The Investigative Science Learning Environment approach (ISLE):
When learning physics mirrors doing physics

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Physics Education Research

Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses

Richard R. Hake[a)]
Department of Physics, Indiana University, Bloomington, Indiana 47405

(Received 6 May 1996; accepted 4 May 1997)

1998

Where's the evidence that active learning works?

2006

Joel Michael
Department of Molecular Biophysics and Physiology, Rush Medical College, Chicago, Illinois

Active learning increases student performance in science, engineering, and mathematics

2014

Scott Freeman[a,1], Sarah L. Eddy[a], Miles McDonough[a], Michelle K. Smith[b], Nnadozie Okoroafor[a], Hannah Jordt[a], and Mary Pat Wenderoth[a]

Secondary analysis of teaching methods in introductory physics: A 50 k-student study

2016

Joshua Von Korff[a)]
Department of Physics and Astronomy, Georgia State University, Atlanta, Georgia 30303

Benjamin Archibeque and K. Alison Gomez

We engage students in active learning.

But what should students learn?

OECD: The future of education and skills
Education 2030 (2018)

Organization for Economic Cooperation and Development

Position paper on what knowledge, skills, attitudes and values today's students will need to thrive and shape their world in future.

OECD: The future of education and skills *Education 2030 (2018)*

Position paper on what knowledge, skills, attitudes and values today's students will need to thrive and shape their world in future.

Disciplinary knowledge will continue to be important….

Epistemic knowledge, or knowledge about the disciplines, such as knowing how to think like a mathematician, historian or scientist, will also be significant, enabling students to extend their disciplinary knowledge.

Procedural knowledge is acquired by understanding how something is done or made …. It typically develops through practical problem-solving…

Next Generation Science Standards (US, 2013)

"Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of HOW those facts were established MISREPRESENTS science."

Three of the major challenges of today's physics education

1. How to achieve active engagement of students at all levels of teaching/learning process?

2. How to help students develop epistemic knowledge of the discipline (how to think like a physicist)?

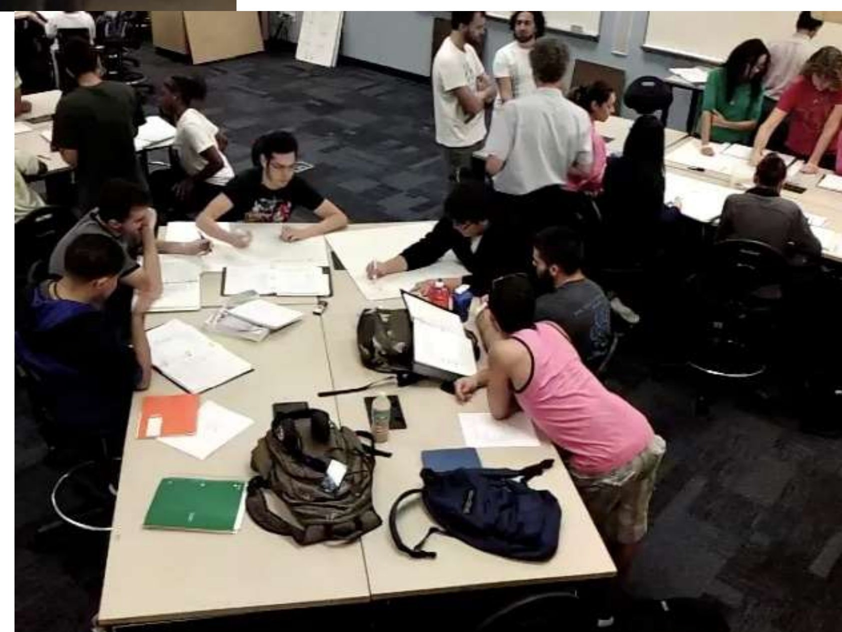
3. How to ensure that all students feel welcome in a physics course, enjoy learning physics, and want to pursue STEM careers?

What is the ISLE approach?

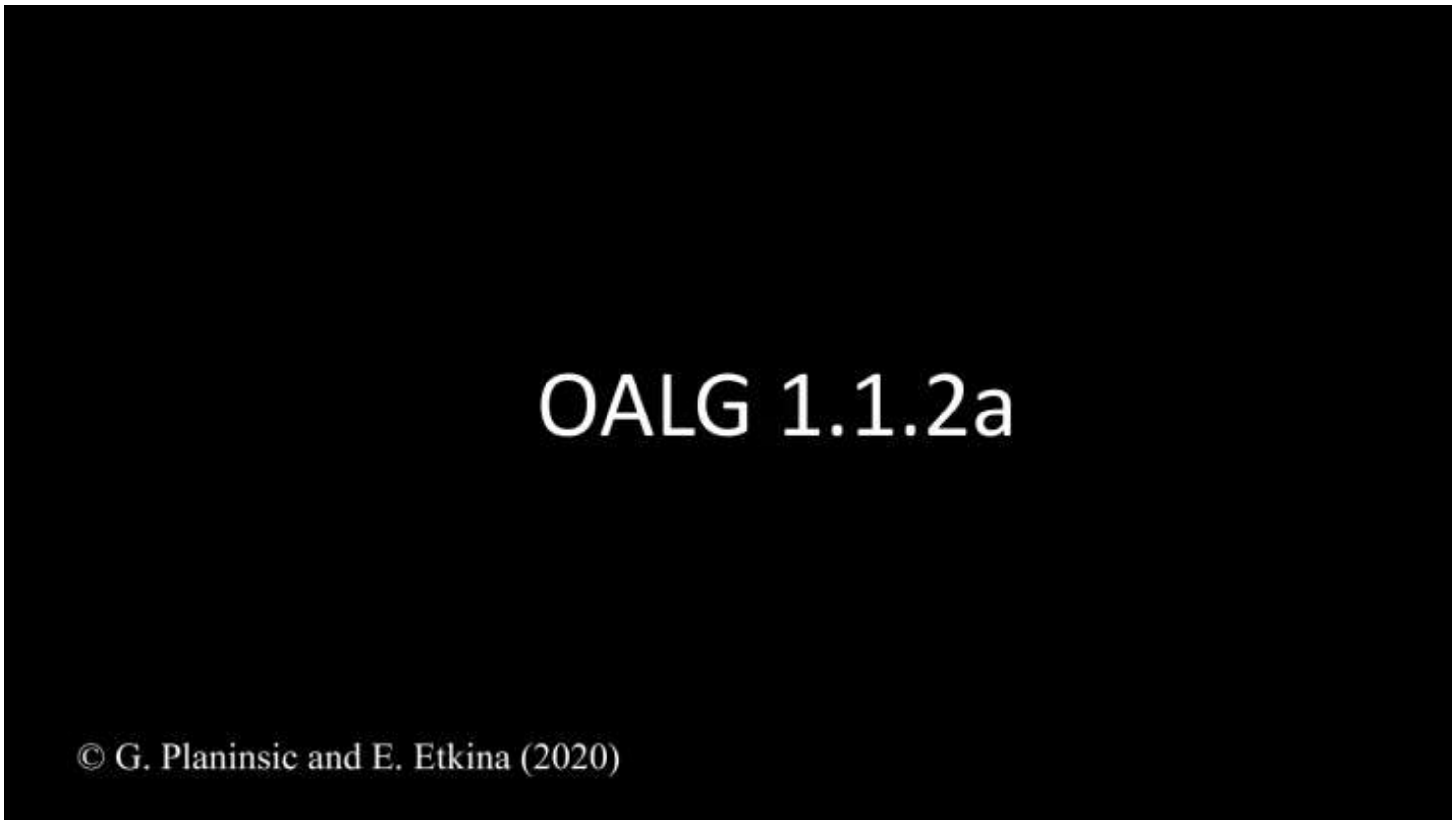
The Investigative Science Learning Environment approach to learning and teaching physics

Rutgers University

Florida International University



A simple example of the ISLE approach in action



What did you observe?

State in simple words that a 5 year-old can understand.

Glass got wet on the outside.

We can see water droplets on the outside.

Come up with a “wild idea” of where the water came from and to design an experiment to test their idea.

Wild idea: Water goes out from the top and settles on the outside.

Experiment: Take a glass filled with cold water and cover it.

Prediction based on the wild idea: It should not get wet.

Etkina et al., On-line Active Learning Guide 2020

Where did the water come from?

~~Goes out from the top and settles on the outside~~

Sips through the glass.

Take an empty glass, put it into a cold place and then take out. It should not get wet.

Etkina et al., On-line Active Learning Guide 2020


Organic
KIRKLAND
Signature
ORGANIC
STRAWBERRY SPREAD
Made with
KIRKLAND
Signature
Spanish Quee
Whole
Milk
Trader Joe's Organic Preserves are
TRADER JOE'S

Where did the water come from?

~~Goes out from the top and settles on the outside~~

~~Sips through the glass~~

The material of the glass ”sweats” and the water comes from the material of the glass.

Pour another cold liquid into the glass. There should still be water on the outside.

Etkina et al., On-line Active Learning Guide 2020

Where did the water come from?

~~Goes out from the top and settles on the outside~~

~~Sips through the glass~~

The glass ”sweats” Failed to reject

Water comes from the outside air.

Use a scale. If “glass sweats”, the mass should stay the same or decrease. If the water comes from the outside air, the mass should increase.

Etkina et al., On-line Active Learning Guide 2020

[redacted]

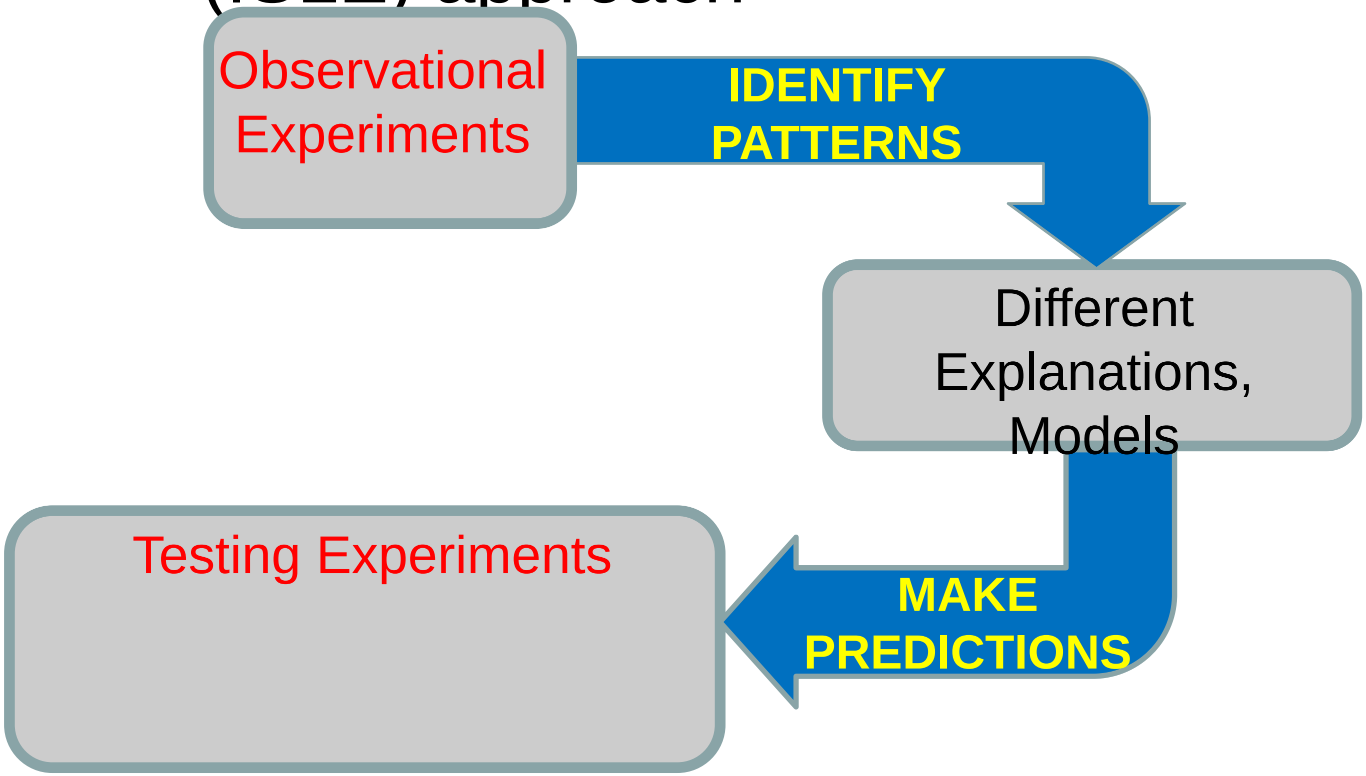
WatAir Dew Harvesting
System Provides Safe
Drinking Water

The Investigative Science Learning Environment (ISLE) approach

Observational Experiments

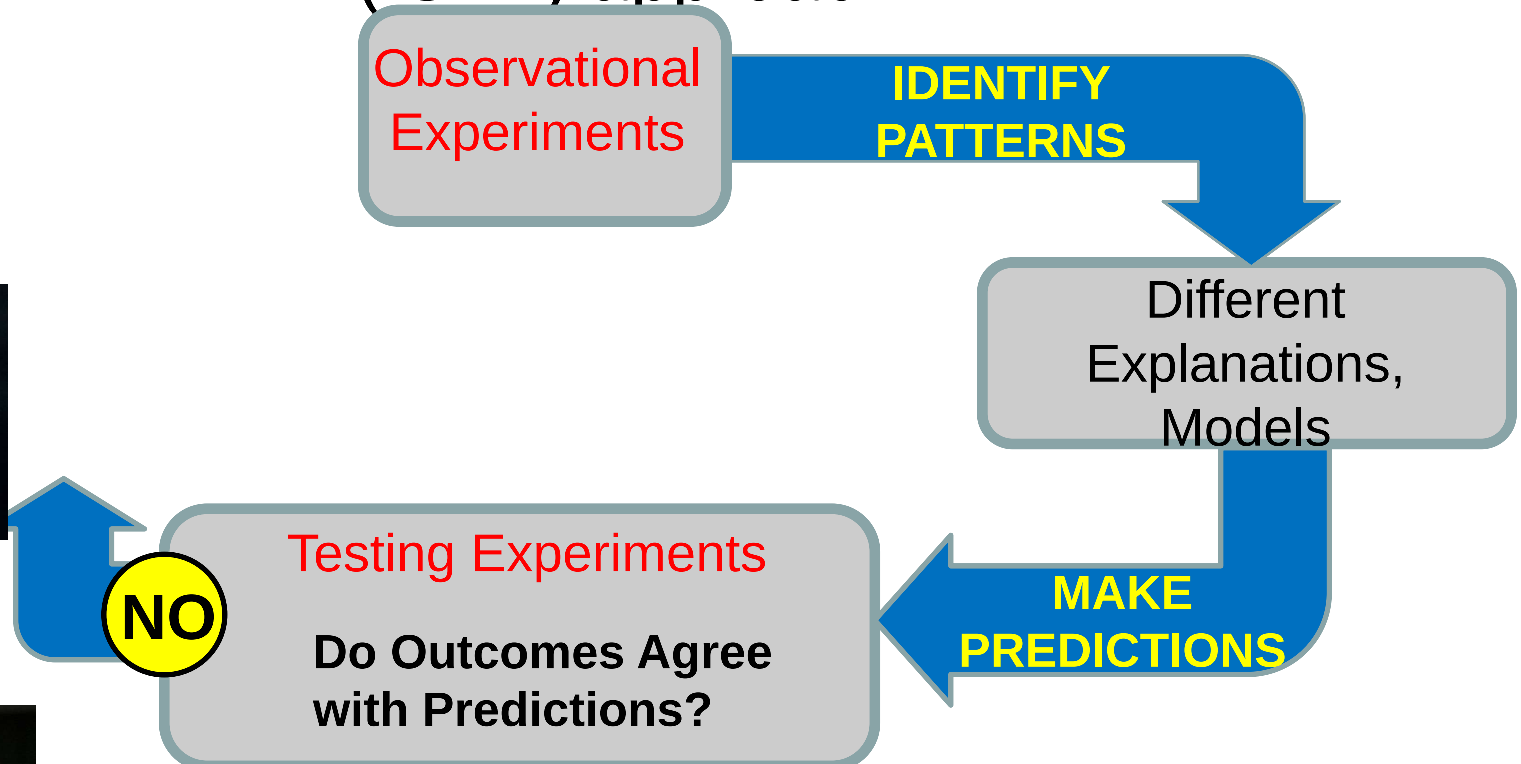
IDENTIFY PATTERNS

The Investigative Science Learning Environment (ISLE) approach

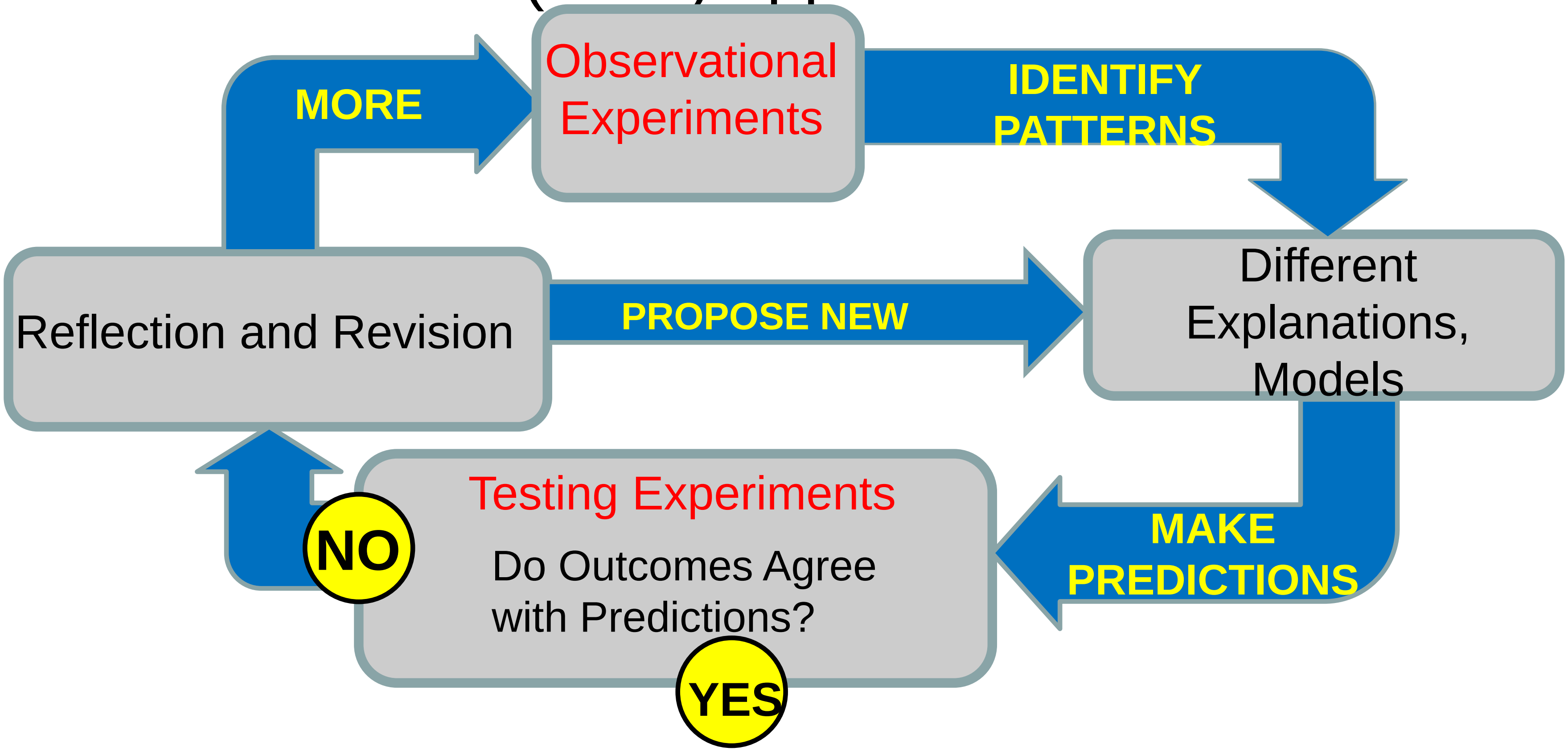


Water coming from the top, sipping through,
coming from the material, coming from the outside.

