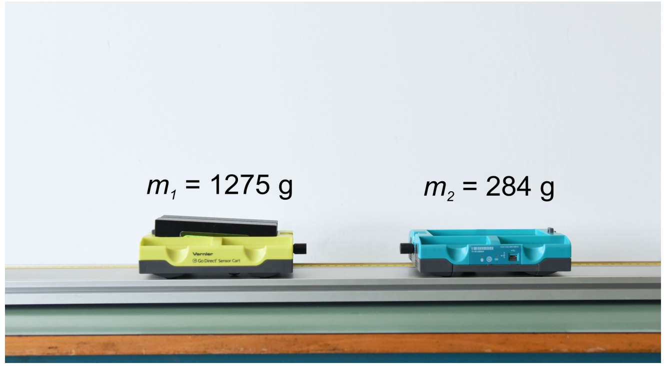


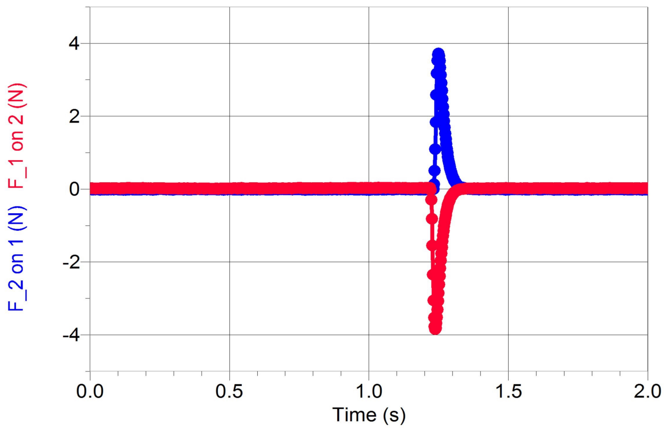


Etkina et al., 2019

As a student you just invented Newton's third law







Etkina et al., 2019

Lab handout for these experiments

OBSERVATIONAL EXPERIMENT: INTERACTING SCALES

The goal of this experiment is to find a relationship between the force that scale 1 exerts on scale 2 and the force that scale 2 exerts on scale 1 when they pulling on each other and then construct a hypothesis about the relationship between the force that an object A exerts on an object B to the force that the object B exerts on the object A.

Available Equipment: Force scales.

TESTING EXPERIMENT: INTERACTION BETWEEN DIFFERENT OBJECTS

The goal of this experiment is to test the hypothesis about the relationship between the force that an object A exerts on an object B to the force that the object B exerts on the object A.

REMEMBER: The goal of a testing experiment is to <u>disprove</u> the hypothesis being tested, not to support it.

Available Equipment: Force probe sensors with bumpers on ends, dynamics track, dynamics carts, objects of different masses to put on carts, computer with Logger Pro.

Scientific habits of mind

Scientific Abilities include the abilities to:

represent information in multiple ways

design and conduct an experiment to investigate a phenomenon

develop and test models/hypotheses/explanations

design and conduct a testing experiment (testing a model/hypothesis/explanation or mathematical relation)

design and conduct an application experiment

collect and analyze experimental data

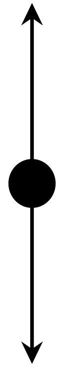
evaluate models, equations, solutions, and claims

communicate scientific ideas

Etkina et al., 2006

Examples of activities that help develop the abilities

An elevator is pulled upwards by a cable so that it moves at a constant upward speed.



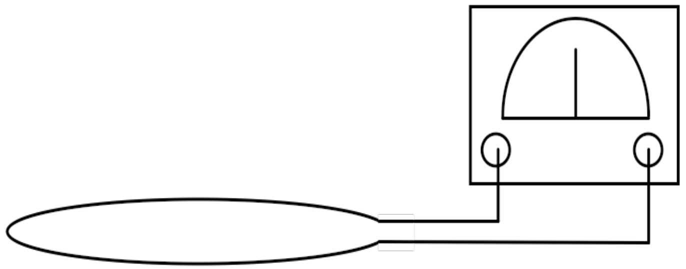
Marianne draws the (unlabeled) force diagram for the elevator shown on the right and says, *"if the elevator is moving upwards at a constant rate, the forces exerted on it must add to zero."*

Jeremy disagrees. Looking at the force diagram he says *"the way you've drawn the force diagram, the elevator will stop moving because there is no net force exerted on the elevator."*

a) Correctly label the force diagram.

b) Who do you agree with and why? For the statement you disagree with, how would you convince them that they are incorrect?

Represent and evaluate, design an experiment to test a hypothesis



You have a loop of wire connected to an ammeter (shown in the diagram), and a bar magnet.

a) Describe an experiment that will make the ammeter needle deflect to the right. Include a labeled diagram. The needle deflecting to the right indicates that current is flowing into the port on the right side of the ammeter.

b) Explain in detail what causes the current to start flowing in that direction.

Design an application experiment, communicate

My students have never designed an experiment –how can they do this?

When students design their own experiments they

are guided by questions that tell them what to think about not what to do;

self-assess their work and improve it with the help of rubrics

Etkina, Murthy, and Zou, 2006

Questions that guide students what to think about

Testing experiments

Propose experiments to test the explanations (do not perform them).

Use the explanations to make predictions of the outcomes of these experiments before you perform them. Write them here.

Perform the experiments and record the outcomes.

Make a judgment about the explanations.

Self-assessment rubrics

https://sites.google.com/site/scientificabilities/

Scientific ability	Missing	Inadequate	Needs Improvement	Proficient
Is able to identify the hypothesis to be tested	No mention is made of a hypothesis.	An attempt is made to identify the hypothesis to be tested but is described in a confusing manner.	The hypothesis to be tested is described but there are minor omissions or vague details.	The hypothesis is clearly stated.
Is able to design a reliable experiment that tests the hypothesis	The experiment does not test the hypothesis.	The experiment tests the hypothesis, but due to the nature of the design it is likely the data will lead to an incorrect judgment.	The experiment tests the hypothesis, but due to the nature of the design there is a moderate chance the data will lead to an inconclusive judgment.	The experiment tests the hypothesis and has a high likelihood of producing data that will lead to a conclusive judgment.

