The TEAL Physics Project: Building a Learning Community at MIT

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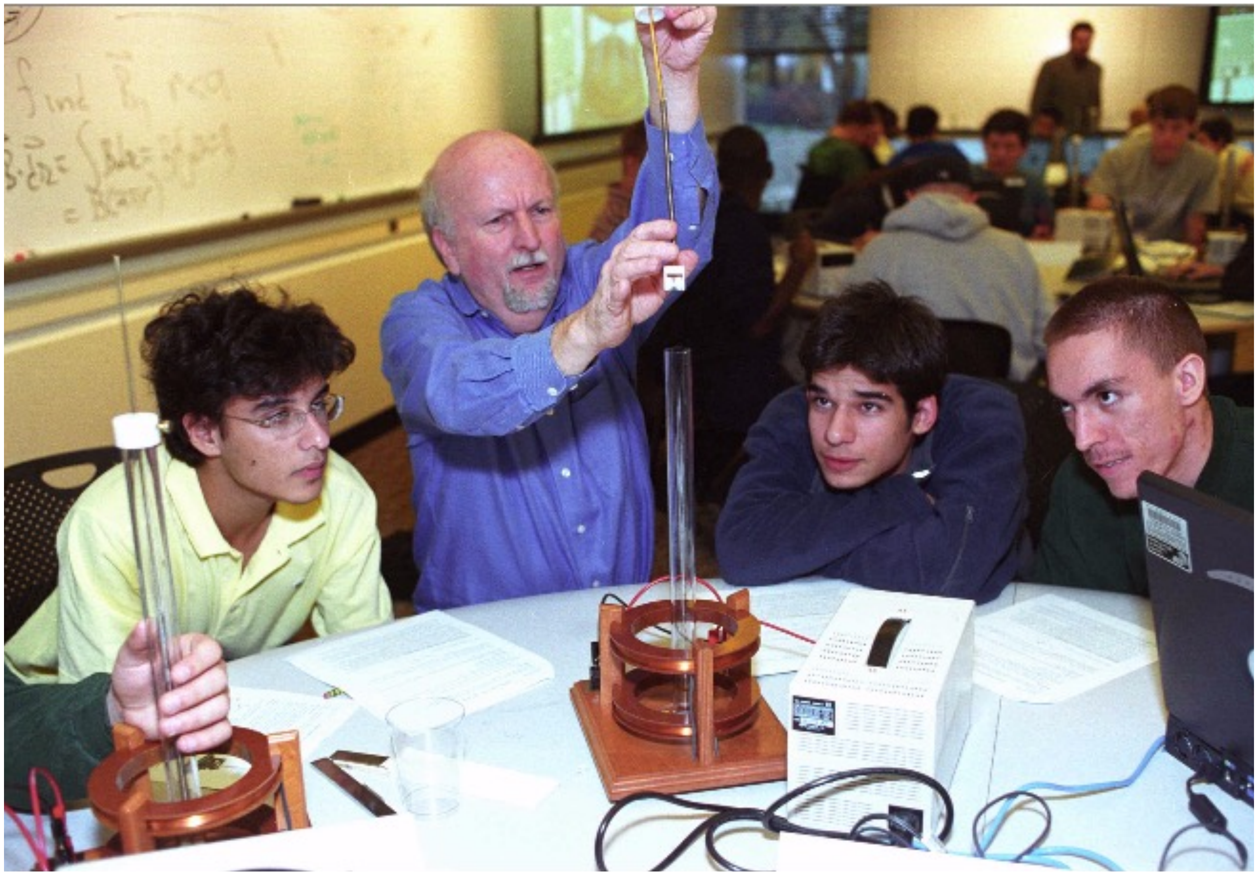
Outline of Talk

- MIT Physics First-Year Program
- Educational Challenges and Goals
- Architectural and Curriculum Design Principles
- TEAL Blended Learning Model
- Building a Learning Community

Physics Education Experiment
Technology Enabled Active Learning (TEAL)

Prof. John Belcher
TEAL Founder



A twenty-five year ongoing **physics educational experiment**

A blending of active learning and online materials into a technologically and collaboratively rich environment

First Year MIT Physics Classes

Two semesters of physics are required as part of the General Institute Requirements (GIR). Students can place out by taking an Advanced Standing Exam.

8.01* Newtonian Mechanics
8.02* Electricity and Magnetism

Fall Semester
8.01 TEAL: 670 students
8.012: 40 students (mathematically more advanced)
8.01L: 30 students (weaker math background)

8.02: 170 students
8.022: 30 students (mathematically more advanced)

Spring Semester
8.02 TEAL: 750 students
8.022: 20 students

First-year Physics Educational Issues

MIT Large first-year physics courses had inherent problems

- Lecture/recitations are passive
- Low attendance
- High failure rate
- Math is abstract, hard to visualize (esp. Electricity and Magnetism)
- Lab exercises do not reflect the research experience

MIT/Physics Learning Goals

Enhance conceptual understanding

Enhance problem-solving abilities

Develop communication skills

Develop collaborative learning

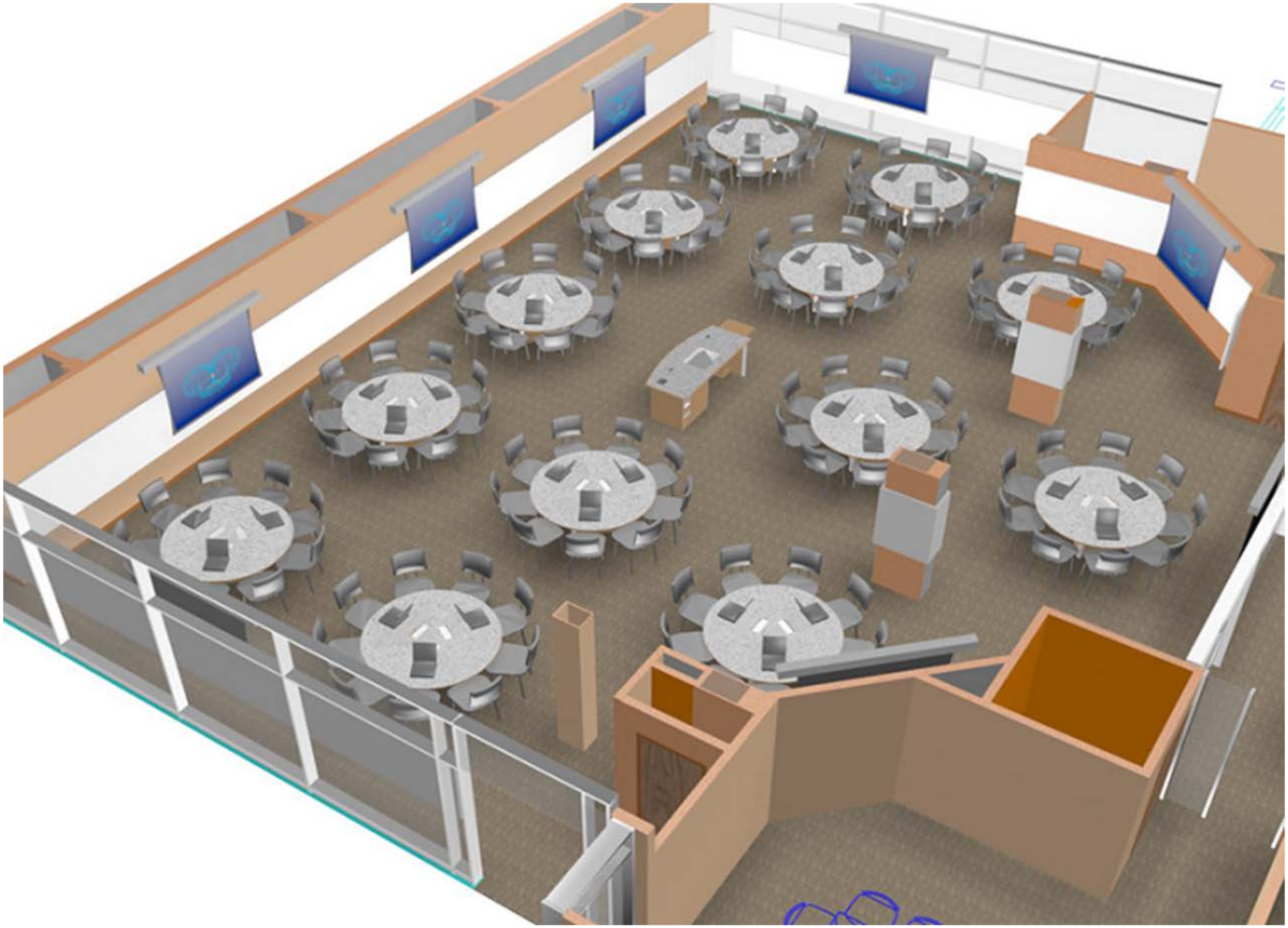
Encourage undergraduates to teach

Learning Space: Design Guidelines

Architectural space (classroom) should reflect:

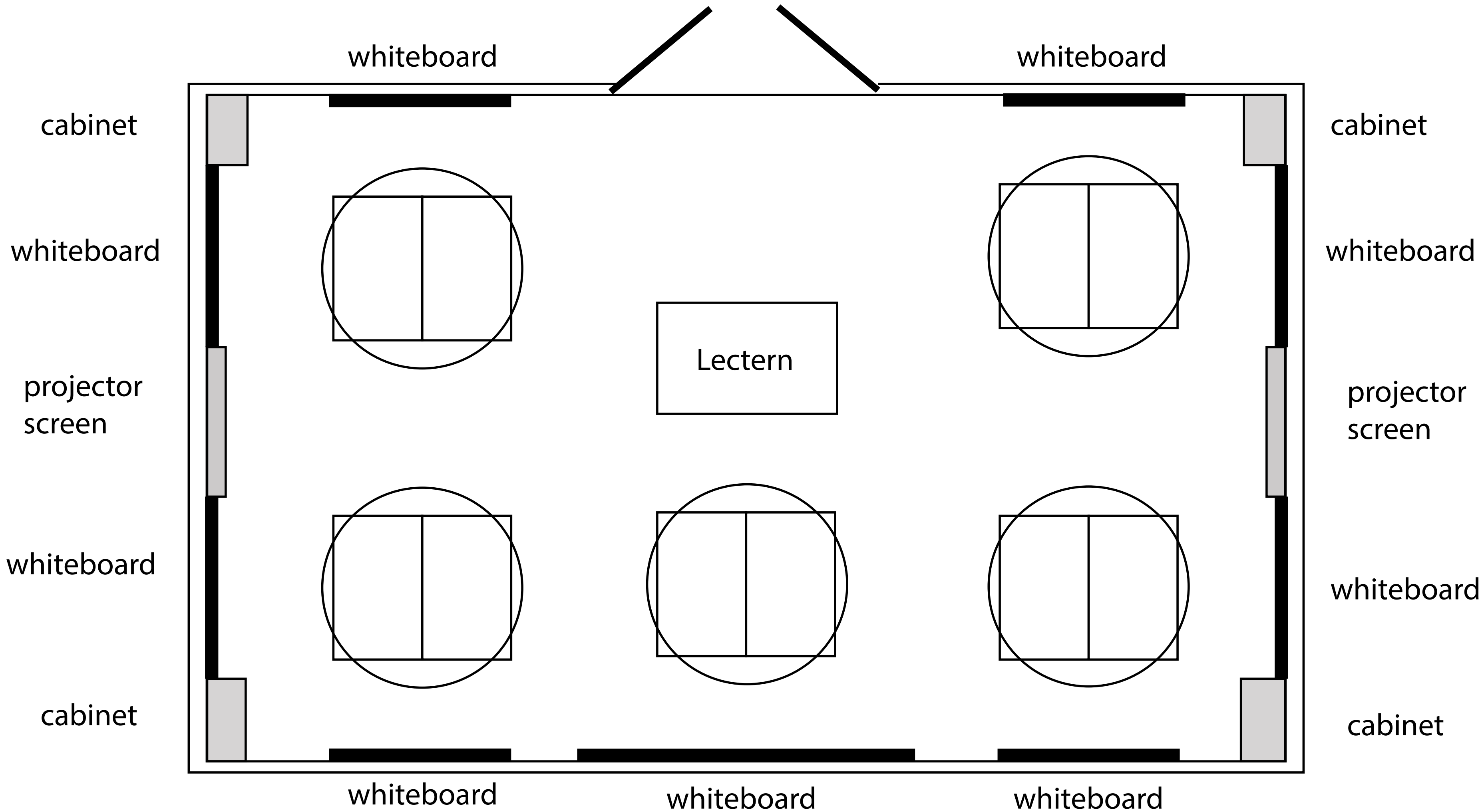
- how people interact and learn
- the pedagogical model: interactive learning
- enable learning space to become a laboratory for experimenting with active learning techniques

TEAL Classroom



TEAL Classroom

Essential Elements for the Learning Space



Should have plenty of **whiteboard space for students to work together on problem solving**

Backwards Course Design

Traditional Course Design

- Course Content
- Assessment

Result

- Course Defined by Content

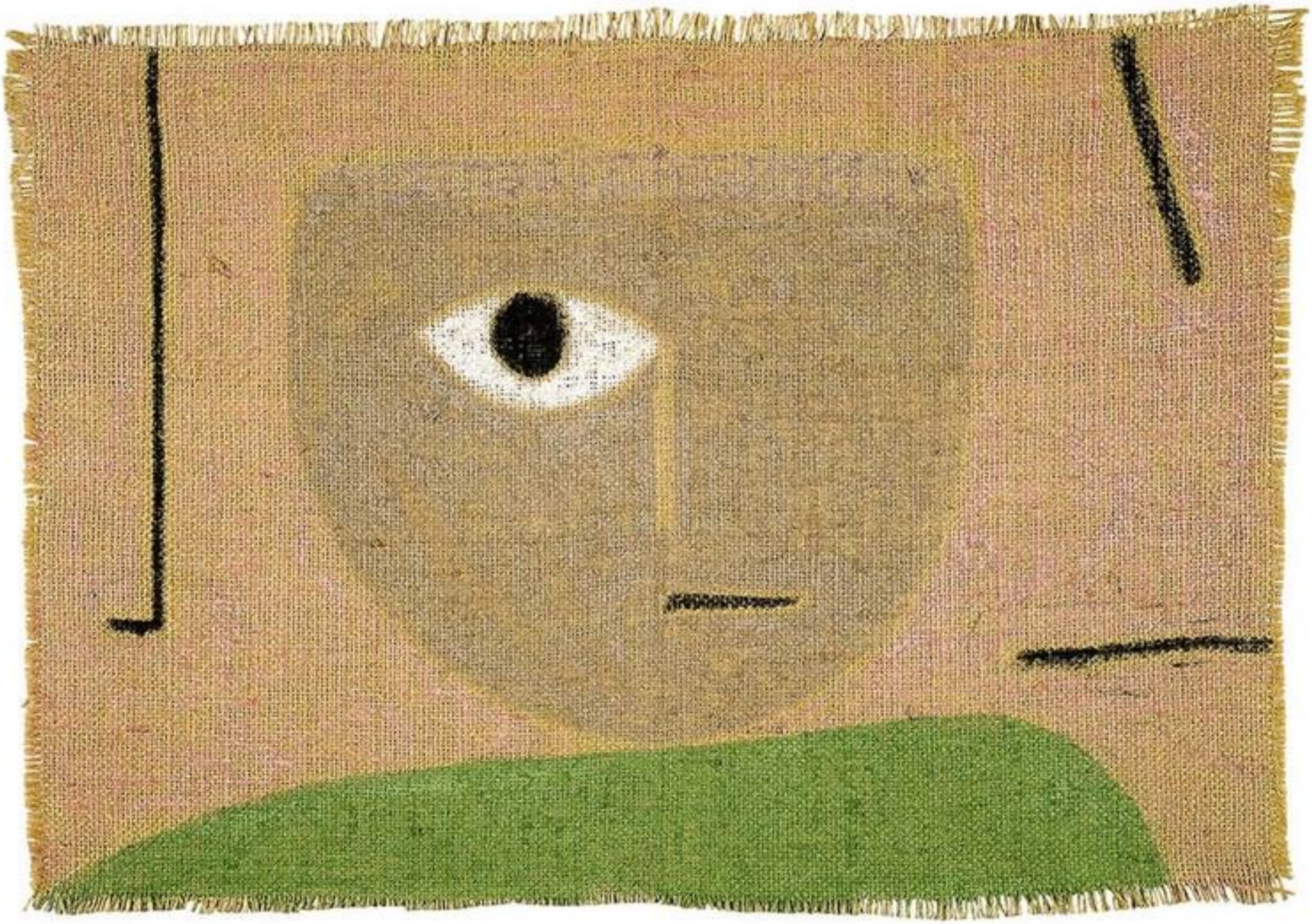
Backwards Course Design

- Desired Outcomes: Learning Objectives
- Acceptable Evidence
- Instructional Approach