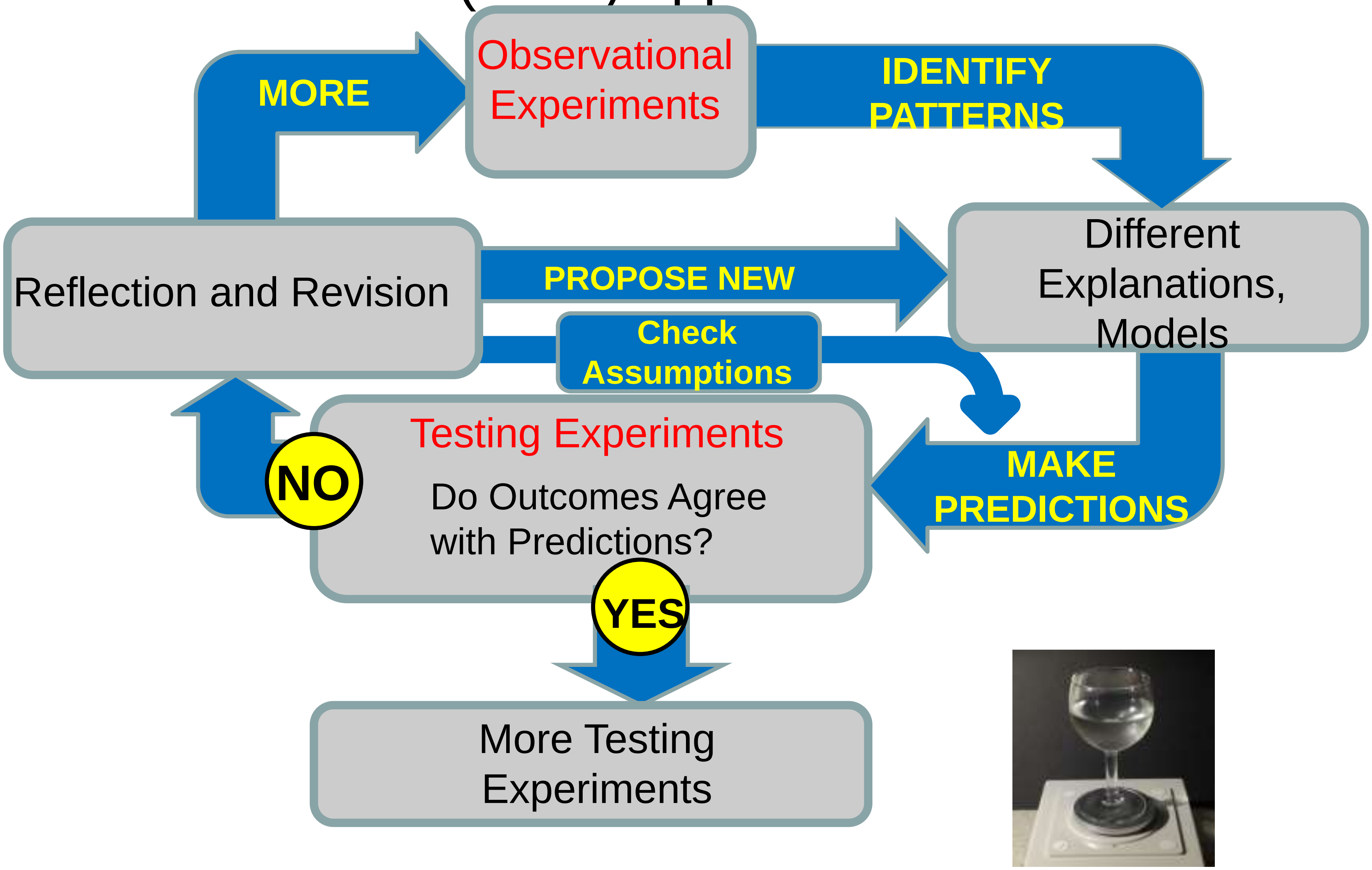
The Investigative Science Learning Environment (ISLE) approach



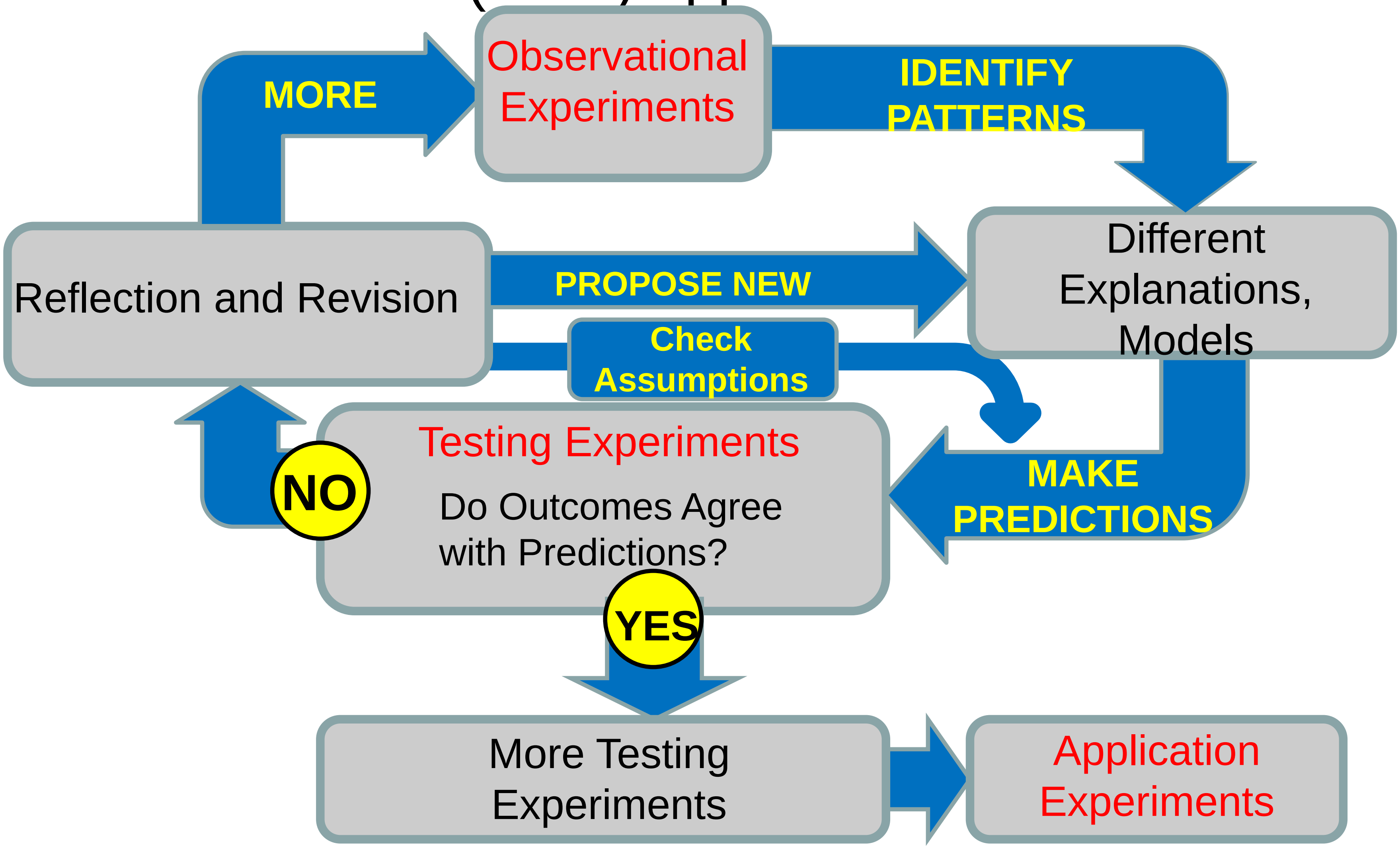
The Investigative Science Learning Environment (ISLE) approach



The Investigative Science Learning Environment (ISLE) approach

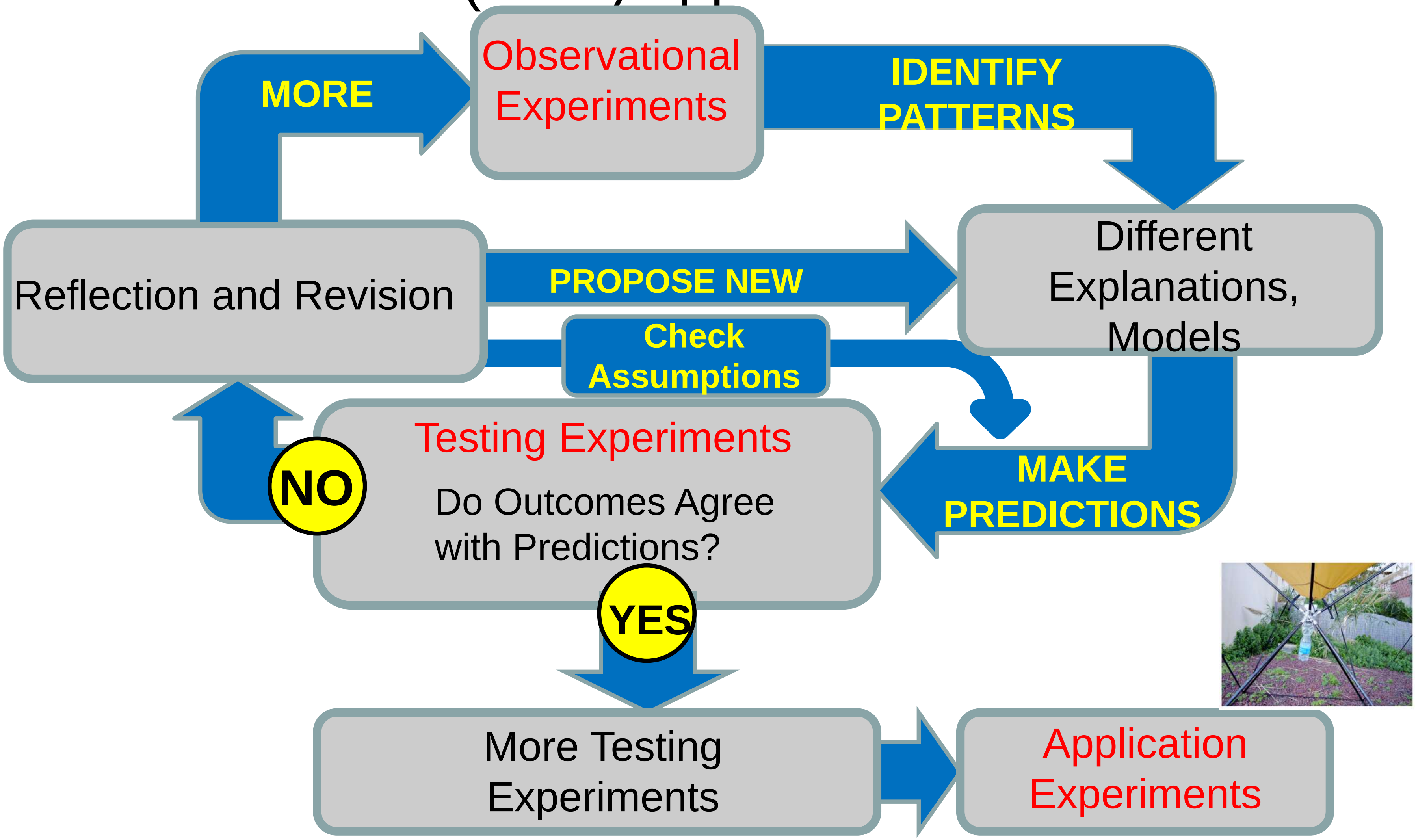


The Investigative Science Learning Environment (ISLE) approach



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

The Investigative Science Learning Environment (ISLE) approach



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

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.

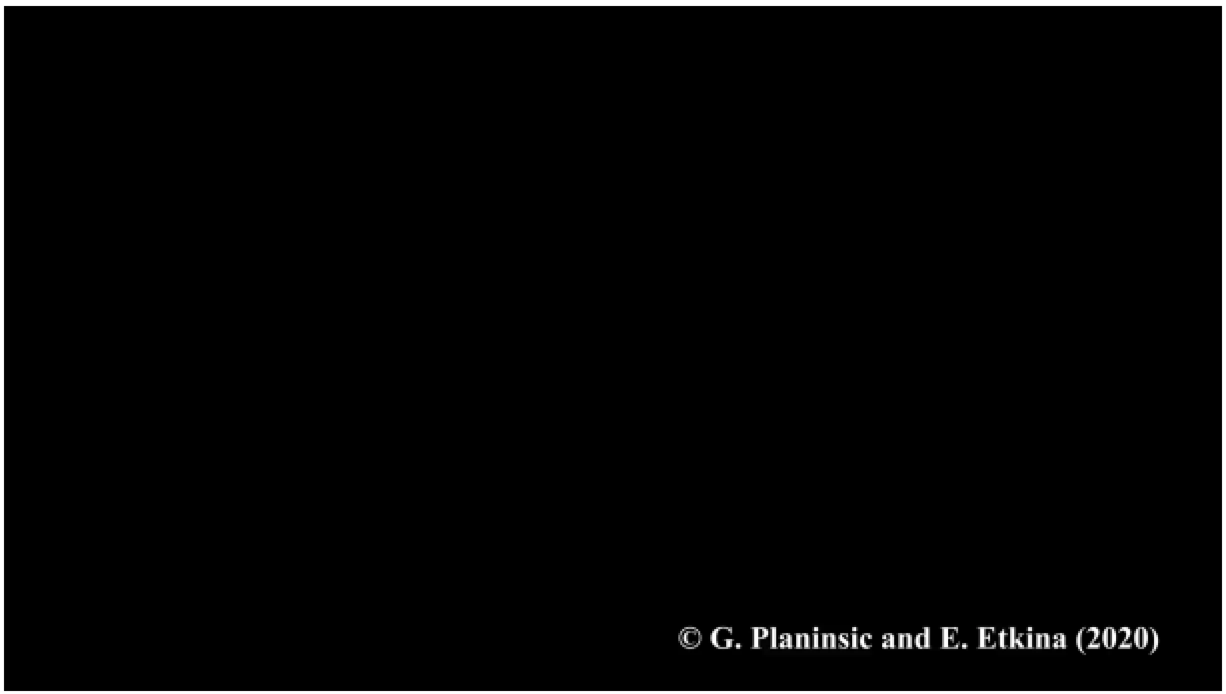
It looks like it is not a good explanation. Maybe UV light kicks electrons out of the zinc plate?

If this is correct, then the neutral electroscope should become positively charged when UV light shines on it.

Why didn’t the electroscope get charged? Oh, we assumed that if the electrons get ejected, they leave the electroscope. Maybe the electroscope does get charged but the electrons come back to the positively charged electroscope… How can we test that?

If our reasoning is correct, then the electroscope on which we shone UV light should be charged positively.

How can we check this?



