Piloting Inquiry-Based Learning in First-Year Physics for Engineers

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Why redesign these courses?

Alignment with 1st year engineering

❖ Project-based integrated learning course

Adaptation for the age of AI

❖ Easy for students to offload thinking
❖ Need to intentionally support the development of expert-like reasoning

Update with the latest PER findings

❖ Problem first approach to active learning
❖ Use of cognitive apprenticeship model

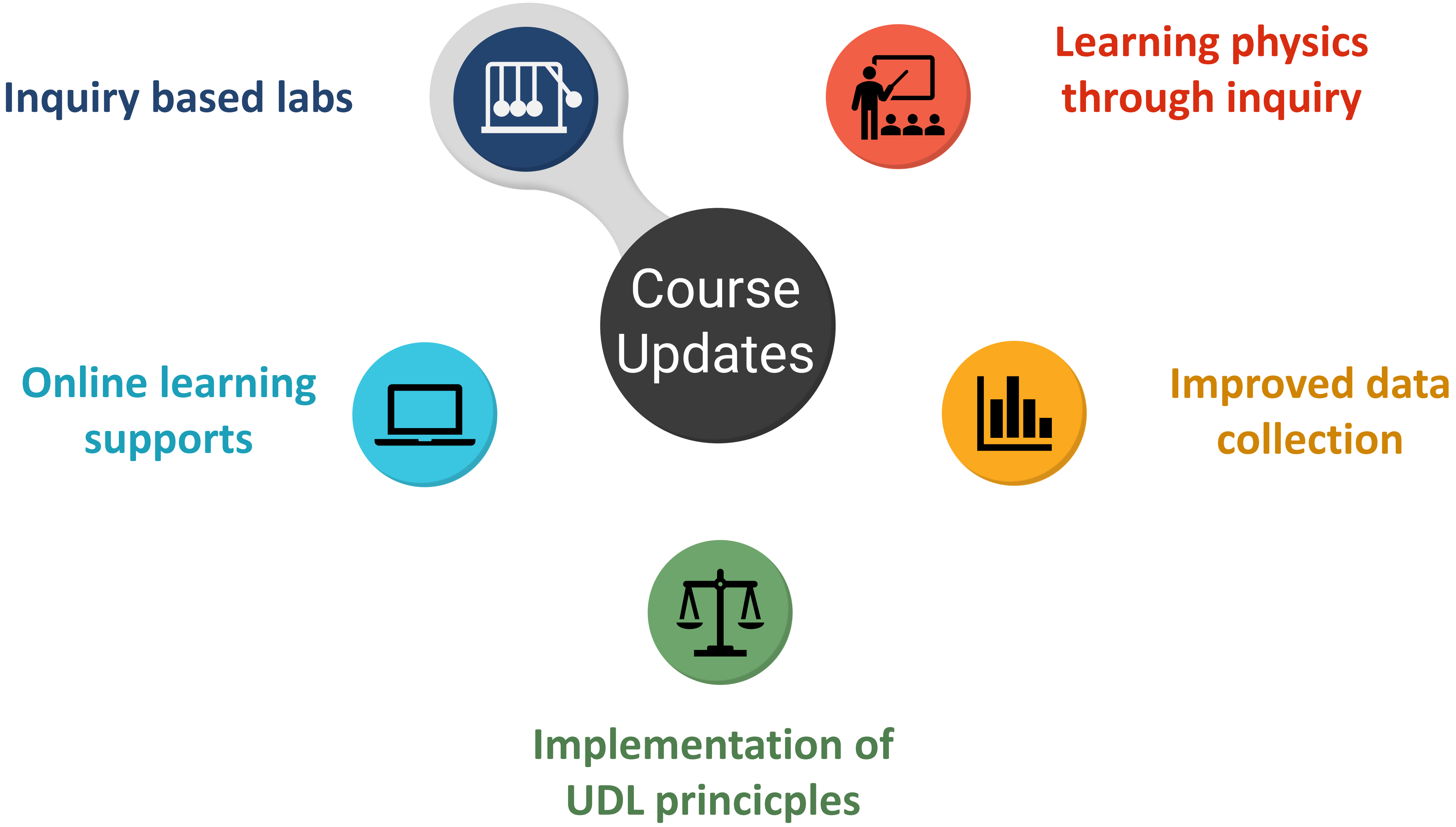
Central course philosophy:

As often as possible, I want the students to *DO* physics

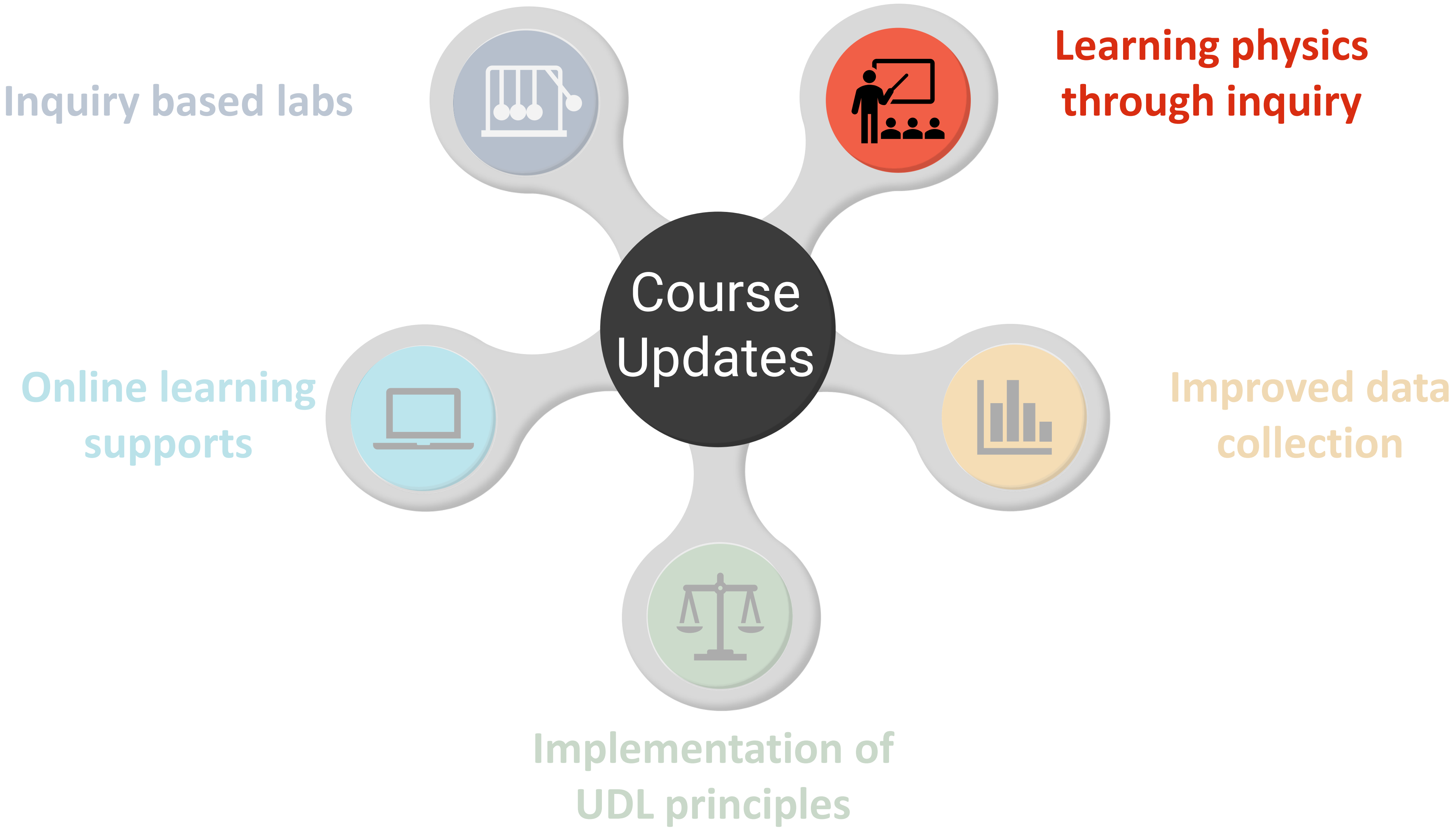
Changing course components

Course Updates

Changing course components

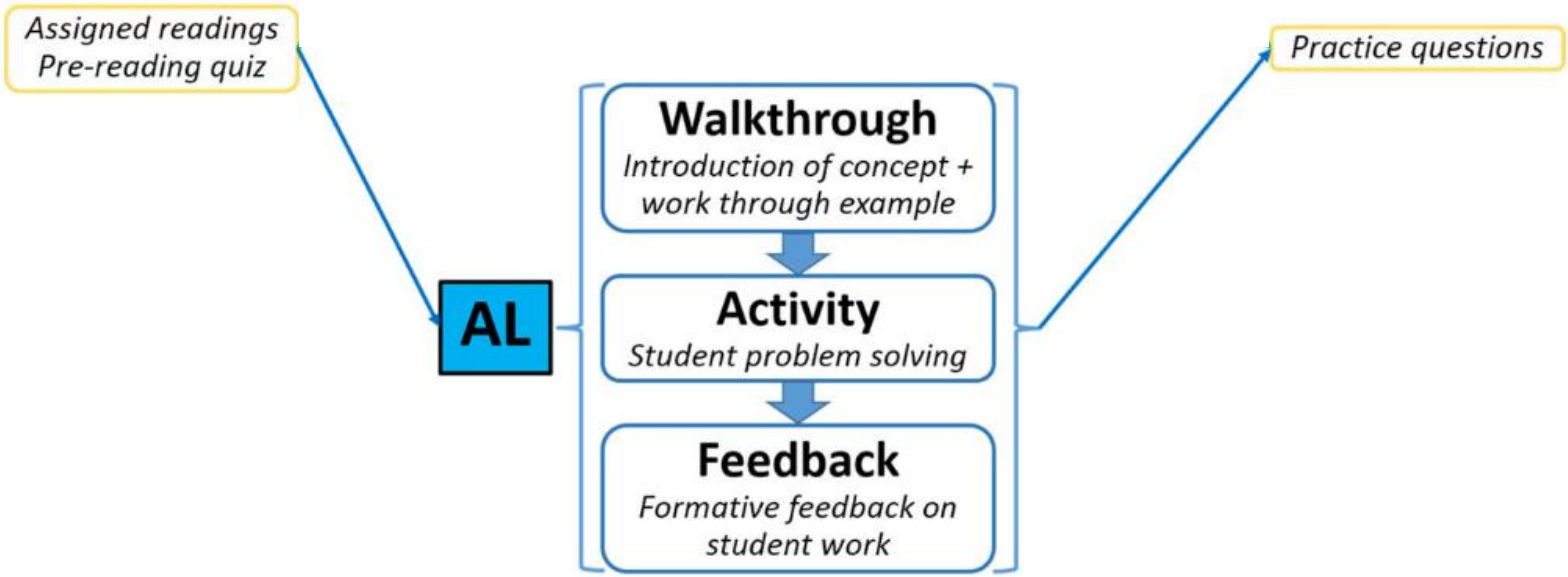


Let’s look at an example



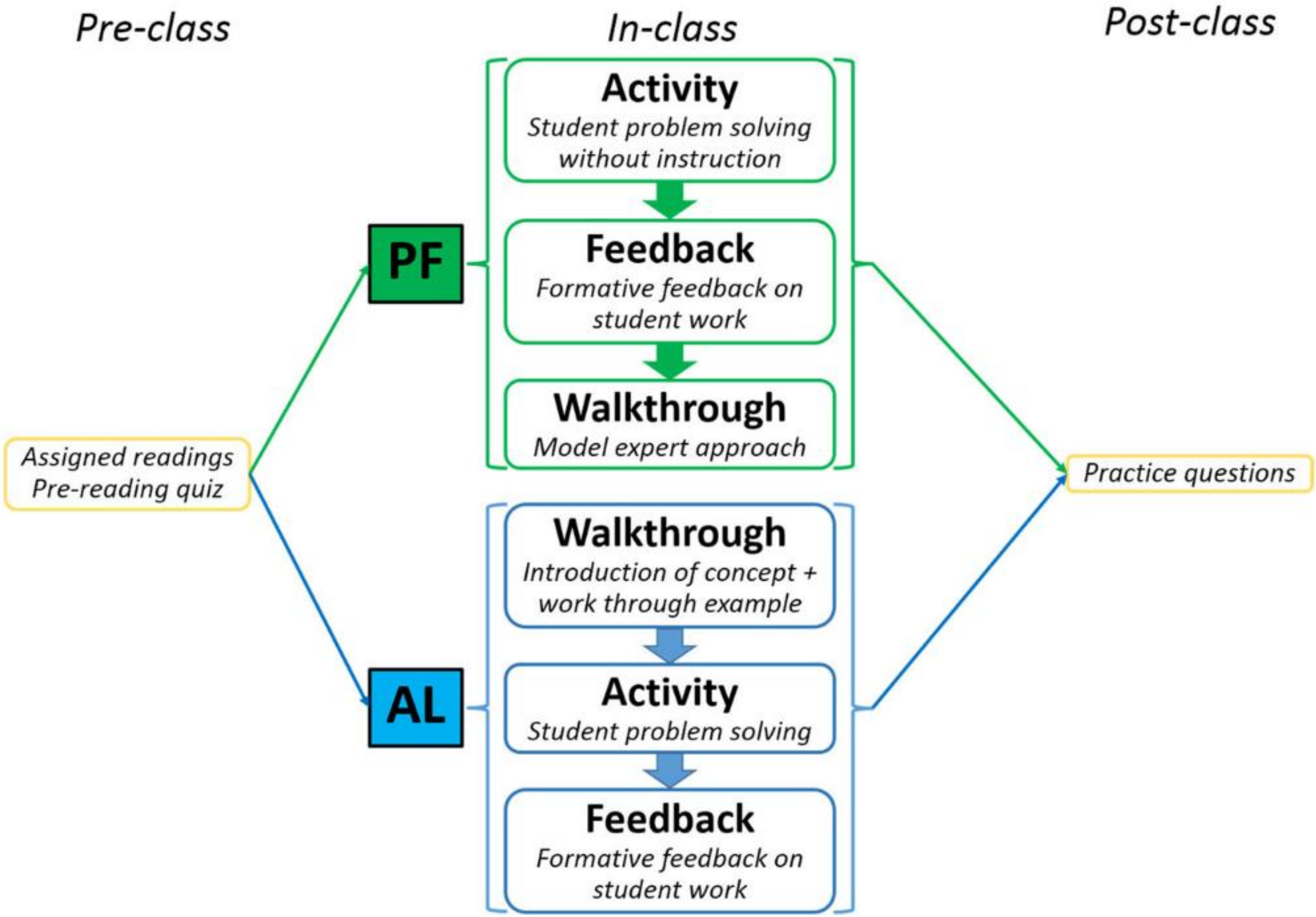
Choosing an approach to active learning

Pre-class | *In-class* | *Post-class*



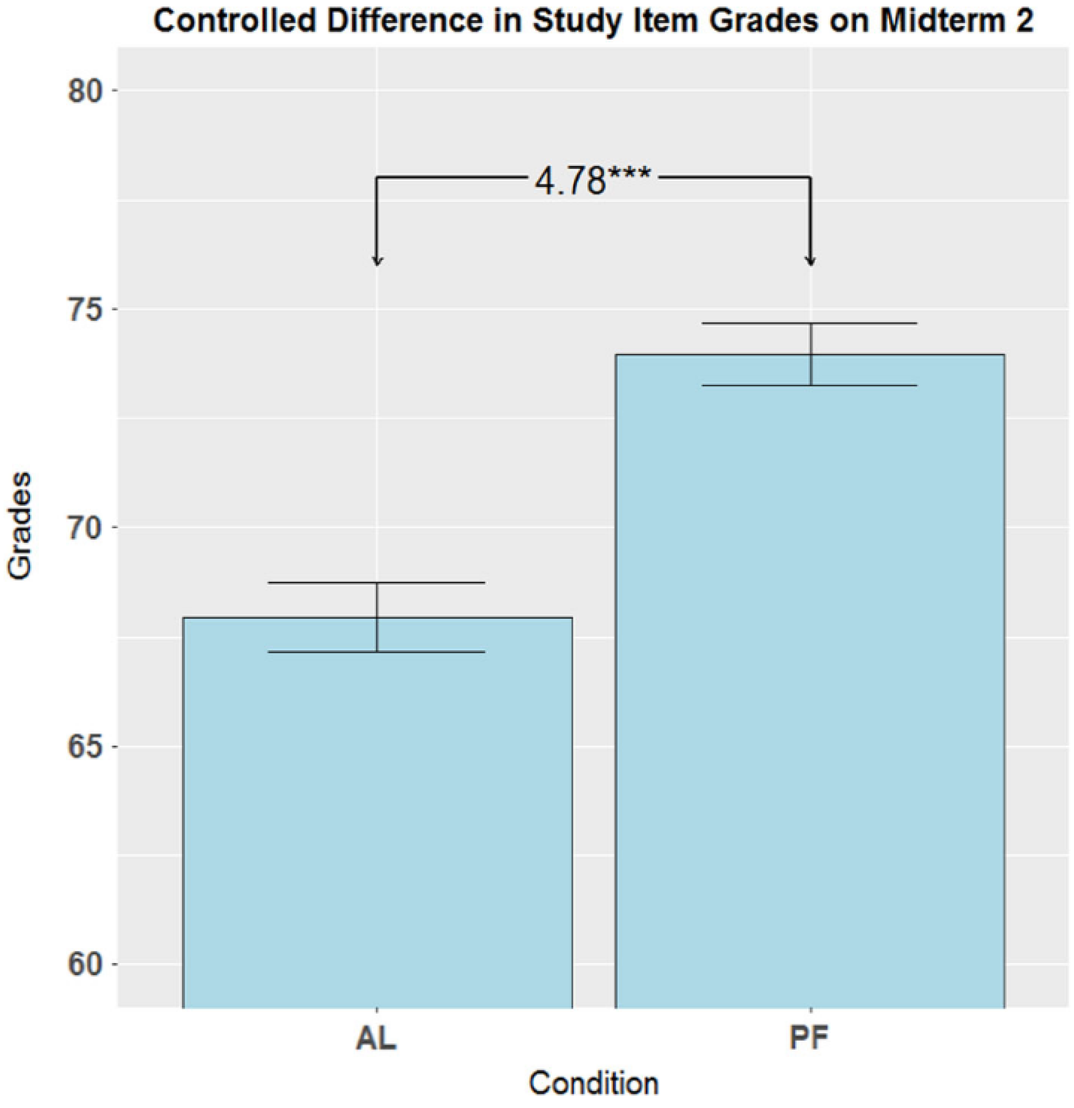
[1] Chowira et al. (2019)

Choosing an approach to active learning

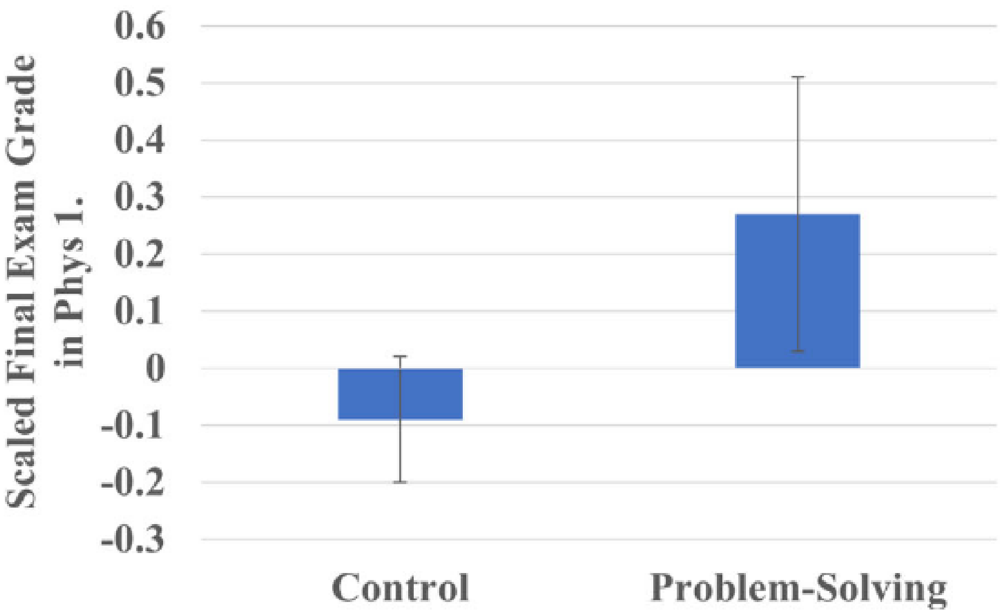


[1] Chowira et al. (2019)

Productive failure is superior to traditional active learning



[1] Chowira et al. (2019)



[2] Burkholder et al. (2023)

Instruction through real-world problem solving and inquiry

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **18,** 020124 (2022)

Equitable approach to introductory calculus-based physics courses focused on problem solving