Etkina et al., PhysREV ST PER 2006

Basic rubric structure (total of 39)

LEVEL / ABILITY	Missing (0)	Not adequate (1)	Needs improvement (2)	Proficient (3)
Small sub ability Drawing a force diagram Comparing results of two experiments	A student does not know that they need to address this issue	A student knows that they need to write something but what is written is vague (description of what is missing)	A student writes relevant things with some minor omissions (description of what is missing)	As perfect as we can expect (a list of all good stuff)

https://sites.google.com/site/scientificabilities/

How?

Give students an opportunity to practice those again and again

Give them feedback

Giving them an opportunity to revise and improve their work WITHOUT PUNISHMENT

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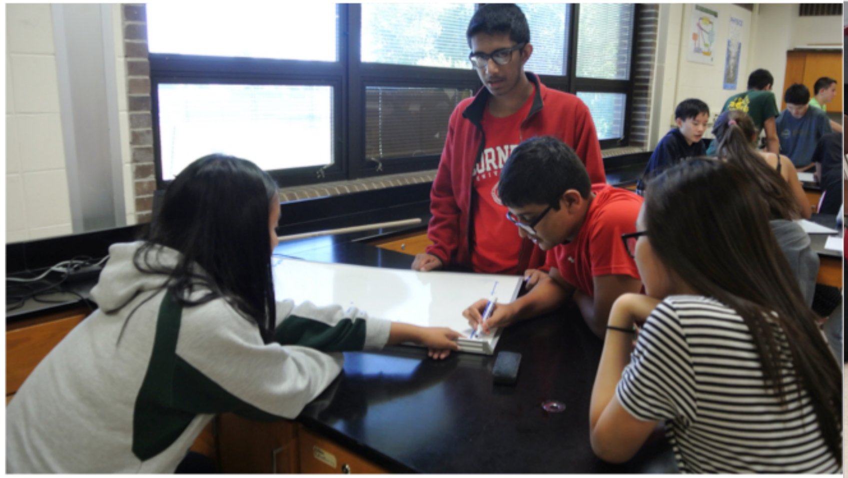
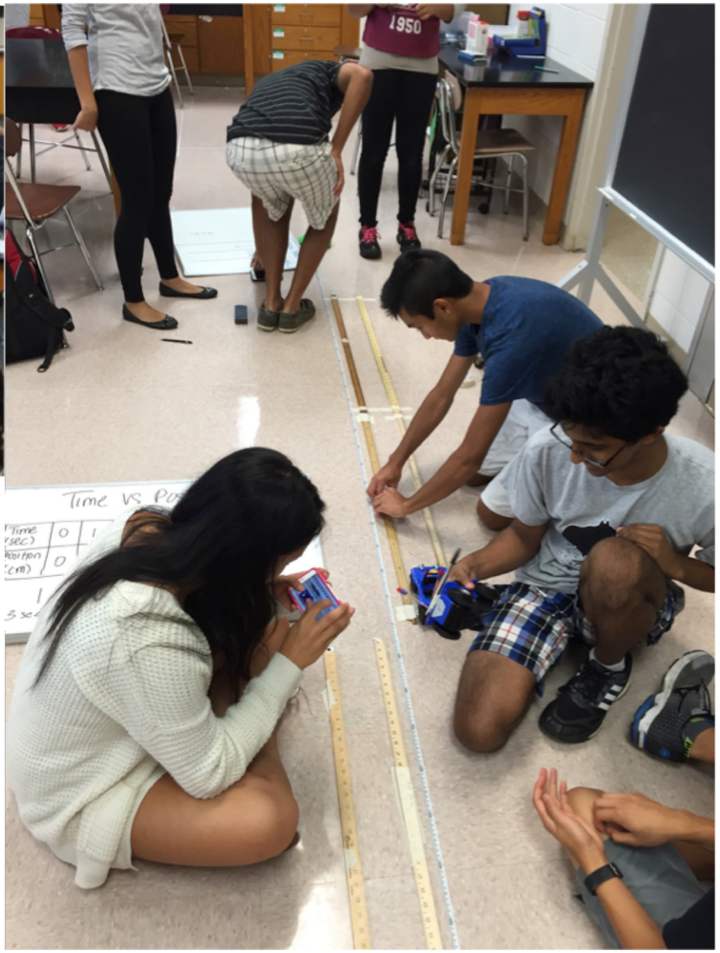
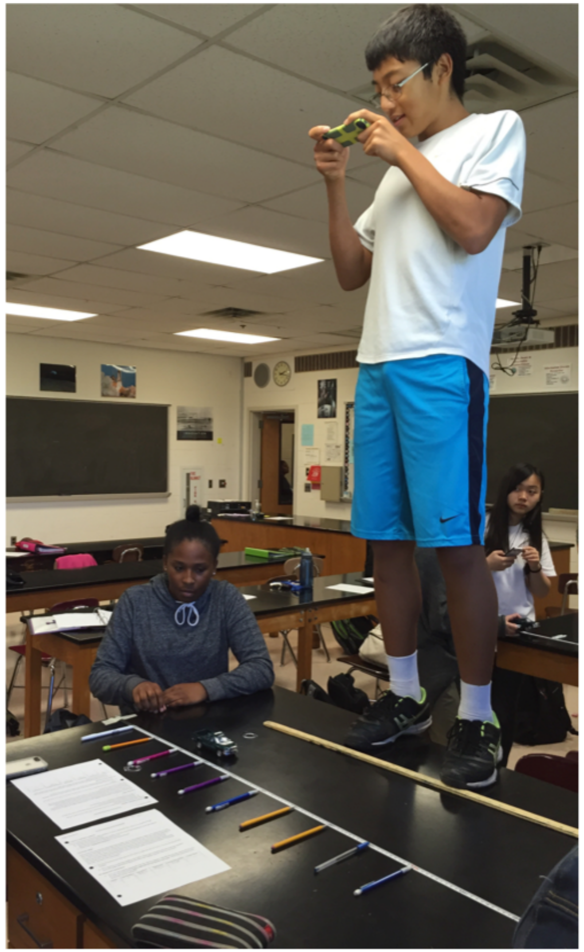
Students of Danielle Bugge (WWPHS)