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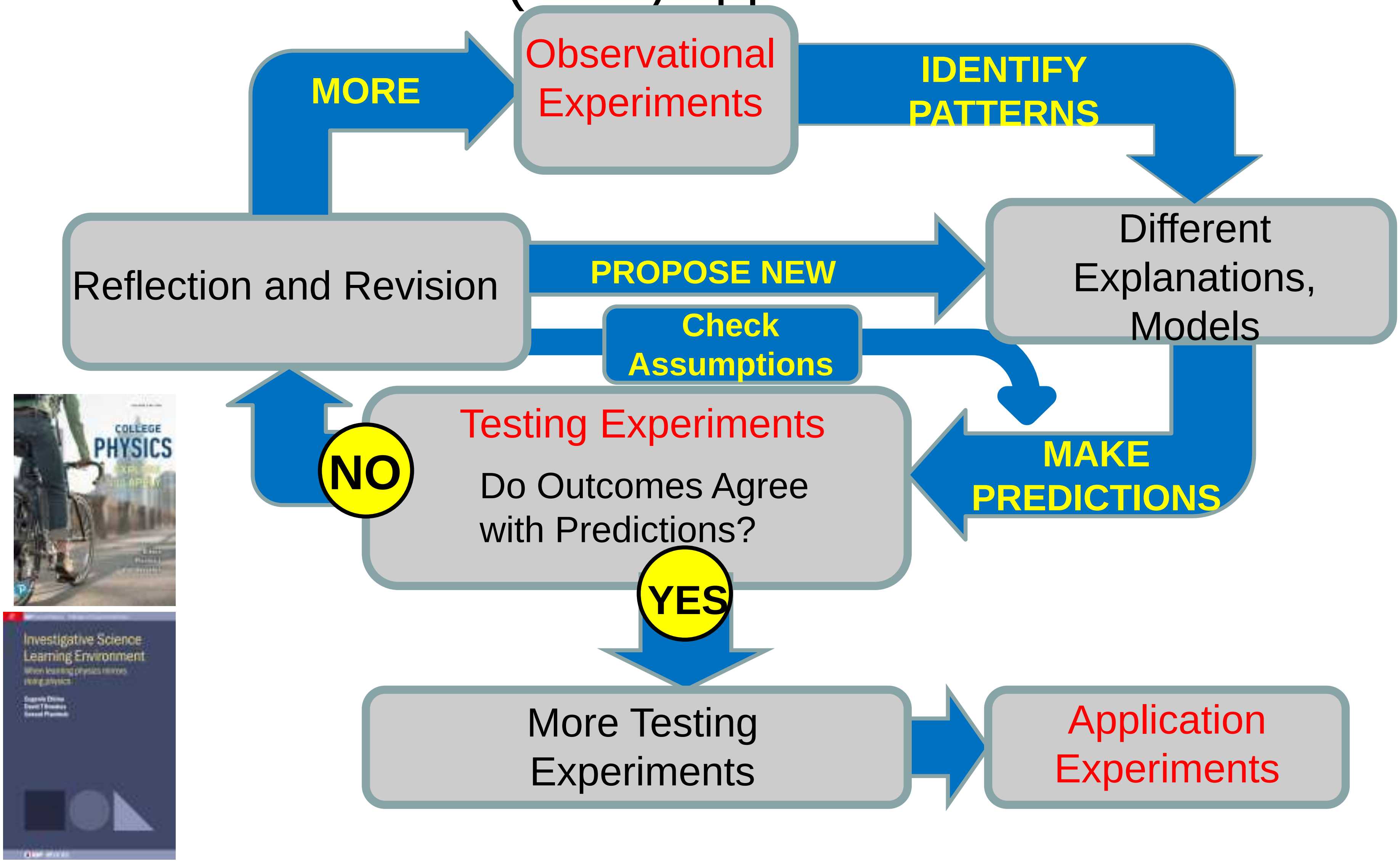

Etkina and Van Heuvelen, 2001, 2007; Etkina, 2015, Etkina et al., 2019

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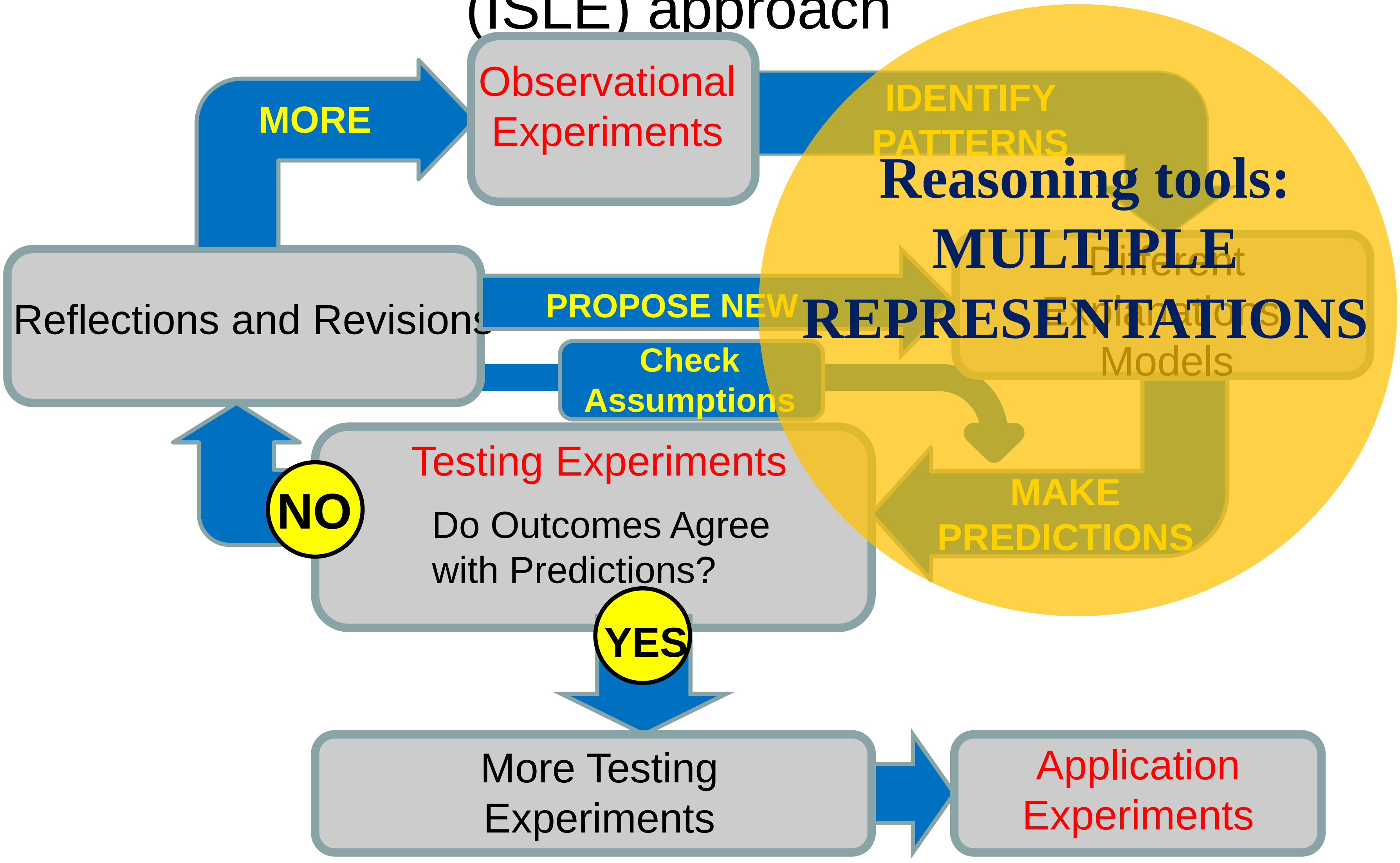

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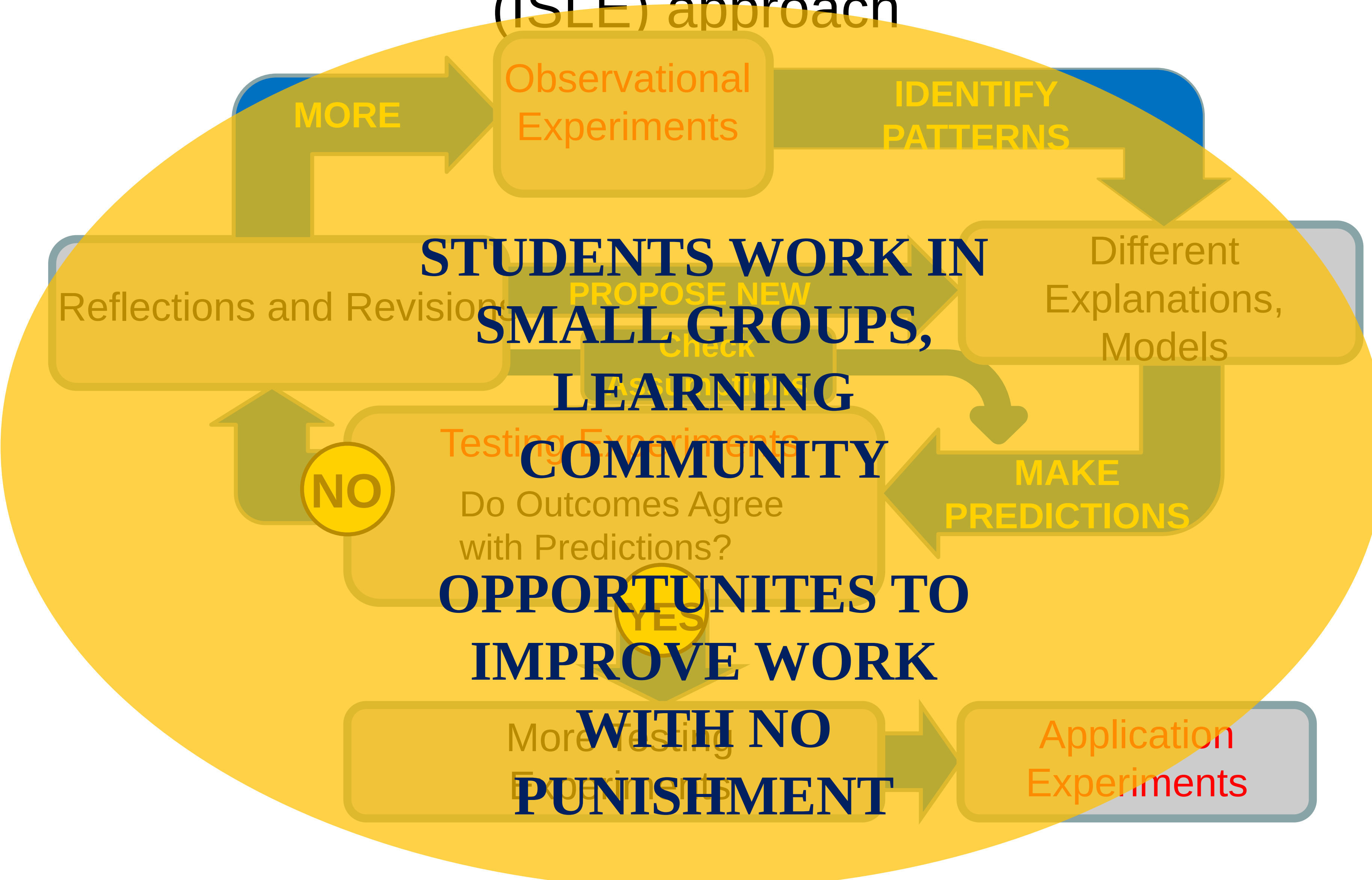


The ISLE approach– an intentional approach to curriculum design

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.

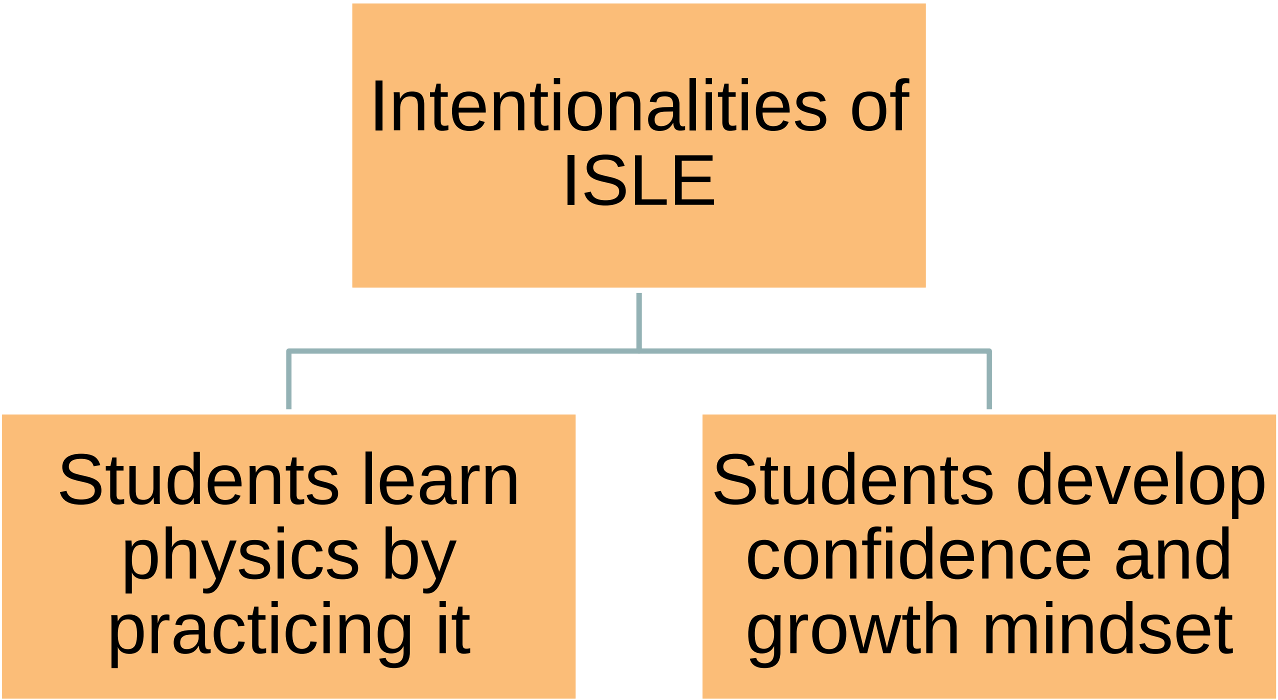
What and how students learn

How students feel about learning physics

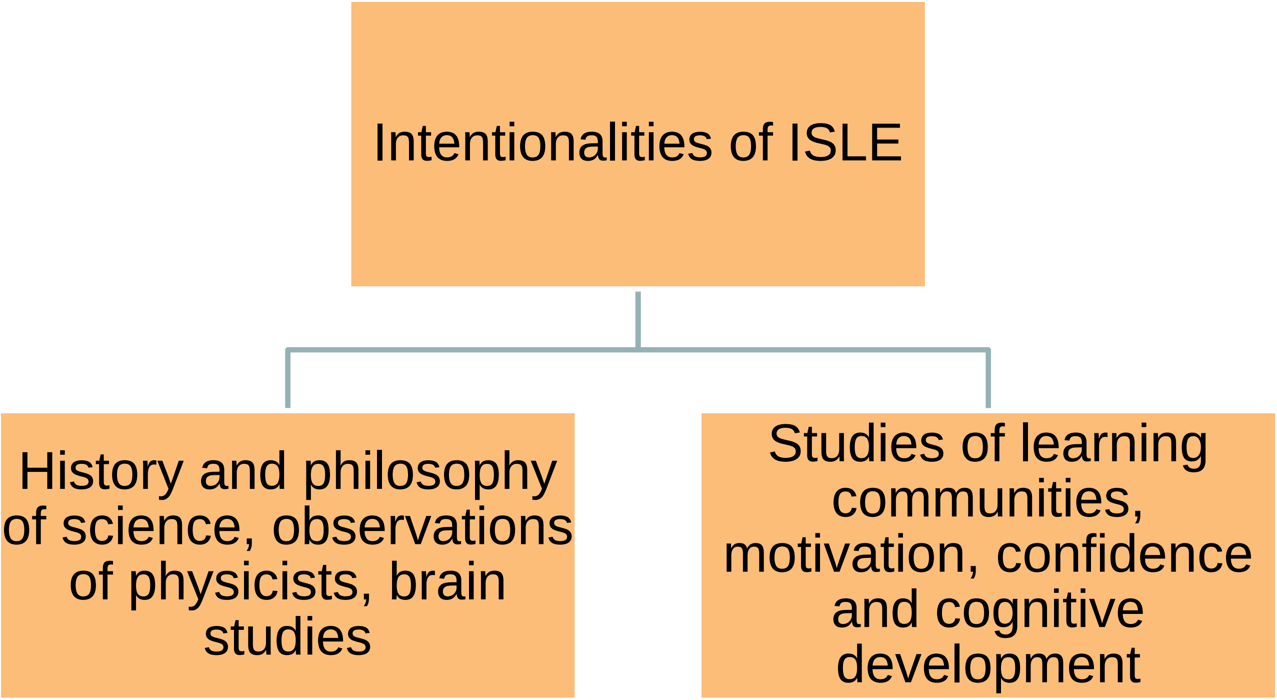
Intentionality: the product of knowledge cannot and should not be separated from the means by which it came to be known.