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(Received 8 August 2022; accepted 23 September 2022; published 10 October 2022)

Introductory calculus-based mechanics ("Physics 1") is an important gateway course for students desiring to pursue a science, technology, engineering, and mathematics (STEM) career. A major challenge with this course is the large spread in the students' incoming physics preparation. This level of preparation is strongly predictive of a students' performance because of the overlap between Physics 1 and high school physics courses. Because the level of students' incoming preparation is largely determined by the quality of their high school physics courses, Physics 1 can amplify K–12 educational inequities and be a barrier for marginalized students wishing to pursue a STEM career. Here, we present a novel introductory course design to address this equity challenge. The design and implementation are based on the concept of deliberate practice as applied to learning real-world problem solving. Students explicitly practice research-identified decision-based skills required for problem solving in the context of solving real-world problems

Core course philosophy:

As often as possible, I want the students to *DO* physics

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- Model building with iterative complexity
- Theory ↔ Experiment with demos & simulations
- Exploring real-world problems

As often as possible, I want the students to *DO* physics

Let’s look an example, how I now teach torque

Model building with iterative complexity

Exploring real-world problems

Theory ↔ Experiment with demos & simulations

Context for sample torque investigation

Course context

- Week 2 of the semester
- Students have done 1D and 2D forces
- Only equilibrium, no acceleartion