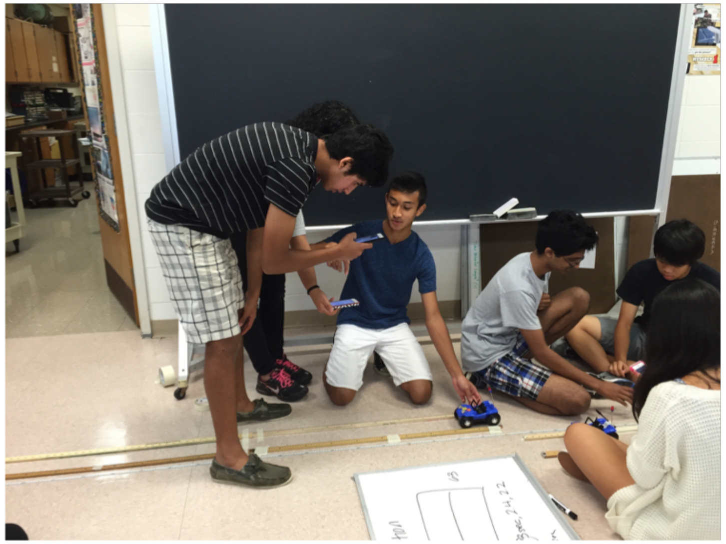
Danielle Bugge, graduate of 2010,
FCI gains 0.5-0.6
Received her PhD in 2020
being a full time teacher

Students of Danielle Bugge (WWPHS) – Where will the cars meet?







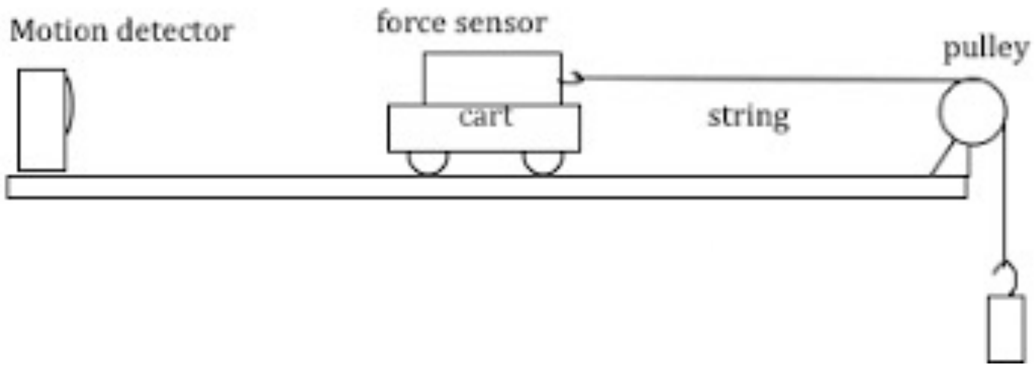


Scientific abilities ability rubrics – see https://sites.google.com/site/scientificabilities/

	Ability	Missing	Inadequate	Needs Improvement	Proficient
C5	Is able to identify the assumptions made in making the prediction	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but the assumptions are irrelevant or are confused with the hypothesis.	Relevant assumptions are identified but are not significant for making the prediction.	Sufficient assumptions are correctly identified, and are significant for the prediction that is made.
C6	Is able to determine specifically the way in which assumptions might affect the prediction	No attempt is made to determine the effects of assumptions.	The effects of assumptions are mentioned but are described vaguely.	The effects of assumptions are determined, but no attempt is made to validate them.	The effects of the assumptions are determined and the assumptions are validated.