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

The ISLE approach– an intentional approach to curriculum design

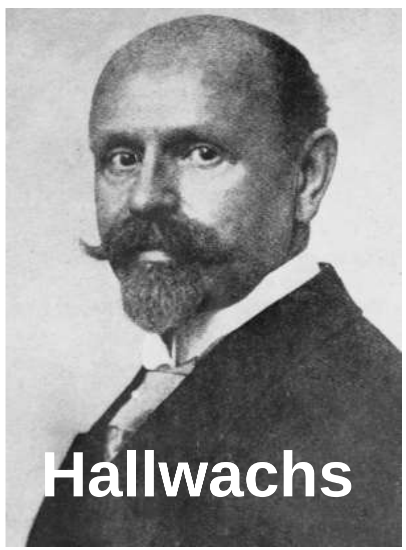


The ISLE approach– an intentional approach to curriculum design

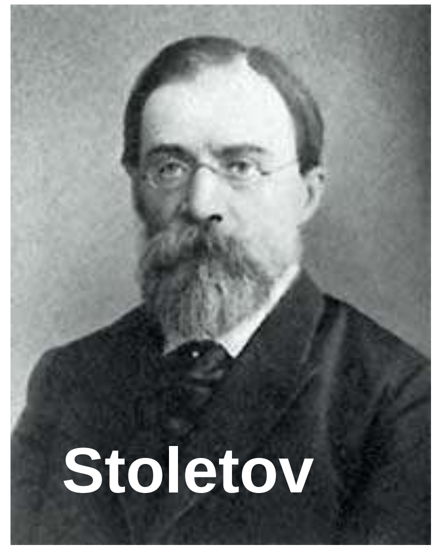


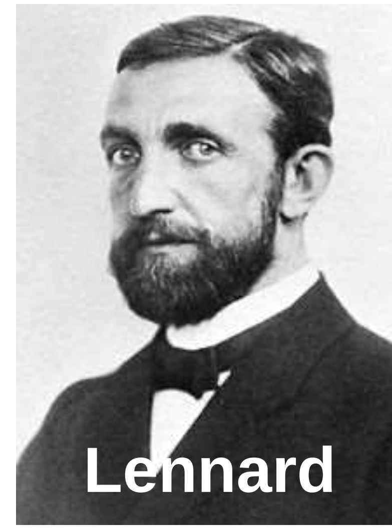
History of science: Photoelectric effect

Accidental observation



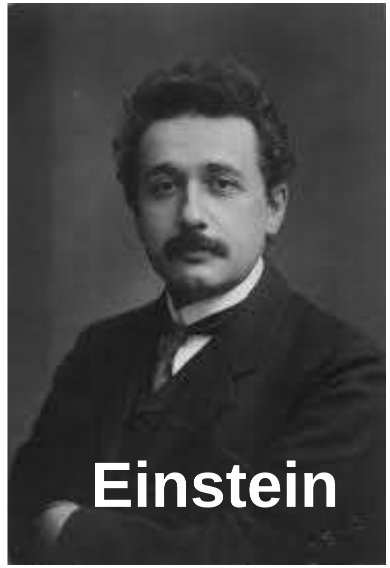
Qualitative observational experiments





Quantitative observational experiments and explanations

Assumption

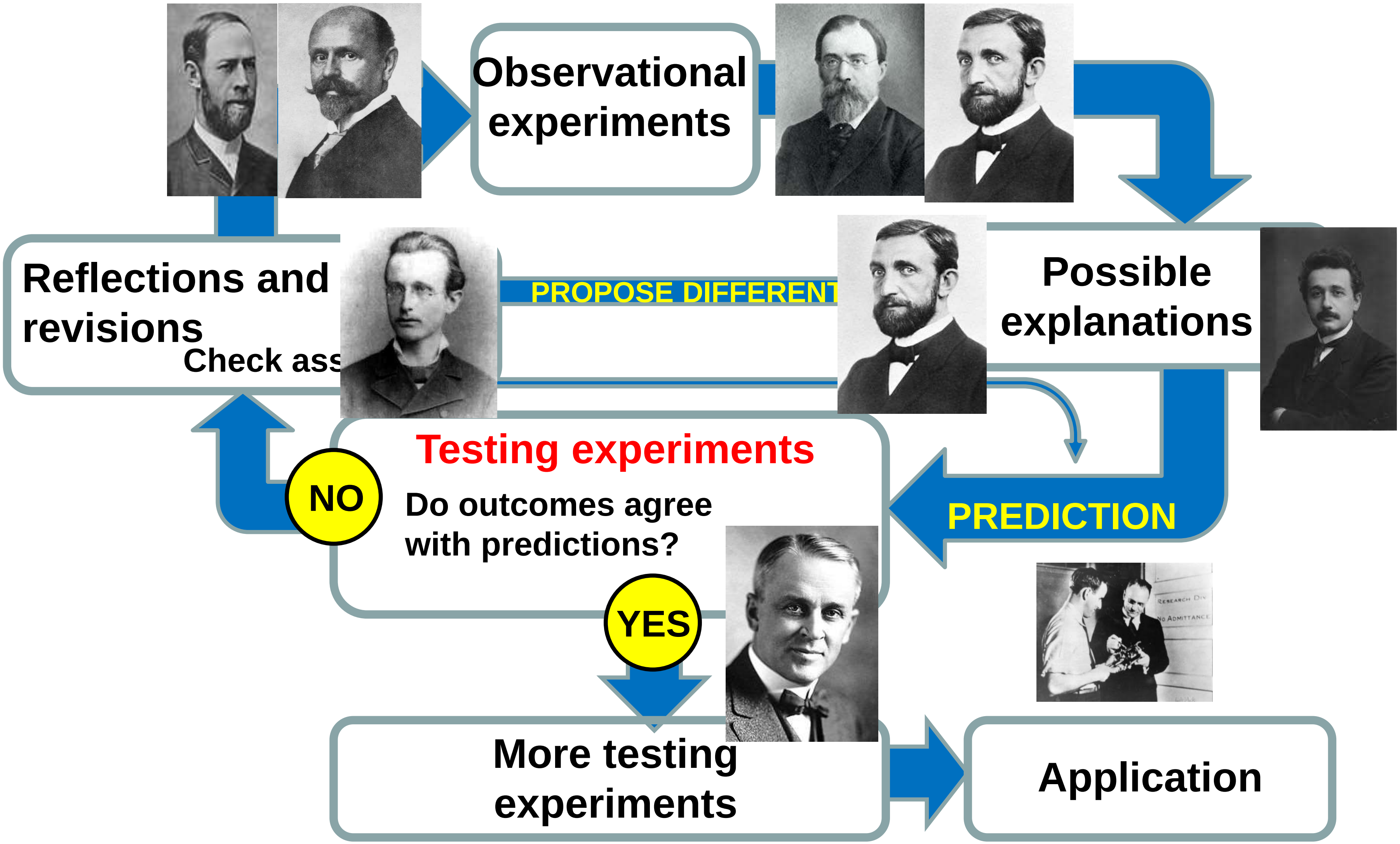


Explanation

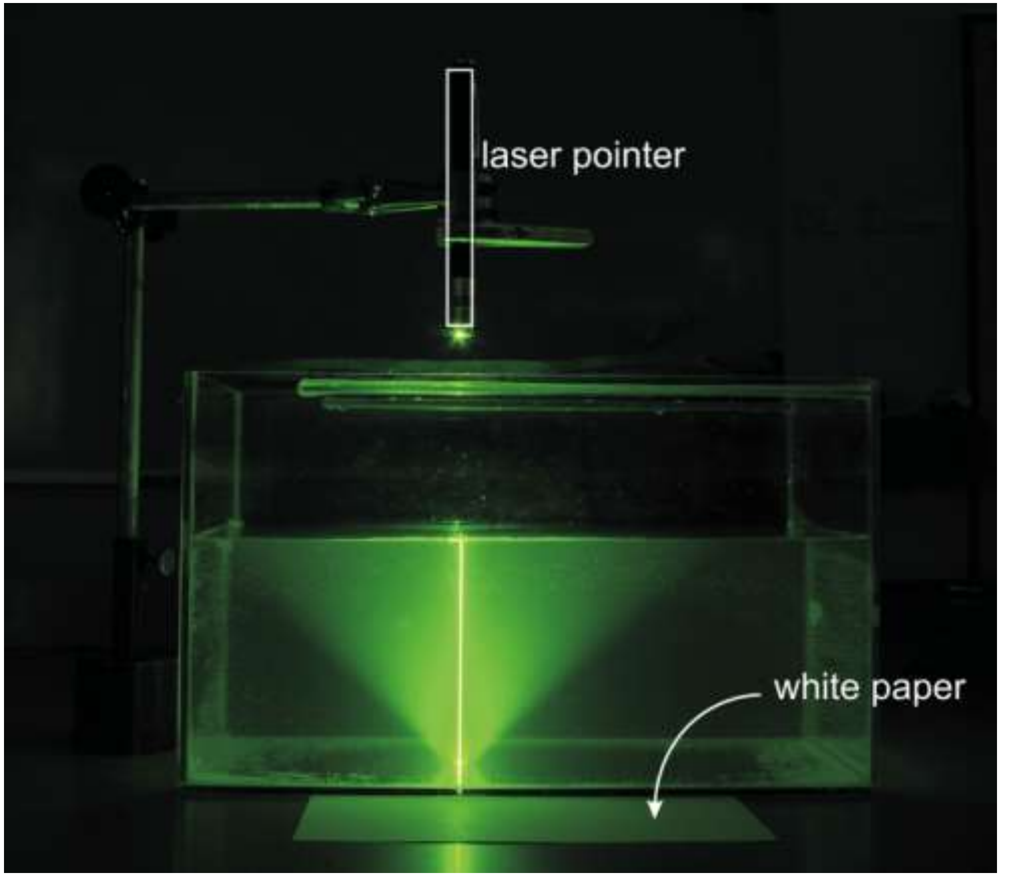
Testing experiment, prediction, outcome

Application (photomultiplier tube)

Investigative Science Learning Environment - ISLE



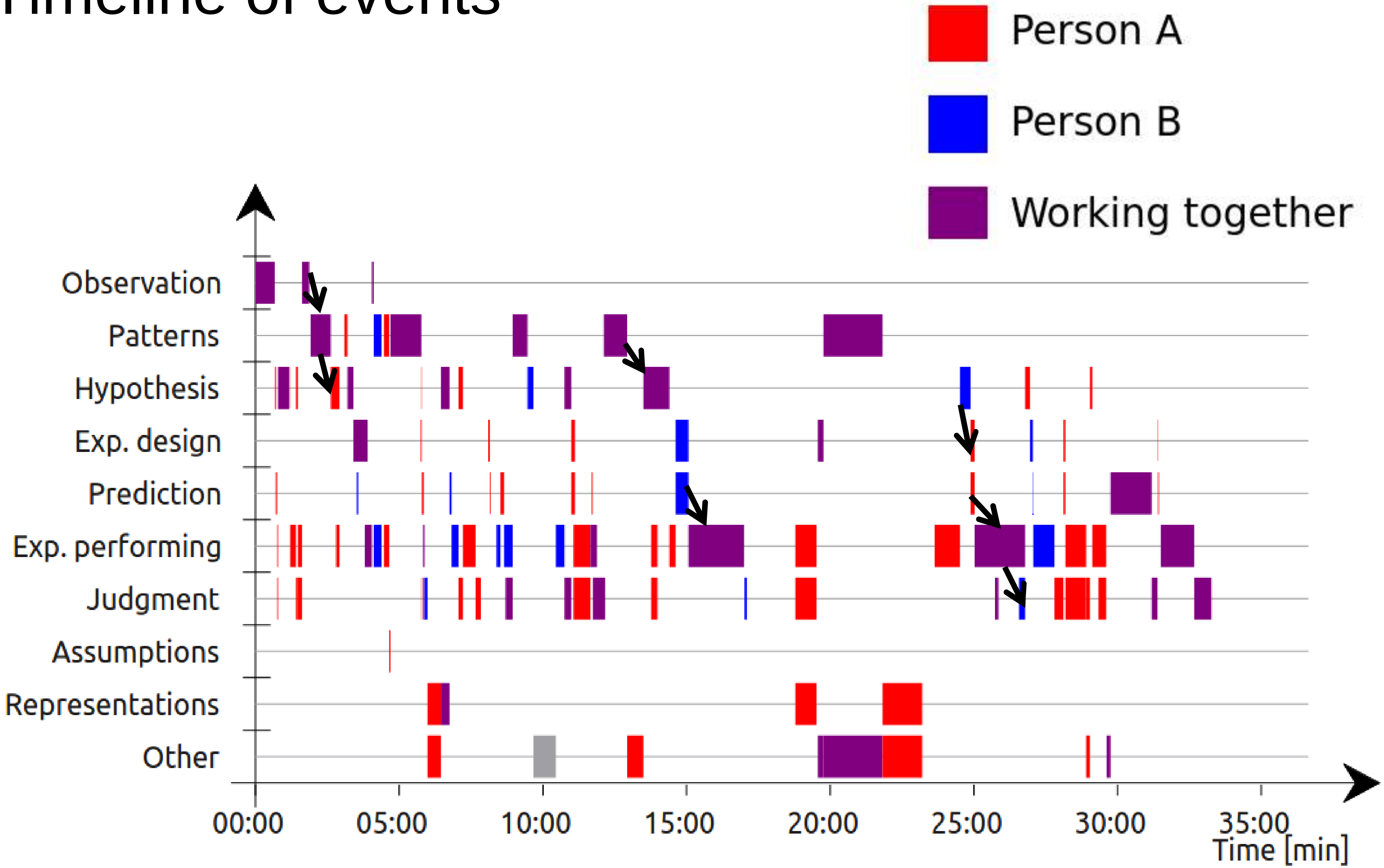
How do we know that physicists actually work this way in real time?



