

# Flat space, deep learning



BLC 2015  
Austin, TX, 28 March 2015



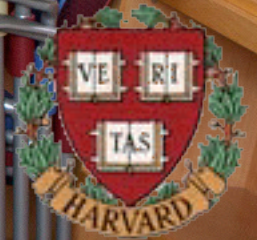
# Flat space, deep learning

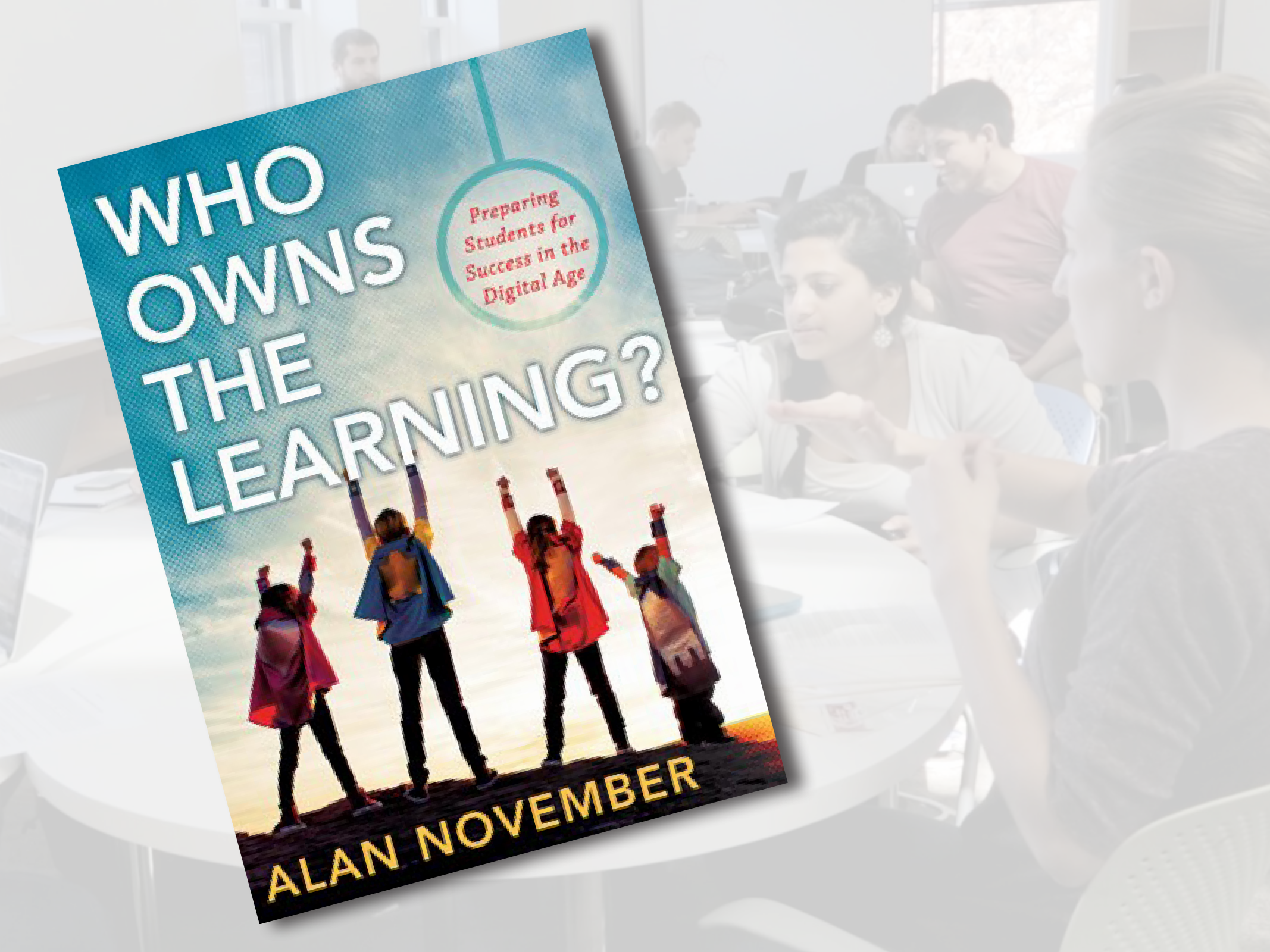
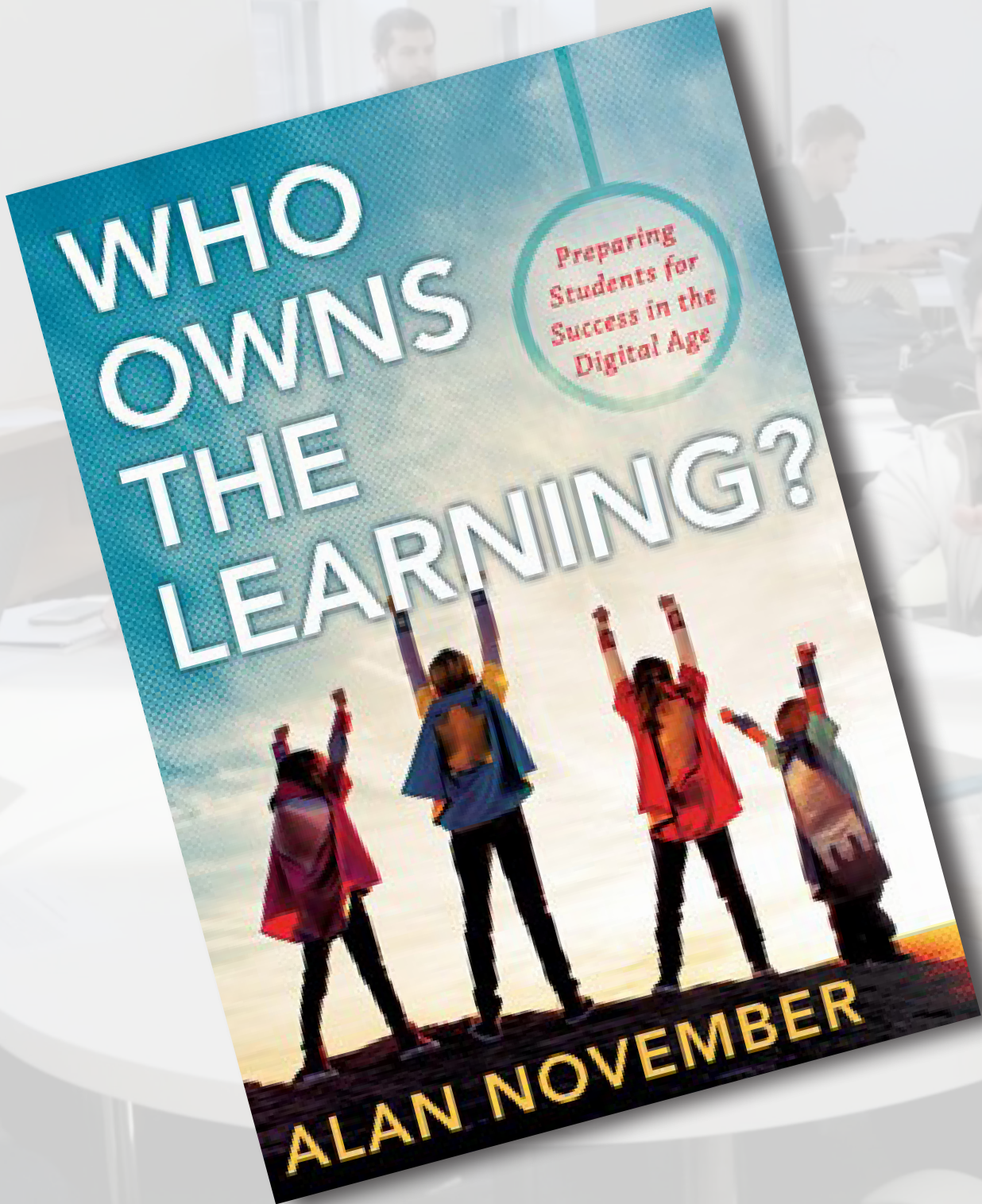


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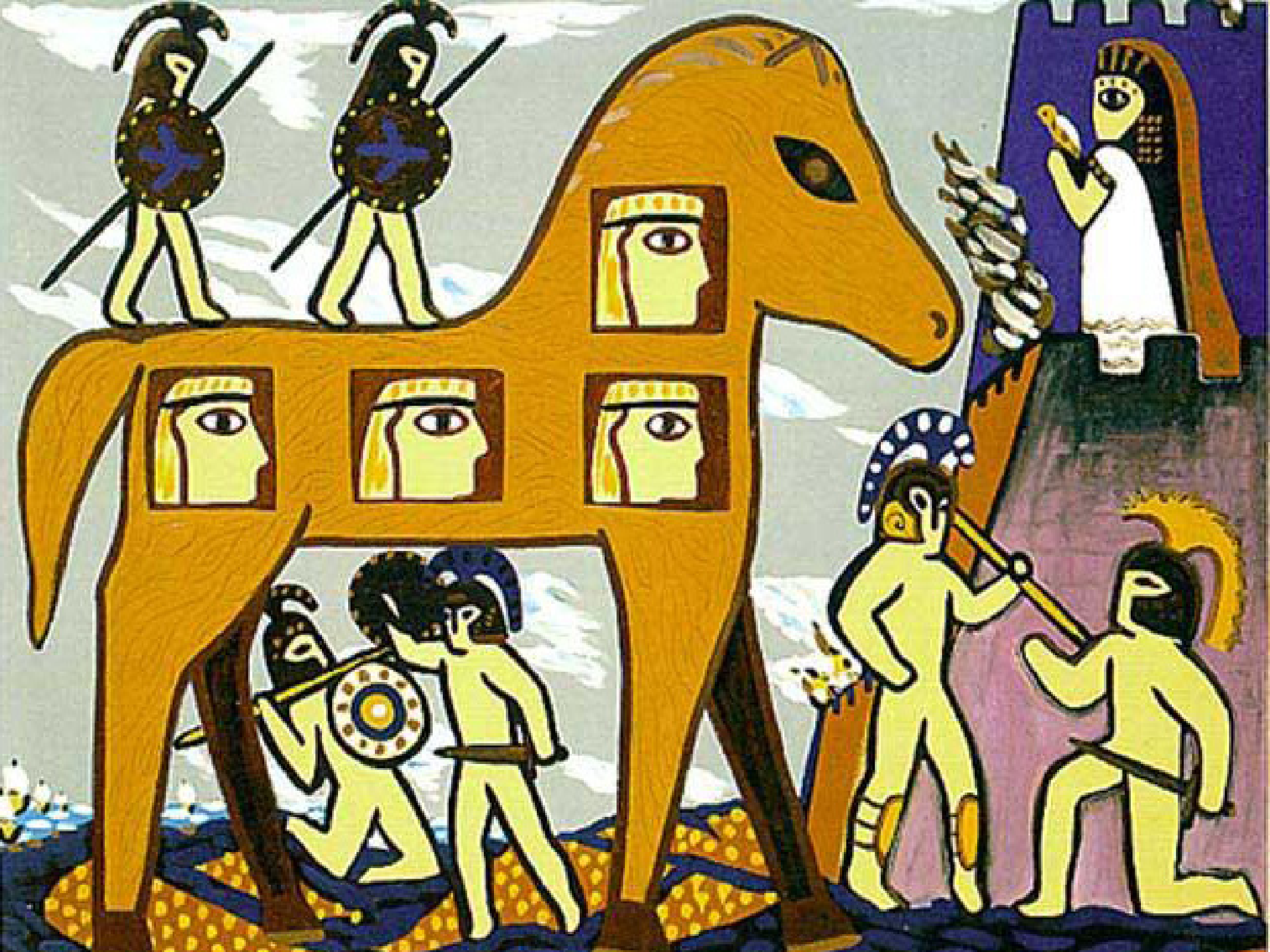
@eric\_mazur







**Ownership of learning *physics*?**





**team & project-based approach**

A stylized illustration of a brown horse with several human faces on its body, surrounded by various figures in a landscape. The horse is the central focus, with a large face on its head and three smaller faces on its body. The background features a landscape with a blue sky, a purple mountain, and a yellow sun. There are several figures: two figures on the horse's back, a figure on a mountain, and two figures on the ground. The overall style is reminiscent of ancient Egyptian art.