Result

- Course Content Determined by Outcomes

Expert Problem-Solving Skills



Problem Solving Skills

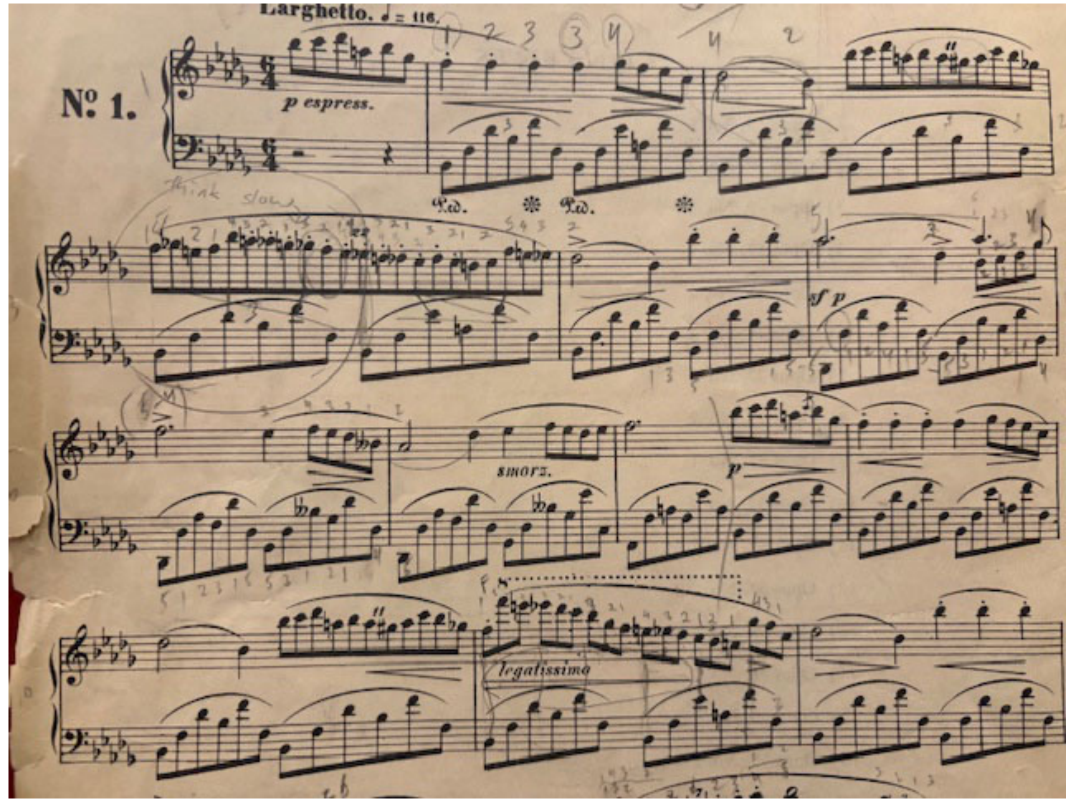
Students learn to become expert problem solvers through practice

Develop confidence based on experience

Necessary for innovation and creative thinking

Enables students to understand how to approach complex problems in any discipline

Spaced Practice: Musical Analogy



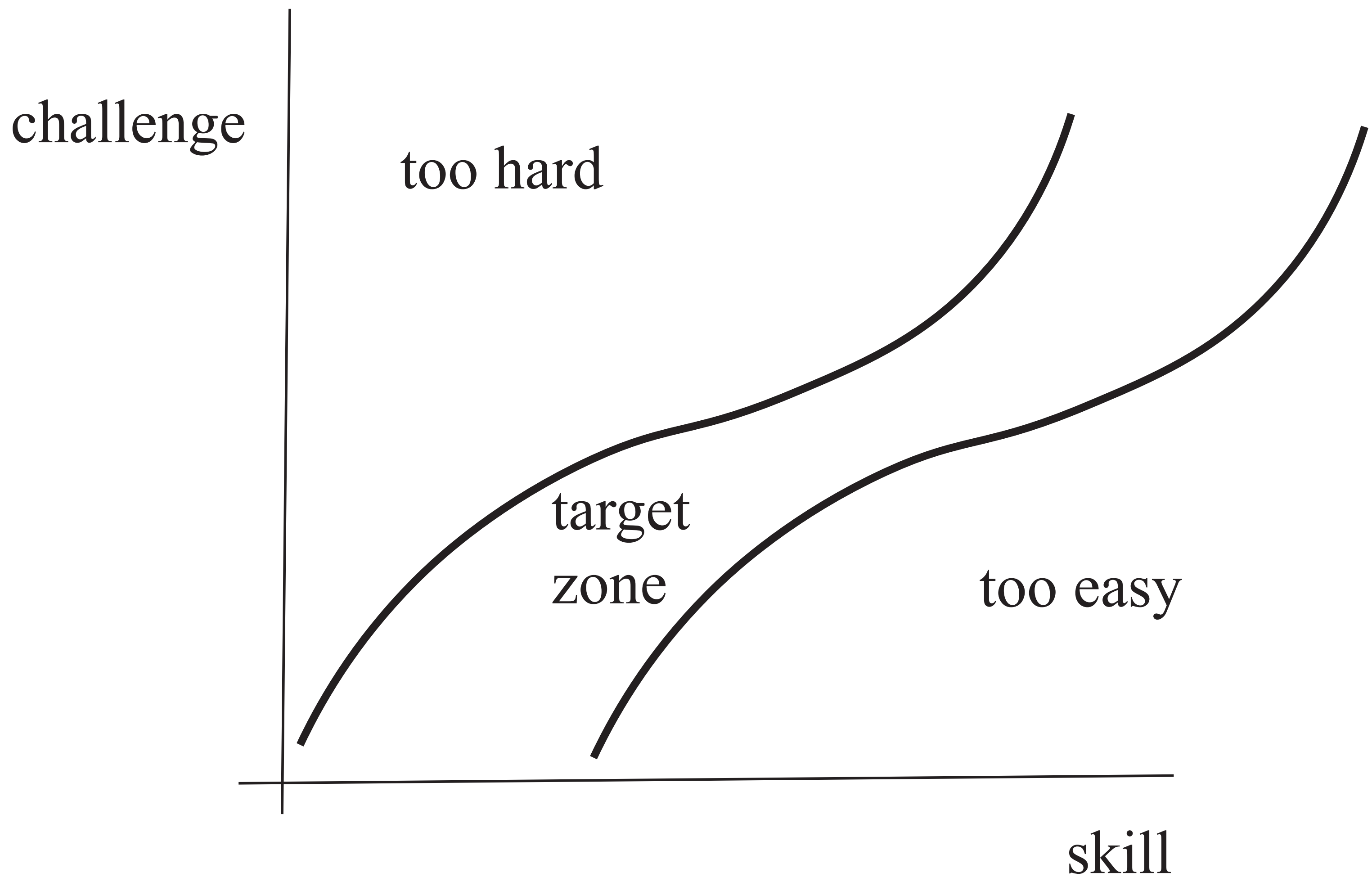
Suppose a musician **chooses** to play this score for the first time

Expert musicians have years of experience and a deep understanding of music structure. They are able sight-read and play the score effortlessly but will **still need to practice.**

A non-expert will need **to practice** measure by measure many times over with a music **teacher as a ‘coach’.**