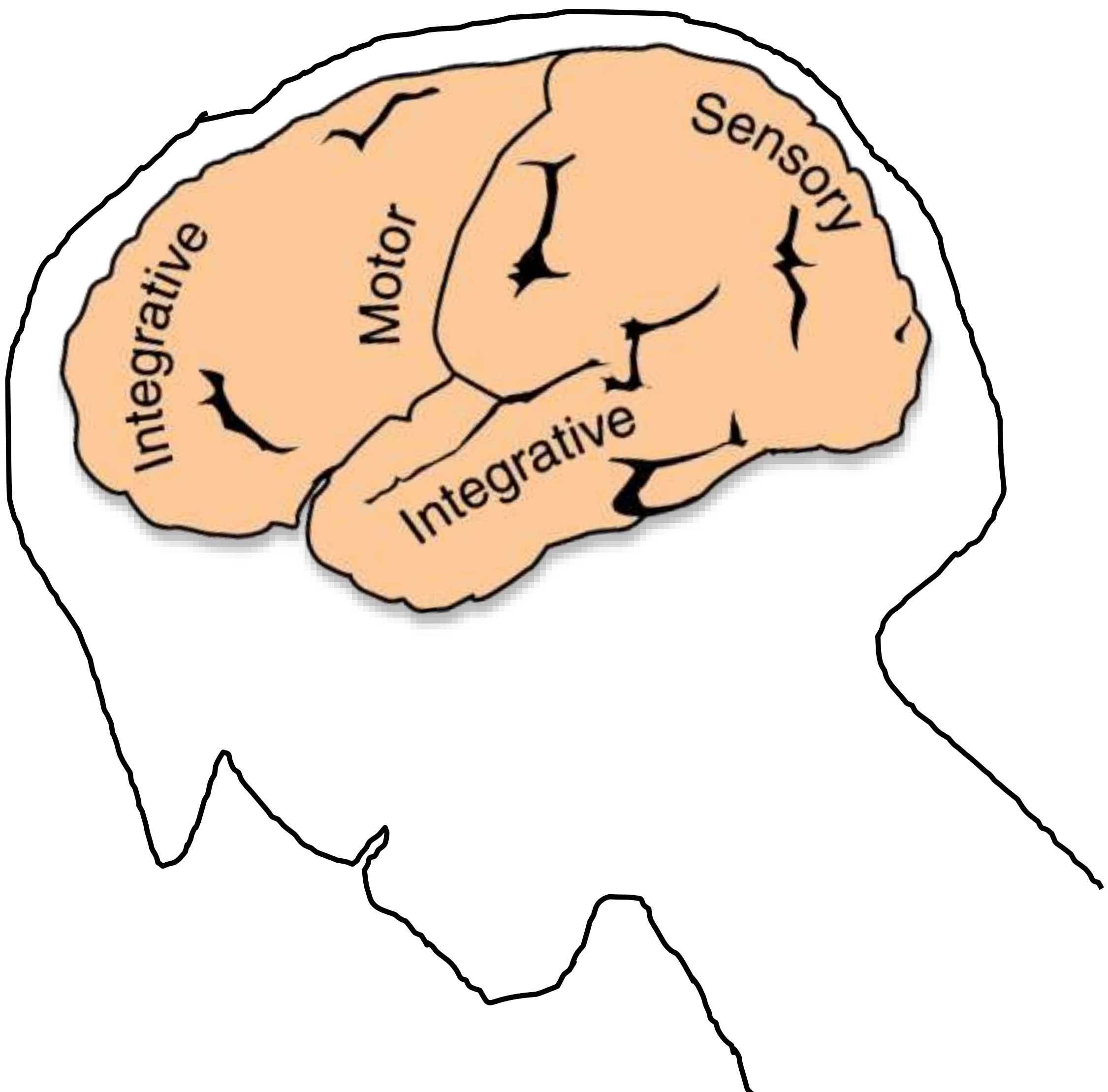
Study of expert physicists

Poklinek, Planinsic
and Etkina, AJP, 2015

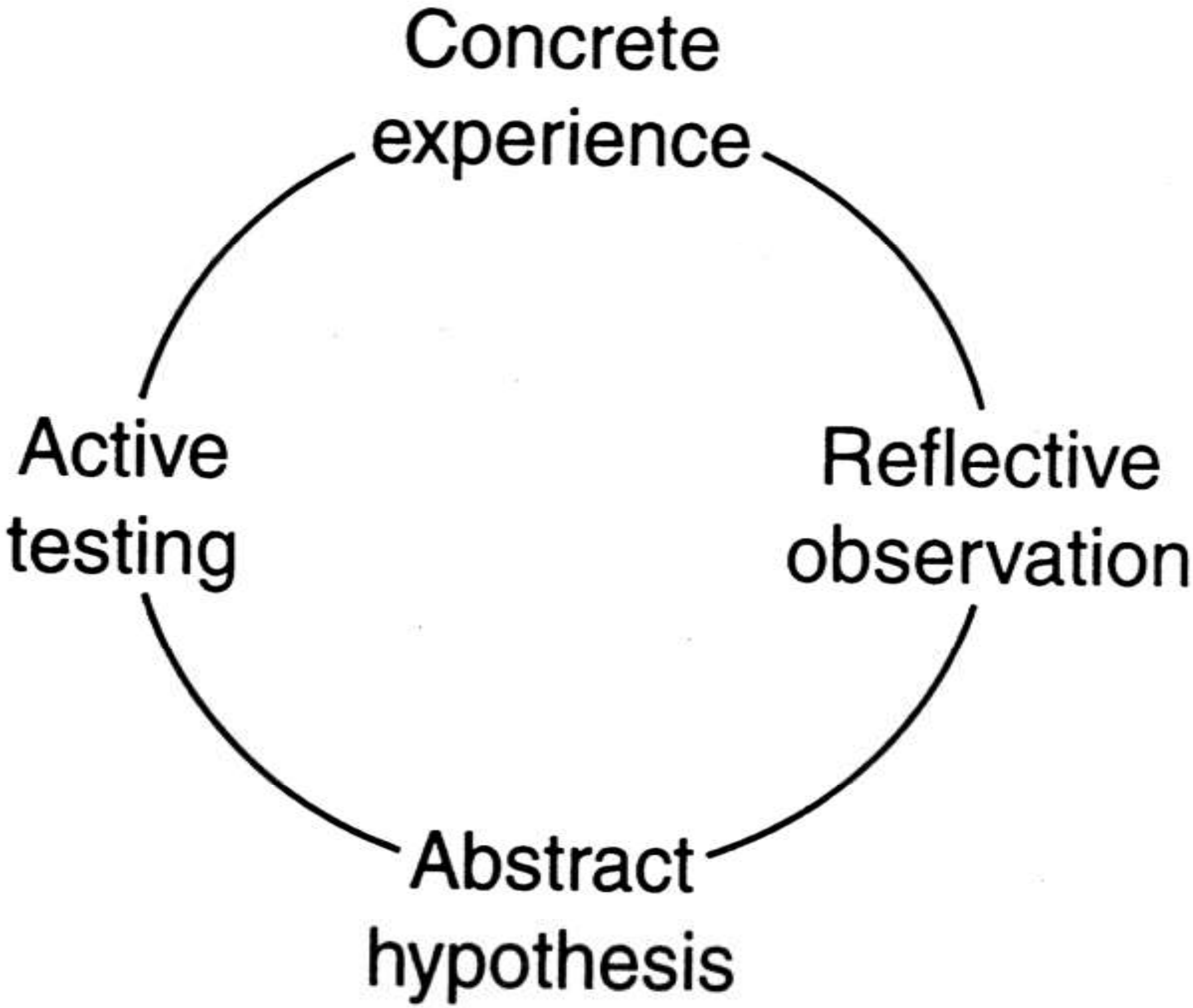
Timeline of events



Brain research

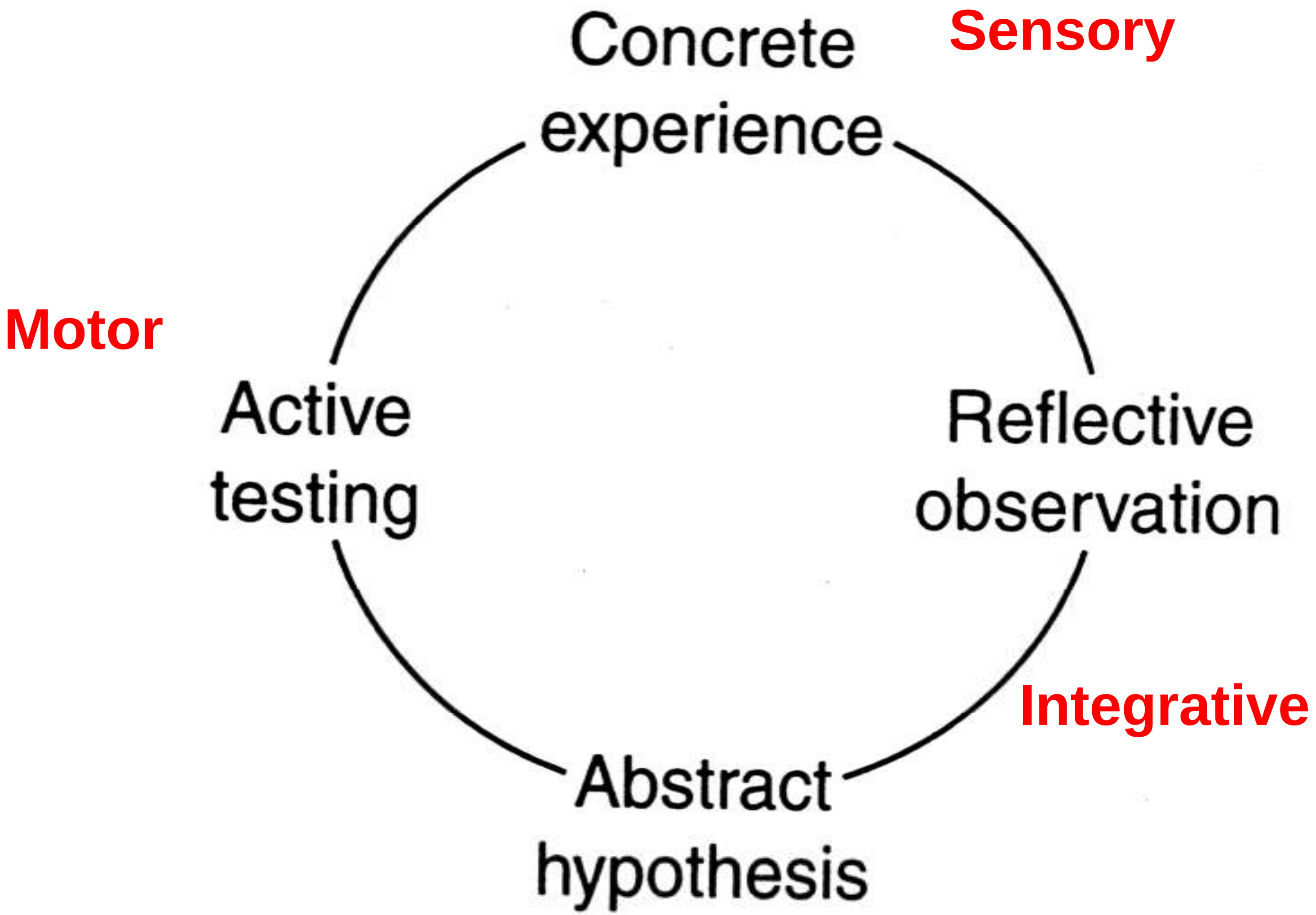


Brain learning cycle



Kolb's brain learning cycle (Kolb, 1984)

Brain learning cycle



According to brain research

Learning is a visible physical change in the neuronal connections in the brain (and the whole body) of the learner.

Zull, The Art of Changing the Brain, 2002

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).

Do we need to teach these ideas to our students?

Dirt

Observe

Looks like chocolate…

Observe

Hypothesize

When eat, will taste like chocolate


Observe
Hypothesize
Predict
Test

They are all skilled in:

Testing ideas experimentally

Perseverance

Working together

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

Then, what is the problem?

The problem is that traditional (and even reformed) teaching goes against much of what we are good at, much of what we know helps people learn, and much of what is needed for success in 21st century:

The answers come before questions – no “need to know”

Ready knowledge is provided – no creativity

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)

Solution? Universal Design for education

The term "universal design" was coined by the architect Ronal Mace to describe the concept of adapting the environment to be accessible by everyone, regardless of their age, ability, or status in life.

What does it have to do with learning physics?

Universal Design for physics education – make physics accessible to all students

Why is the ISLE approach an example of Universal Design for Education? (The argument was made in the book by Julie Maybee, professor of disability studies in her 2019 book “Making and Unmaking Disability”.)

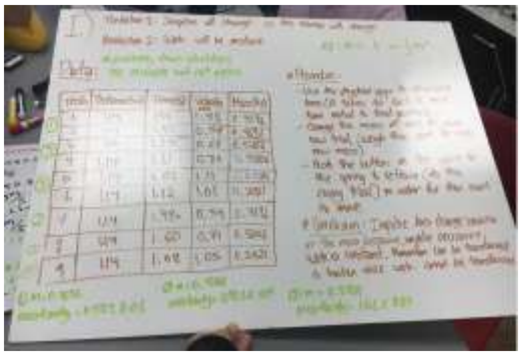
Students learning physics through the ISLE approach:

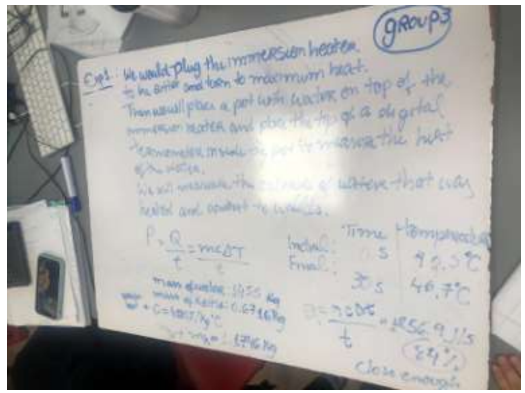
1. Start on the same page – observe simple phenomena – adaptation and confidence
2. Do not use fancy language - adaptation and confidence
3. Use representations that help –adaptation based on bran research
4. Develop their own ideas creatively and test them right away CREATIVELY! – adaptation and encouraged creativity
5. Progress at their own pace – adaptation and growth mindset
6. Improve their work without punishment –adaptation and growth mindset
7. Are a part of a community with shared expertise – confidence, avoiding impostor syndrome
8. Develop productive habits – set up for 21st century success

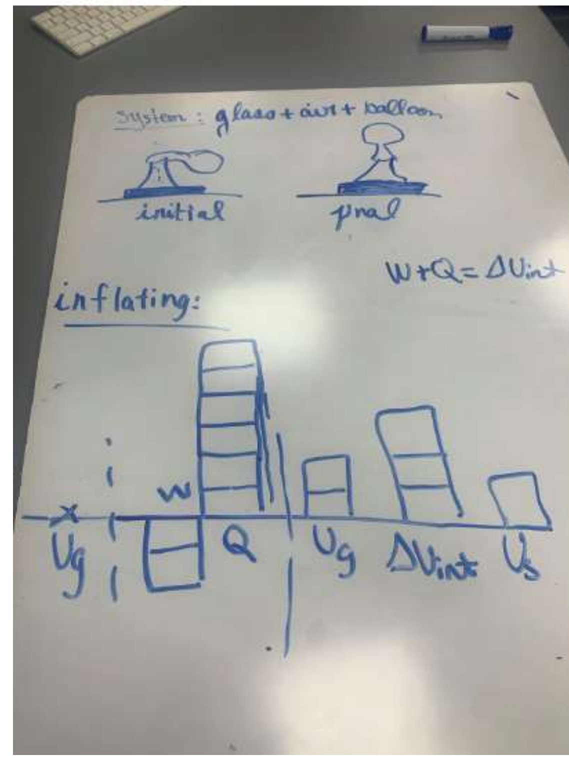


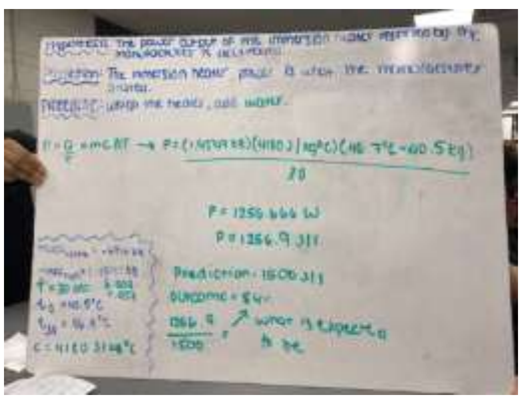


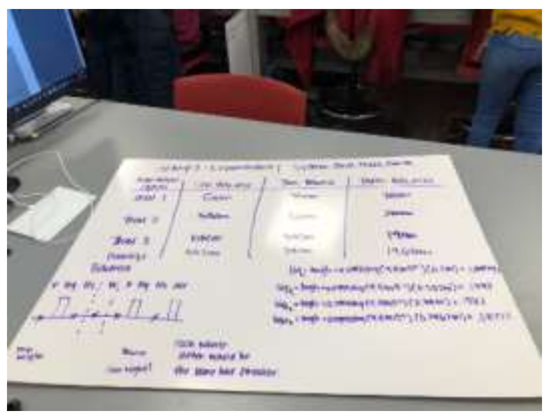

Student whiteboards











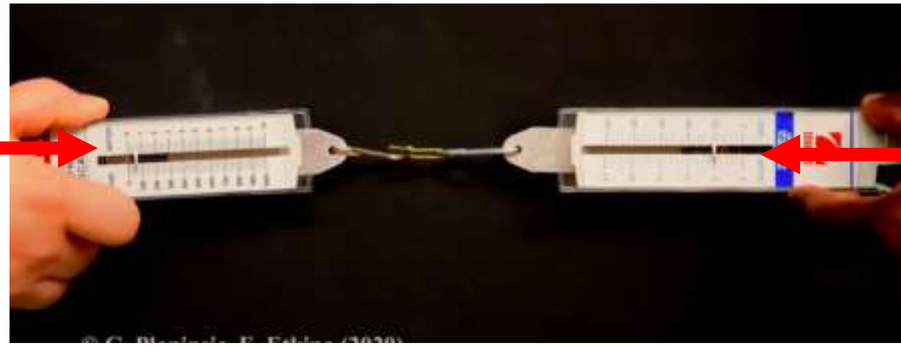
ISLE process depicted on the diagram is a way of thinking about learning and teaching physics – we can apply it to any concept.

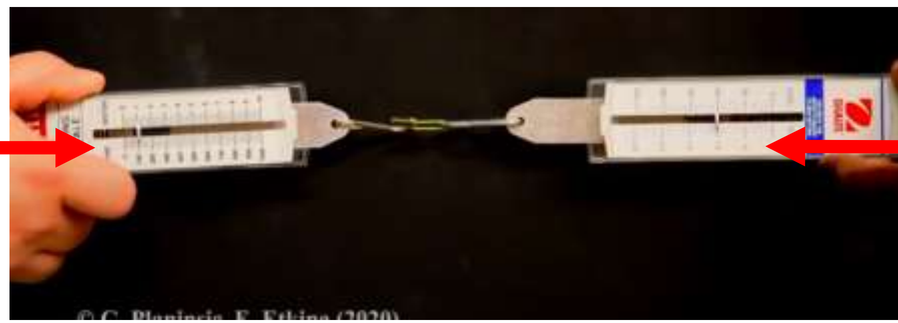
In the ISLE approach the lab is the place where students construct and test ideas and the “lecture” or whole class meeting time is dedicated to activities that are based on what the students did in the lab.

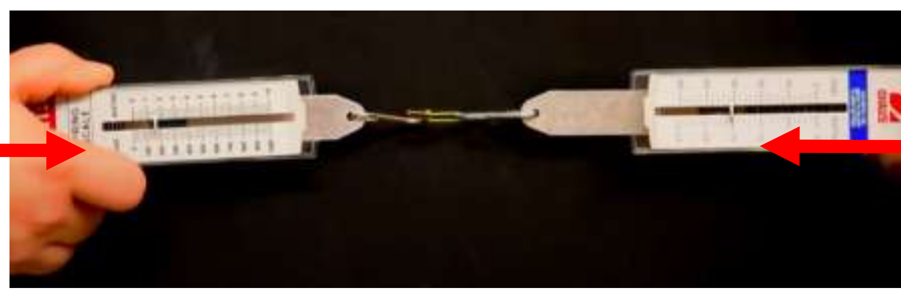
Therefore all students do the same lab during the same week and it is closely coordinated with everything else that they do this week.

Lab: 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

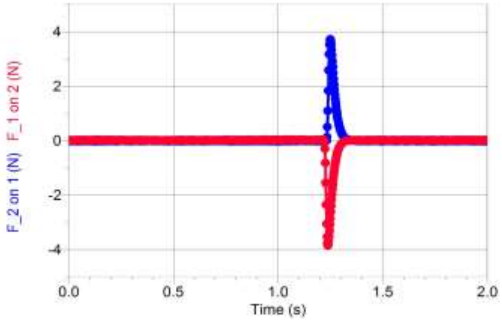
They use tools to analyze patterns

$\boldsymbol{F}_{\textbf{scale 1 exerts on scale 2}}$ $\boldsymbol{F}_{\textbf{scale 2 exerts on scale 1}}$

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.

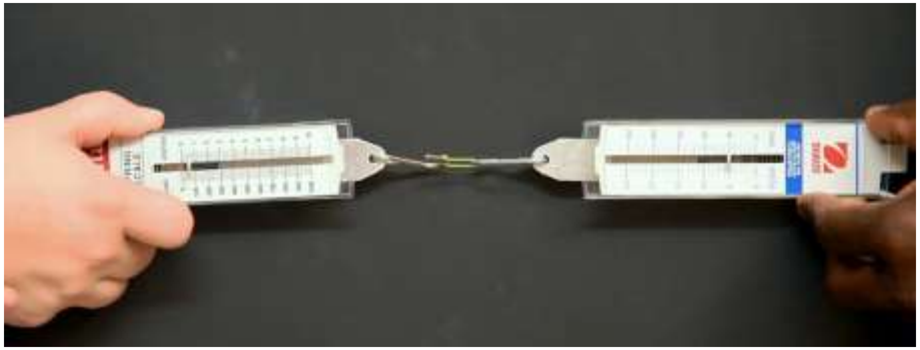
While it sounds rather wild, how can we test it?

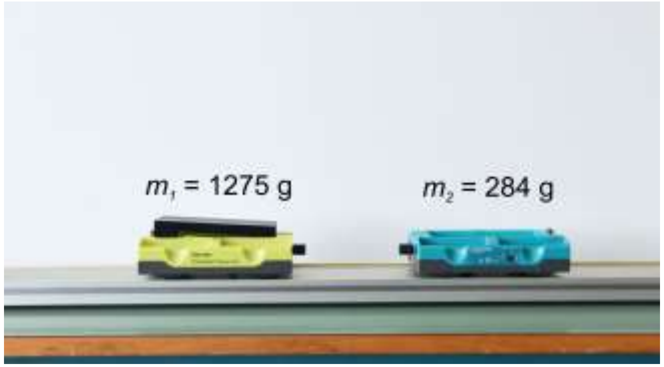
They design testing experiments

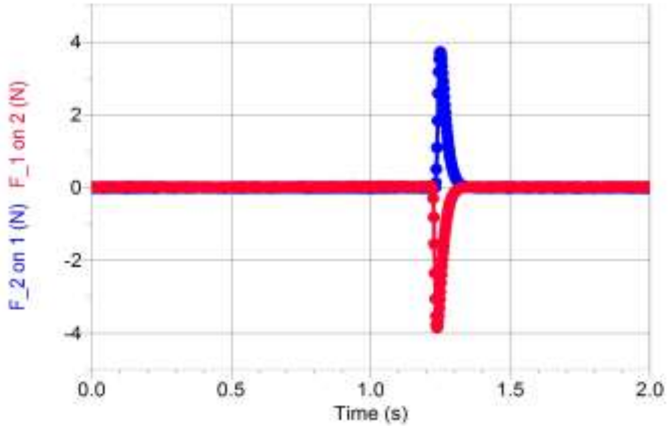


Etkina et al., 2019

As a student you just invented Newton's third law







Etkina et al., 2019

What happens in class after?