# ProTeam Learning







**1** design

**2** approach

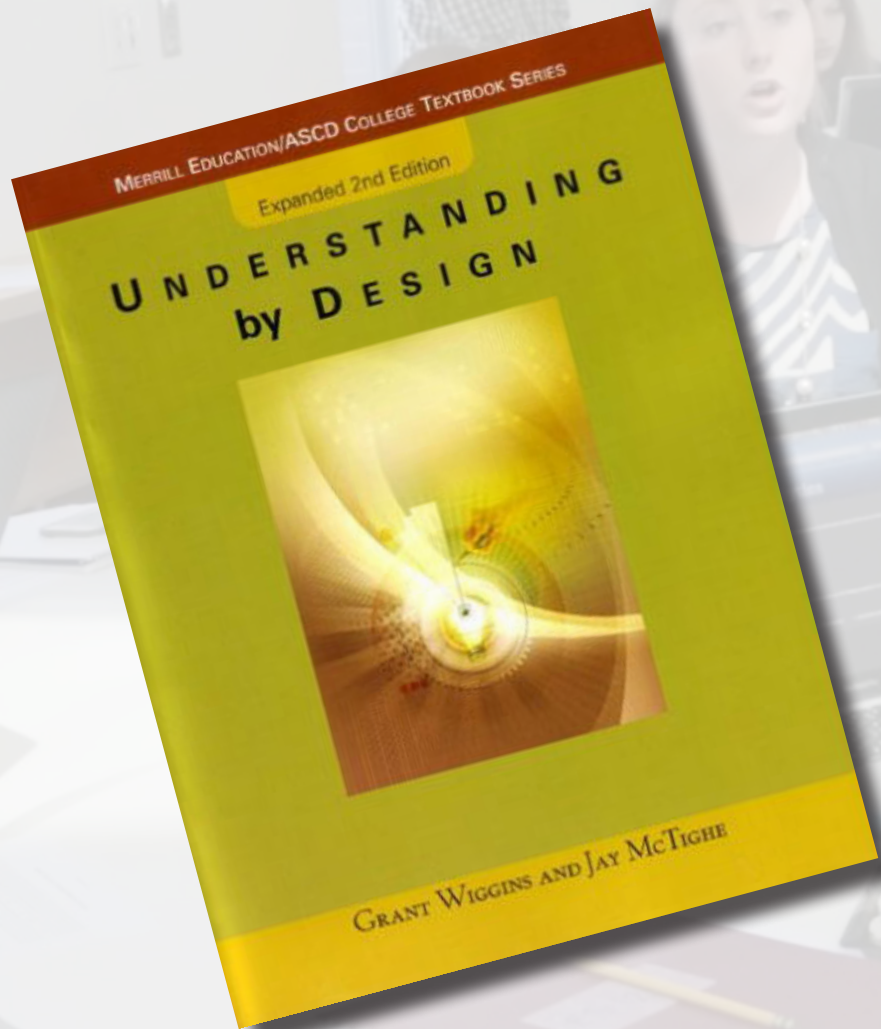


**1** design

**2** approach

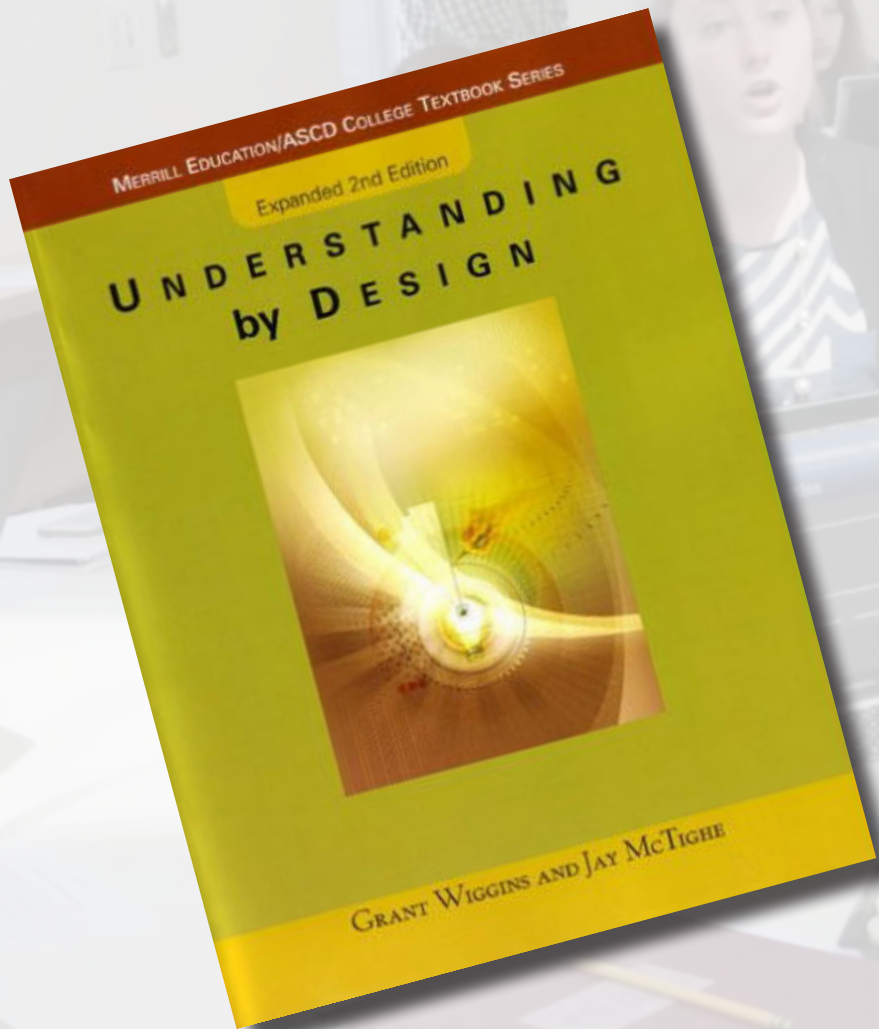
**3** results

## Setting learning goals



Grant Wiggins and Jay McTighe, *Understanding by Design* (Prentice Hall, 2001)

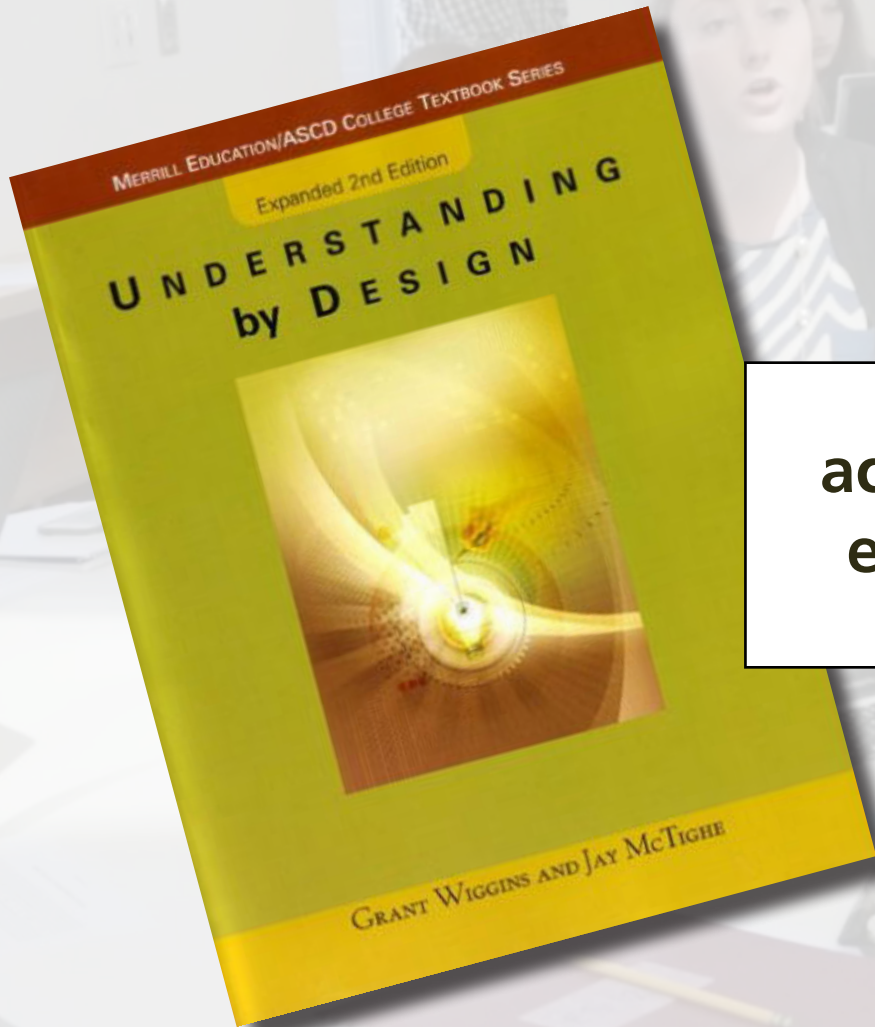
## Backward design



**desired  
outcomes**

Grant Wiggins and Jay McTighe, *Understanding by Design* (Prentice Hall, 2001)

## Backward design



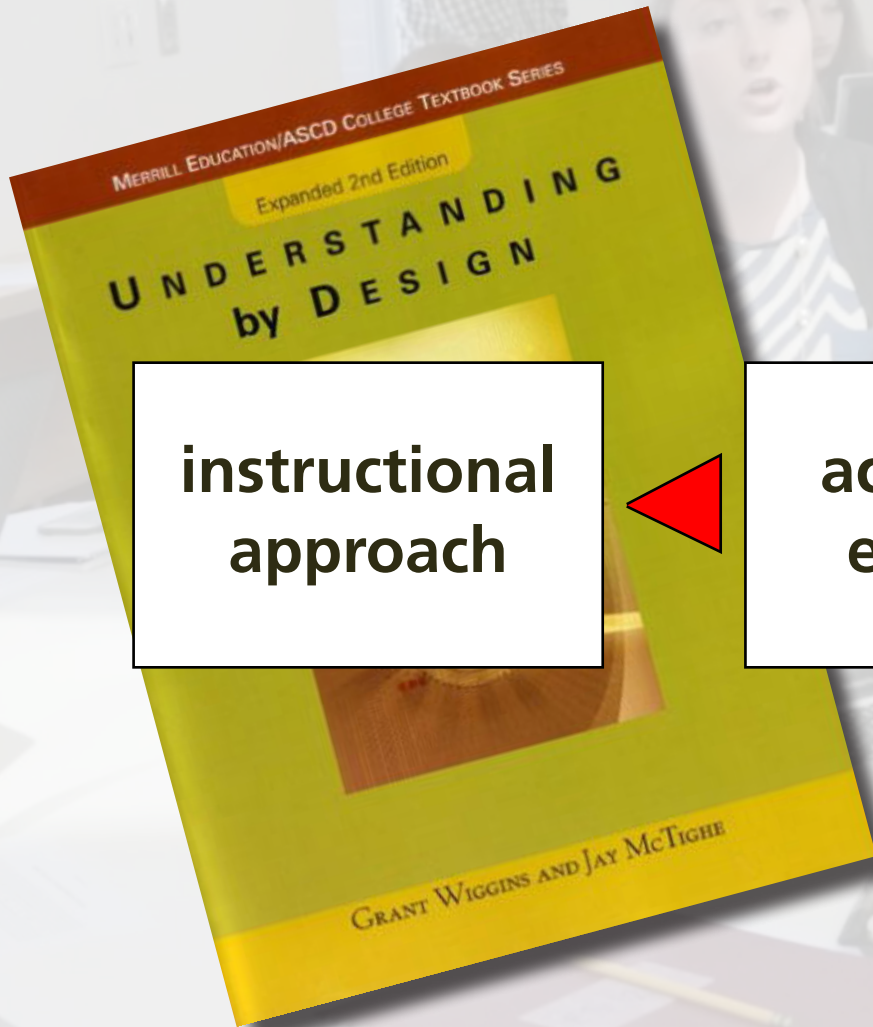
acceptable  
evidence



desired  
outcomes

Grant Wiggins and Jay McTighe, *Understanding by Design* (Prentice Hall, 2001)

## Backward design



**instructional  
approach**

**acceptable  
evidence**

**desired  
outcomes**



Grant Wiggins and Jay McTighe, *Understanding by Design* (Prentice Hall, 2001)

also designed to

- **Qualitative Analysis:** The ability to analyze and to solve problems in scientific disciplines qualitatively, including estimation, and visual thinking.
- **Quantitative Analysis:** The ability to analyze and to solve problems in scientific disciplines quantitatively, including use of appropriate tools, quantitative solving, and experimentation.
- **Diagnosis:** The ability to identify and resolve problems within complex identification, formation and testing of a hypothesis, and recommending solutions.
- **Design:** The ability to develop creative, effective designs that solve creation, problem formulation, application of other competencies, balance and which integrate knowledge, beliefs and modes of inquiry from multiple perspectives.
- **Teamwork:** The ability to contribute effectively in a variety of roles while respecting everyone's contributions. You will develop communication, questioning, listening, and identifying multiple approaches and point of view.
- **Communication:** The ability to convey information and ideas effectively to identify and address your own contributions, fluency in use of communication, and both positively

# competencies

## COURSE GOALS

After successful completion of this course, you will be able to... (with...)

- Use independent study and research to tackle a problem
- Apply the scientific method to advance your knowledge and to design
- Use a variety of techniques to get a handle on problems: represent
- perform order of magnitude estimates, use dimensional analysis
- symmetries, evaluate limits, and/or relate the problem to cases w
- Set up, solve, and interpret relevant equations
- Know how to evaluate the correctness of a solution
- Explain assumptions made in a model and know how to justify
- Analyze a system, explain why it works, and how to optimize
- Use information to build a case for a specific design or measur
- Describe how a measurement is performed and the limitations
- software to control simple experiments and accumulatio
- identify sources of uncertainty, and minimiz
- measurement in order to develo
- and presentat

# course goals



# content-specific goals

<http://bit.ly/ap50visitor>





**information transfer**

**faculty-centered**





**interaction**

**student-centered**



**1** design

**2** approach



**CLASS**

1st exposure



**ROOM**

deeper understanding

**1** design

**2** approach





1st exposure



deeper understanding



1st exposure



deeper understanding

**no lectures**

**no exams**

**1 design**

**2 approach**



## Three major components:

- **information transfer (out of class)**
- **in-class activities**
- **projects**

**1** design

**2** approach

# Information transfer

## social document annotation system

1 design

2 approach

# Information transfer

6/34 105%

Home Practice Exam Midterm 2

CHAPTER 29 Changing magnetic fields

any relative motion between the magnet and the loop causes the magnetic flux to change. This change in magnetic flux is changing in situations that means current is induced in the loop in some cases.

Evaluate result: A current is induced in the loop, but only in case 4 is a magnetic force exerted on the current. Faraday's law tells me, however, that there will be a current whenever there is a changing magnetic flux through the loop, so my answers must be 1, 2, 3, and 4.

29.3 Is a magnetic force exerted on the (moving) charge carriers in the loop of wire held by the magnet in Figure 29.7b?

## 29.3 Electric fields accompany changing magnetic fields

Example 29.2 and Checkpoint 29.3 lead to a surprising conclusion: although no magnetic force is exerted on the charge carriers in a stationary loop, a current is still induced! Figure 29.10 shows this situation in more detail. Experiments show that as a magnetic field moves past a stationary conducting rod, a charge separation and hence a potential difference develop between the ends of the rod even though no magnetic force is exerted on stationary charge carriers.

The potential difference that develops between the ends of the rod shown in Figure 29.10 is the same as that which would develop if the magnetic field were stationary and the rod were moving to the right (recall Figure 29.1). Any relative motion of rod and magnet-

2

## CHAPTER 28 Magnetic fields of charged particles in motion

In this chapter we investigate further the relationship between the motion of charged particles and the occurrence of magnetic fields. As we shall see, all magnetism is due to charged particles in motion, whether moving along a straight line or spinning about an axis. It takes a moving or spinning charged particle to create a magnetic field, and it takes another moving or spinning charged particle to "feel" that magnetic field. We shall also discuss various methods for creating magnetic fields, which have wide-ranging applications in electromechanical machines and instruments.

### 28.1 Source of the magnetic field

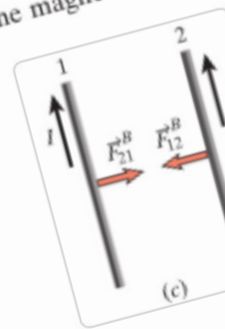
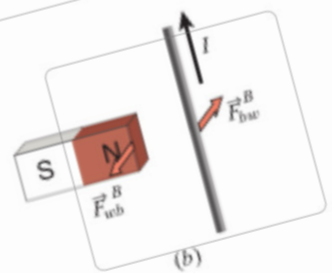
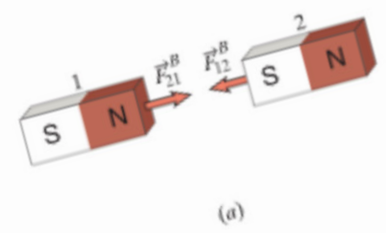
As we saw in Chapter 27, magnetic interactions take place between magnets, current-carrying wires, and moving charged particles. Figure 28.1 summarizes the interactions we have encountered so far. Figures 28.1a-c show the interactions between magnets and current-carrying wires. The sideways interaction between a magnet and a current-carrying wire (Figure 28.1b) is unlike any other interaction we have encountered. The forces between the wire and the magnet are not central — they do not point directly from one

Concepts

object to the other. As we saw in Section 27.7, the magnetic force exerted on a current-carrying wire is the sum of the magnetic forces exerted on many individual moving charge carriers. Similarly the magnetic field due to a current-carrying wire is the sum of the magnetic fields of many individual moving charge carriers. Figures 28.1d and 28.1e illustrate the magnetic interactions of moving charged particles. Note that for two charged particles moving parallel to each other (Figure 28.1e), there is, in addition to an attractive magnetic force, a (much larger) repulsive electric force.