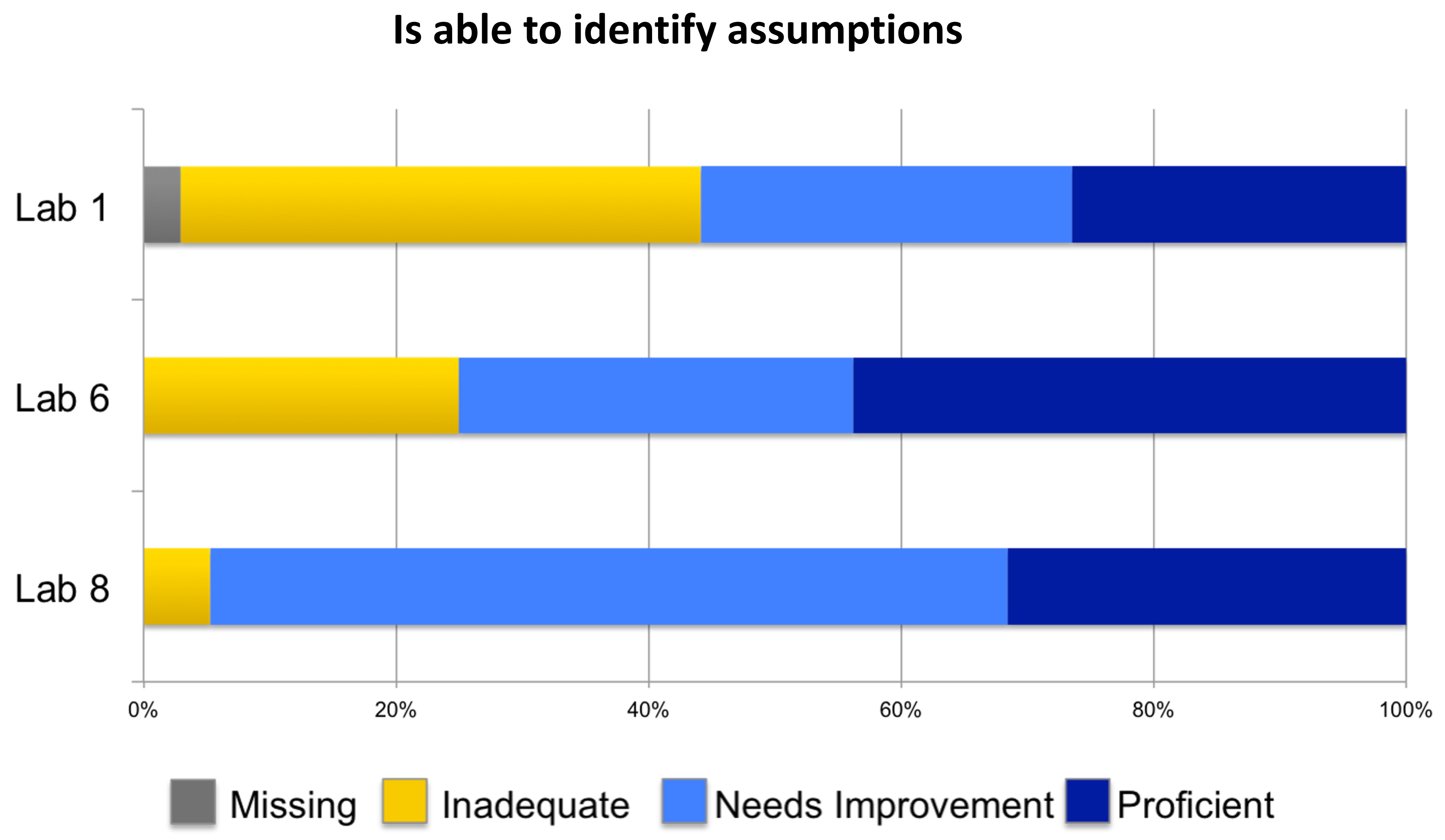
Assumption	Effect	Validation
The car will travel in a perfectly straight path.	The position (x) is accurate.	We gently tapped the car back into a straight path if it went to the side.

Assumption	Effect	Validation
The car will travel in a perfectly straight path.	The position (x) is accurate.	We gently tapped the car back into a straight path if it went to the side.
	The position (x) of the car is not affected by any deviations from the straight marked path. If it does deviate, the distance measured along a straight line will be shorter than the actual distance traveled.	Because the car had a natural tendency to curve to the right, we gently tapped the car back onto the straight path if it looked like it was about to curve off to the side.