8. A book sits on a tabletop. What force is the Newton's third law pair to the force that Earth exerts on the book? Choose the correct answer with the best explanation.
   (a) The force that the table exerts on the book because it is equal and opposite in direction to the force that Earth exerts on the book
   (b) The force that the table exerts on the book because the table and the book are touching each other
   (c) The force that the table exerts on the book because it describes the same interaction
   (d) The force that the book exerts on Earth because it describes the same interaction
   (e) The force that the book exerts on Earth because it is equal and opposite in direction to the force that Earth exerts on the book

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   (d) The force that the book exerts on Earth because it describes the same interaction
   (e) The force that the book exerts on Earth because it is equal and opposite in direction to the force that Earth exerts on the book

What do students think? – Interviews of students of David Brookes

Did you take a physics class before? If yes, what was it like?

Why did you take this class?

How does it compare to other science classes you are taking?

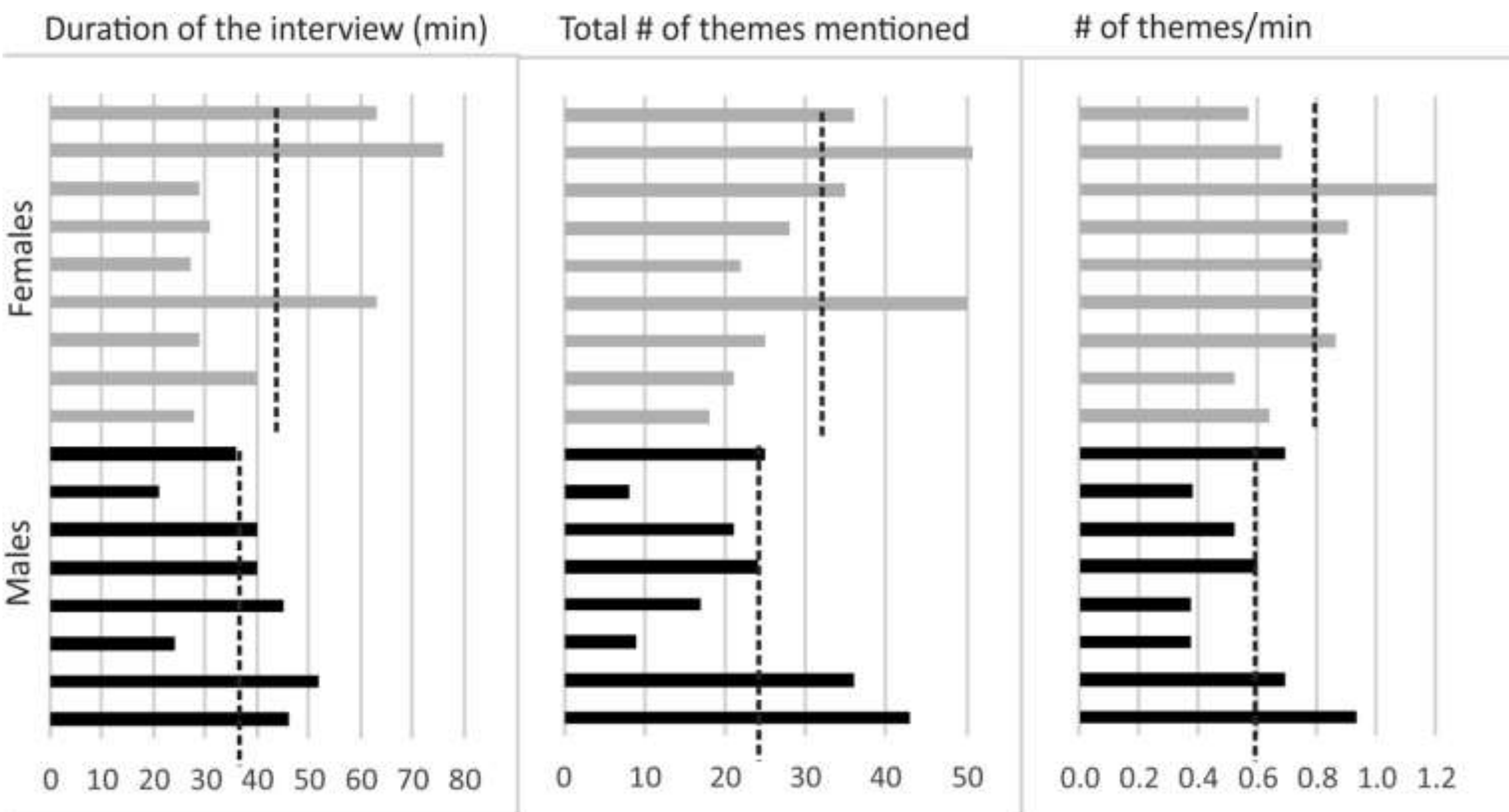
Would you like to change anything in how this class is taught?

Examples of elaboration questions are: What do you mean? Can you be more specific? Can you give an example?

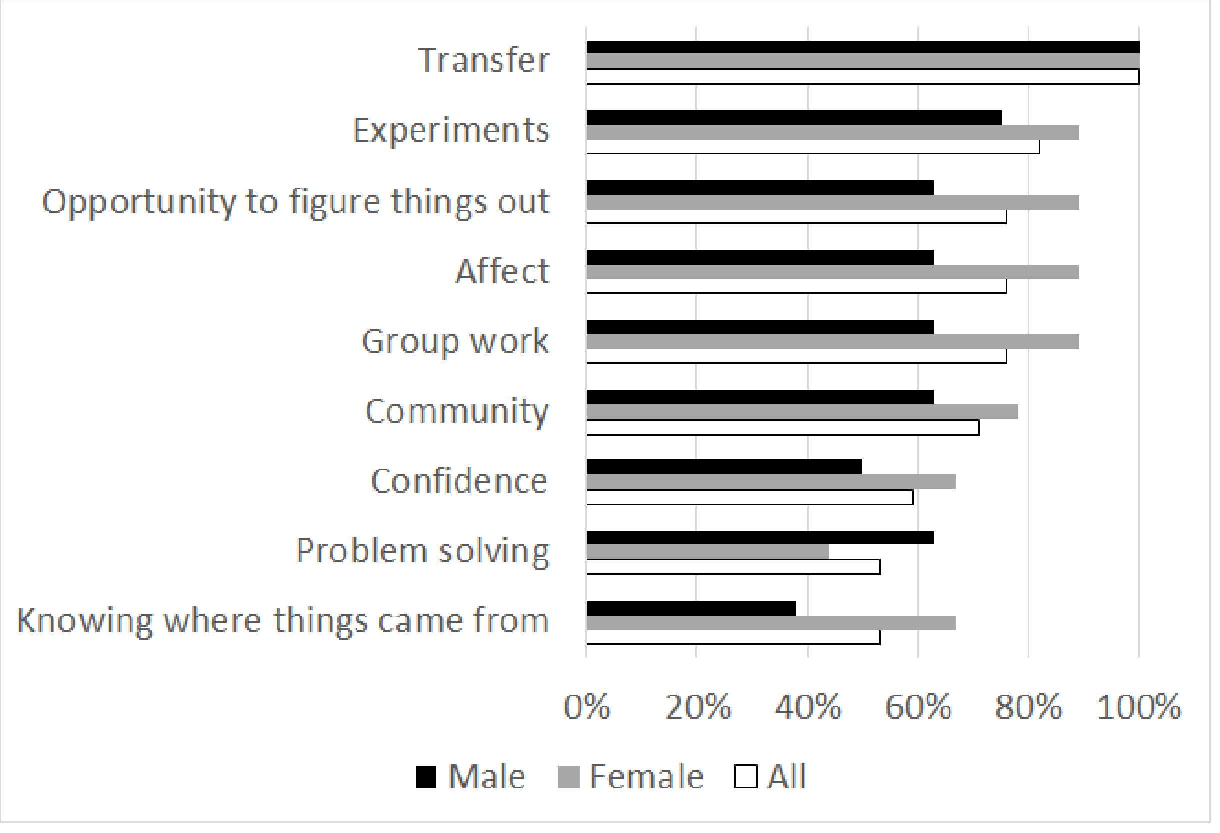
17 students (self-identified as 9 females and 8 males)

Brookes, Planinsic and Etkina, 2020

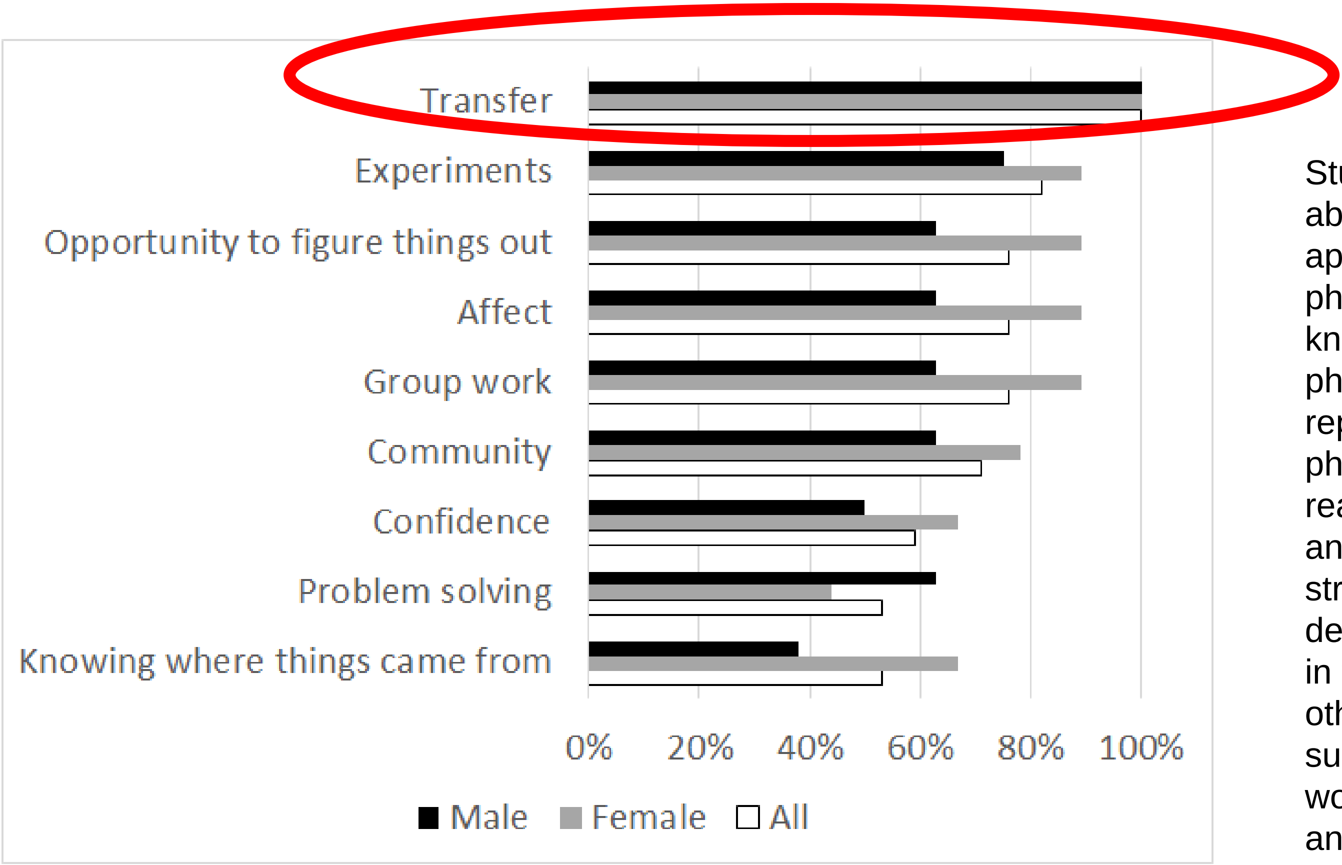
Duration and themes N=17 (9 female and 8 male)



Most common themes



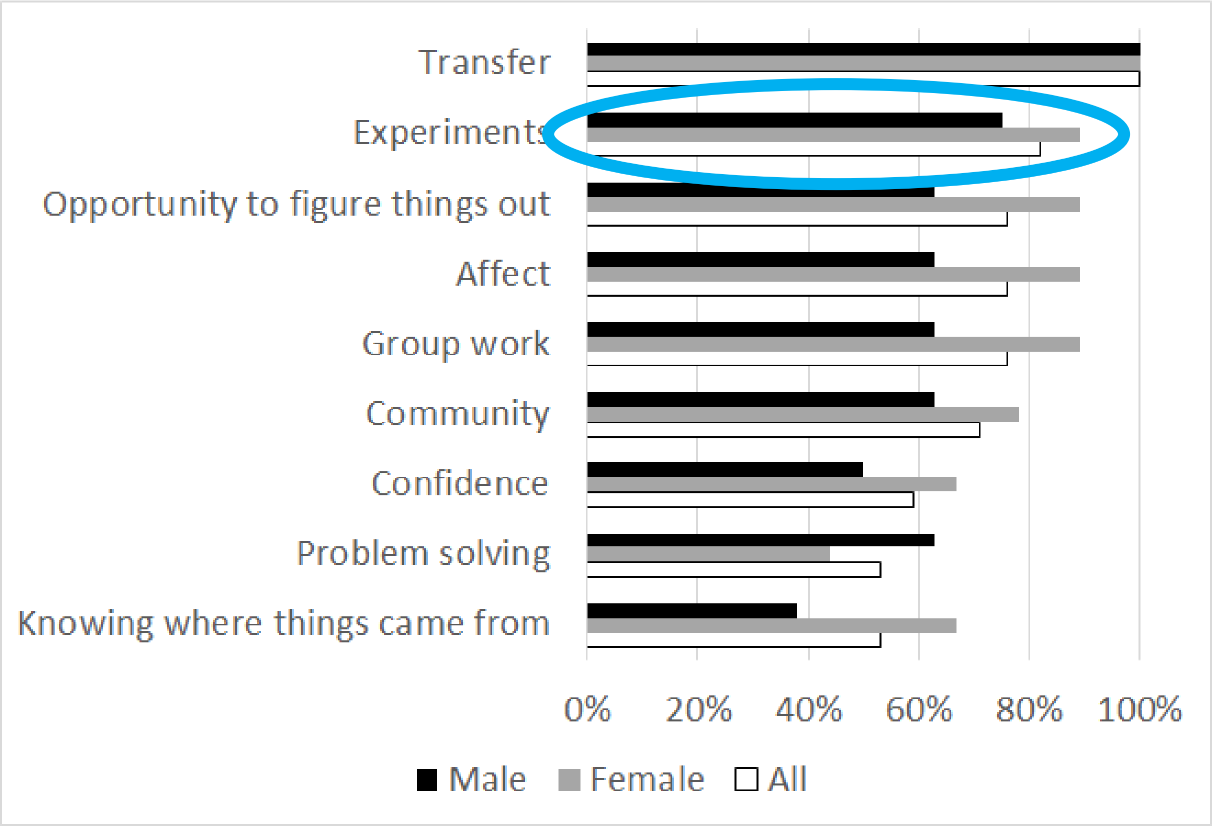
Most common themes



Students talked about how they applied physics knowledge, physics representations, physics reasoning skills and learning strategies they developed in the course in other contexts such as outside world and other courses.

“So even if I’m in a class where the professors like a robot, just talking, reading, Power Points, I can go home and turn it into something that’s going to be interesting to me, because you guys made us think about how we learned and what the best way to learn is.”

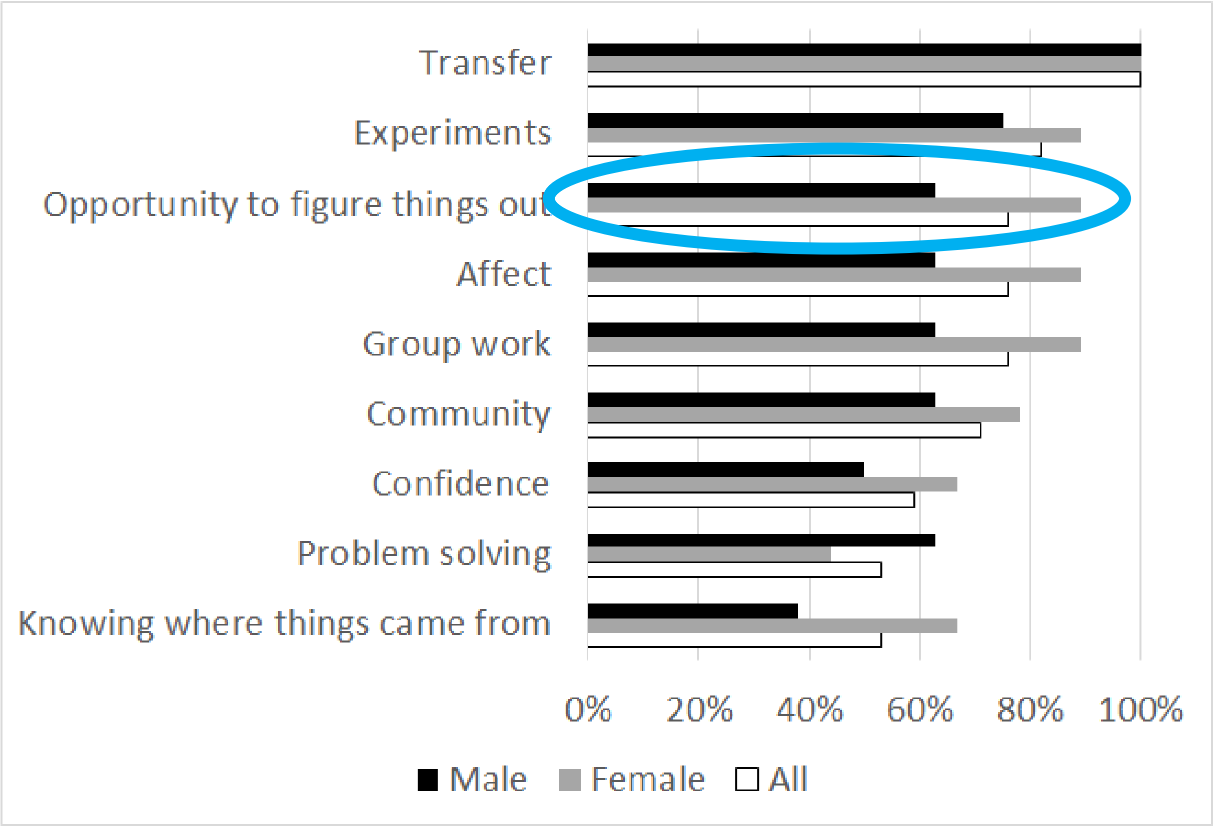
Most common themes



“But the way that we learn these things, it’s not as hard as what the regular physics students. They’re like, oh, my God, this equation is so difficult to derive and this and that.