First year inequities are explained by K-12 preparation

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **15**, 020114 (2019)

Editors' Suggestion

Demographic gaps or preparation gaps?: The large impact of incoming preparation on performance of students in introductory physics

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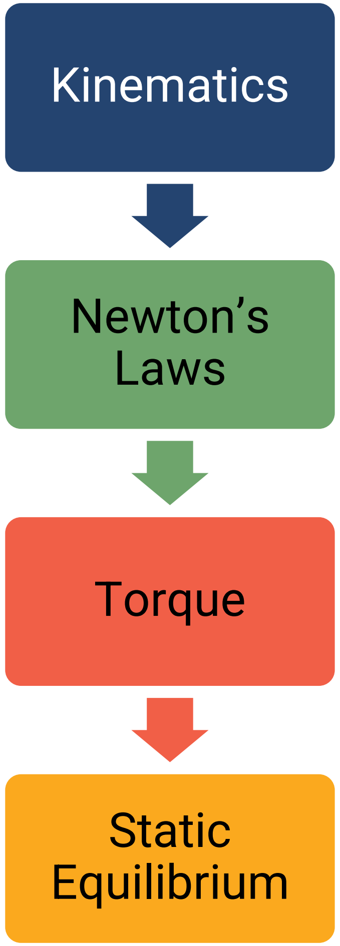
"although there appear to be gaps in exam performance if one considers only demographic variables (gender, underrepresented minority, first generation), once… incoming preparation [is] controlled for, there is no longer a demographic gap."

So don’t repeat K-12 education

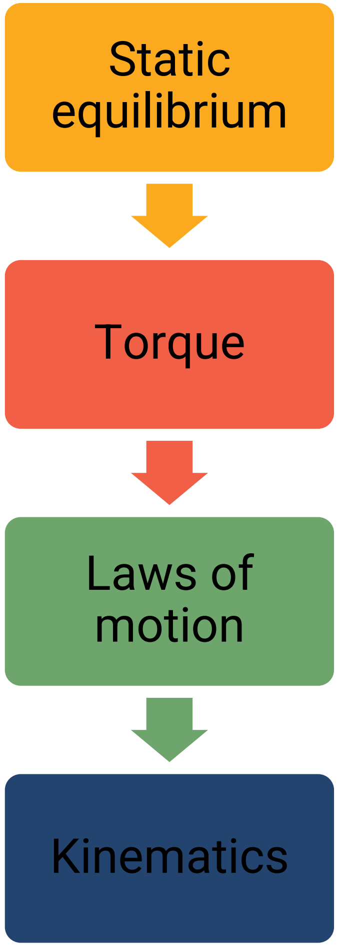


Traditional order of topics

- Largely a repeat of grade 12 physics
- First new topic (torque), >1 month into the course

New order of topics

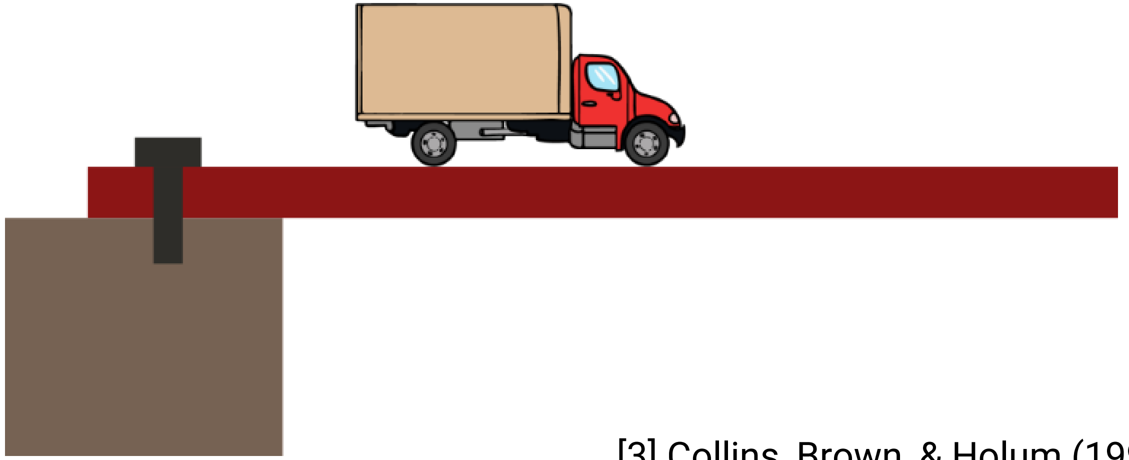
- Begin with static equilibrium
- Highly applicable to engineers
- Nothing moves (yet)
- Torque in week 2… this isn’t just grade 12 again



Scaffolding as cognitive apprenticeship

Using a cognitive apprenticeship model

- Scaffold an investigation to guide students' thinking
- Thinking process of an expert is made exclicit[3]
- Directly challenge their existing model of static equilibrium



[3] Collins, Brown, & Holum (1991)

Investigating static equilibrium

1. **Represent.** Graphically represent the forces **acting on the dock**, and symbolically describe their balance using net force.

Graphical Representation	Mathematical Representation

2. **Reason.** What if the truck drove to the far end of the dock instead (as shown)? Would you expect the force of the bolt onto the dock to change?

3. **Represent.** Graphically depict all the forces acting on the dock in this new scenario.

Context for sample torque investigation

4. **Interpret.** We now want to compare these two different situations.
    a. Is the truck's weight, or the dock's weight, changing as the truck moves?

    b. Is the force the bolt exerts on the dock changing?

    c. Explain how both of your answers can be consistent.

5. **Observe and Evaluate.** Your instructor has an experiment set-up to test these ideas. Record your observation and decide if they match with your answers above.