It is important to note that the magnetic interaction depends on the state of motion of the charged particles. No magnetic interaction occurs between a bar magnet and a stationary charged particle (Figure 28.1f) or between two stationary charged particles (Figure 28.1g). These observations suggest that the motion of charged particles might be the origin of all magnetism. There are two problems with this assumption, however. First, the magnetic field of a wire carrying a constant current looks very different from that of a bar magnet (Compare Figures 27.13 and 27.19). Second, there is no obvious motion of charged particles in a piece of magnetic material.

Figure 28.2a shows the magnetic field lines



1 design

2 approach

# Information transfer

## Student 1 – 25 Feb, 04:55PM

Yeah, this is where I'm confused. From the first paragraph: "It takes a moving or spinning charged particle to create a magnetic field..." however there is no obvious motion of charged particles in a piece of magnetic material (bar magnet for example?). How does this reconcile?

## Student 2 – 26 Feb, 08:29PM

Maybe they are trying to say that there is no OBVIOUS motion, but they are moving via a current. Therefore, it meets their definition that it takes moving particles to create a magnetic field

## Student 3 – 2 Mar, 09:00AM

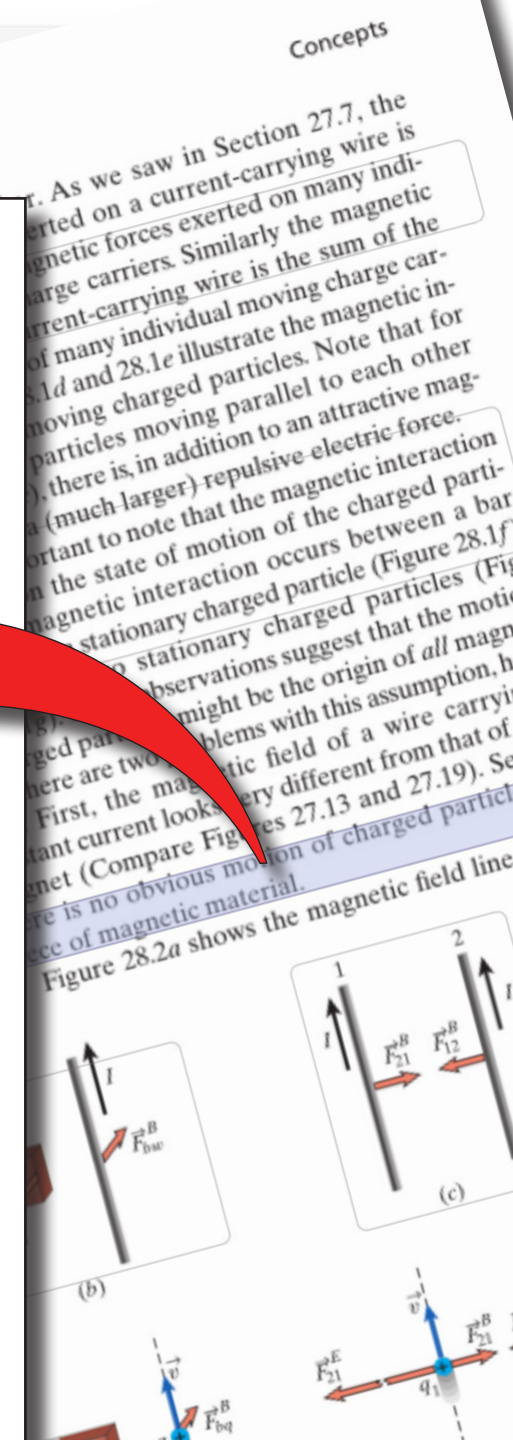
I agree that the motion is not "obvious" in that it is not visible to the naked eye. The cause must be atomic.

## Student 2 – 2 Mar, 11:37AM

Oh the answers to this question kind of address my question above - I guess there isn't a force if the particle is stationary, but since even when an object is stationary (thus no obvious motion), there is a magnetic force. It's when everything, including the particles, are stationary that there is no obvious motion.

## Student 4 – 4 Mar, 01:05PM

Is there ever a situation in reality where everything, even the particles are not ...



# Information transfer

## Student 1 – 25 Feb, 04:55PM

Yeah, this is where I'm confused. From the first paragraph, "It takes a moving or spinning charged particle to create a magnetic field." There is no obvious motion of charged particles in a piece of magnetic material (the magnet example?). How does this reconcile?

## Student 2 – 26 Feb, 12:11PM

Maybe they're trying to say that there is no Oersted's motion, but they are in fact moving in a different way. Therefore, it meets their definition that it takes moving particles to create a magnetic field.

## Student 3 – 2 Mar, 09:00AM

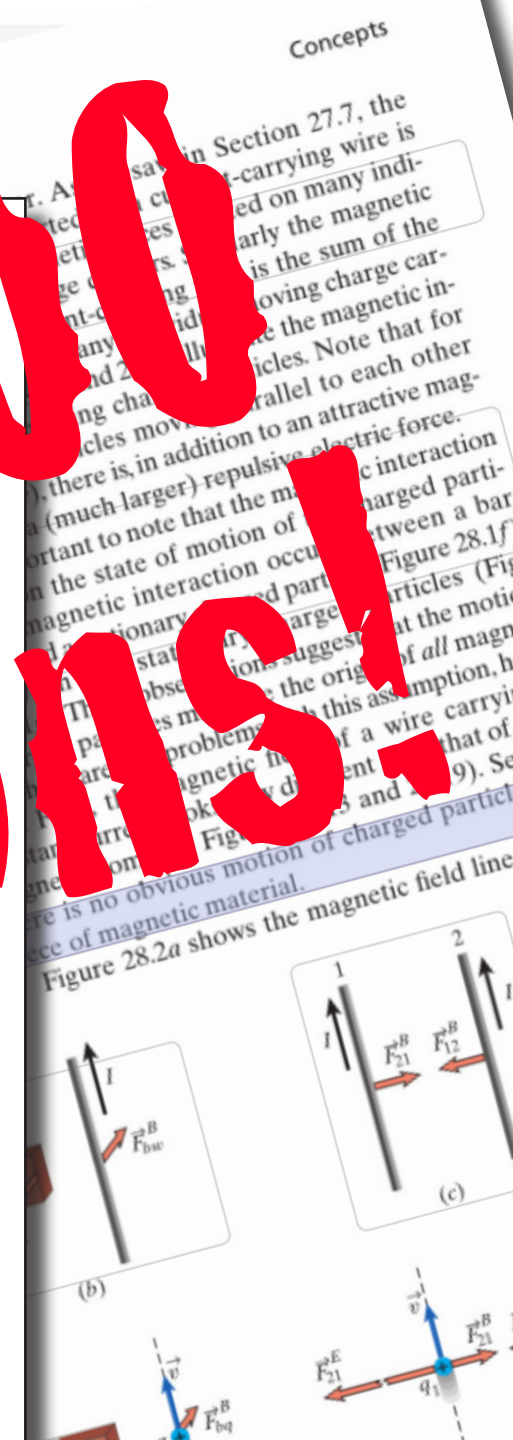
I agree that the motion is not "obvious" in that it is not visible to the naked eye. The cause must be atomic.

## Student 2 – 2 Mar, 11:37AM

Oh the answers to the question and the question above - I guess there isn't a force if the particle is stationary, but since even when an object is stationary (thus no velocity motion) there is a magnetic force. It's when everything, including the particles, is stationary that there is no obvious motion.

## Student 4 – 4 Mar, 01:05PM

Is there ever a situation in reality where everything, even the particles are not ...



# Information transfer

AP50 Spring 2015

## Annotation Rubric

Your annotations of the textbook on NB will be evaluated on the basis of quality, quantity, and timeliness, as shown below. Your goal in annotating each chapter is to demonstrate *timely and thoughtful reading of the text*. When we look at your annotations we want them to reflect the effort you put in your study of the text. It is unlikely that that effort will be reflected by just a few annotations per chapter, unless your annotations are unusually thoughtful and stimulate a deep discussion. About 7–20 *thoughtful* annotations per chapter spread out over the chapter is about right, but keep in mind that quality is more important than quantity!

About 4 days after the deadline of the last chapter in each unit, we will provide an overall assessment of your annotations in that unit using the usual three-point scale (0–3), by combining your annotation scores for the three categories.

**Quality** The textbook replaces the lectures (us reading the textbook to you) so that we can do more interesting things in class. Therefore it is important you read the text thoughtfully and attempt to lay the foundation for the work in class.

- 2 = Demonstrates thorough and thoughtful reading AND insightful interpretation of the chapter
- 1 = Demonstrates reading, but no (or only superficial) interpretation of the chapter
- 0 = Does not demonstrate any thoughtful reading of the chapter

See the examples on the next page to see the quality criterion applied to sample annotations.

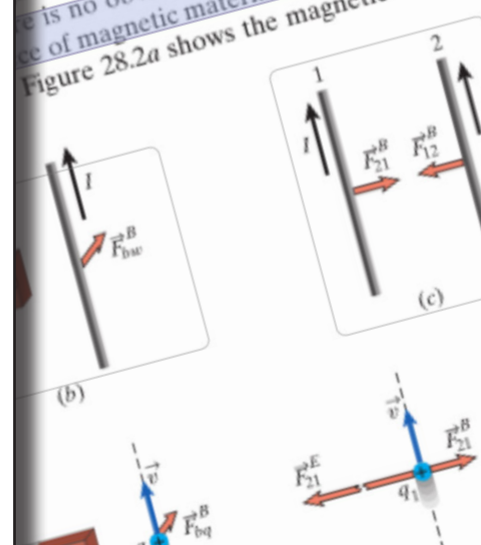
**Quantity** To lay the foundation for understanding the in-class activities, you must at least familiarize yourself with the entire chapter — not just the first few pages.

- 2 = 7–20 thoughtful annotations that cover each section of the chapter
- 1 = 7–20 thoughtful annotations, but not each section is annotated
- 0 = 6 or fewer annotations

**Timeliness** The work done in class depends on you having done the reading in advance, so completing the reading on schedule is important. Your annotations can be questions, comments, or responses to existing questions or comments. Responses are allowed up to three days beyond the posted deadline.

Concepts

As we saw in Section 27.7, the magnetic forces exerted on many individual moving charge carriers. Similarly the magnetic force on a current-carrying wire is the sum of the forces on many individual moving charge carriers. *Figure 28.1d and 28.1e illustrate the magnetic interaction between two parallel wires carrying current in the same direction. Note that for wires carrying current in the same direction, there is, in addition to an attractive magnetic force, a (much larger) repulsive electric force. It is important to note that the magnetic interaction between two parallel wires carrying current in the same direction is not the same as the magnetic interaction between a stationary charged particle and a stationary charged particle (Figure 28.1f). These observations suggest that the motion of charged particles might be the origin of all magnetic forces. There are two problems with this assumption. First, the magnetic field of a wire carrying current looks very different from that of a magnet (Compare Figures 27.13 and 27.19). Second, there is no obvious motion of charged particles in a piece of magnetic material. Figure 28.2a shows the magnetic field lines*



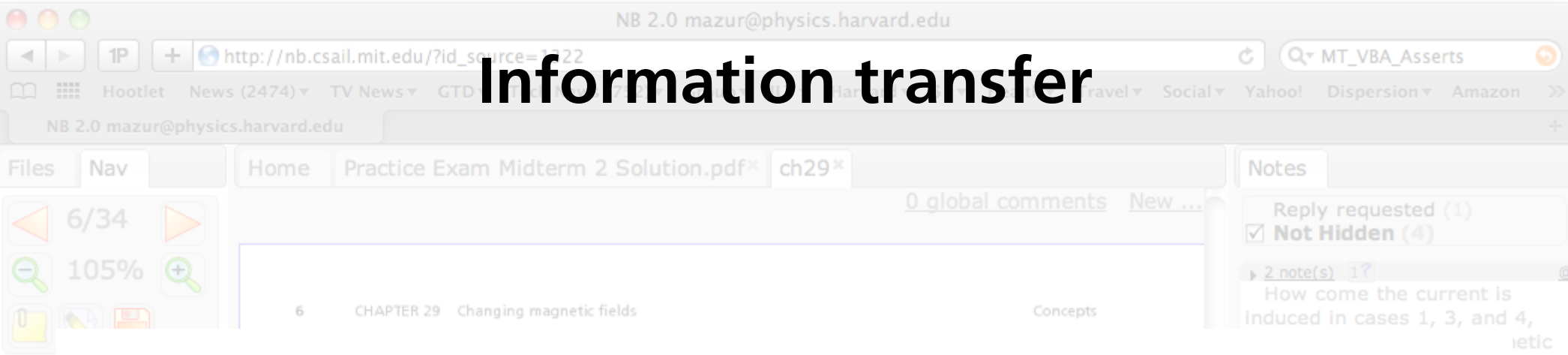


# Information transfer

## Annotation rubric

- Quality (must be thoughtful)
- Quantity (7–20 thoughtful & distributed)
- Timeliness

# Information transfer



READING SCHEDULE

JAN		FEB				MAR					APR									
27	29	3	5	10	12	17	19	24	26	3	5	10	12	24	26	31	2	7	9	14
		6		7		8	8		8			9								10
22	23	24		25	26	27	28		29		30	31	32						33	34

↑ sections 27.4 and 27.8 optional

on the charge carriers in a stationary loop, a current is still induced! Figure 29.10 shows this situation in more detail. Experiments show that as a magnetic field moves past a stationary conducting rod, a charge separation and hence a potential difference develop between the ends of the rod even though no magnetic force is exerted on stationary charge carriers.