But our class, we’re like, well, it’s easy because if you grasp this and you think about the situation when you get this, and it’s cool because we got to do all those experiments that we understand already how it works.”

Most common themes



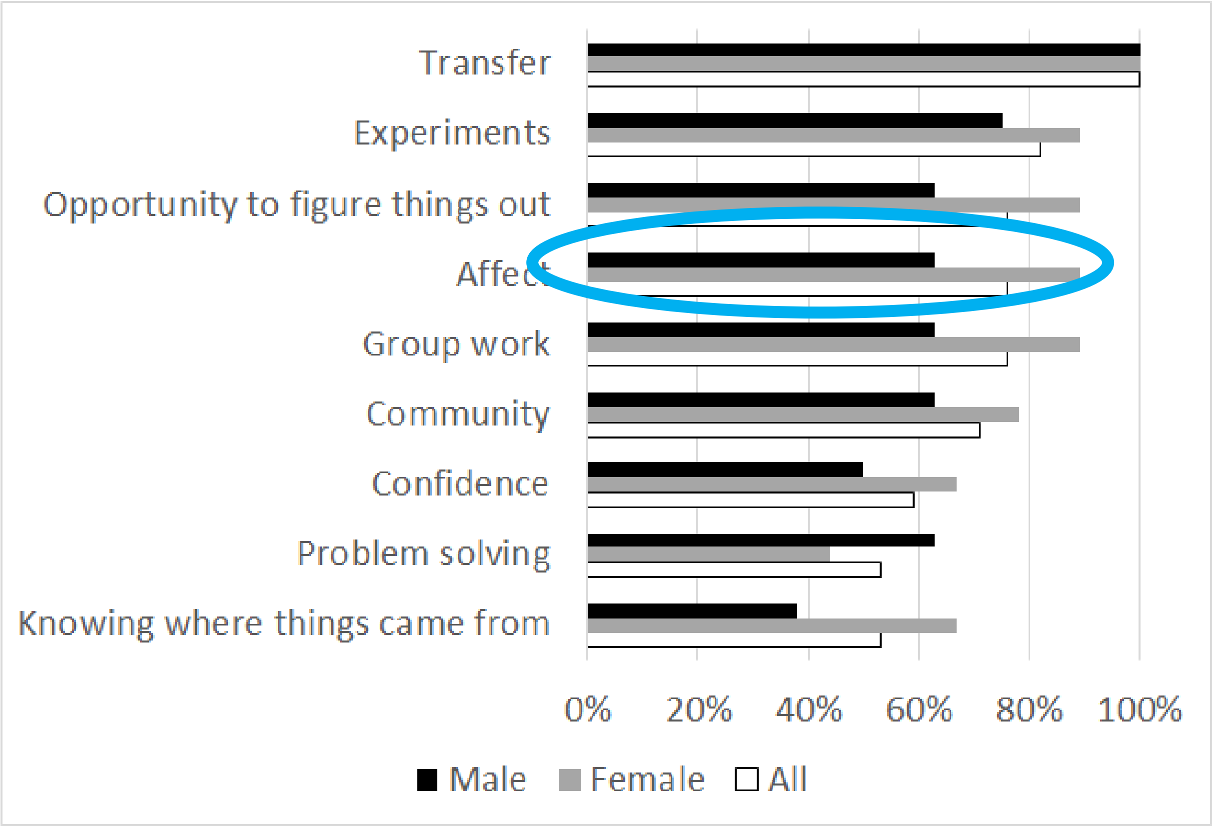
“It was a learning process because I was so used to be fed information and remembering it and repeating it that here at the beginning I didn’t like it because I was not shared information.

I said, what the heck is this, how am I supposed to learn anything, the professor didn’t tell me anything.

And I was so used—you’re so accustomed to being fed all this information and memorizing it that you have no idea what’s going on.

Here I have to figure out what was going on, and then a true understanding could arise.”

Most common themes

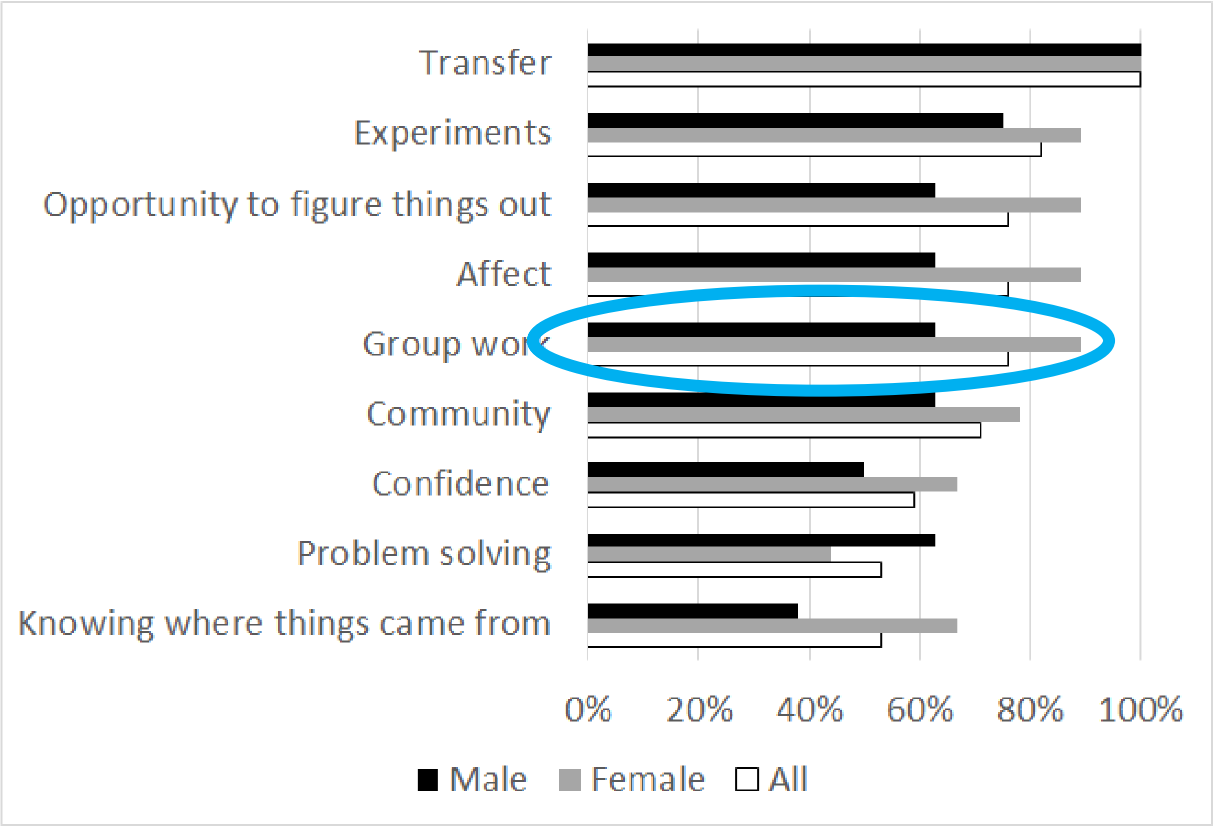


“I definitely do enjoy Physics. In terms of interaction and stuff like that, I like Physics a lot, a lot. At first I come to class and I’m like, "Oh what crazy thing are we gonna do today? Let’s see what happens."

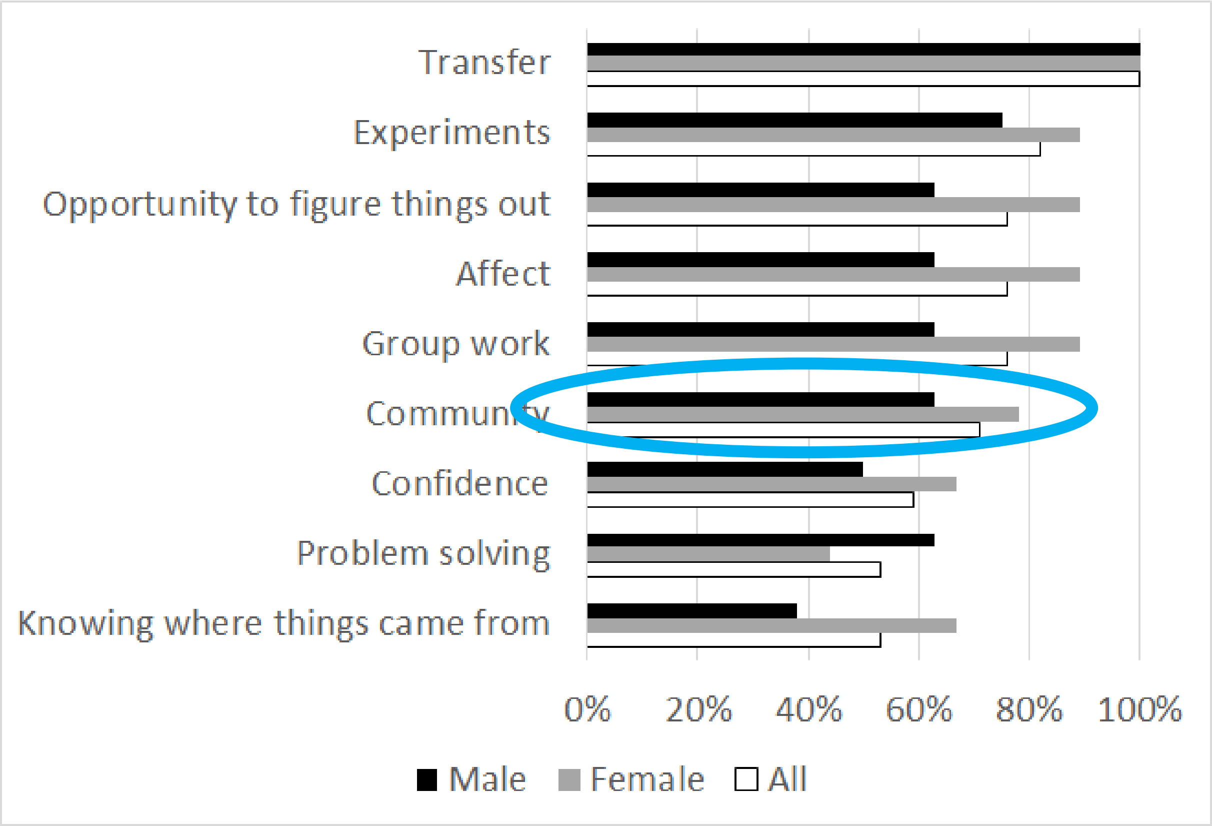
And then when we’re actually doing it I’m just so hyped and I’m so excited and magnets, you know I love magnets. My magnets, oh those are my babies, I love my magnets.

But with magnets and with mirrors and with lenses it was exciting, it was cool and it was like I knew I was gonna leave with something that was gonna blow my mind.”

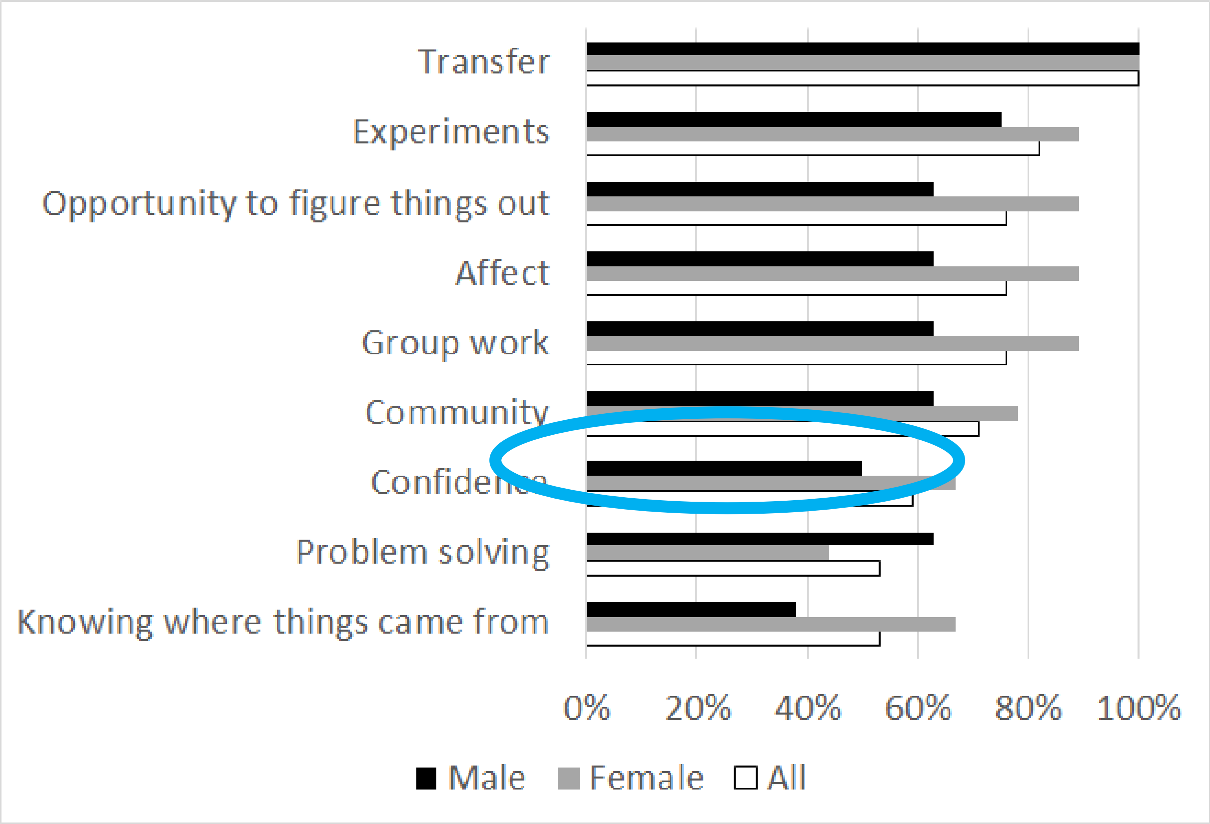
Most common themes



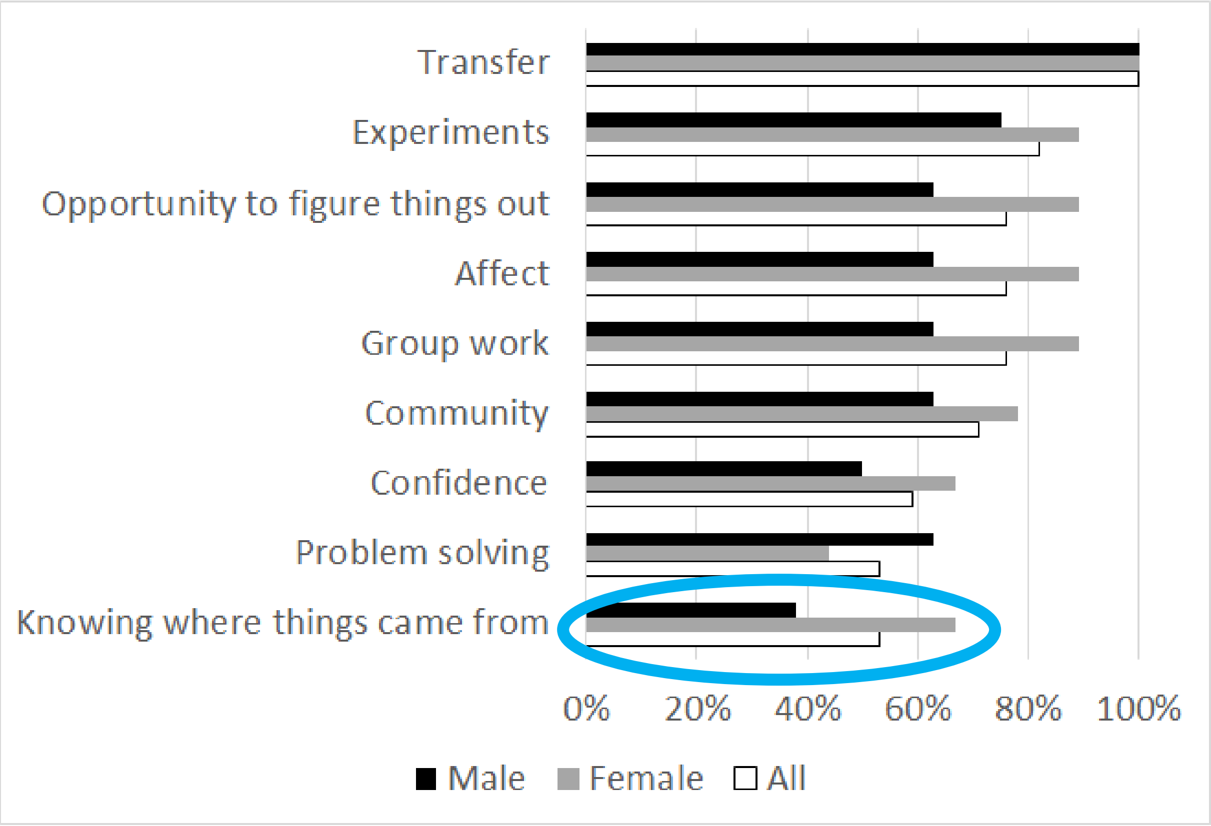
Most common themes



Most common themes



Most common themes



ISLE students reflecting on learning in pandemic times

- "I can say with no hesitation that this is the first and only class where I worked with a group successfully. In my previous experience, I have only been in situations where I be the one working and leading the group and trying to catch up with other groups in the class as other teammates do not contribute. So, I learned how to be part of a hard-working and a successful group this semester. Another thing that I really enjoyed is boosting my self-confidence as I am used to be lectured and having a set of rules and formulas to follow in solving problems rather than going from the different problems in order to come up with a formula. So, teaching myself and teaching and being taught by other students helped me a lot rely more on myself."