Teaching with ~~demos~~ experiments

Classroom demonstrations: Learning tools or entertainment?

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(Received 20 September 2002; accepted 20 February 2004)

We compared student learning from different modes of presenting classroom demonstrations to determine how much students learn from traditionally presented demonstrations, and whether learning can be enhanced by simply changing the mode of presentation to increase student engagement. We find that students who passively observe demonstrations understand the underlying concepts no better than students who do not see the demonstration at all, in agreement with previous studies. Learning is enhanced, however, by increasing student engagement; students who predict the demonstration outcome before seeing it, however, display significantly greater understanding.

[DOI: 10.1119/1.1707018]

Teaching with ~~demos~~ experiments

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Catherine H. Crouch[a)]
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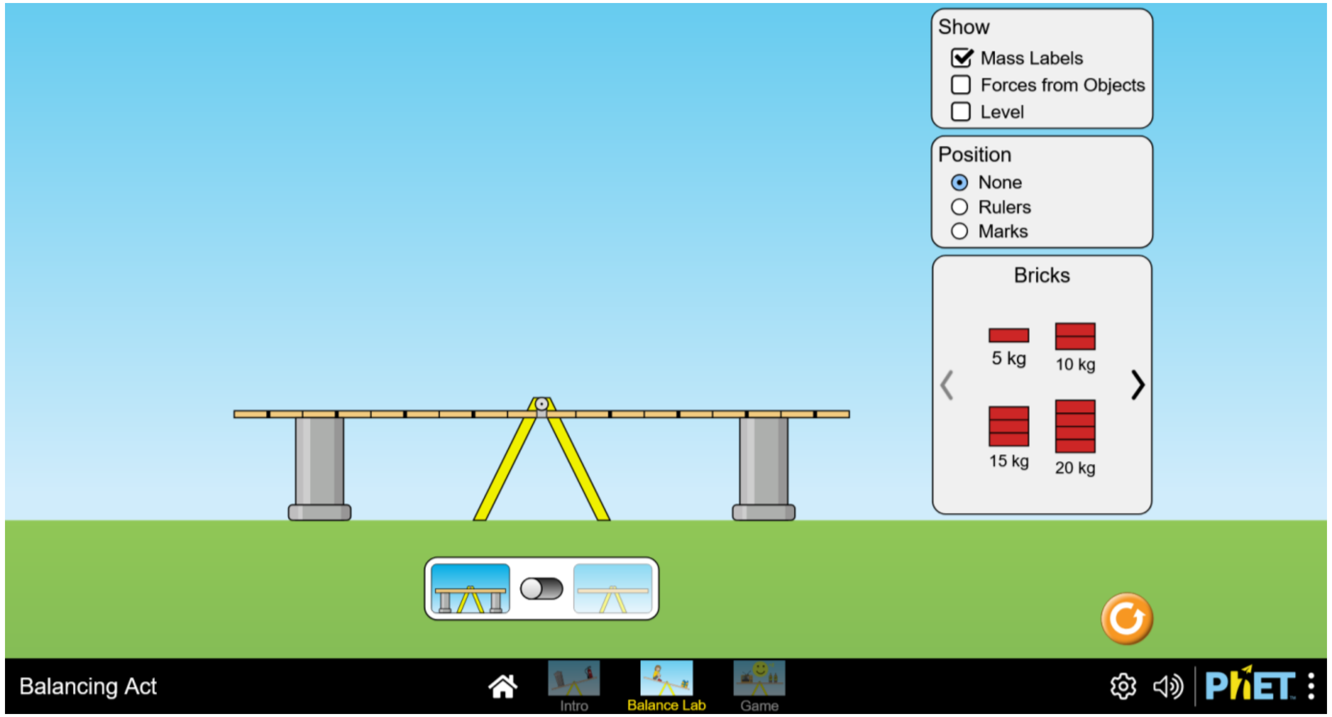
Student build their model with simulations

PhET Balancing Lab simulation

- Continue investigation in groups
- Some prompting questions, but largely left to explore
- End up with *our* preliminary model for torque
- Make predictions with model… and test immediately
- Experiment with choice of pivot



The model we built together

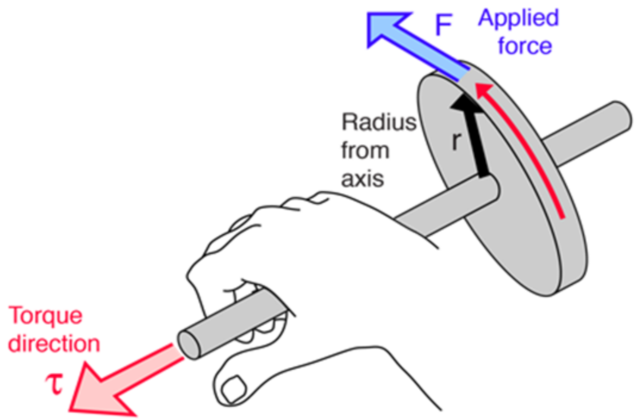
Building our Model

Our preliminary model for Torque:

$$\tau = rF$$

$\tau \rightarrow$ torque
$r \rightarrow$ distance from the pivot
$F \rightarrow$ force acting on the beam