The potential difference that develops between the ends of the rod shown in Figure 29.10 is the same as that which would develop if the magnetic field were stationary and the rod were moving to the right (recall Figure 29.1). Any relative motion of rod and magnet-

*A changing magnetic field is accompanied by an electric field.*

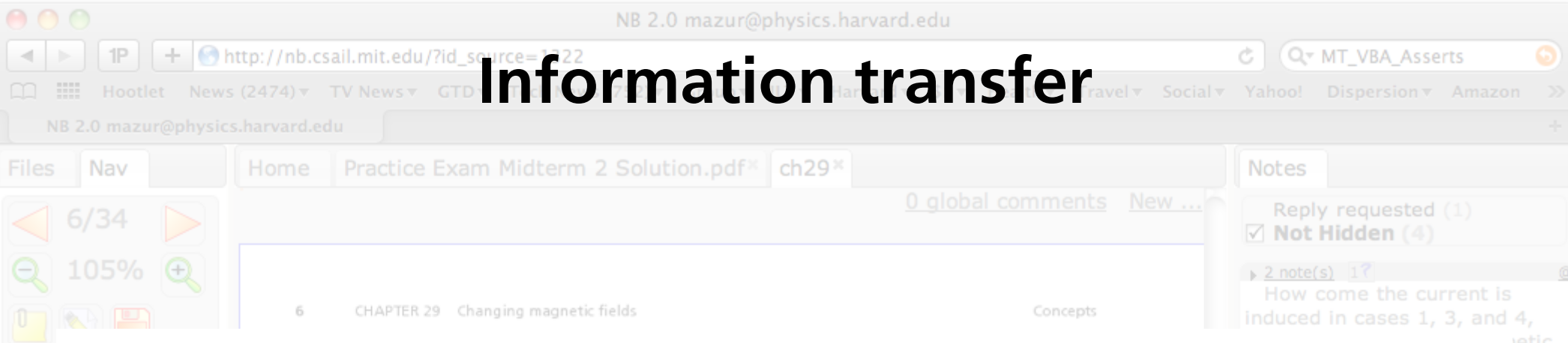


**29.4** In Figure 29.1, charge accumulates at the ends of the moving rod until the amount at each end reaches an equilibrium value. Mechanical equilibrium is established when the magnetic force due to the motion of the rod counterbalances the electric force due to the charge separation. In Figure 29.10, what two forces determine the equilibrium state of the charge separation in

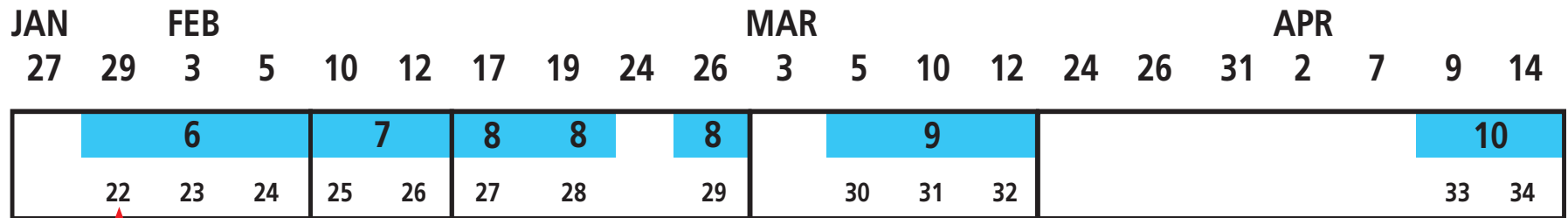
1 design

2 approach

# Information transfer



READING  
SCHEDULE



sections 27.4 and 27.8 optional

chapter deadline

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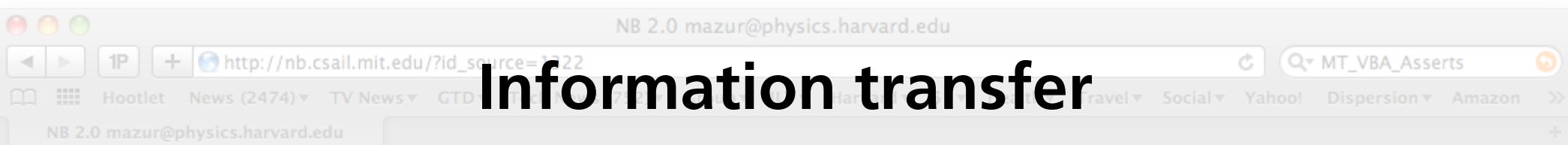
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1 design

2 approach

# Information transfer



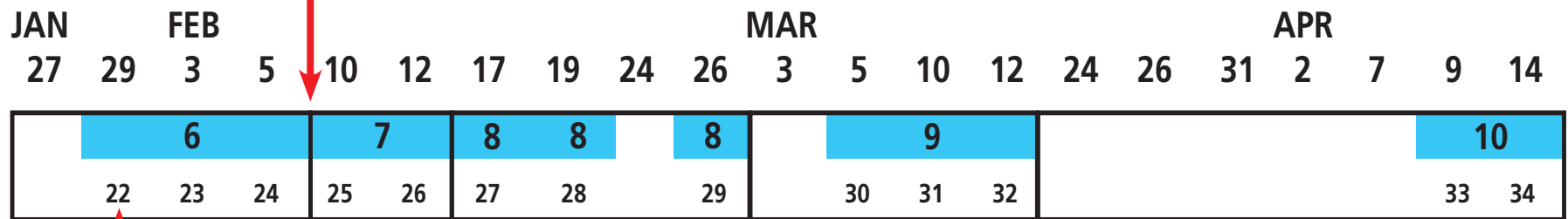
Files Nav Home Practice Exam Midterm 2 Solution.pdf\* ch29\* 0 global comments New ...

6 CHAPTER 29 Changing magnetic fields Concepts

Notes  
Reply requested (1)  
 Not Hidden (4)  
2 note(s)  
How come the current is induced in cases 1, 3, and 4,

**unit deadline**

**READING SCHEDULE**



sections 27.4 and 27.8 optional

**chapter deadline**

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**1** design

**2** approach

# Information transfer

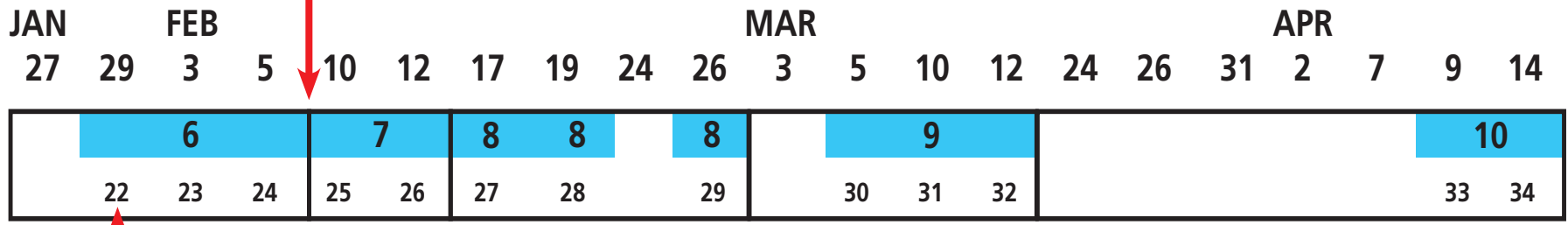
Files Nav Home Practice Exam Midterm 2 Solution.pdf\* ch29\* 0 global comments New ...

6 CHAPTER 29 Changing magnetic fields Concepts

Notes  
Reply requested (1)  
 Not Hidden (4)  
2 note(s)  
How come the current is induced in cases 1, 3, and 4,

**unit deadline**

**READING SCHEDULE**



sections 27.4 and 27.8 optional

**chapter deadline**

**three extra days for answers to questions**

**1 design**

**2 approach**

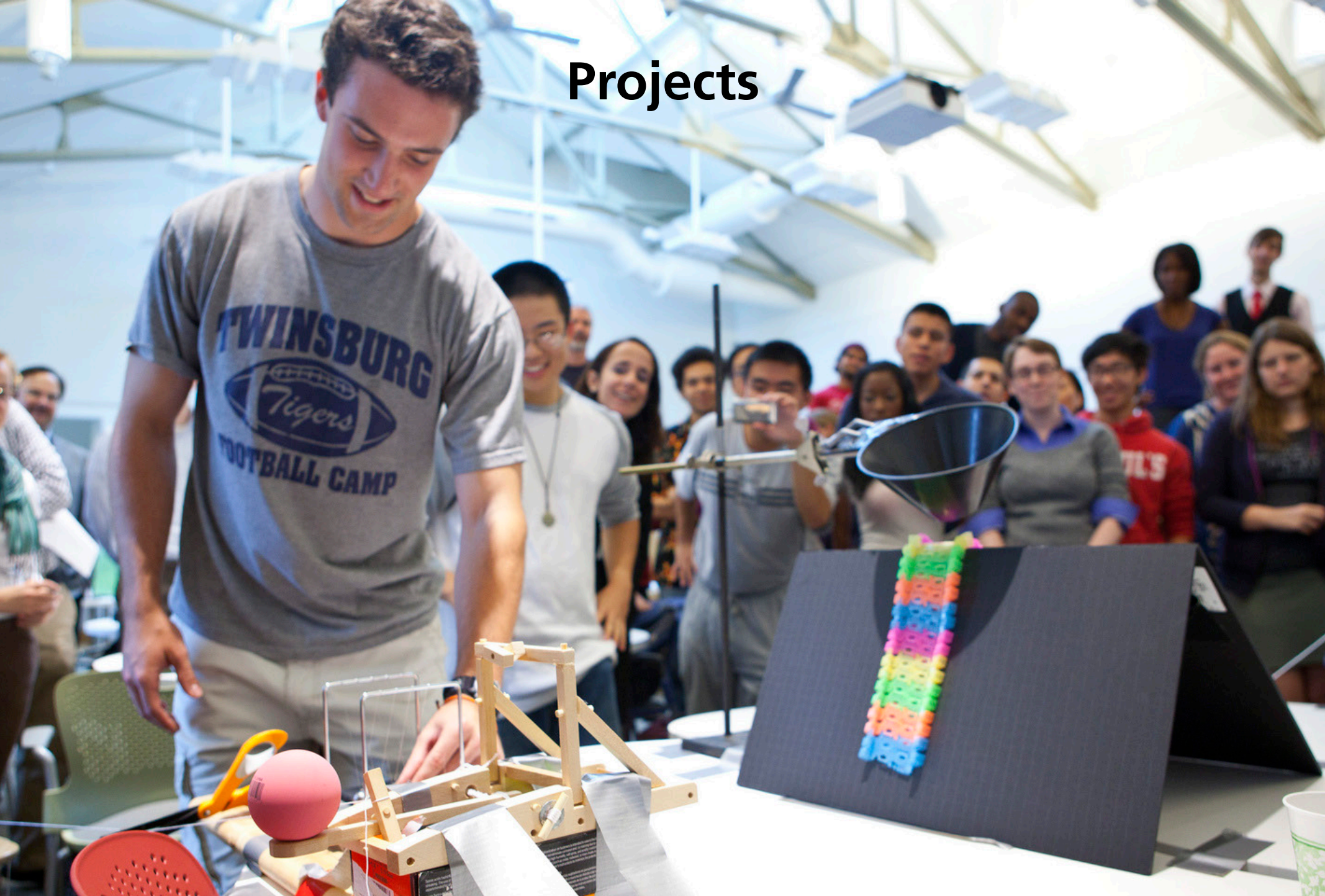
# Information transfer

95% of students complete *all* readings!

1 design

2 approach

# Projects



1 design

2 approach

# Projects

- 1 projects/month (6 over 2 semesters)
- new team formation for each project
- projects not prescriptive, but open-ended
- 3 types of project “fairs”
- external evaluators



# Projects

## Project fair types:

- design competition
- oral presentation
- poster presentation

**1** design

**2** approach

# Projects

## Rule-based team formation using GroupEng

[www.GroupEng.org](http://www.GroupEng.org)

1 design

2 approach

# Projects

## Rule-based team formation using GroupEng

- gender
- year
- self-efficacy & learning attitude
- class performance
- exclude previous team mates

[www.GroupEng.org](http://www.GroupEng.org)

# Projects

**To be successful, the projects must**

- require practical application of skills**
- be linked to real world problems**
- have compelling narrative (help/do good)**

# Projects

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**Fall**

**Rube Goldberg**

**Mission to Mars**

**Symphosium**

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**Spring**

**Ecotricity**

**Crack-a-Thon**

**inSPECT Fair**

---

**1 design**

**2 approach**

AP50 FALL 2014

Project Brief

---

Rube C

Mission

Sympho

---

Symphosium



**1** design

**2** approach

# Projects



1 design

2 approach



# Projects

**Build a beautifully sounding instrument  
from recycled parts**

**1** design

**2** approach

# Projects

**Build a beautifully sounding instrument  
from recycled parts**

- **musical range**
- **Q-factor**
- **harmonic spectrum**
- **sound level**
- **tuning stability**

# Projects

## Milestones:

- **team contract**
- **proposal**
- **fair**
- **report**
- **team, peer, and self assessment**

# Projects

## Milestones:

- **team contract (at beginning)**
- **proposal**
- **fair**
- **report**
- **team, peer, and self assessment**

# Projects

## Milestones:

- **team contract (at beginning)**
- **proposal (+1 week)**
- **fair**
- **report**
- **team, peer, and self assessment**

# Projects

## Milestones:

- **team contract (at beginning)**
- **proposal (+1 week)**
- **fair (+3 weeks)**
- **report**
- **team, peer, and self assessment**

# Projects

## Milestones:

- **team contract (at beginning)**
- **proposal (+1 week)**
- **fair (+3 weeks)**
- **report (+1 week +3 days for revision)**
- **team, peer, and self assessment**

# Projects

## Milestones:

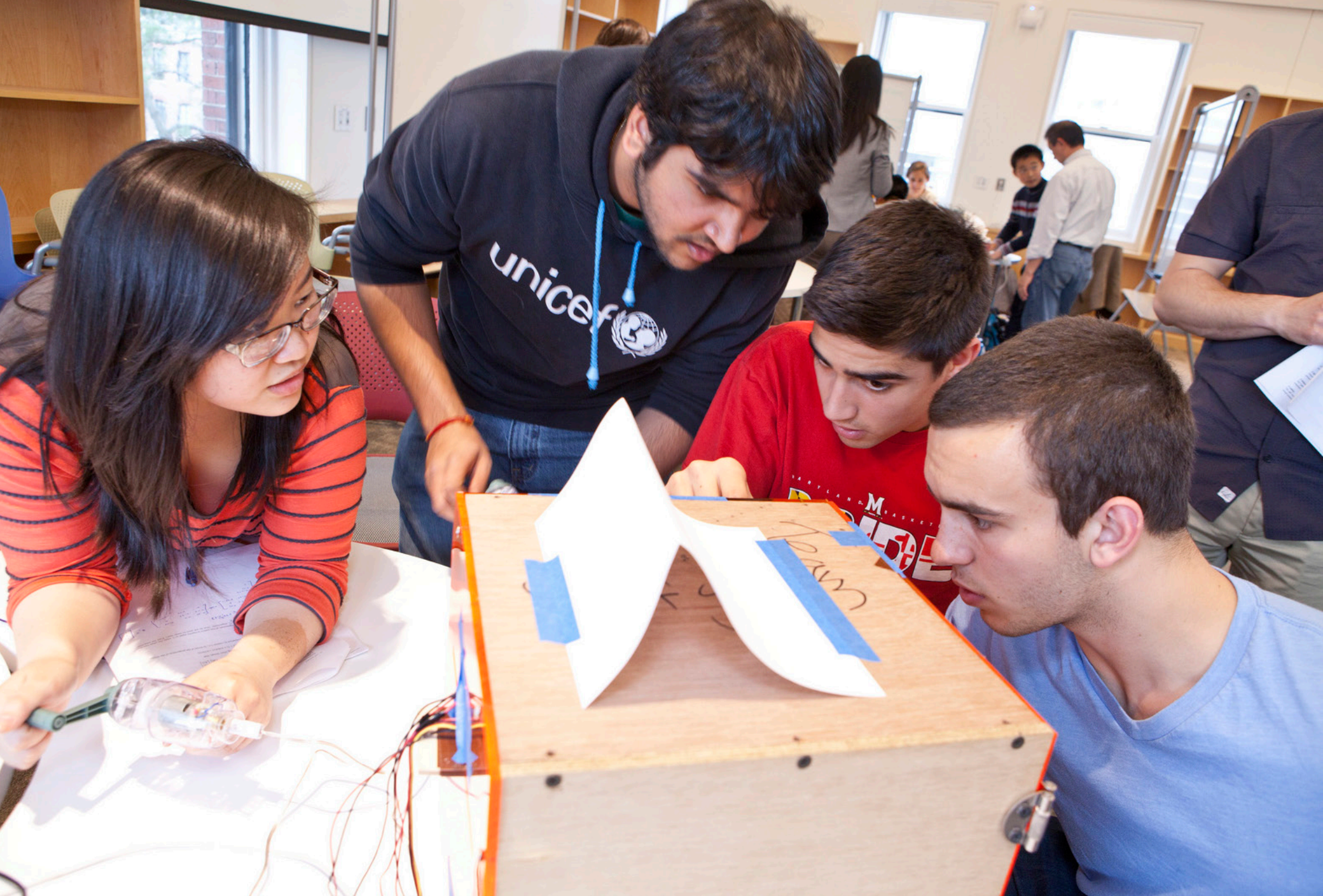
- **team contract (at beginning)**
- **proposal (+1 week)**
- **fair (+3 weeks)**
- **report (+1 week +3 days for revision)**
- **team, peer, and self assessment (at end)**