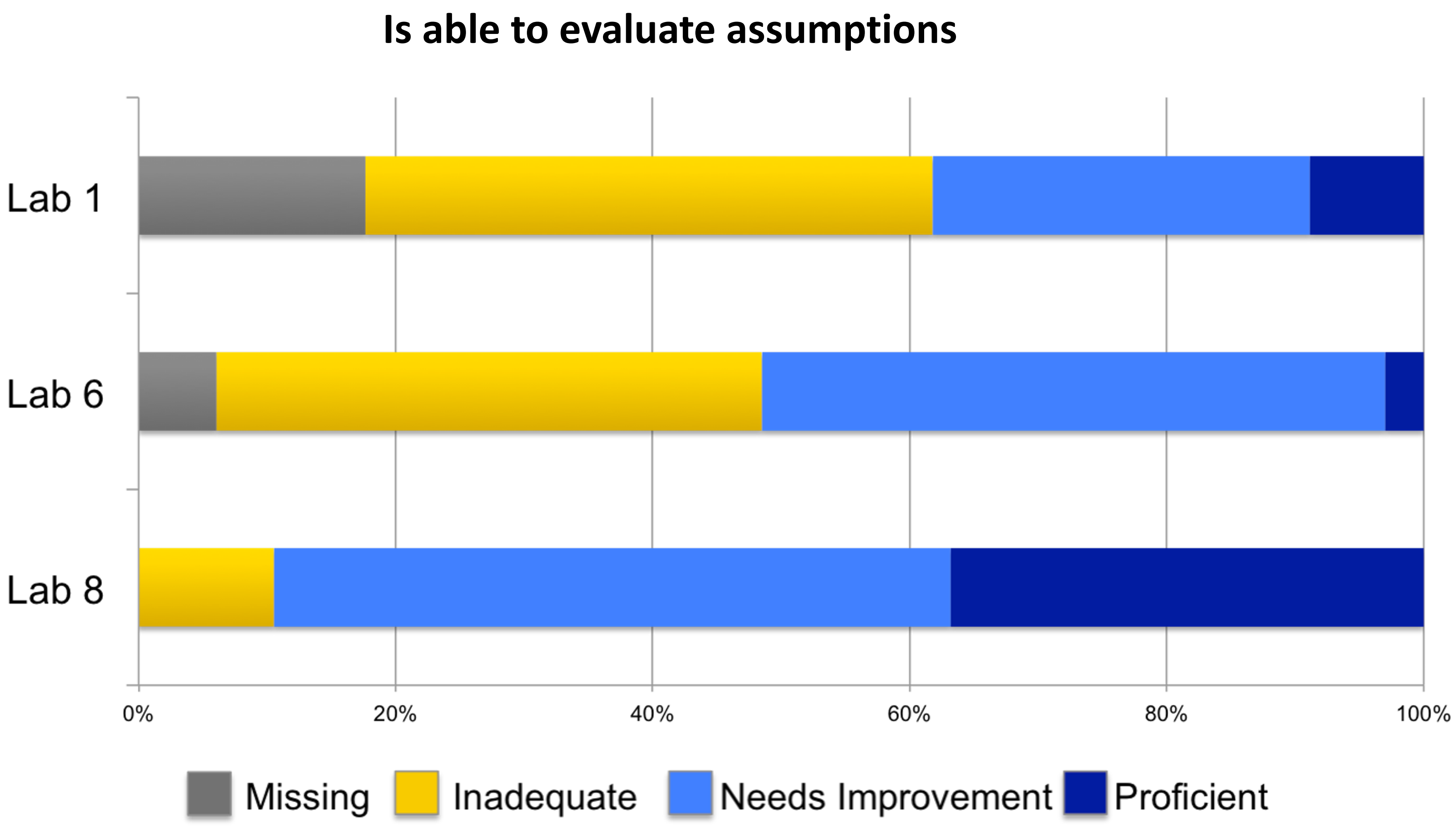


"If the table/track was on an incline, then the change in velocity would have increased faster than if the table was flat which would mean that the force [of the string on the cart] would be lower than expected. However, this assumption was validated because when the cart was put on the track and no one touched it and there was no weight at the other end, the cart did not move, indicating that the table was flat."

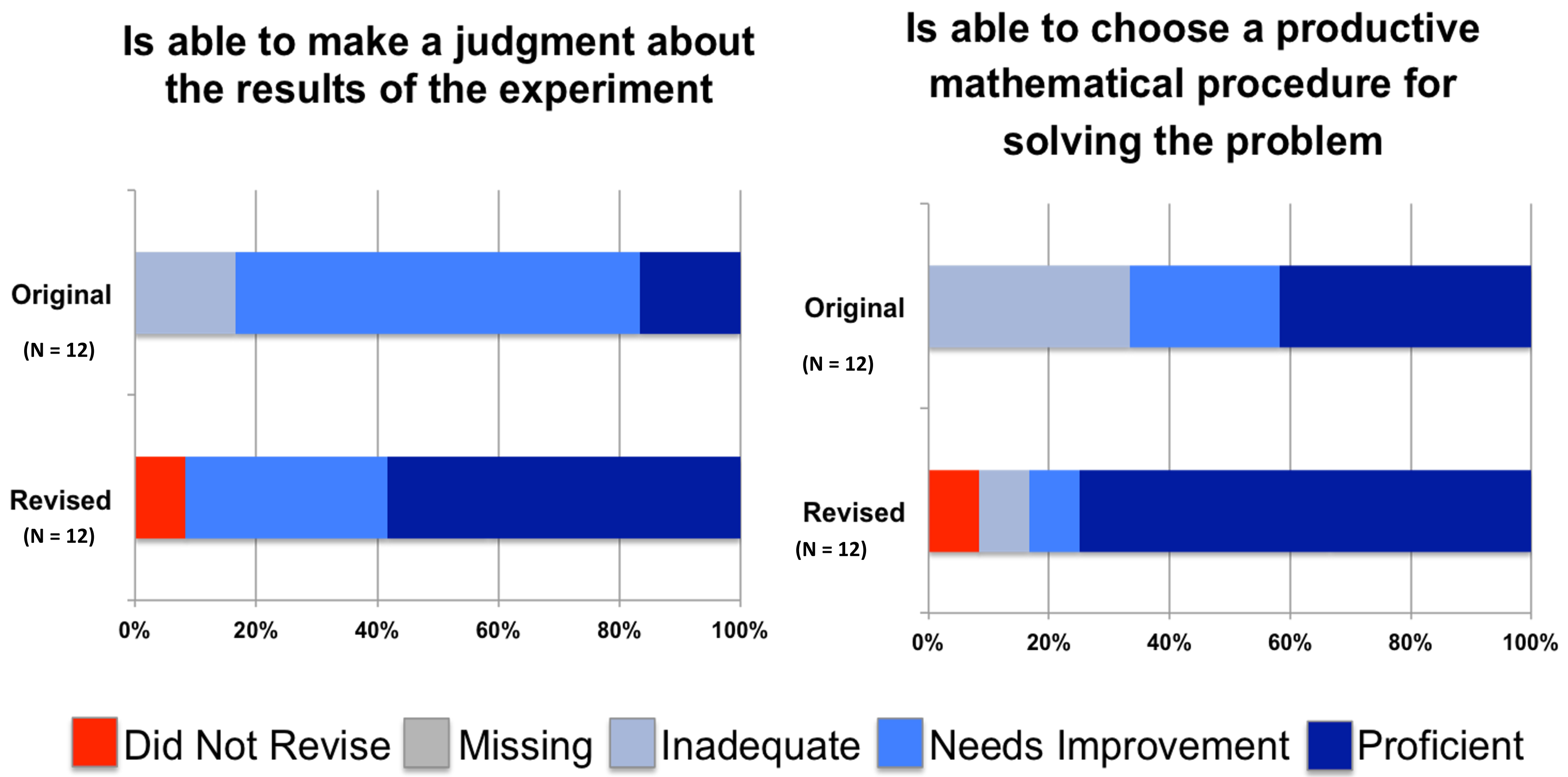
Danielle's students scientific ability rubric scores