Competency: Challenge vs. Skill

Create opportunities for effective spaced practice on the part of students



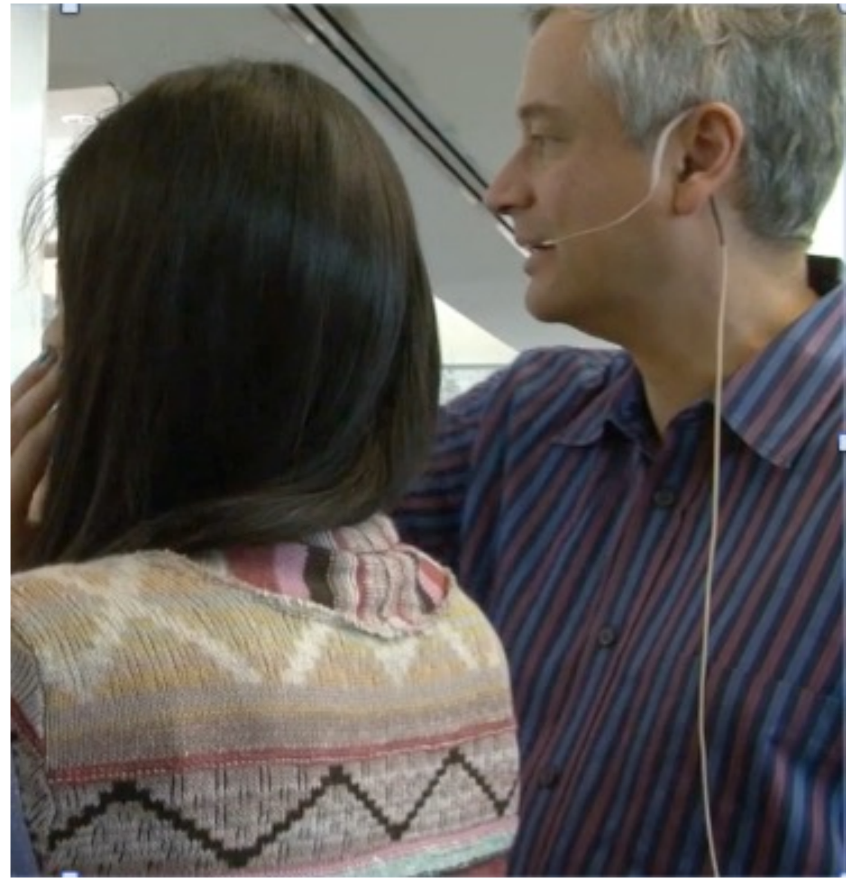
Challenge: Introduce Expert Thinking

Experts have a mental framework for organizing their knowledge

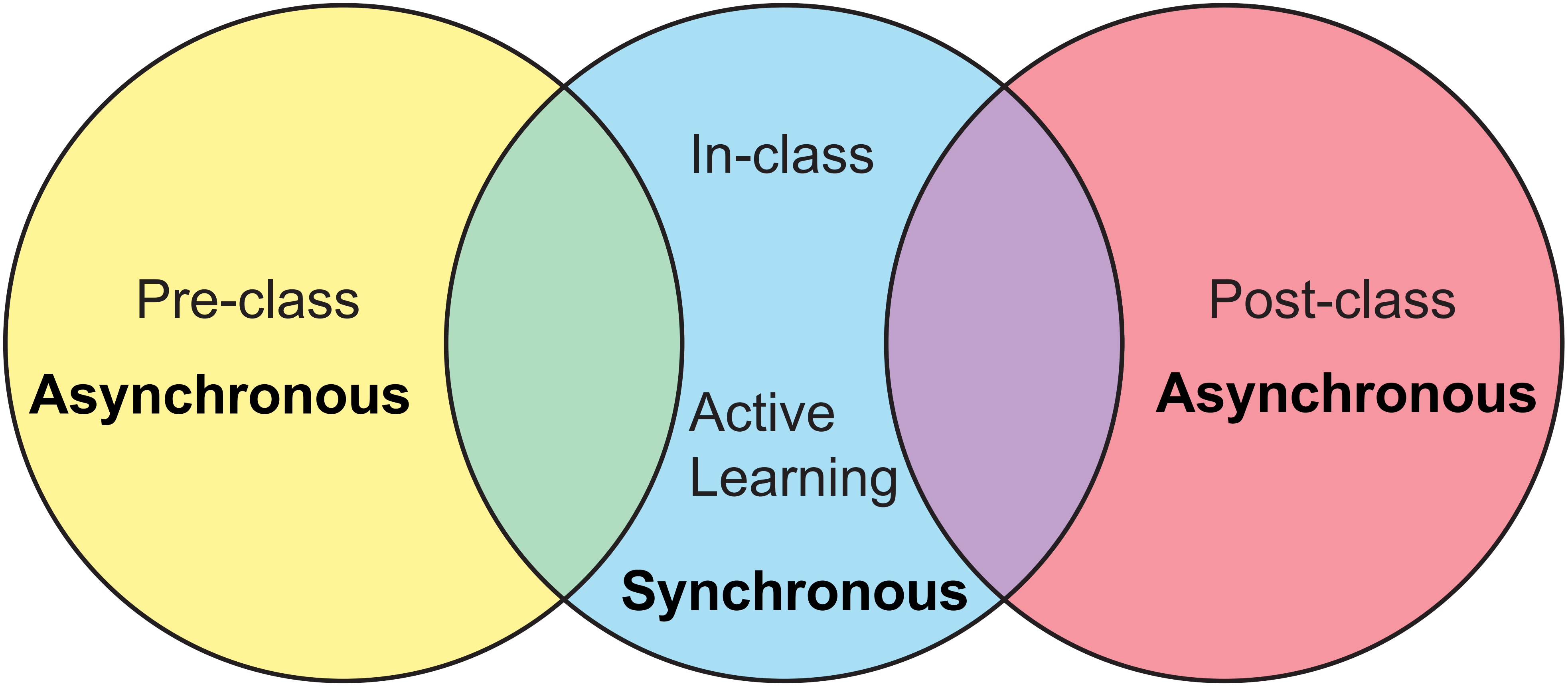
Perceive structure in evidence or situations

Recognize whether seemingly unrelated cases have the same underlying structure (ask the right questions)

Recognize when data, ideas, or conclusions conflict with prior knowledge



Blended Learning Model

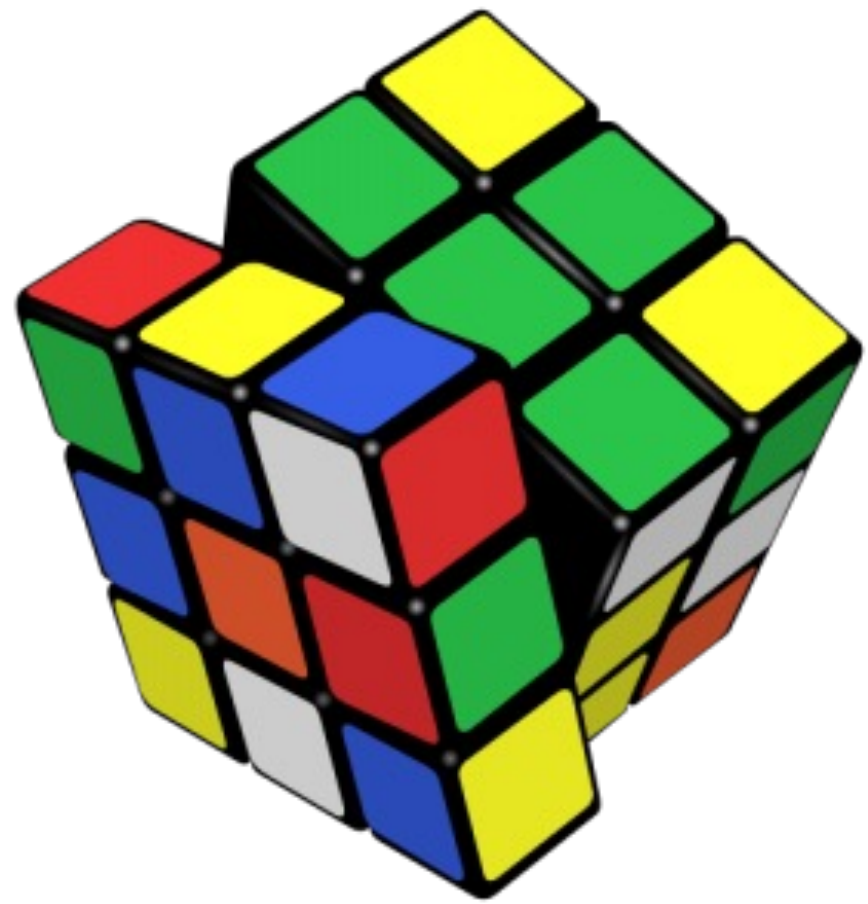


Why Blended Learning?

Learning problems associated with lecture-based classes are well documented

Active Learning classes are more successful at engaging student but are not well designed for content delivery

Blended Learning provides the glue that bonds content, conceptual understanding and practice



Blended Model: Weekly Modules

Pre-class:
Learning sequences on MITx course platform which introduces the content of the weekly modules.

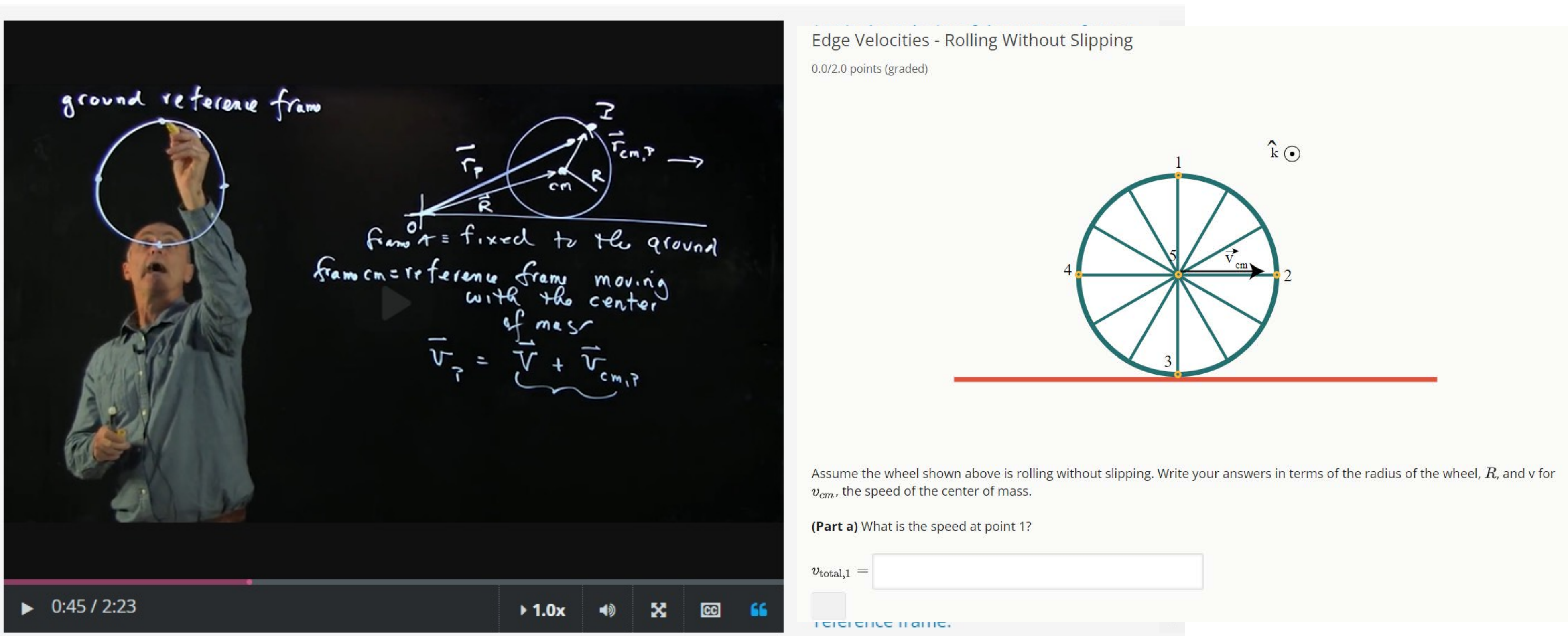
In-class:
Two 1 ½ hour classes per week. These sections are not lectures, but opportunities for active learning.