**1** design

**2** approach



**1** design

**2** approach

A group of students are gathered around a table in a classroom, working on a project. A male student in a black hoodie with 'unicef' written on it is leaning over the table, looking at a white paper structure. A female student with glasses and a red and orange striped shirt is using a soldering iron on a circuit board. Other students are visible in the background, some standing and some sitting at tables. The room has large windows and a bright, airy atmosphere.

**competition instead of  
social good/empathy as motivator**

**1** design

**2** approach



1 design

2 approach

# In-class activities



**1** design

**2** approach

# In-class activities

**2 weekly 3-hour class periods**

**1** design

**2** approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



bring device

Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

## blend of 6 "best practices"

apply



Estimate quantities  
Develop individual strategy  
Discuss and solve as team



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



bring device

evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class  
Discuss with team, mark up  
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone  
Open book, open internet  
Part 2: solve with team



bring device

1 design

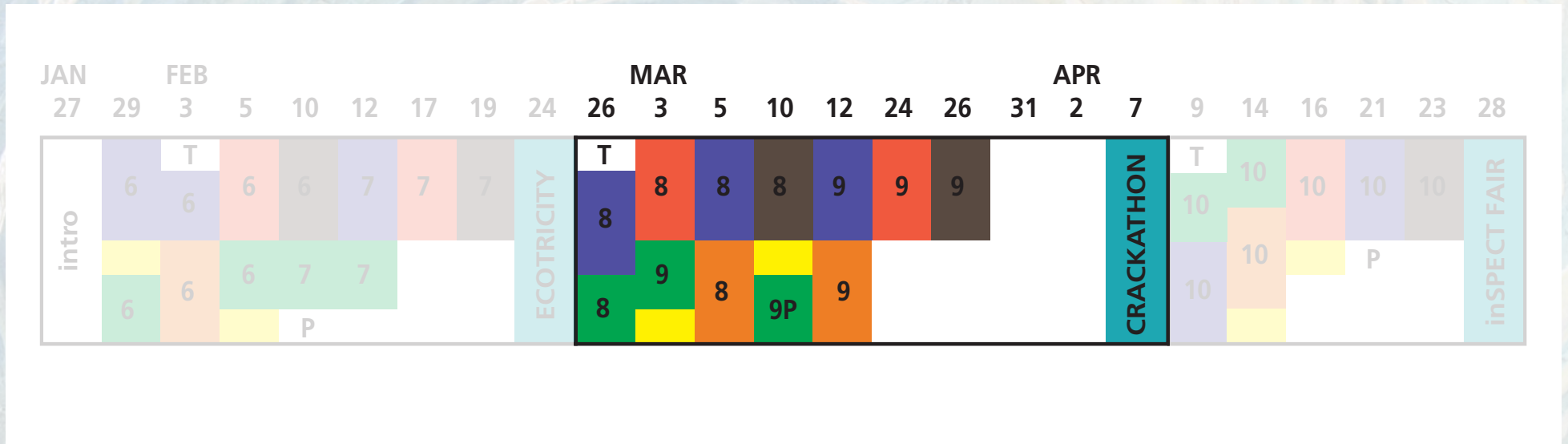
2 approach





# In-class activities

## one project

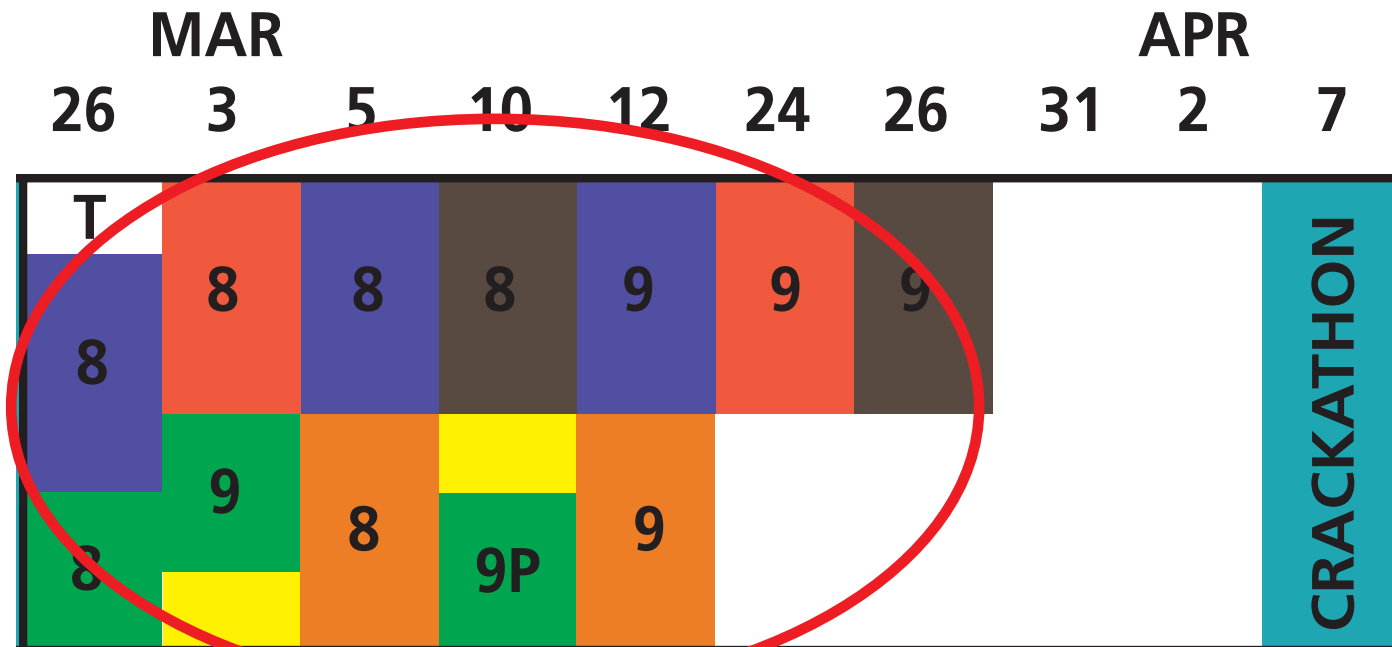


1 design

2 approach

# In-class activities

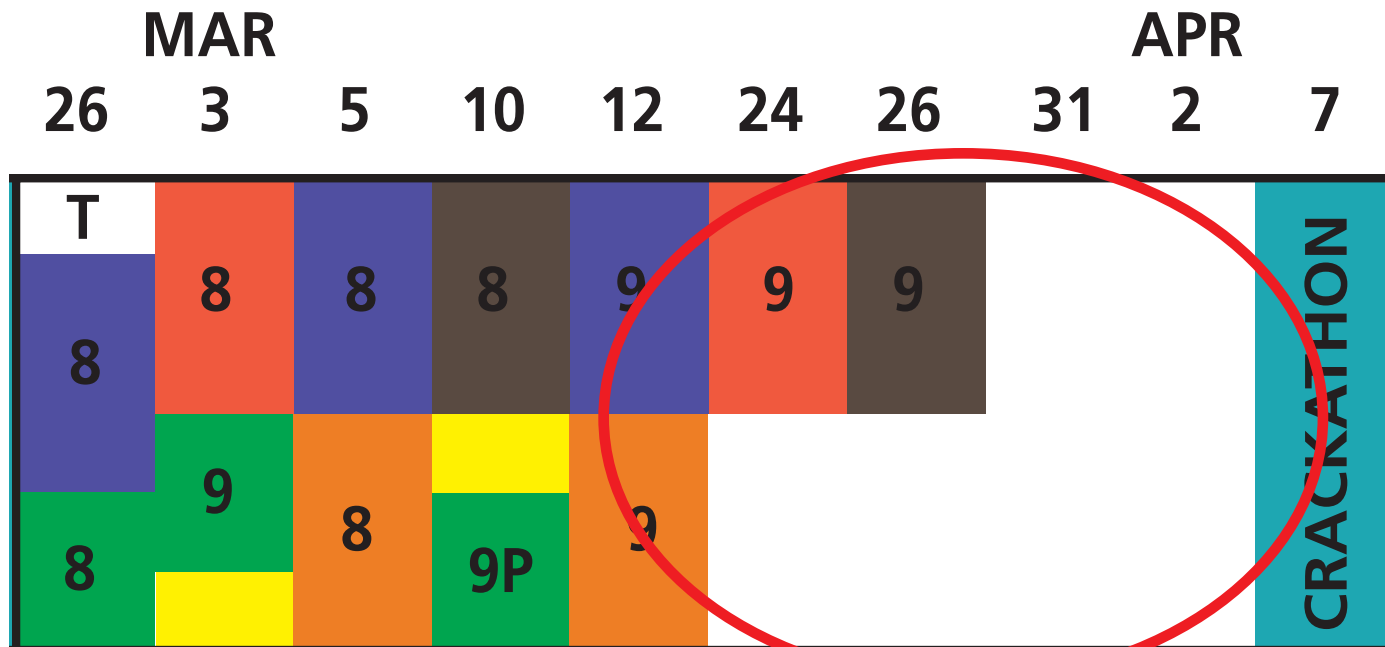
2/3 scaffolded, guided



1 design

2 approach

# In-class activities



1/3 unguided

1 design

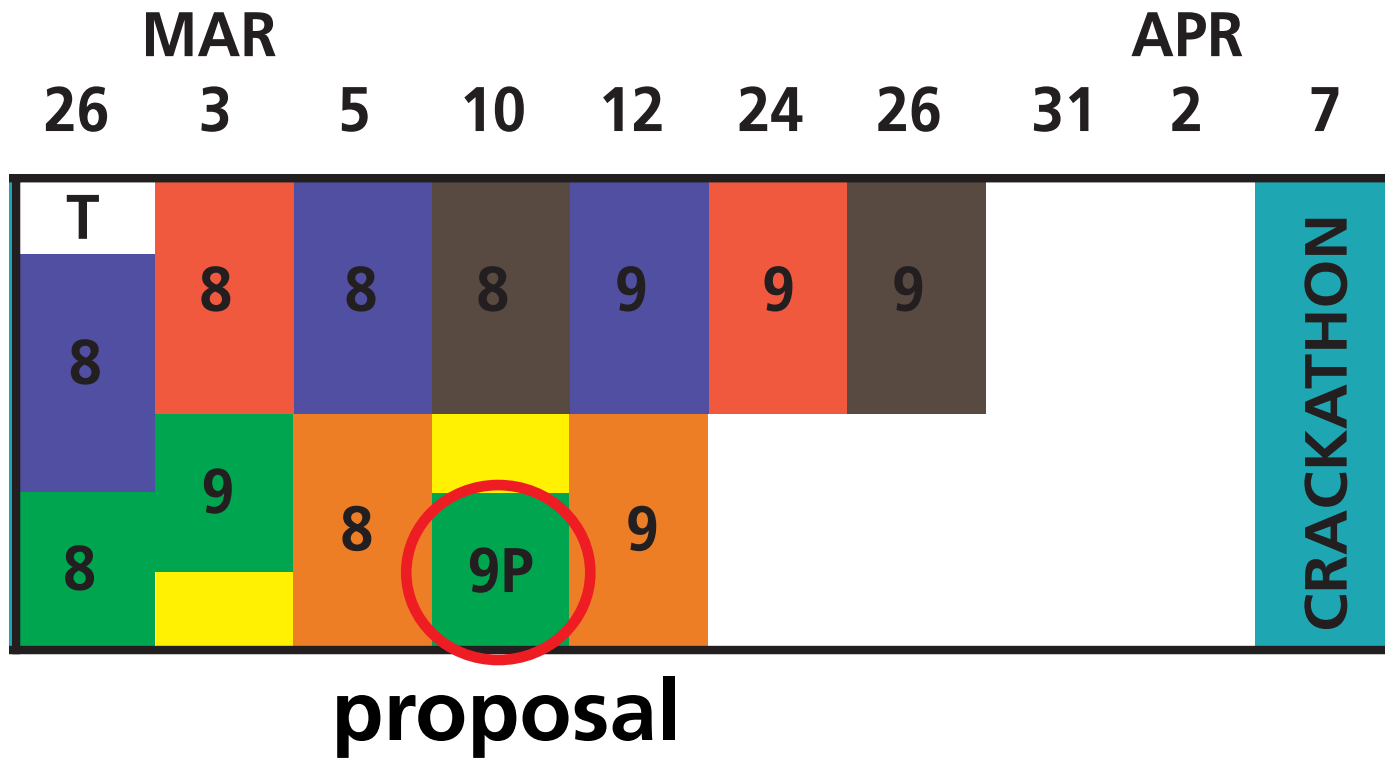
2 approach

# In-class activities

## team intro



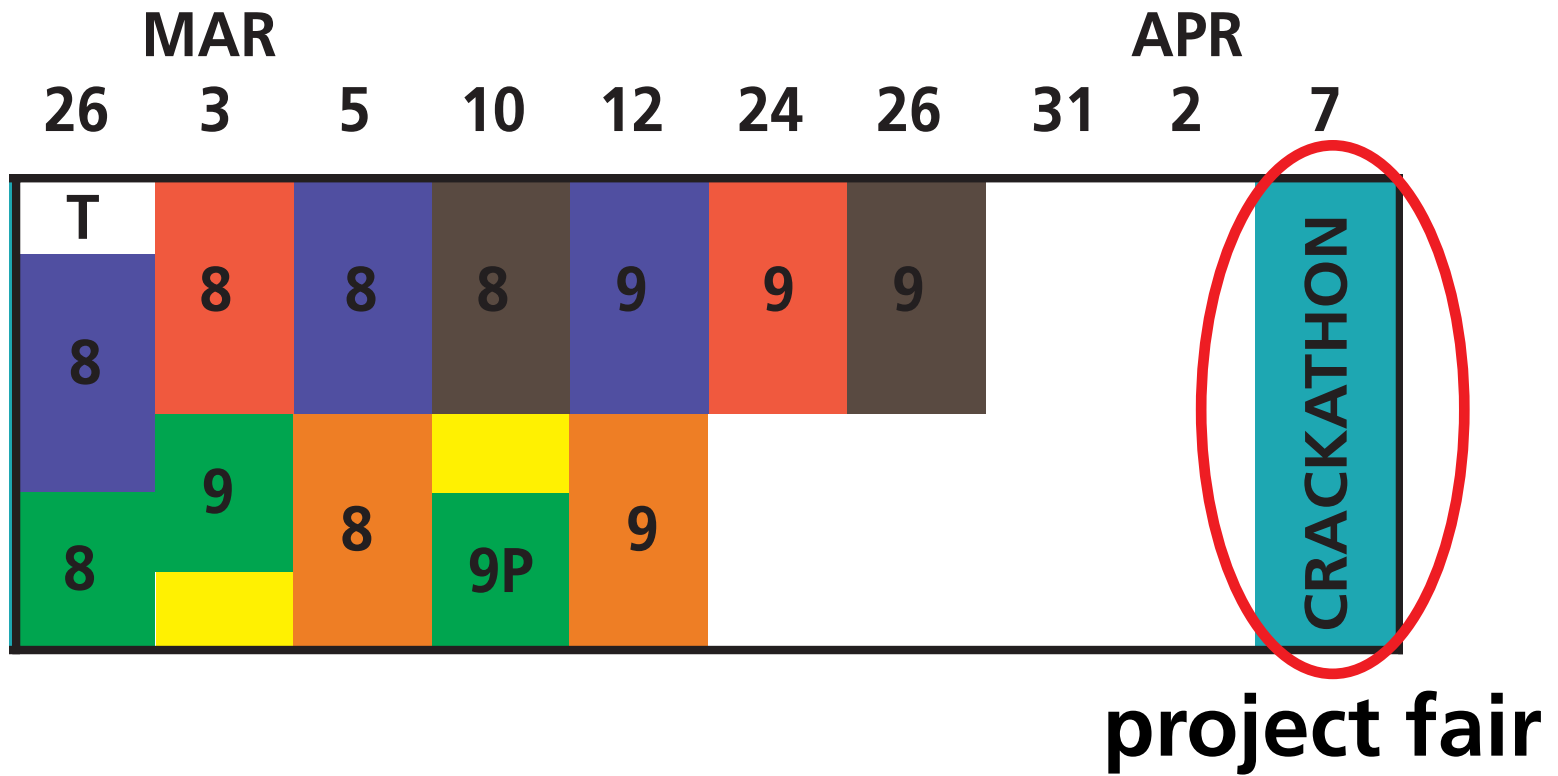
# In-class activities



1 design

2 approach

# In-class activities



1 design

2 approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

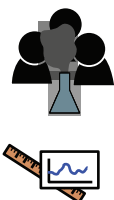
apply

EA: Estimation Activity 30 min



Estimate quantities  
Develop individual strategy  
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class  
Discuss with team, mark up  
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone  
Open book, open internet  
Part 2: solve with team



# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities  
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## learning | catalytics