- "The biggest lesson I've learned from this class is how to be a better group-mate. My group has been a great help this semester and they have been my rock when it comes to being caught up on physics. I'm going to make sure in the future to pass on the good vibes they've passed on to me."

- "This class has first and foremost been a re-enforcer of the idea that is ok to make mistakes. Growing up my school taught me to be fixed on the 'right' answer, rather than the process and means to the end. This class has helped me to slow down and not just gun for the right answer, but to puzzle and question the work that I have done up until point to see how far I can get, even if that is not entirely to the answer."

Perseverance

Grit is one of the predictors of success.

We find that designing their own experiments develops perseverance while doing traditional labs does not.

On average the time spent by ISLE students making sense of experiments (designing, analyzing data, revising, etc.) is 4 - 5 times longer than for the students in traditional labs where they follow directions.

Etkina et al., 2010

What else do we know about ISLE students?

High gains on standardized tests (FCI, CSEM, MBT, etc.)

(Etkina and Van Heuvelen, 2001; 2007, Etkina, 2015)

Spontaneous use of representations other than mathematics when solving problems

(Rosengrant et al., 2009)

Ability to design experiments, collect and analyze data, evaluate assumptions and communicate findings

(Etkina et al. 2006, 2008, 2010; Bugge and Etkina, 2016, Bugge 2020)

Difficulties in implementing the ISLE approach to learning physics

Instructors need to learn to think about physics and student learning differently. They need to act differently in class.

Students need to learn to think about their learning and instructor’s teaching differently. They need to act differently in class.

Lots of research shows that both are very difficult problems to solve and are subjects for another conversation…

Resources to implement ISLE

Big team!

ISLE website - https://www.islephysics.net/

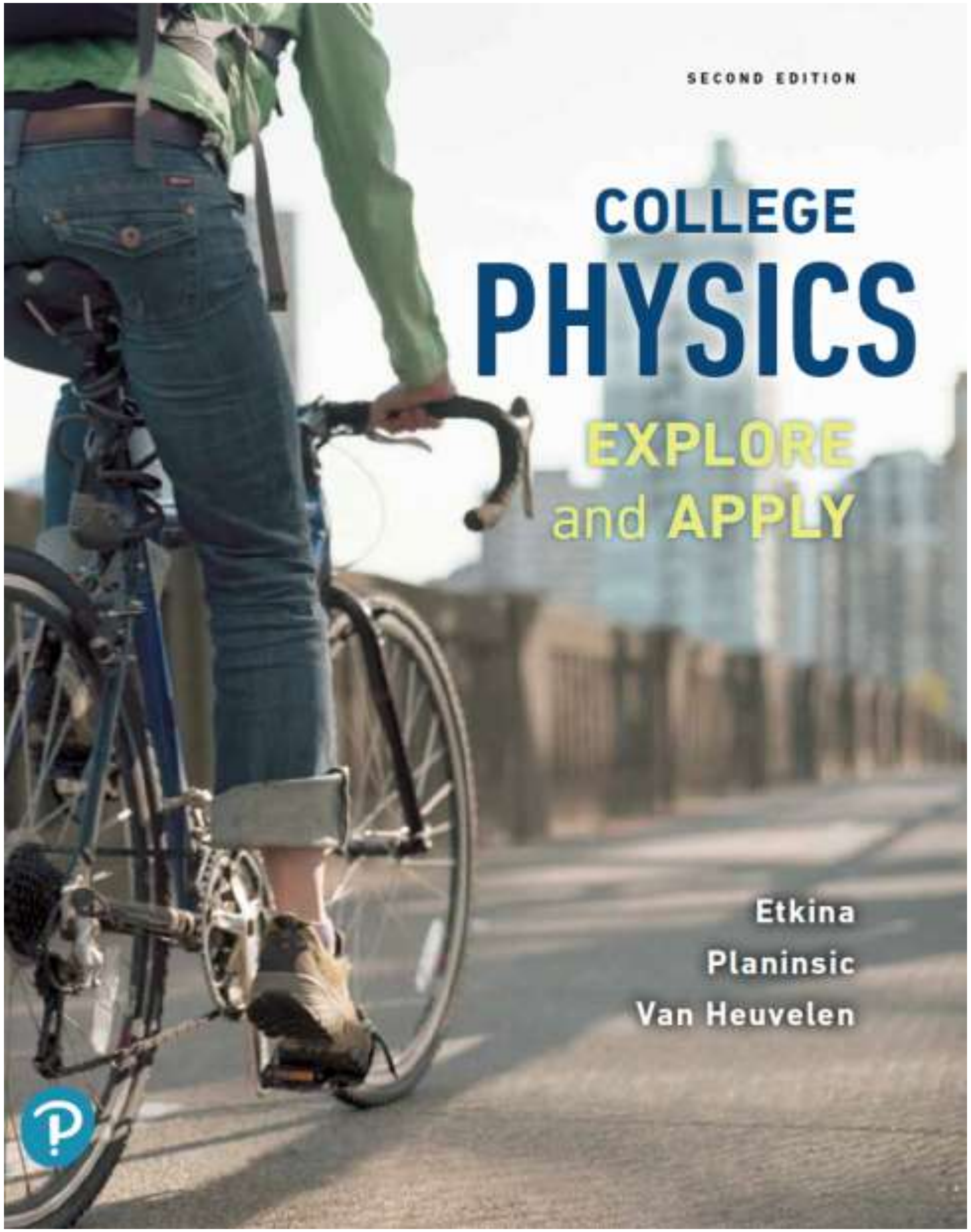
IOP Concise Physics | A Morgan & Claypool Publication

Investigative Science Learning Environment

When learning physics mirrors doing physics

Eugenia Etkina
David T Brookes
Gorazd Planinsic

IOP | ebooks

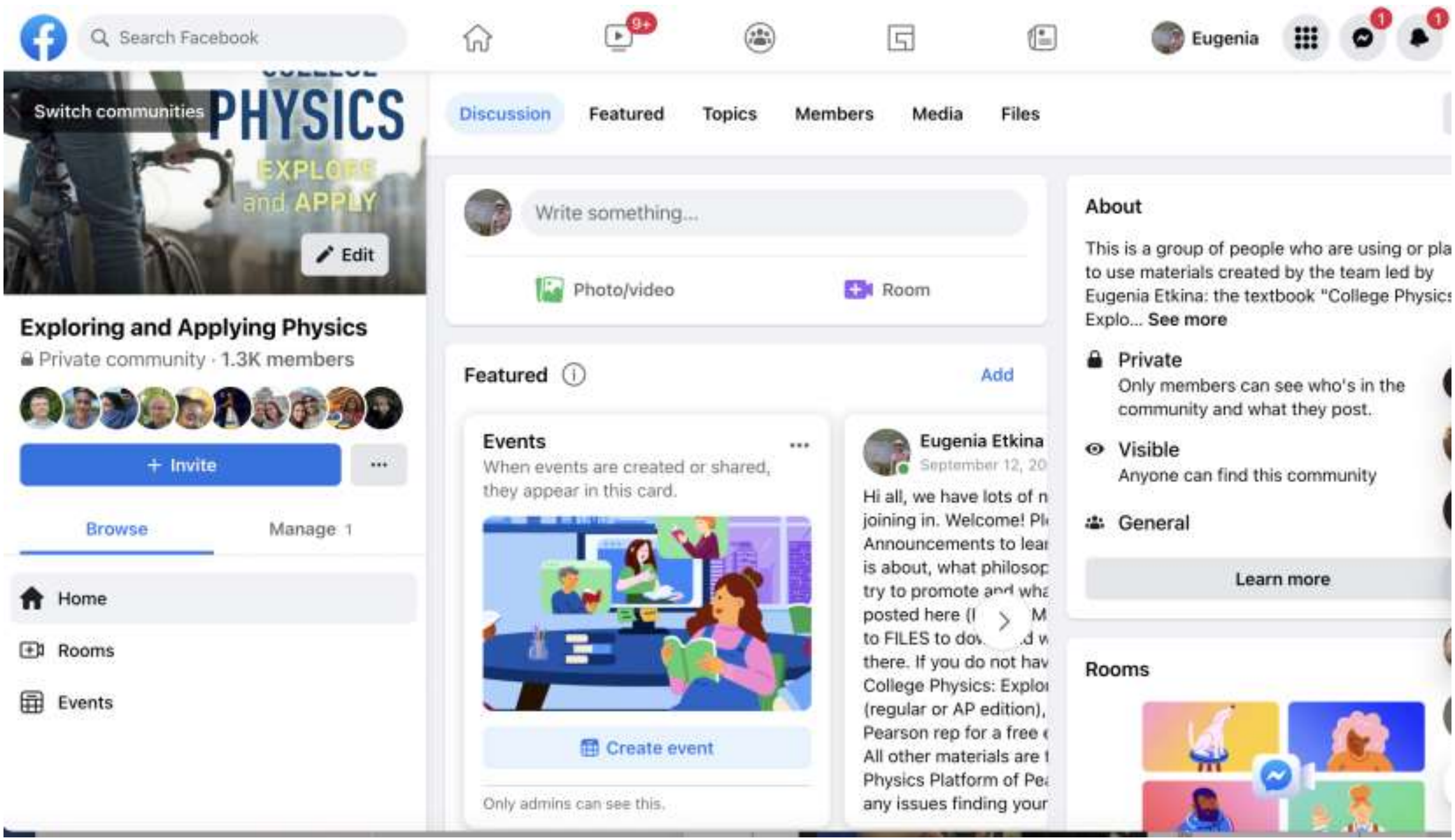


Active Learning Guide and On-line Active Learning Guide

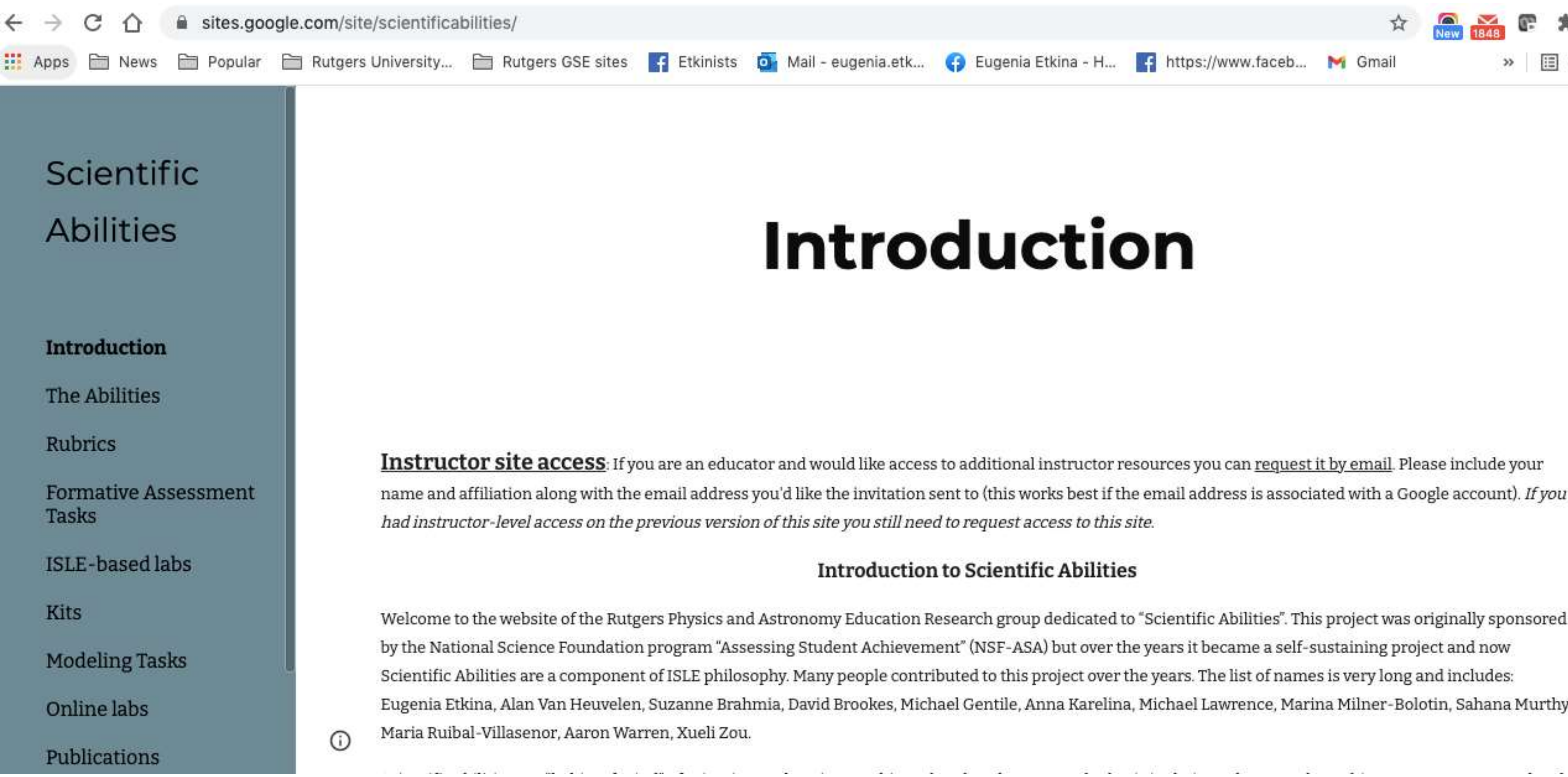
Instructor Guide

Over 300 videos freely available to use without adopting anything

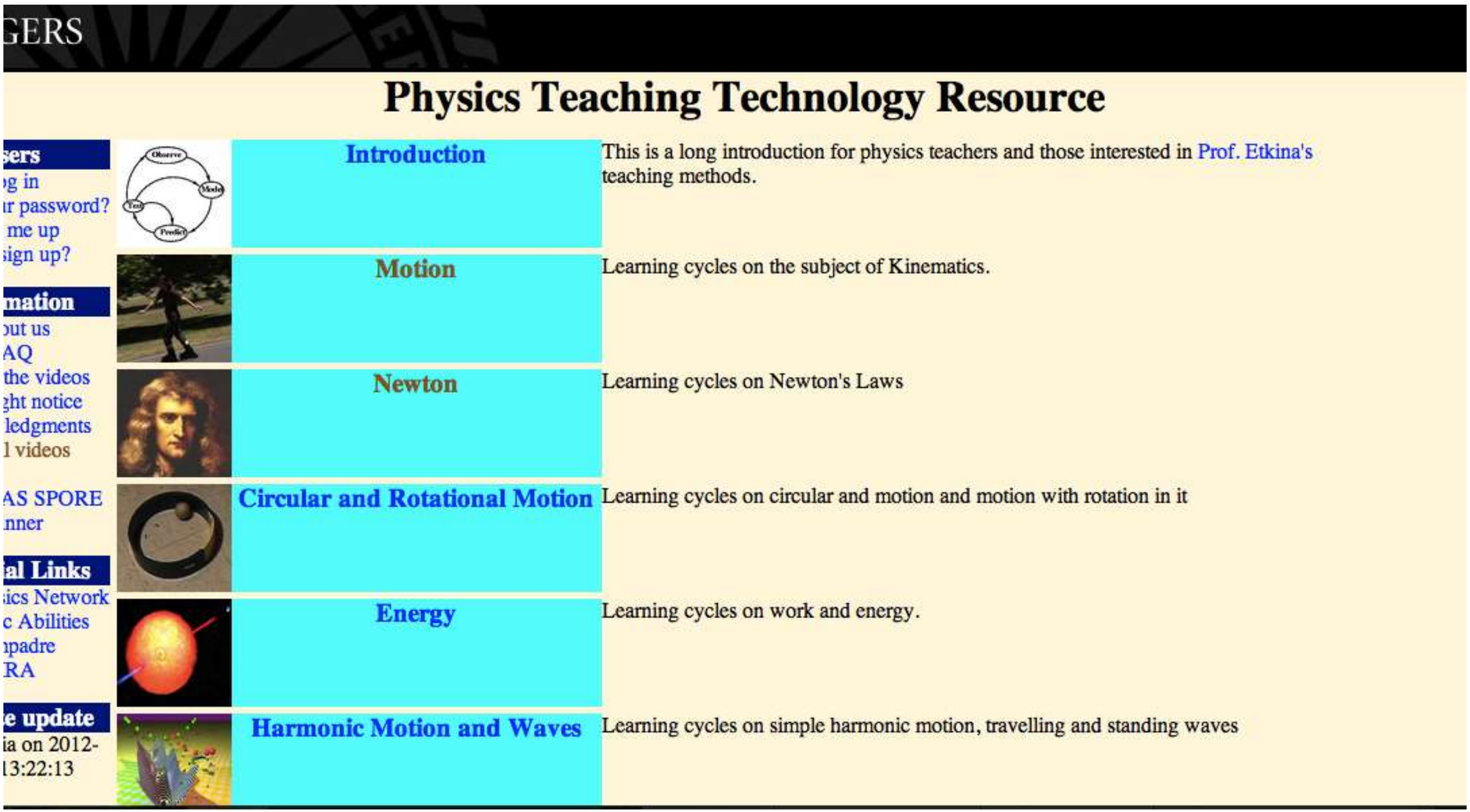
Exploring and Applying Physics Facebook group with over 1300 members from all over the world (including Sweden)



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



http://islevideos.net/



ISLE-oriented physics teaching computer games

http://www. universeandmore.com

Matt Blackman, Ridge High school

Few points to take away

Learning means physical change in the brain and body of the learner.

Brain cycle proceeds from sensory experiences to reasoning and to motor functions for active testing.

Scientific inquiry engages similar processes.

ISLE is the real path that scientists take!

Students can participate in real science making!

The ISLE approach is designed to empower all students to learn physics creatively – it is an example of the UD for education.

Thank you

Eugenia.etkina@gse.rutgers.edu

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

Scientific habits of mind – scientific abilities

Scientific Abilities (work started in 2003) 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

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	Adequate
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)	Adequate (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/