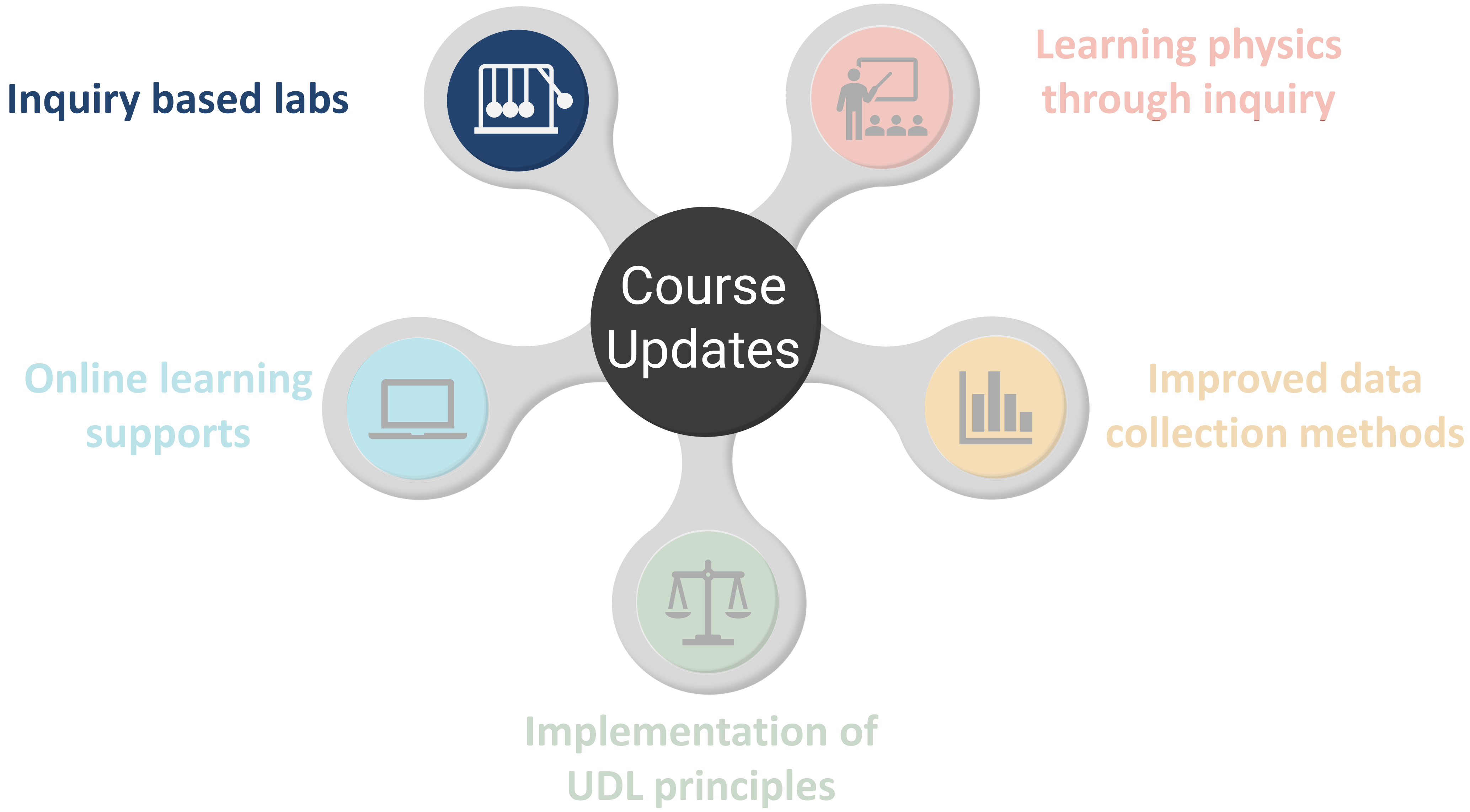
Has direction → is a vector $\vec{\tau}$



Choice of Pivot is <u>arbitrary</u>

- Often best to choose a pivot at a force that we don't know

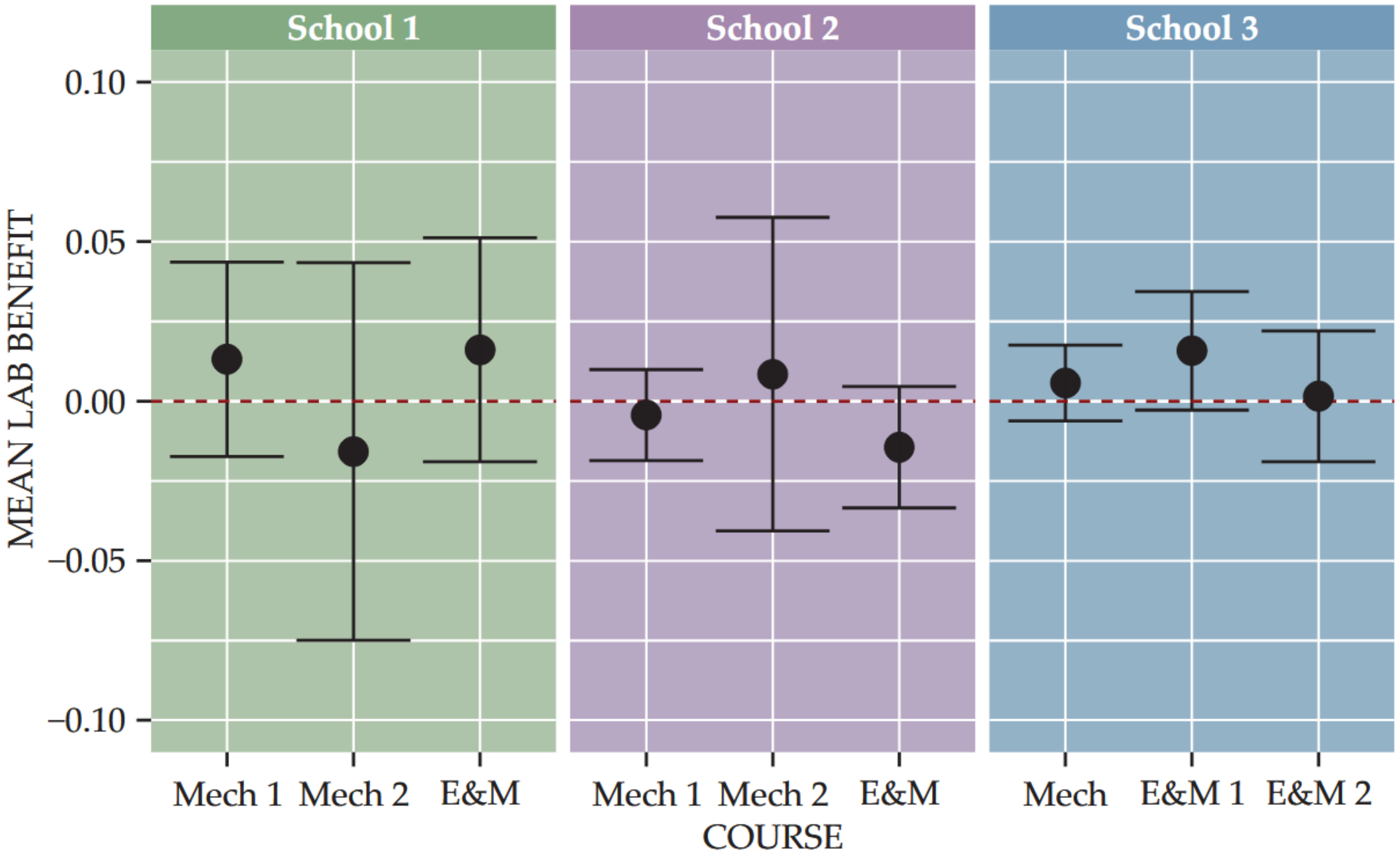
But what about the labs?