Workshop class: skill development "emphasis on spaced practice"

Post-class:
Graded problem set with optional answer checkers on MITx platform

Pre-Class Content Delivery: Learning Sequences

Learning Sequences: a collection of online videos, text and graded problems for students to complete before every class, on platform MITx.




Lightboard
Videos

(Most) Course Content delivered using Lightboard Videos

Short video clips (3-9 minutes) embedded in learning sequence with well defined outcomes

Each video is focused on a particular topic

Interactive questions between clips

Students view the videos when they are ready to learn (in contrast to when we are ready to teach)

Students can use videos for content, review, problem solving help

Lightboard Video: Spring Potential Energy

https://www.youtube.com/watch?v=_7JPHNCT1Qo&t=2s

In Class Active Learning

(Some) Elements of Active Learning

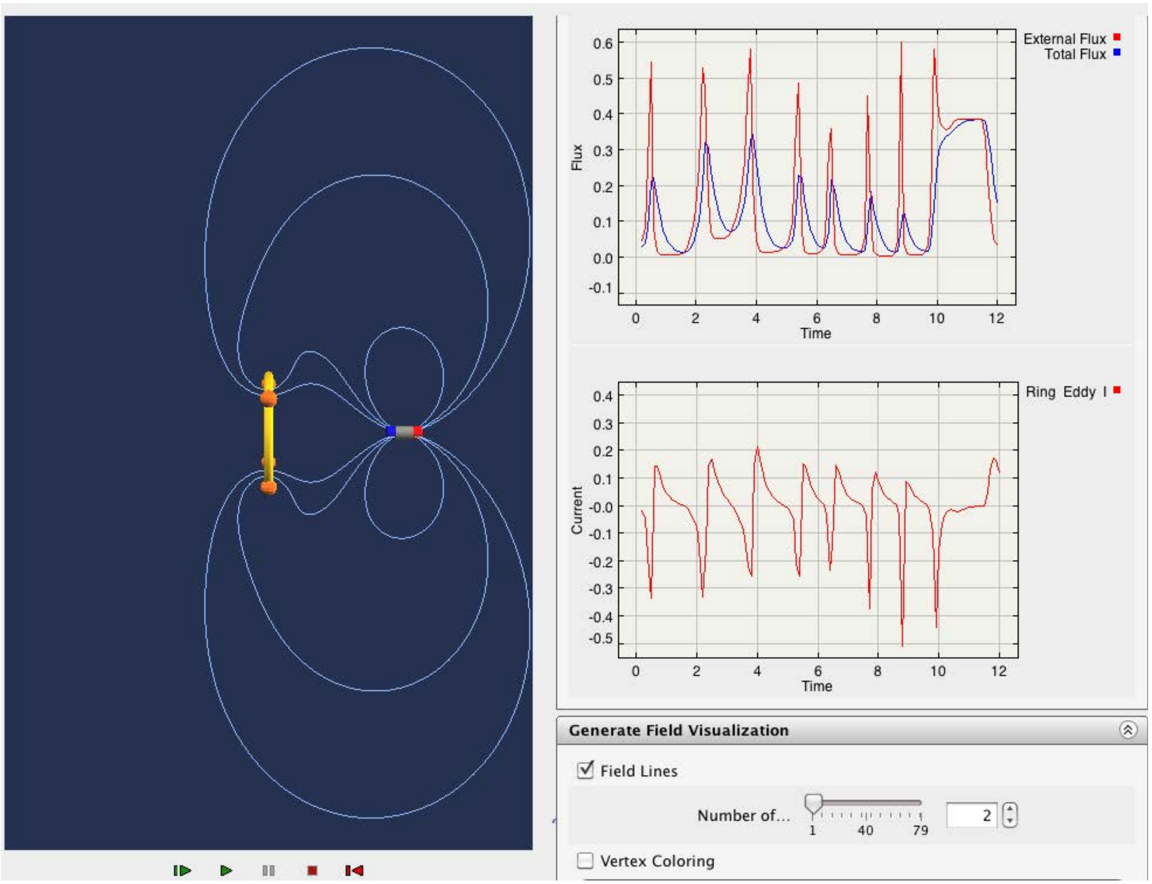
- Simulations and Visualizations

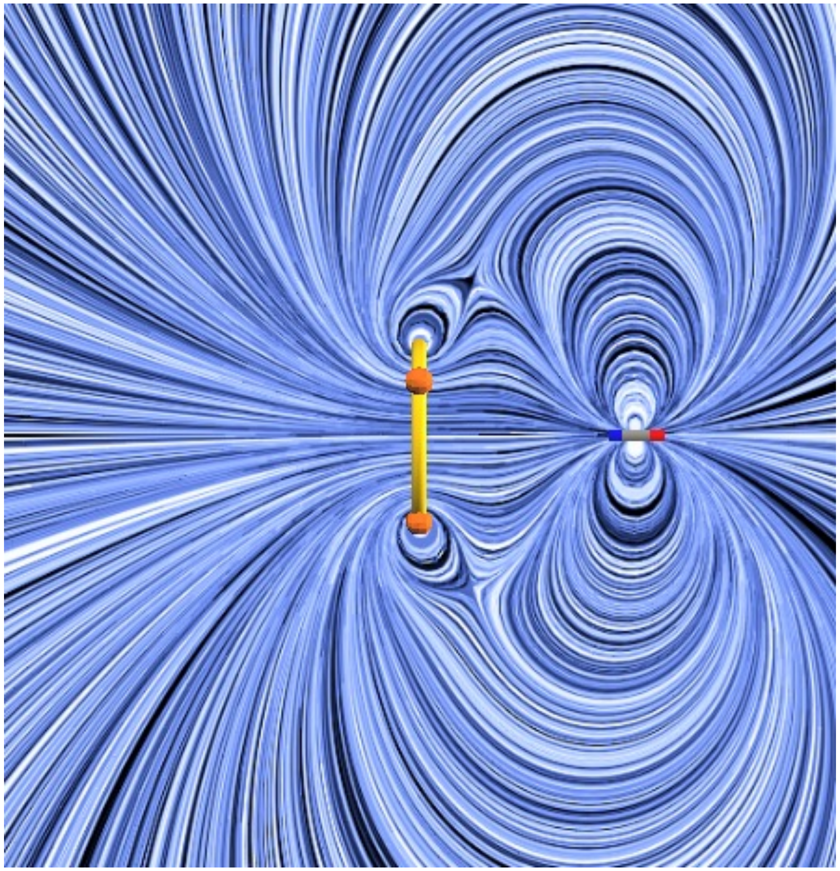
- Peer Instruction and Concept Tests

- Group Problem Solving

- Desk-top and Take-home Experiments

Visualizations and Simulations: Faraday Law Discovery Activity



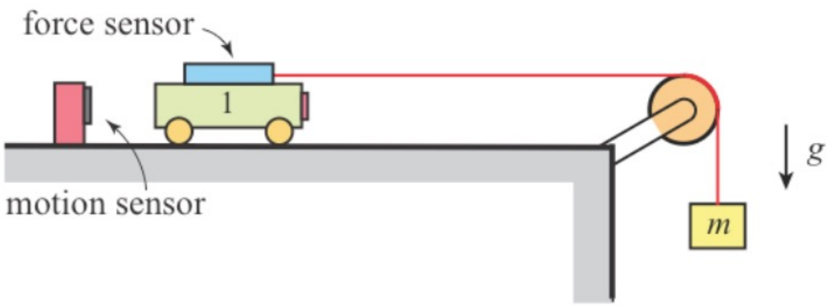


Student discovery activity: what is the relationship between magnetic flux in the induces current in the coil

http://public.mitx.mit.edu/gwt-teal/FaradaysLaw2.html

Just-in-Time Teaching: Concept Questions

CQ: Tension



A cart is placed on a nearly frictionless surface. A force sensor on the cart is attached via a string to a hanging weight. The cart is initially held. When the cart is released and in motion does the tension in the string

1. increase?
2. stay the same?
3. decrease?