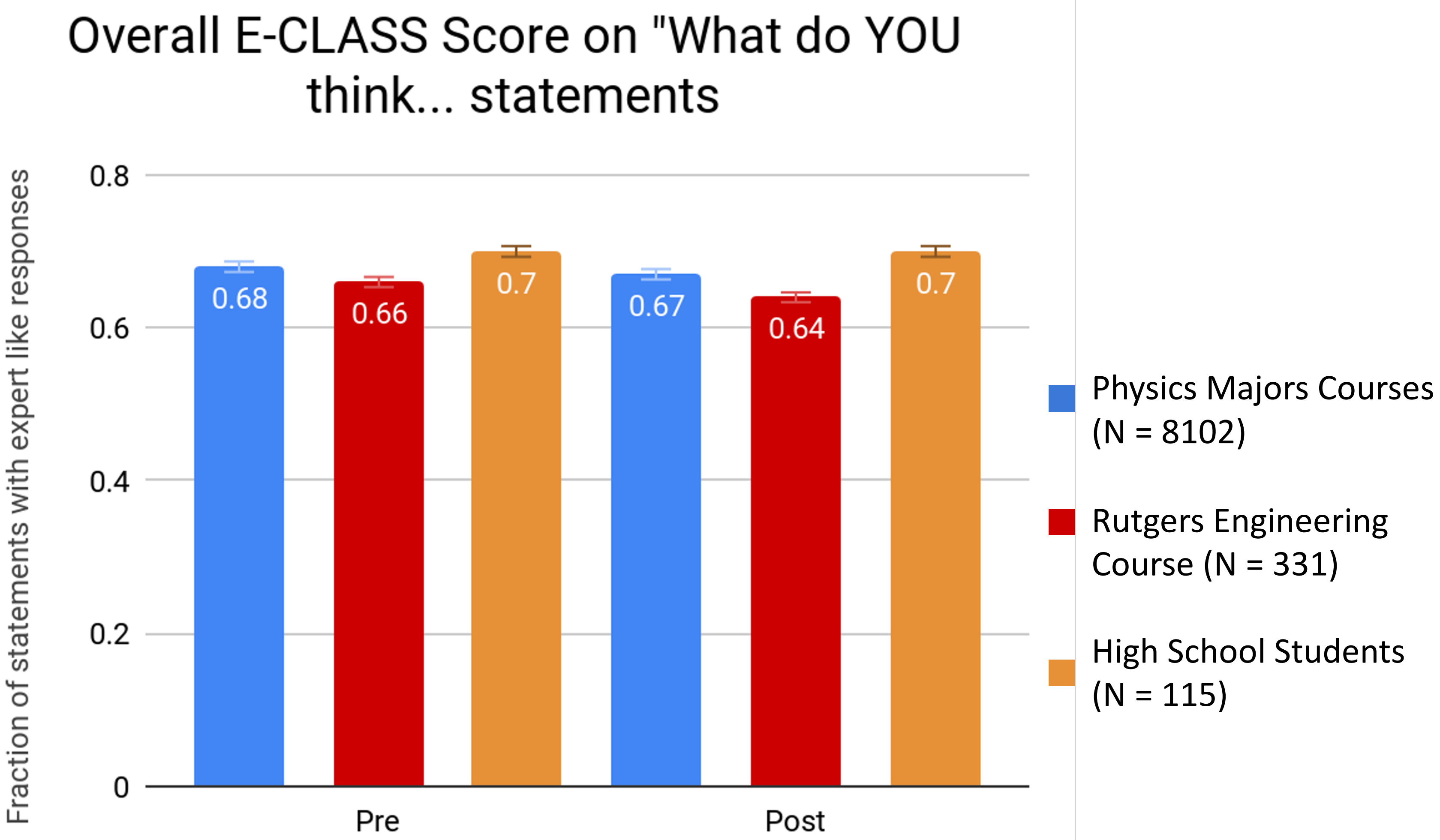
Danielle's students scientific ability rubric scores



Revisions


Is able to make a judgment about the results of the experiment
Original
(N = 12)
Revised
(N = 12)
0%
20%
40%
60%
80%
100%
Is able to choose a productive mathematical procedure for solving the problem
Original
(N = 12)
Revised
(N = 12)
0%
20%
40%
60%
80%
100%
Did Not Revise
Missing
Inadequate
Needs Improvement
Proficient

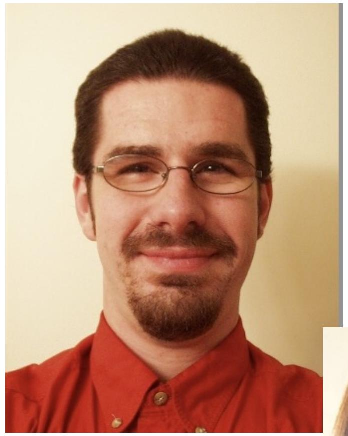
E-CLASS



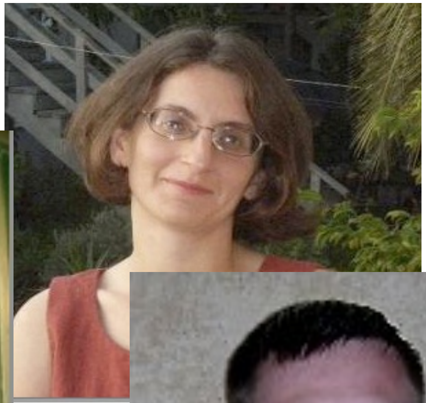
Data comparison from Rutgers Fall 2018 Engineering Course

Big team!