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optics i

current session: 766079 | 69 students

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Jump to ▾

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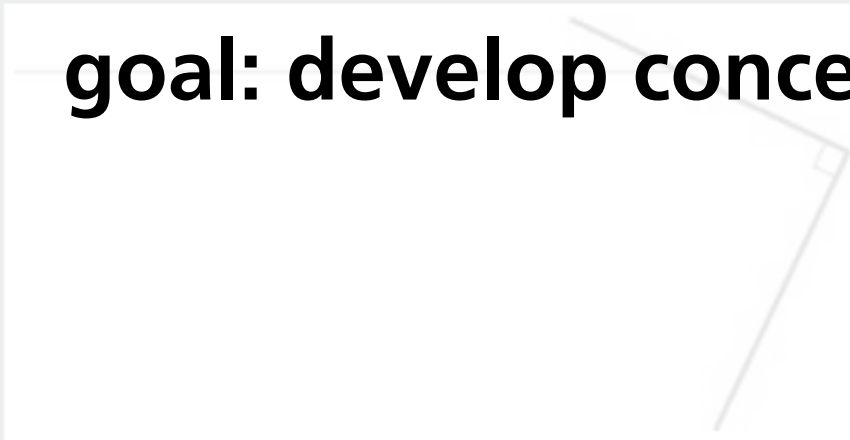
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4. direction Light enters horizontally into the combination of two perpendicular mirrors as shown below.

[Deliver](#) [Show all results](#)**goal: develop conceptual understanding**

Indicate the direction of the incident light after it reflects off of both mirrors.



feedback &amp; support

**1** design**2** approach

# learning | catalytics

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4. direction Light enters horizontally into the combination of two perpendicular mirrors as shown below.

[Deliver](#) [Show all results](#)



Indicate the direction of the incident light after it reflects off of both mirrors.



feedback & support

1 design

2 approach

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current session: **766079** | 69 students

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perpendicular mirrors as shown below.

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[feedback & support](#)



1 design

2 approach

# learning | catalytics

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current session: **766079** | 69 students

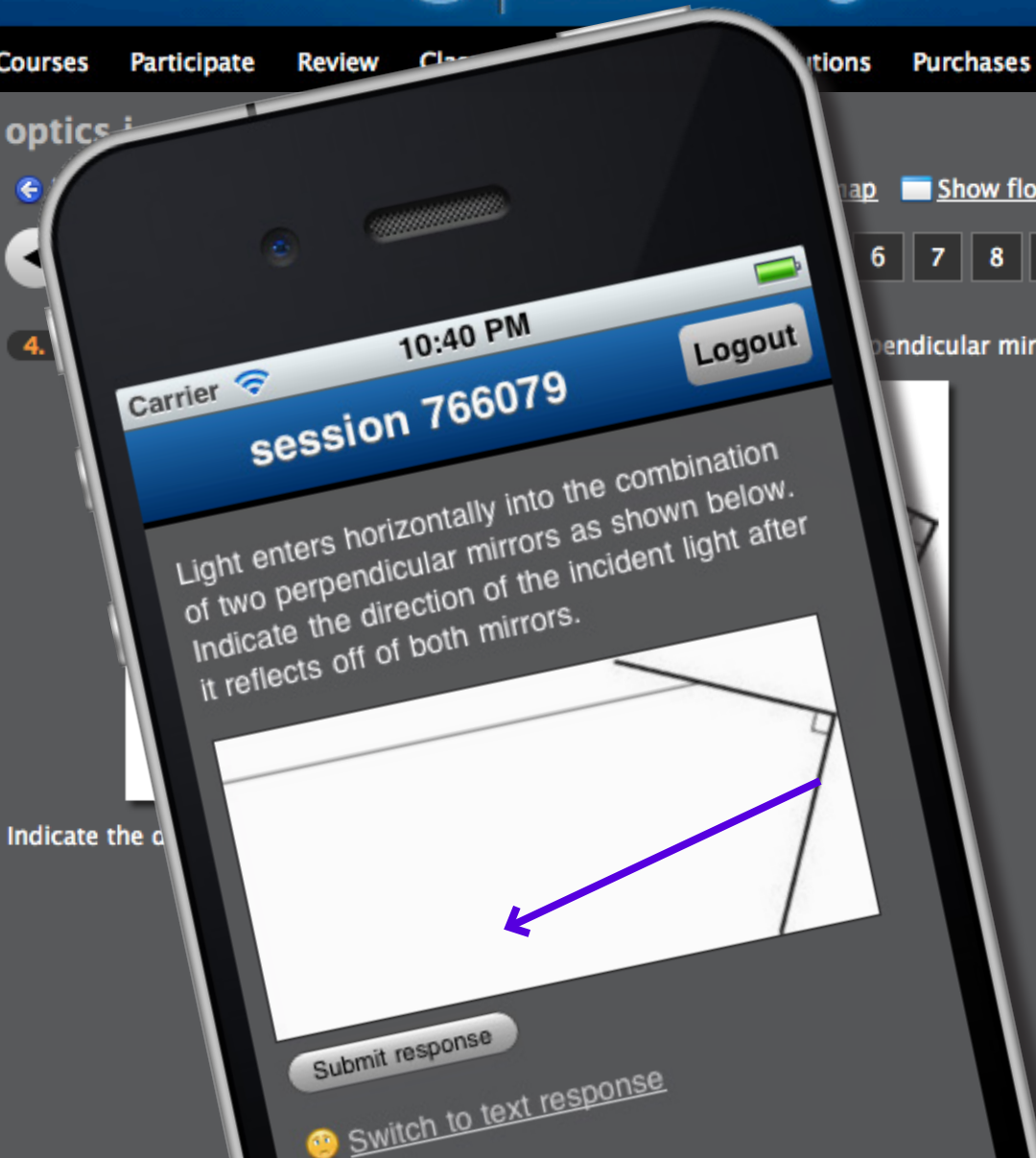
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6 7 8 9 10 11 12 13 14 15

perpendicular mirrors as shown below.

[Deliver](#) [Show all results](#)

[feedback & support](#)



1 design

2 approach

# learning | catalytics

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current session: **766079** | 69 students

[Map](#) [Show floating session ID](#) [Edit](#) [Delete](#)

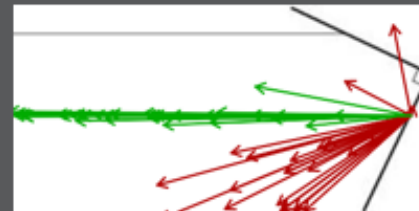
6 7 8 9 10 11 12 13 14 15

perpendicular mirrors as shown below.

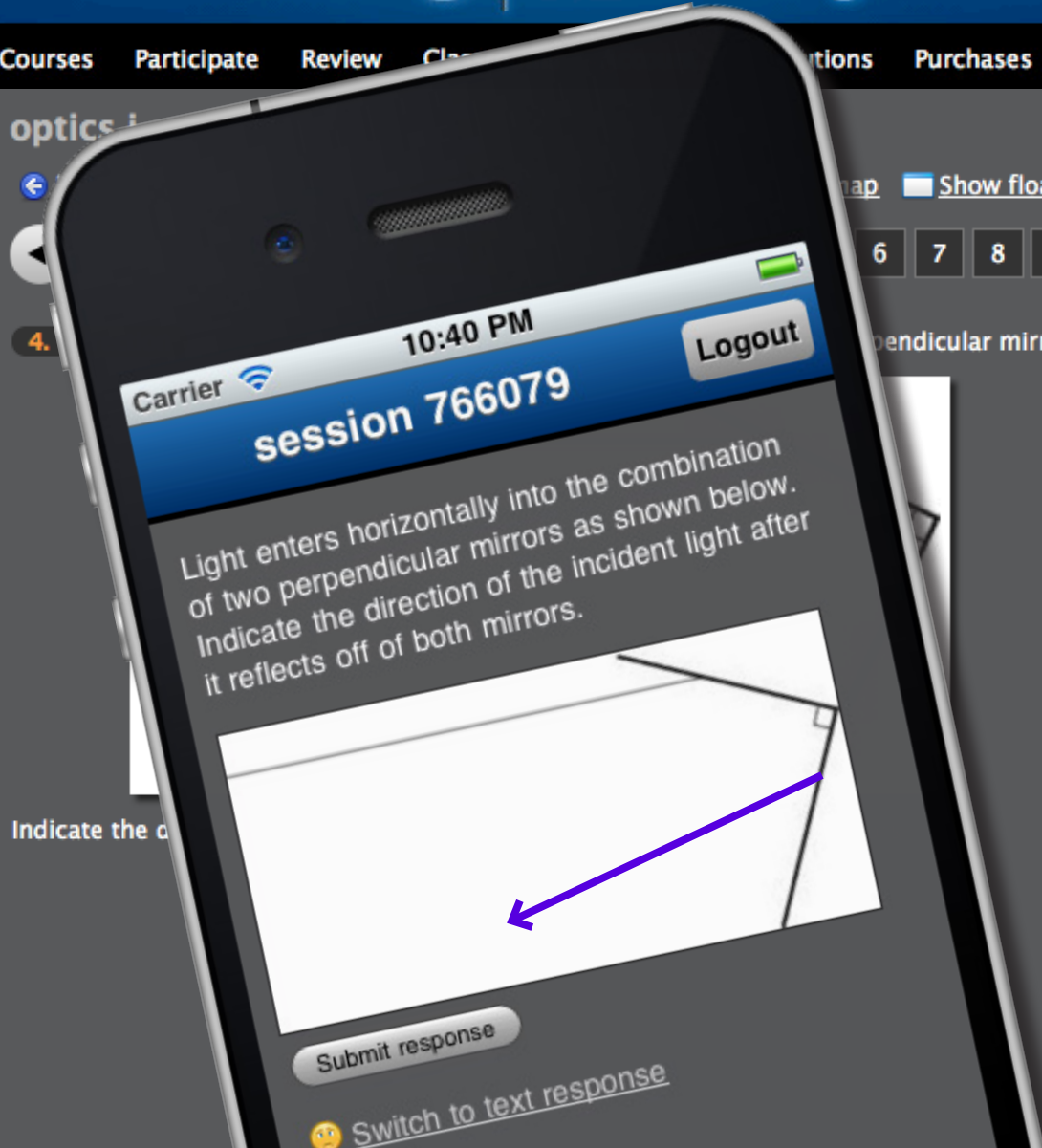
[Deliver](#) [Show all results](#)

Round 1 ✖  

● 57 responses, 58% correct



 [feedback & support](#)



**1** design

**2** approach

# learning | catalytics

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current session: **766079** | 69 students

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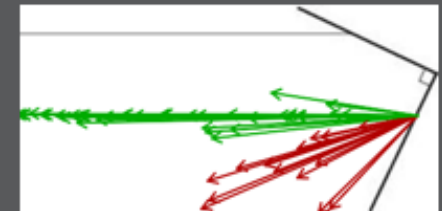
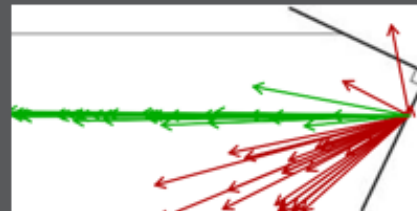
6 7 8 9 10 11 12 13 14 15

perpendicular mirrors as shown below.