ANSWER THE QUESTION BELOW (EXTERNAL RESOURCE) (1.0 points possi

Problem is closed

Open problem

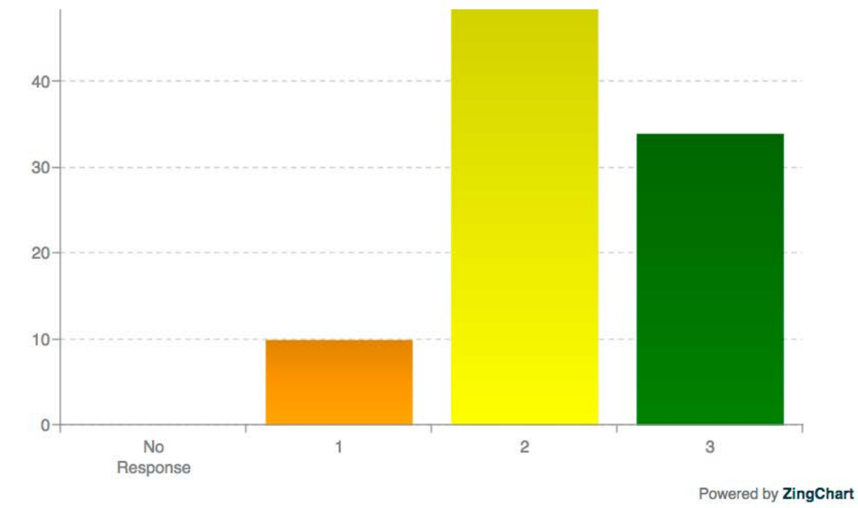
Plot 1:

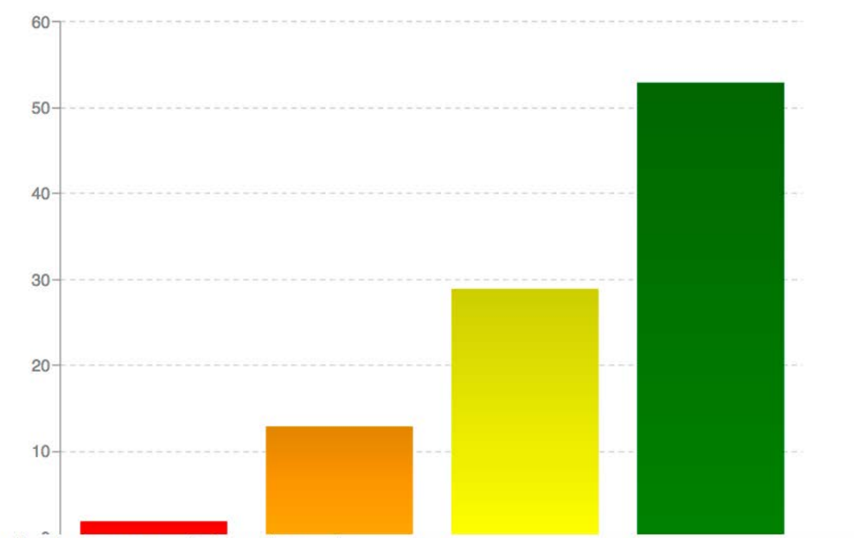
(Sep 11th 2017, 10:03:57) Section 1 Take 1, 97 responses

Plot 2:

(Sep 11th 2017, 10:06:49) Section 1 Take 2, 95 responses

ANSWER THE QUESTION BELOW (EXTERNAL RESOURCE) (1.0 points po:





Feedback on your work from the grader:

Take-home Experiment:
Measure the Period of a Pendulum

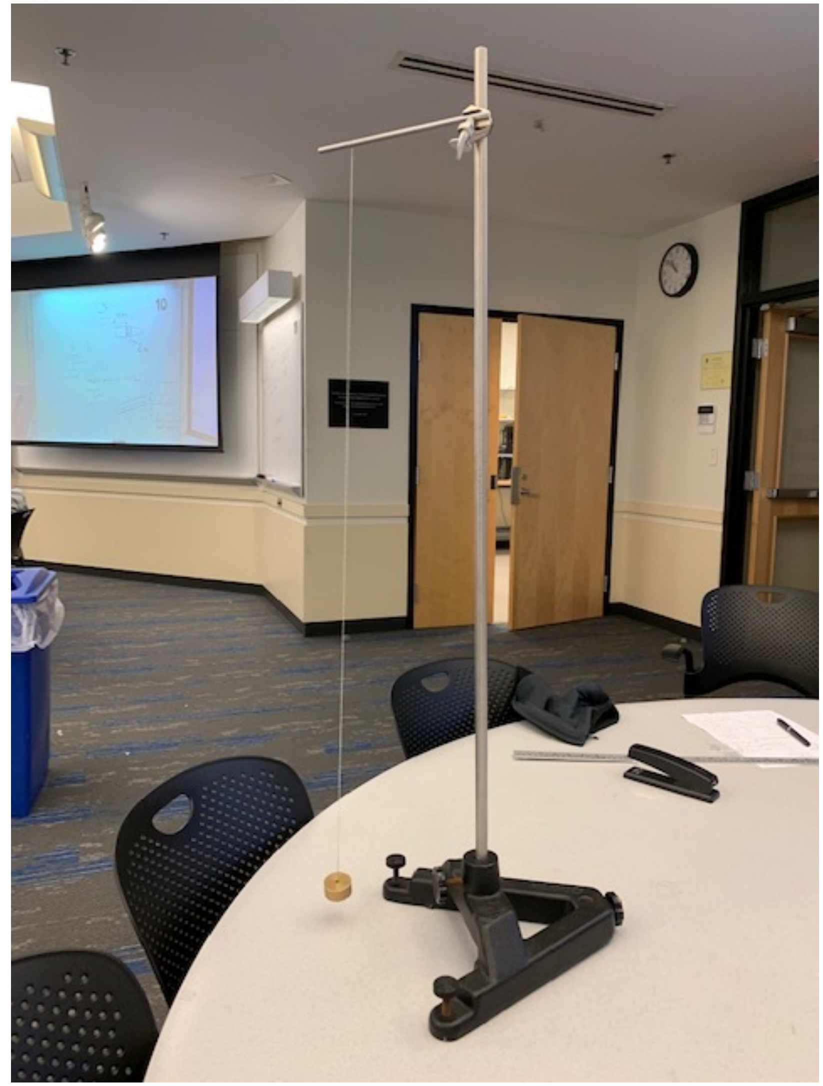
Design apparatus

Make and Test Models

Take data and analyze

Measure period

Improve measuring technique: precision and accuracy



Group Problem Solving: Whiteboards

Develop collaborative learning skills

Students work in small groups at the whiteboards solving problems with instructor feedback

Pólya: How to Solve it!

1. Getting Started – identify assumptions and givens, identify what information is needed and what should be neglected
2. Plan the Approach – articulate a strategy that may involve multiple concepts and problem solving methodologies,
3. Carry out the plan – use multiple types of representations, equations, graphs, visualizations
4. Reflection and Modification: Ability to modify plan in a constructive manner.
5. Review - does the answer make sense? Reflect on the limits of the model.

(Some) Characteristics of a ‘Good’ Learning Experience

- Allow a **fair degree of student choice** and control of their learning (ownership of the learning process)
- Develop **conceptual and analytic understanding**
- **Personal relevance and interest**
- Through patience, **spaced practice** (time on task), and attendance, students can successfully master content.
- Include opportunities for developing students’ abilities to discuss scientific concepts

Community of Learners

Members of the Learning Community

Faculty: Conductor. Provides subject expertise, motivation, measures learning outcomes

Graduate Teaching Assistant: and Technical Instructor: Learn to teach

Undergraduate Teaching Assistant: Encourages student teaching. Role model for students.