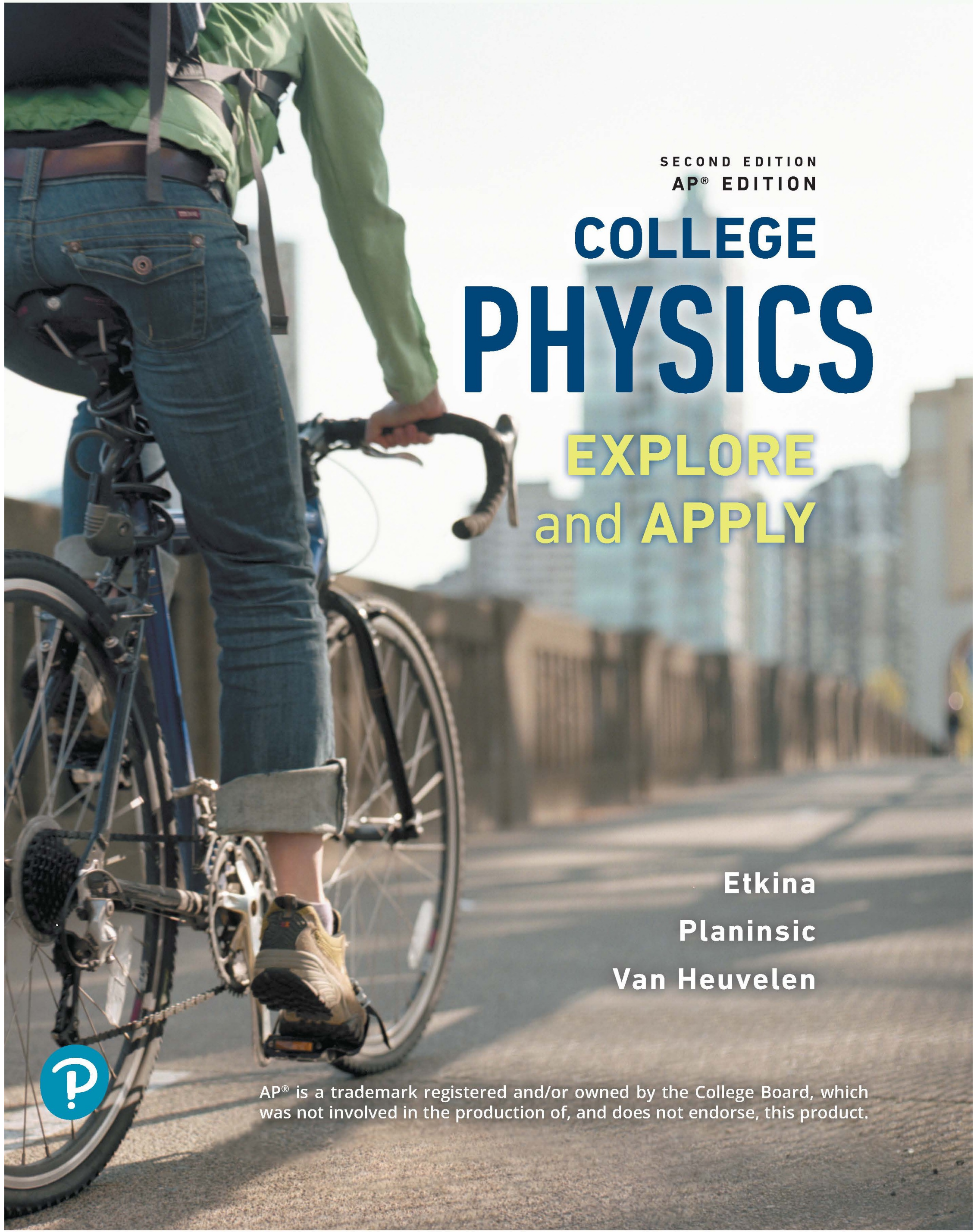
IOP Concise Physics | A Morgan & Claypool Publication