We know that labs don’t effectively teach content

- Common belief for students[4,5] and faculty[6] that labs ***Reinforce Lecture Content***

- Research shows this is simply not effective[6]



[6] Holmes & Wieman (2018)

[4] Hu et al., (2017), [5] Smith, Stein, Walsh, et al., (2020)

Traditional labs lead to flawed behaviour and thinking

Students believe primary goal is to "Verify Theory" [7]

Mindset

Behaviour

Students leave 1st year labs acting and thinking *less* like experts compared to when they started[5]

Students show lower critical thinking, blindly following instructions [8]

Students will engage in unethical behaviour, prioritizing confirmation[9]

[7] Mohtar et al. (2015); [5] Smith et al. (2020); [8] Walsh et al. 2022; [9]Smith et al. 2020

TA focus groups identified the same flaws

STUDENTS DON'T THINK

STUDENTS DON'T DEVELOP EXPERIMENTAL SKILLS

FLAWED APPROACH TO LEARNING

STRUCTURAL ISSUES WITH LAB DESIGN AND TAS

TA focus groups identified the same flaws

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Explicit activities to build effective & equitable groups

Time for iteration

Most labs run over two-week x2 hours. Giving space to interate

Teamwork as LO

Group formation activities in lab to support collaboration

Integrated coding

Labs done in Jupyter notebooks; integrate simple python coding

Guide don't tell

Everywhere you would normally give an instruction, ask a question

Equity in tasks

Assigned groups with rotating roles to address gender imbalances

Overview of 1D03 Labs

Lab Number	Physics Topic	Central Learning Outcome
Unit 1 Session 1	Simple Pendulum	
Unit 1 Session 2	-	
Unit 2	Objects in flight	
Unit 3 Session 1	Stretchy things	
Unit 3 Session 2	-	

Overview of 1D03 Labs

Lab Number	Physics Topic	Central Learning Outcome
Unit 1 Session 1	Simple Pendulum	**Obtaining a high-quality measurement** • Reducing uncertainty • Calculating and reporting statistics from repeated trials
Unit 1 Session 2	-	**Comparing measurements** • Deciding whether results agree within uncertainty • Interpreting variability and disagreement
Unit 2	Objects in flight	**Testing a theoretical model** • Comparing data to predictions • Evaluating whether the model explains the data
Unit 3 Session 1	Stretchy things	**Designing a model-testing experiment** • Using least-squares fitting • Developing a research question and plan
Unit 3 Session 2	-	**Implementing and communicating an investigation** • Carrying out the experimental design • Analyzing and presenting results

Sample of what this looks like, lab #5

Stretchy things - Part 2

Run the code cell below to mount your Google Drive.

```
[ ]
# Start up

from google.colab import drive
drive.mount('/content/drive')

# Set this to the folder where your lab notebooks and utilities file are saved on Drive.
# For example, if your files are in a folder called "Colab Notebooks", use:
# working_dir = "/content/drive/My Drive/Colab Notebooks"

working_dir = "/content/drive/My Drive/. . ."  # <- fill in your folder path here

%run "{working_dir}/utilitiesV3.ipynb"
```

Keep experimenting

If you ran out of time in Session I, spend the first five minutes today designing your investigation. Then spend the lab session pursuing your investigation and documenting all your decisions, methods, improvements, and results in your lab notes online.

Refer to Session I for any plotting or fit code templates you may need to present and analyze your data.

Share your investigation

Towards the end of the lab session, you will present one graph of results to another group. While you show them the graph, you will briefly describe your experimental question, how you produced the data in the graph, and how you are interpreting the graph.

You'll each have **TWO** minutes to present and then **TWO** minutes to discuss (5 minutes total).

We can teach our students to *DO* physics, not just solve rote equations

Real-world problem solving, model building & inquiry

- Begin with complex, real-world phenomena rather than isolated equations
- Explicitly build iterative models
- Scaffold collaborative student investigations

Inquiry-based labs

- Prioritize skill development over reinforcing content
- Avoid verification and confirmation
- Provide space for students to think and interate

Questions?