Students: Peer Instructors

Mentors: Additional support for students

Faculty Member's Role in Active Learning

Teachers provide motivation and design content

During active learning teachers circulate and give guidance; **"coach of thinking"**

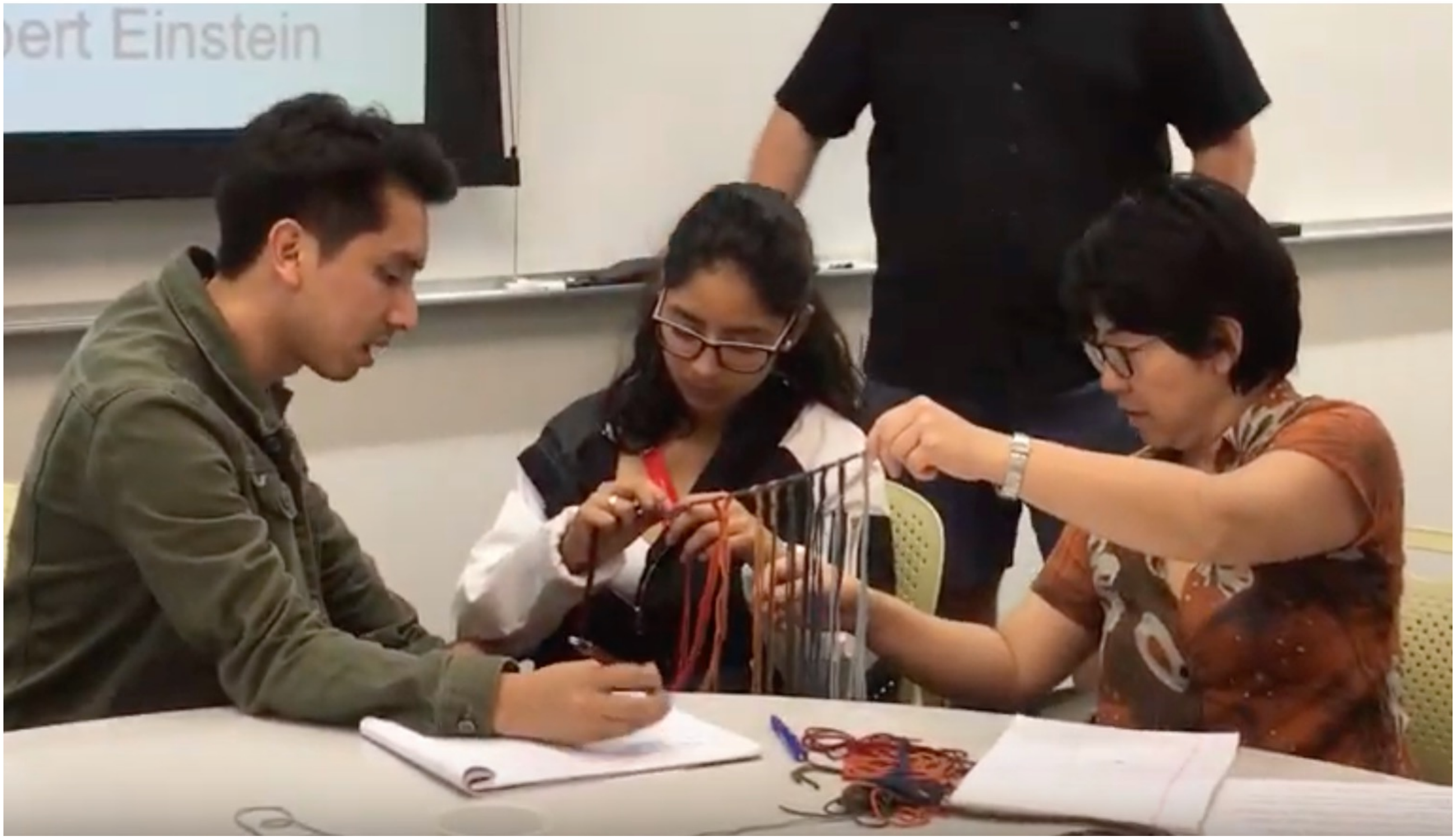
At the end of any activity, teachers provide explanation **(closure)**

Undergraduate Teaching Assistants

Undergraduate teaching experience enhances understanding the subject matter and of their own experience as students

Transformed classroom culture.

Mentors



Motivator, Listener, Information Provider, Helper

Mentor-Mentee Program

Faculty, staff, graduate students and undergraduates act as mentors

Initiated at the start of the Covid pandemic

Physics Mentor program: Class of 750 students, 17 mentors and 110 students joined program

Comparison of pre-online and online performance showed that mentees had a greater improvement in test scores

Some Concluding Thoughts

Sustaining Educational Innovation

All educational experiments should be rooted in the cultural practices of the home university

Sustaining educational reform requires commitment and patience

Necessary elements for sustaining educational reform:

- Long term institutional support
- Adapt teaching to local institutional / faculty / student cultures
- Address faculty concerns regarding interactive learning

Reflections

- **Motivation** is important for learning and is an essential part of effective teaching
- Think of yourself as a **“coach of thinking”** rather than as a “dispenser of information”
- **Feedback** that is timely and specific is crucial for learning
- Teach students **how to be self-learners**

Course Transformation Guide: Center for STEM Learning University of Colorado
http://www.cwsei.ubc.ca/resources/files/CourseTransformationGuide_CWSEI_CU-SEI.pdf

Lifelong Learners

"The development of general ability for independent thinking and judgment should always be placed foremost, not the acquisition of special knowledge. If students master the fundamentals of their subject and have learned to think and work independently, they will surely find their way and besides will better be able to adapt themselves to progress and changes..."

Albert Einstein

Assessment

1. Pre-test

1. In-class work

2. Homework

3. Study Guides

5. Mid-term Examination

6. Final Examinations

7. Post-test

4. Long-term Retention

Pre-Test and Post-Test

Many standardized pre-and post-test exists to measure learning gains with respect to various aspects of science and engineering learning outcomes

https://www.ncsu.edu/per/TestInfo.html

Hecke g-factor measures relative learning gains where N is the total number of questions on the test.

$$\langle g \rangle = \left(\frac{\#\mathrm{Correct}_{post-test} - \#\mathrm{Correct}_{pre-test}}{\mathrm{N} - \#\mathrm{Correct}_{pre-test}} \right)$$

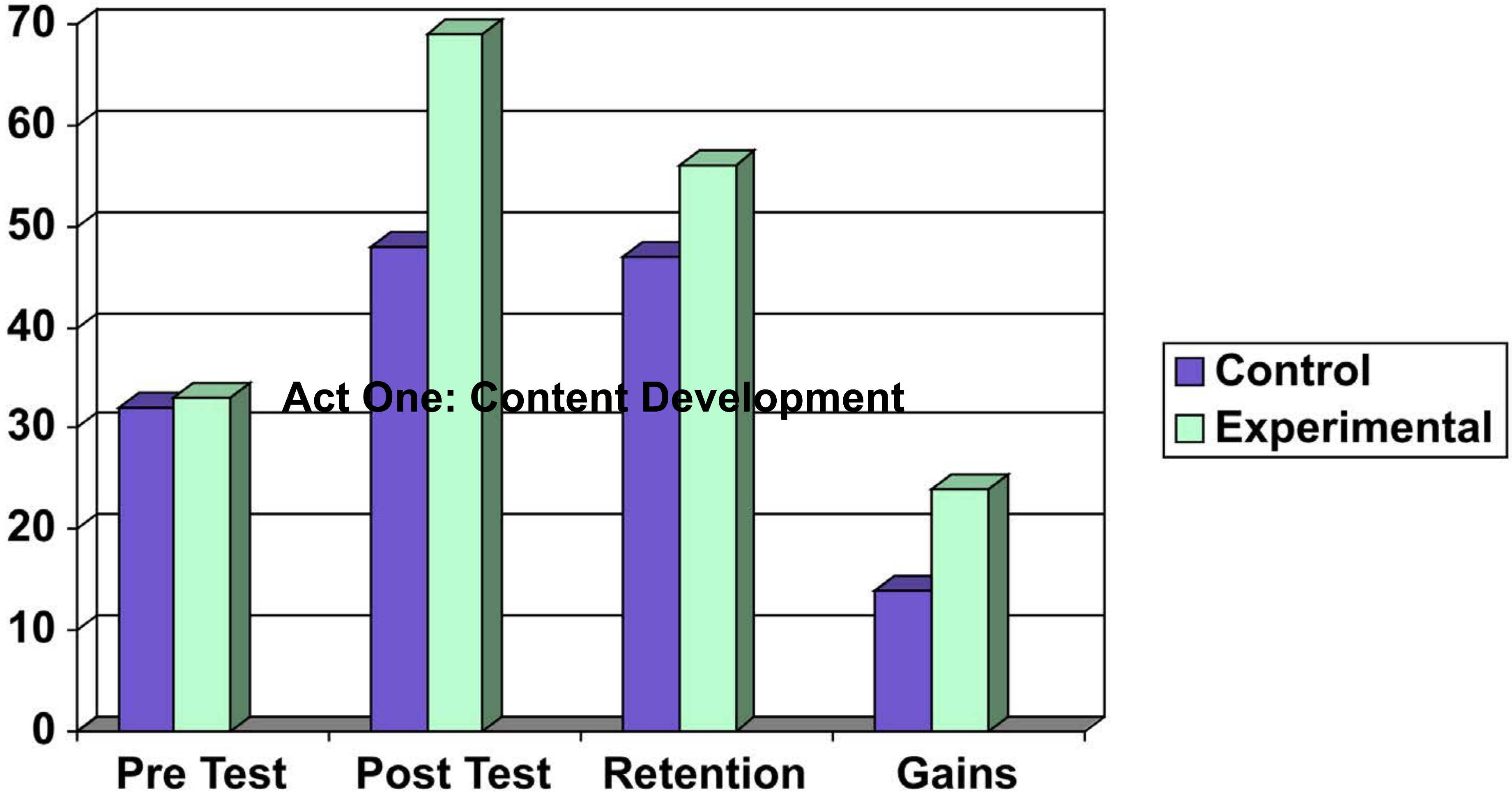
MIT TEAL: Pre/Post Conceptual Test Results

$$\langle g \rangle = \left(\frac{\#\text{Correct}_{post-test} - \#\text{Correct}_{pre-test}}{\text{N} - \#\text{Correct}_{pre-test}} \right)$$