Investigative Science Learning Environment

When learning physics mirrors doing physics

Eugenia Etkina
David T Brookes
Gorazd Planinsic

IOP | ebooks



Active Learning Guide and
On-line Active Learning Guide

Instructor Guide

Over 300 videos freely
available to use without
adopting anything

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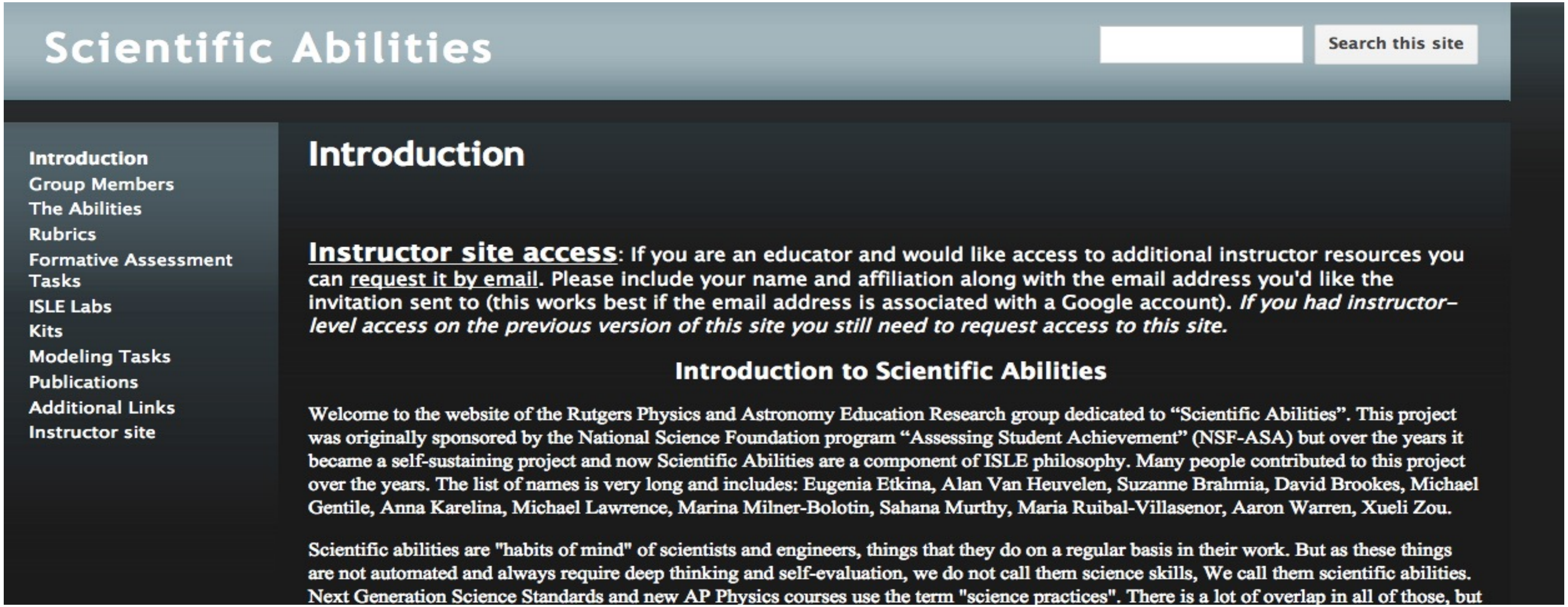
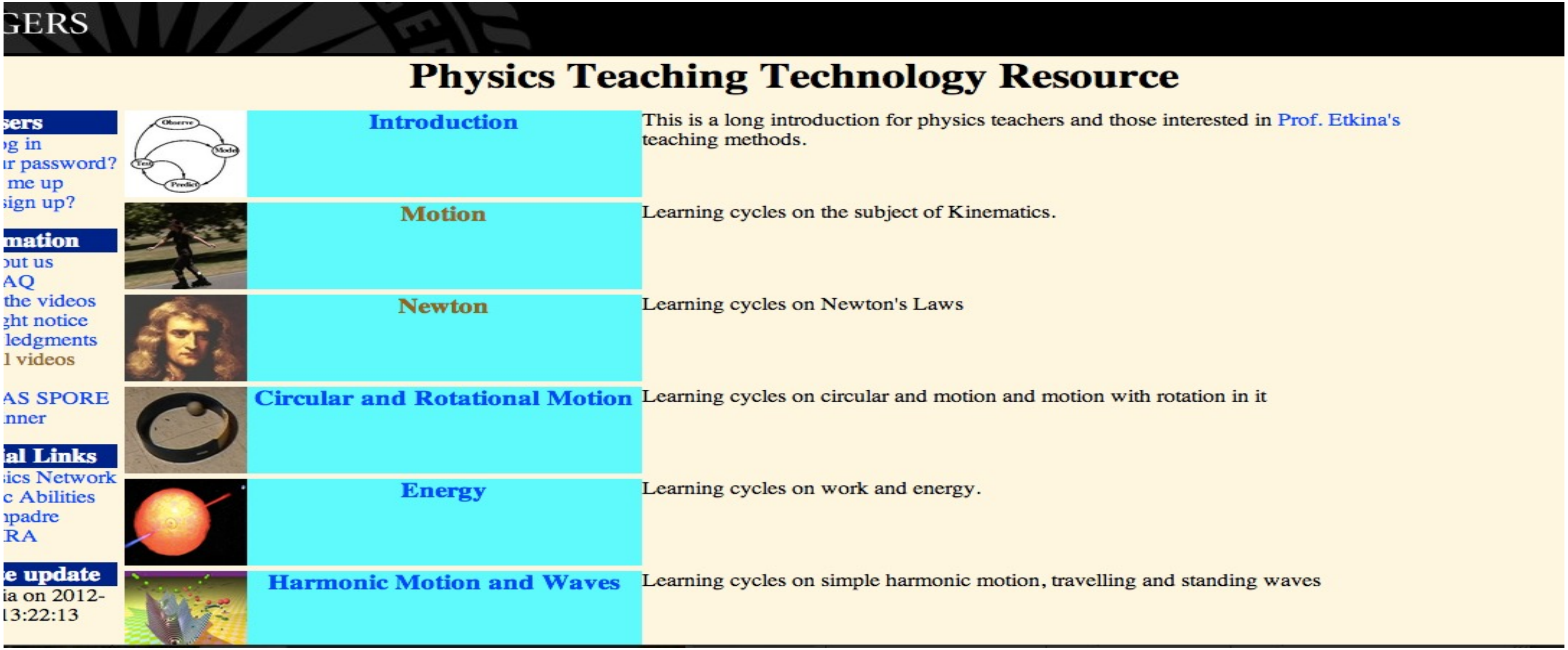


http://www.islephysics.net/pt3/



http://pum.islephysics.net/

RUTGERS

Home | Who are we? | Curriculum | PUM Talks and Events | Teacher Resources

PUM

Physics Union Mathematics

PUM is a physics/physical science curriculum that strongly links middle and high school physics curricula and builds on the intrinsic mathematical reasoning to develop and strengthen students' mathematical concepts at the pre-algebra, algebra and algebra 2 levels. *PUM* curriculum consists of logically connected modules that allow students to build their conceptual understanding of physics concepts, develop relevant mathematical reasoning and simultaneously learn how to think like scientists. The following modules are developed and are available upon request:

- Physics I (these can be used in middle school physical science courses, high school physical science courses, and high school conceptual physics courses): Motion; Forces, Energy, Matter.
- Physics II: (can be used in all high school physics courses including AP B): Kinematics, Dynamics, Momentum, Energy, Electrostatic Forces, Electric Fields, DC circuits (circular motion, geometrical optics and magnetism are under development).

PUM modules contain lesson activities, homework questions, daily quiz questions and final tests. They use simple equipment that any school is likely to have. In case of the lack of needed equipment, Rutgers has a small lending library. The modules work with any textbook and can be implemented "as is" or used to supplement any materials that the teacher already uses. Each module contains about 20-25 lessons.

To obtain the password to download the PUM modules, please contact E. Etkina at eugenia.etkina@gse.rutgers.edu

In *PUM*

- Students learn physics by engaging in practices similar to that of physicists constructing and

PUM Events

Monday, July 7	
9:00am	PUM Worksho
Tuesday, July 8	
9:00am	PUM Worksho
Wednesday, July 9	
9:00am	PUM Worksho
Thursday, July 10	
9:00am	PUM Worksho
Friday, July 11	
9:00am	PUM Worksho
Sunday, July 27	

ISLE-oriented physics teaching computer games

http://www. universeandmore.com

Matt Blackman, Ridge High school, 2012-now

Thank you!

eugenia.etkina@gse.rutgers.edu