Hecke g-factor

Group	Trial 2001		Control 2002		Spring 2003	
	N	g	N	g	N	g
Entire population	176	0.46	121	0.27	514	0.52
High	58	0.56	19	0.13	40	0.46
Intermediate	48	0.39	50	0.26	176	0.55
Low	70	0.43	52	0.33	300	0.51

MIT TEAL: Increases Seen Long Term



- Source: Dori, Y.J., E. Hult, L. Breslow, & J. W. Belcher (2005). "The Retention of Concepts from a Freshmen Electromagnetism Course by MIT Upperclass Students," paper delivered at the NARST annual conference.

Appendix

Ongoing Projects

- **Using AI**
- Introduction of Computational Projects
- Course Management Technologies
- Incorporating Research-based Course Content
- **Sustainability of Educational Innovations**

Second Chance Feature in Learning Sequences

If you've exhausted all your attempts on any of the problems above without getting full credit, you can submit your self-reflections on what went wrong and how to improve your approach using the button below, with the chance to receive credit for the missed problem.

Please note that the teaching team reviews your Second Chance responses and MITx submissions to make sure you attempted the problem and completed Second Chance with genuine effort.

Click here to submit Second Chance responses.

Effective Potential - Force

Please describe what mistakes you made and reflect on what misconceptions led you to the wrong answer *

Please explain in detail what the right approach would have been to this problem *

Submit

Summarizing Second Chance Responses with AI for Instructers before In-class work

A summary of the main issues students faced in the pre**-class component is** then AI generated and automatically inserted in the class slides **for instructors to use in class.**

Example summary slide

AI Generated Summary of Students' Mistakes

- - Many students incorrectly assumed that when torque is zero, angular momentum must also be zero.
- - Several students failed to understand the relationship between torque and angular momentum.
- - A common mistake was neglecting the fact that the force and position vector are not always parallel.
- - Students should have considered the direction of tension as a vector and compared it to the position vectors at each point.
- - Drawing free-body diagrams and visualizing the forces acting on the object would have helped in understanding the torques.
- - Students should have properly checked their calculations and values before submitting their answers.

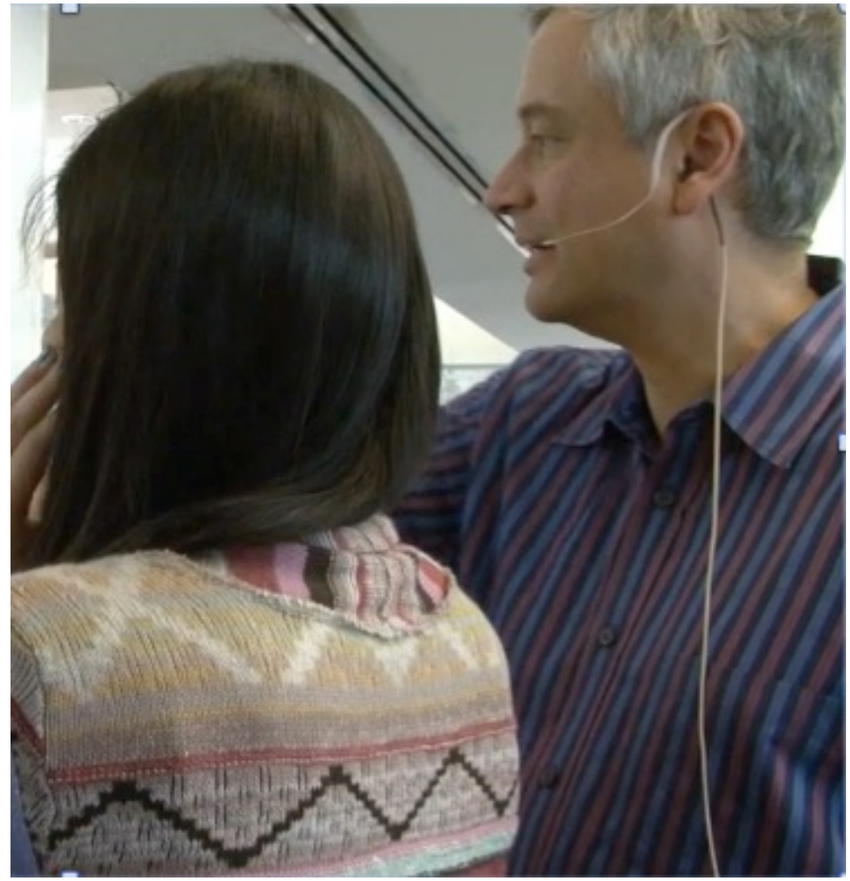
Developing Expert Problem Solving Skills: Group Learning

Develop Student Trust: You Are There To Help Them Learn

1. Information Provider
2. Motivator
3. Mentor

Expert Thinking

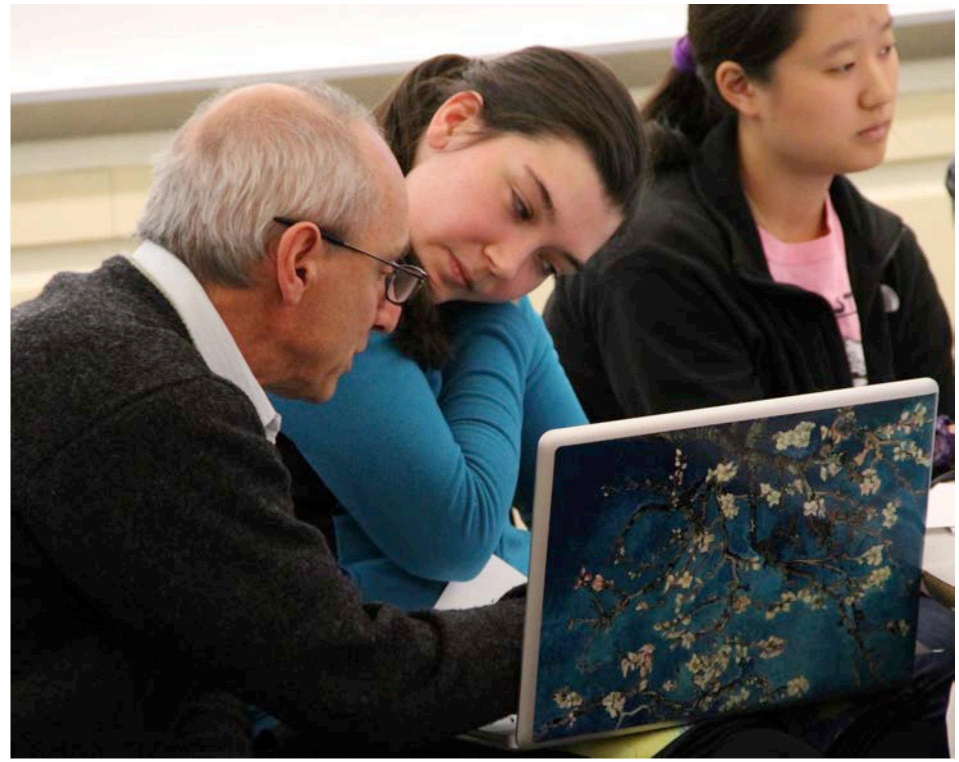
Experts have a mental framework for organizing their knowledge



- Effortless retrieval of relevant collected facts from memory
- Fast reasoning through a chain of possibilities
- Recognition of data, ideas, or conclusions that conflict with prior knowledge
- Efficient integration of related ideas

Expert Thinking

Experts perceive structure in evidence or situations



- Notice relevant structures that cues them to next step
- Recognize whether disparate instances have the same underlying structure
- Spend time to organize cases and evidence to find structure
- Identify empirical discrepancies that can drive the high effort of idea revision

STEM Learning Goals

Develop scientific, mathematical and engineering literacy so that the next generation is capable of making informed decisions on issues arising from complex systems.

- technological transformations (ex. AI)
- economic development,
- environmental change,
- development of renewable energy sources.

Group Problem: Heading a Football

If a player heads a ball in the opposite direction, estimate the force of the ball on the head.

In your groups: discuss what models and concepts may apply. What information is needed and what can be neglected?