[Deliver](#) [Show all results](#)

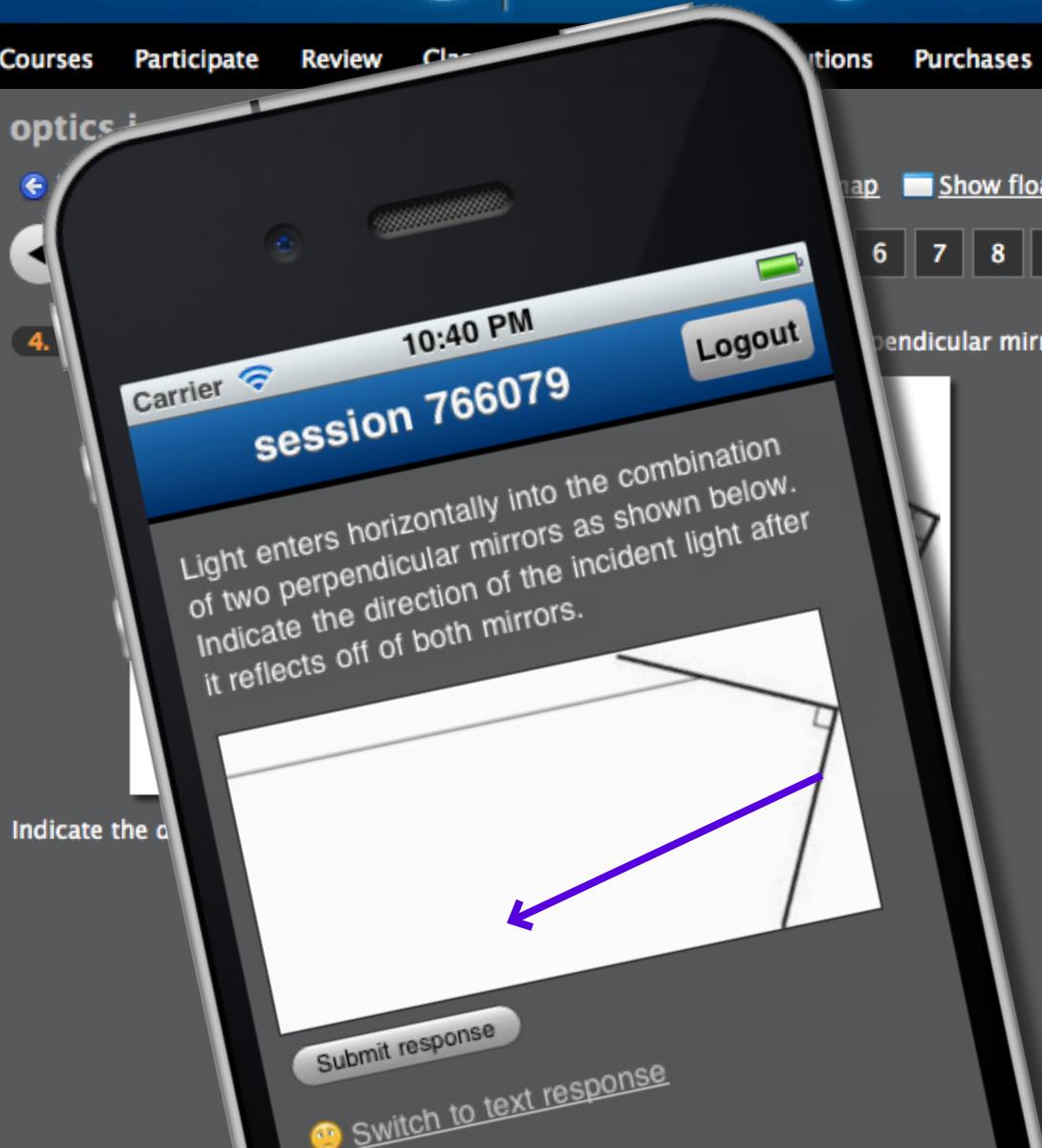
**Round 1** [✖](#) [📊](#) [📄](#)  
● 57 responses, 58% correct

**Round 2** [✖](#) [📊](#) [📄](#)  
● 51 responses, 73% correct



✓ 8 get it now  
✗ 0 still don't get it

[📣 feedback & support](#)



1 design

2 approach

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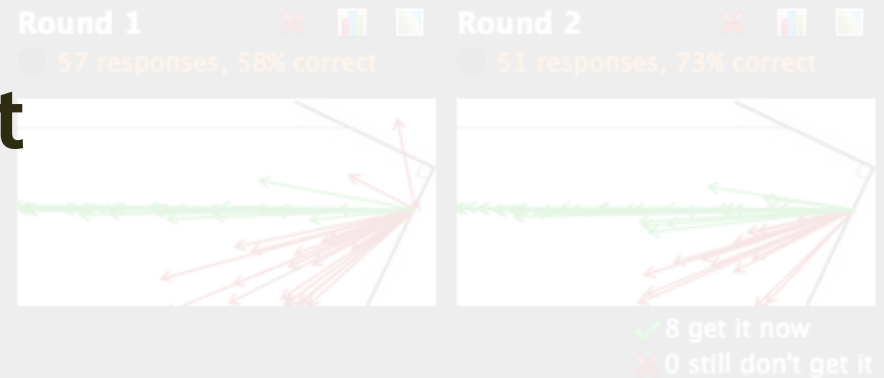
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4. direction Light ray is directed into the corner of a right-angled prism. [Show all results](#)**3. Enter email, click Start****4. Join session 1234567**

Indicate the direction of the incident light after it reflects off of both mirrors.



feedback &amp; support

**1** design**2** approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity 30 min



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evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class  
Discuss with team, mark up  
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RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone  
Open book, open internet  
Part 2: solve with team

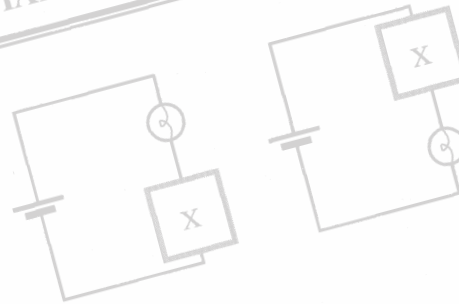




# A MODEL FOR CIRCUITS PART 2: POTENTIAL DIFFERENCE

## I. Current and resistance

- A. The circuits at right contain identical batteries, bulbs, and unknown identical elements labeled X.



How do the bulbs compare in brightness? Explain.

In each circuit, how does the current through the bulb compare to the current through element X? Explain.

- B. The circuits at right contain identical batteries and bulbs. The boxes labeled X and Y contain different unknown elements. (Assume there are no batteries in either box.)



It is observed that the bulb on the left is brighter than the bulb on the right.

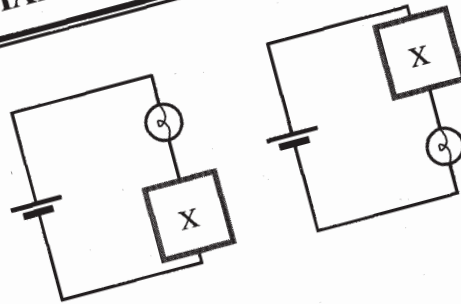
1. Based on this observation, how does the resistance of element X compare to that of element Y? Explain.
2. In each circuit, how does the current through the bulb compare to the current through the unknown element?
3. In each circuit, how does the current through the bulb compare to the current through the battery?

McDermott et al., *Tutorials in Introductory Physics* (Prentice Hall, 2002)

# A MODEL FOR CIRCUITS PART 2: POTENTIAL DIFFERENCE

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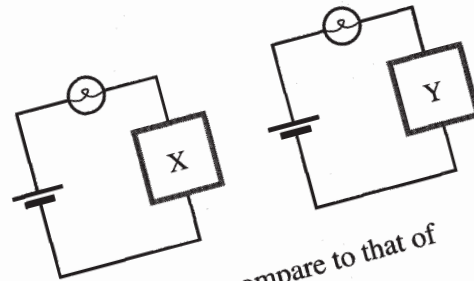
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- Based on this observation, how does the resistance of element X compare to that of element Y? Explain.
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McDermott et al., *Tutorials in Introductory Physics* (Prentice Hall, 2002)

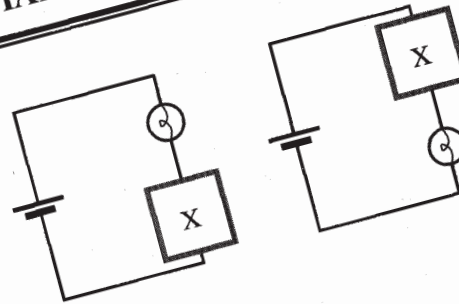


brightness

# A MODEL FOR CIRCUITS PART 2: POTENTIAL DIFFERENCE

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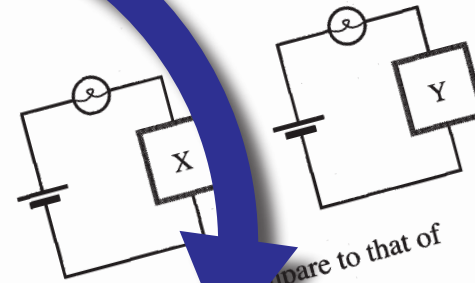
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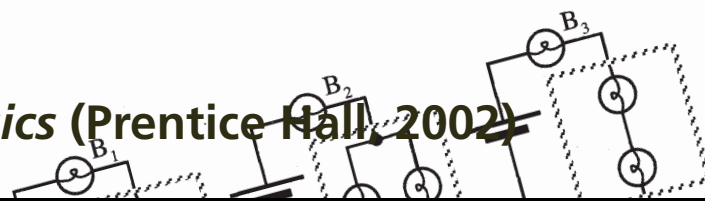
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brightness



elicit

resolve

confront

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities  
Develop individual strategy  
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class  
Discuss with team, mark up  
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone  
Open book, open internet  
Part 2: solve with team



AP50 Fall 2014

## Estimation Activity

Th Oct 9

**Instructions:** Estimate (not Guess or Google!) the quantities below to the nearest order of magnitude. Report all your answers as an order of magnitude (using the indicated units). Spend the first five minutes thinking *individually* about a strategy, then go at it with your team. You have 30 minutes exactly, so think fast!

When your team has completed all six questions, check your answers with a teaching staff member.

**Important:** Start from what you know; do not look up any values. Pretend you are being asked these questions at a job interview. Or you want to surprise people at a dinner party.

# goal: develop qualitative reasoning skills

1. Estimate the chemical energy released during the explosive separation of a professional fireworks shell. Answer units: [J]
2. Estimate the relative speed of the moon as seen from an observer on the earth. Answer units: [m/s]
3. Estimate the power output by an average person completing a "stadium workout" (run up and down the 30 sections of the Harvard Stadium as fast as they can). Answer units: [W]
4. Estimate the force of the atmosphere exerted on the entire surface of one person's skin. Answer units: [N]
5. Estimate the height of the mountain a college student could climb with the energy saved by turning out their dorm lights instead of keeping the lights on for an all-nighter homework assignment. Answer units: [m]

1 design

2 approach

## Estimation Activity

Th Oct 9

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AP50 Fall 2014

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**“Estimate the chemical energy released during the explosive separation of a professional fireworks shell. Answer units: [J]”**

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2. Estimate the relative speed of the mountain as seen by an observer on the earth. Answer units: [m/s]
3. Estimate the power output by all the people completing a 100m sprint. Answer units: [W]
4. Estimate the force of the atmosphere exerted on the entire surface of a person's skin. Answer units: [N]
5. Estimate the height of the mountain a college student could climb with the energy saved by turning out their dorm lights instead of keeping the lights on for an all-nighter homework assignment. Answer units: [m]

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

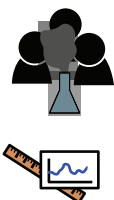
apply

EA: Estimation Activity 30 min



Estimate quantities  
Develop individual strategy  
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class  
Discuss with team, mark up  
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone  
Open book, open internet  
Part 2: solve with team



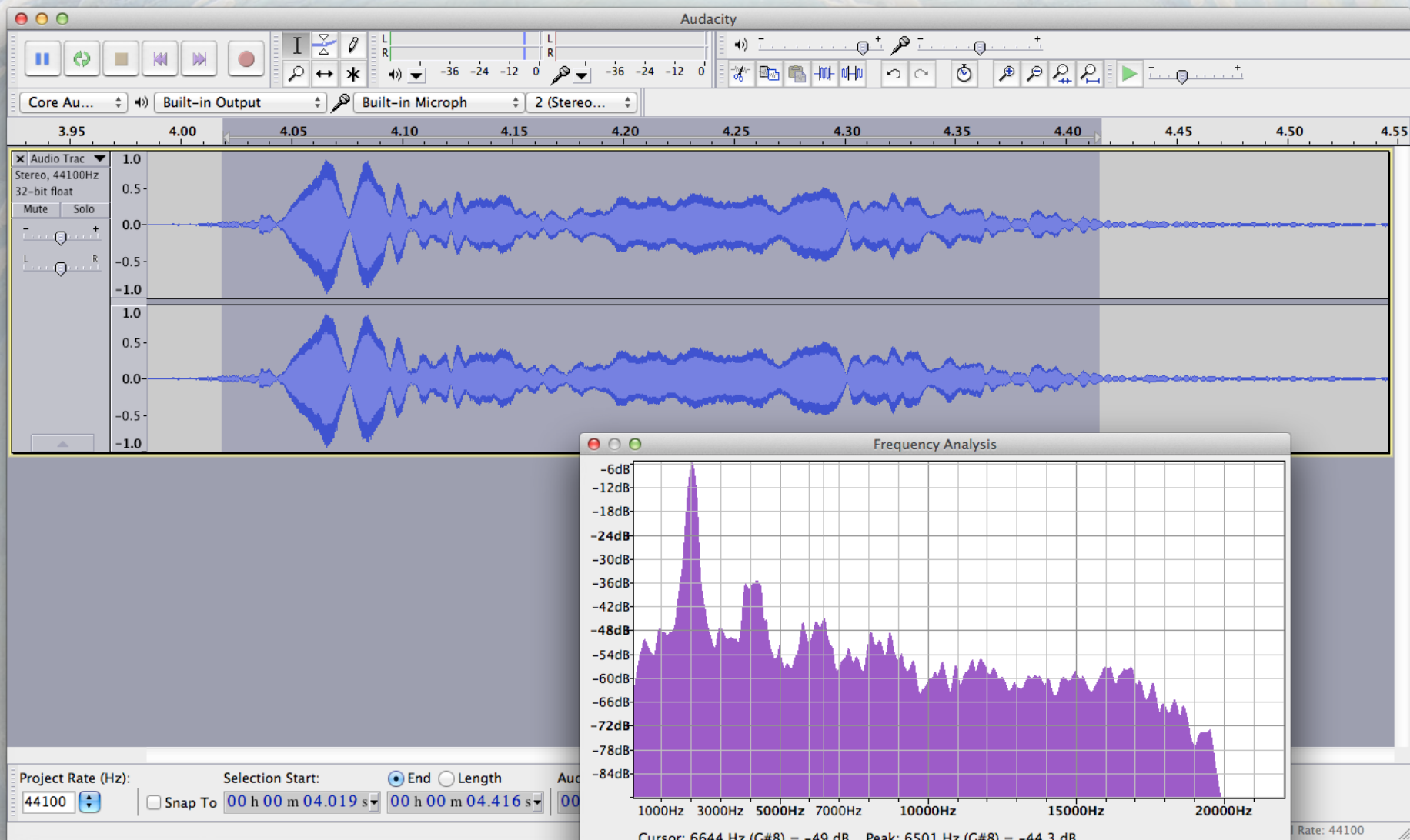




**goal: develop experimental skills**

**1** design

**2** approach



1 design

2 approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



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AP50b Fall 2013

## Problem Set 1

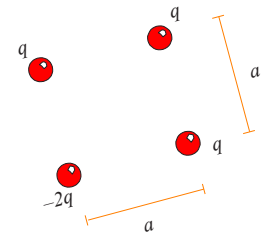
due W Feb 6 in class

Instructions: as we need to quickly scan your work so we can return it before the end of class, please:

- use 8.5 x 11" paper
- no-dog ears or torn out of ring-bound notebook
- dark ink (no light pencils)
- no staples
- name on each page
- single-sided (no writing on back)
- leave margins blank

1. **Ink-Jet Printing.** In an inkjet printer, letters are built up by squirting drops of ink at a piece of paper from a rapidly moving nozzle. The ink drops leave a nozzle and travel toward the paper, passing through a charging unit that gives each drop a positive charge by removing some electrons from it. The drops then pass between parallel deflecting plates where there is a uniform vertical electric field (to be discussed in Chapter 23). Estimate the number of atoms present in a droplet of ink.
2. **Levitation.** One possible way of levitating an object might be to use the forces associated with charged objects. For example, you have two charged particles that are fixed on a vertical pole 0.5 m apart. The lower one has a fixed charge of  $-3.0 \mu\text{C}$ . The upper one has a charge  $q_A$  that can be adjusted. A 30-mg particle with a charge of  $+8.0 \mu\text{C}$  can move freely on the pole below the other two. You wish to levitate (i.e., float) this particle at a distance of 1.0 m below the lower fixed charge. What should the adjustable charge  $q_A$  be to achieve this feat?

3. **Charge Square.** Four charged particles are arranged in a square as shown in the figure to the right, with  $q = 3.9 \times 10^{-4} \text{ C}$  and  $a = 6.9 \text{ mm}$ . What is the net force on the particle at the upper right corner due to the other three?



force between two concentrated ("point-like") masses is very similar in its electrostatic force between two concentrated charges. The vastly different. To illustrate this, consider the following spherical dust grains,  $50 \mu\text{m}$  in diameter, with mass density are electrically neutral, free of other external levitationally. Now suppose that both of  $n$  that would prevent electrons.

AP50b Fall 2013

## Problem Set 1

due W Feb 6 in class

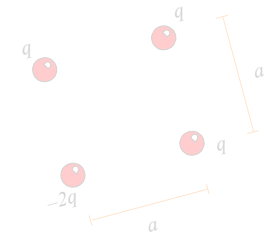
Instructions: We need to quickly scan your work so we can return it before the end of class, please:

- use a pen or ballpoint pen
- no-dog ears or tabs
- dark ink (no light pencils)
- no staples
- name on each page
- single-sided
- leave margins

# goal: develop problem solving and metacognitive skills

1. **Ink-Jet Printing.** In an inkjet printer, ink is ejected by squirting drops of ink at a piece of paper. The drops are ejected from a rapidly moving nozzle. The ink drops leave a positive charge by removing electrons from the paper, passing through a charging unit that gives each drop a positive charge by removing electrons. The drops then pass between two parallel deflecting plates where there is a uniform vertical electric field. The drops then pass between two parallel plates. Estimate the number of atoms present in a droplet of ink.
2. **Levitation.** One possible way of levitating an object might be to use the forces associated with charged objects. For example, you have two charged particles that are fixed on a vertical pole 0.5 m apart. The lower one has a fixed charge of  $-3.0 \mu\text{C}$ . The upper one has a charge  $q_A$  that can be adjusted. A 30-mg particle with a charge of  $+8.0 \mu\text{C}$  can move freely on the pole below the other two. You wish to levitate (i.e., float) this particle at a distance of 1.0 m below the lower fixed charge. What should the adjustable charge  $q_A$  be to achieve this feat?

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1 design

2 approach

AP50b Fall 2013

## Problem Set 1

due W Feb 6 in class

Instructions: as we need to quickly scan your work so we can return it before the end of class, please:

- use 8.5 x 11 inch paper
- no dog ears or torn corners
- dark ink (no light pencils)
- no staples
- one problem per page
- single-sided writing (back)
- leave margins blank

**phase**

**goal**

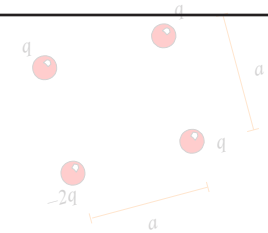
**solve (at home/individual)**

**skills development**

**reflect (in class/team)**

**metacognition**

2. **Levitation.** In an inkjet printer, letters are formed by starting drops of ink at a piece of paper and directing them toward the paper, passing through a charging nozzle. The ink drops leave a nozzle and pass between two parallel deflection plates. There is a uniform vertical electric field (see Chapter 23). Estimate the number of atoms in a single ink droplet of ink.
3. **Charge Square.** Four charged particles are arranged in a square as shown in the figure to the right, with  $q = 3.9 \times 10^{-4} \text{ C}$  and  $a = 6.9 \text{ mm}$ . What is the net force on the particle at the upper right corner due to the other three?



**1 design**

**2 approach**

## Problem Set Rubric

The goal of the problem sets is to develop problem-solving skills, not just to test your ability to obtain the right answer. You will receive the problem sets a week before they are due. Each problem set involves both individual and team work.

**Individual phase (at home):** From the time you receive a problem set to the time it is due in class at 10 am, you are to work on the problem set **alone**. The work you complete during this phase will be evaluated on effort, not correctness. You may only use **blue or black ink** and you must attempt to solve each problem using the following 4-step procedure (see Section 1.8 in the textbook for additional details)

Getting Started

State the important information and summarize the problem. If possible, include a diagram. Note any assumptions you're making.

Devise Plan

Devise a plan of attack before diving into the solution. Break down the problem into smaller, manageable segments. Identify which physical relationships you can apply.

Execute Plan

Carry out your plan, explaining each step. The argument should be easy to follow. Articulate your thought process at each step (including roadblocks). Any variables should be clearly defined, and your diagrams should be labeled.

Evaluate Answer

Check each solution for reasonableness. There are many ways to justify your reasoning: check the symmetry of the solution, evaluate limiting or special cases, relate the solution to situations with known solutions, check units, use dimensional analysis, and/or check the order of magnitude of an answer.

You can consult the textbook and online resources, and you may consult the teaching staff by posting questions to the Problem Set Discussion on the course Web site. However, you may not consult other people, nor collaborate with your peers. It's ok to try hard and not succeed at first (only your effort is evaluated), but you must attempt every problem. If you reach the Evaluate stage and find that your answer does not seem reasonable, try to describe your thought process so you are prepared for a discussion with your team in class.

**Team/Reflect phase (in class):** On the due date of the problem set, you will work with your team in class to improve and/or correct your solutions, reflect on your work, and determine what you need to review. In this stage, you may only use **red ink** to write on your problem sets (pens will be provided in class to review. In additional 45 minutes, your team will be provided with a solution set which you may use to review. In the final additional 45 minutes, your team must submit the marked-up problem sets to the teaching staff. You will receive sheets for the entire team and a team scoring sheet.

It is the team's responsibility to ensure that all team members have a copy of the marked-up problem solutions together with a team score. This is the only way to ensure that all team members have a copy of the marked-up problem solutions together with a team score. This is the only way to ensure that all team members have a copy of the marked-up problem solutions together with a team score.

**Individual phase (at home):** From the time you receive a problem set to the time it is due to work on the problem set **alone**. The work you complete during this phase will be correctness. You may only use **blue or black ink** and you must attempt to solve each problem. Use a 4-step procedure (see Section 1.8 in the textbook for additional details)

**Getting Started** State the important information and summarize the problem. If possible, note any assumptions you're making.

**Devise Plan** Devise a plan of attack before diving into the solution. Break down the problem into manageable segments. Identify which physical relationships you can apply.

**Execute Plan** Carry out your plan, explaining each step. The argument should be your thought process at each step (including roadblocks). Any variables should be defined, and your diagrams should be labeled.

**Evaluate Answer** Check each solution for reasonableness. There are many ways to justify the symmetry of the solution, evaluate limiting or special cases, compare to similar situations with known solutions, check units, use dimensional analysis, and check the magnitude of an answer.

You can consult the textbook and online resources, and you may consult the teaching staff.



**Individual phase (at home):** From the time you receive a problem set to the time it is due to work on the problem set **alone**. The work you complete during this phase will be evaluated on correctness. You may only use **blue or black ink** and you must attempt to solve each problem using a 4-step procedure (see Section 1.8 in the textbook for additional details)

Getting Started

State the important information and summarize the problem. If possible, note any assumptions you're making.

**at home:**

Devise Plan

Devise a plan of attack before diving into the solution. Break down the problem into manageable parts. Determine why a particular approach you can attempt will work.

**implement 4-step procedure**

Execute Plan

Carry out your plan, explaining each step. The argument should be your thought process at each step (including roadblocks). Any variables should be defined, and your diagrams should be labeled.

**(evaluated on effort)**

Evaluate Answer

Check each solution for reasonableness. There are many ways to justify the symmetry of the solution, evaluate limiting or special cases, compare situations with known solutions, check units, use dimensional analysis, and check the magnitude of an answer.

You can consult the textbook and online resources, and you may consult the teaching staff for help.

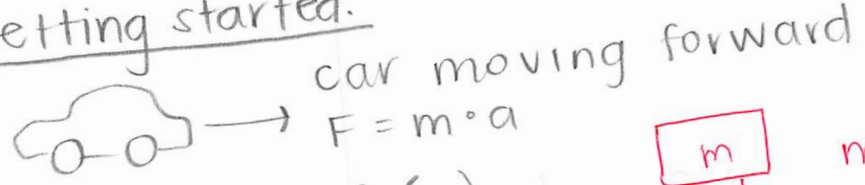
**1 design**

**2 approach**

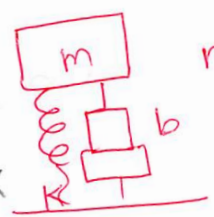
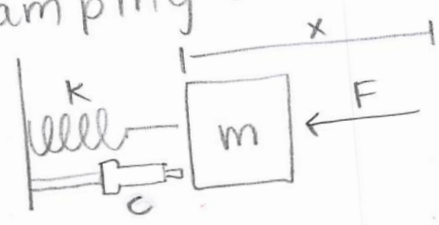
# Applied Physics 50a

① Estimate damping coeff. for a shock absorber on a midsize car.

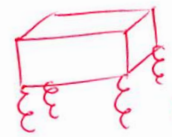
Getting started.



Damping coeff (c)



$$m \frac{d^2x}{dt^2} + b \frac{dx}{dt} + kx = 0$$



$$k_1 + k_2 + k_3 + k_4 = 4k_1$$

Create a plan.

Set  $F_s + F_d$  equal to force of car moving forward and solve for c.

- Approximate  $k$  of spring = 490.5 N/m
- $x$  (distance compressed) = 0.1 m

Execute plan.

$$F = m \cdot a$$

$$\sum F_x = F_{Ec}^G - F_{sc}^c = \Delta mg - k(x_{eq} - x_0)$$

Translational eq =  $\sum F_x = 0$

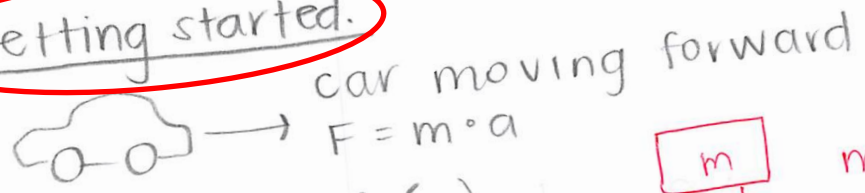
- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s

$$k = \frac{\Delta mg}{x}$$

Applied Physics 50a

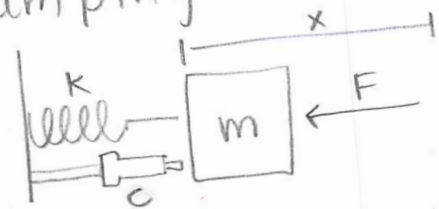
① Estimate damping coeff. for a shock absorber on a midsize car.

Getting started.

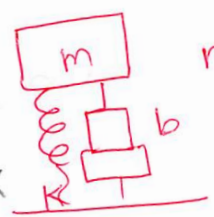


$F = m \cdot a$

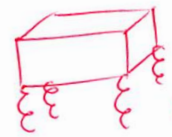
Damping coeff (c)



$F_s = -kx$   
 $F_d = -cv$



$m \frac{d^2x}{dt^2} + b \frac{dx}{dt} + kx = 0$



$k_1 + k_2 + k_3 + k_4 = 4k_1$

Create a plan.

Set  $F_s + F_d$  equal to force of car moving forward and solve for c.

- Approximate  $k$  of spring = 490.5 N/m
- $x$  (distance compressed) = 0.1 m

Execute plan.

$F = m \cdot a$

- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s

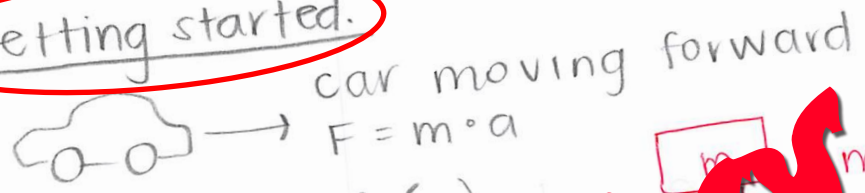
$\sum F_x = F_{Ec}^G - F_{sc}^c = \Delta mg - k(x_{eq} - x_0)$   
Translational eq =  $\sum F_x = 0$

$k = \frac{\Delta mg}{x}$

Applied Physics 50a

① Estimate damping coeff. for a shock absorber on a midsize car.

Getting started.



Damping coeff (c)



**25 pages!**

Create a plan.

Let  $F_d$  equal to force of car moving forward and solve for c.

- Approximate  $k$  of spring = 490.5 N/m
- $x$  (distance compressed) = 0.1 m

Execute plan.

$F = m \cdot a$

- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s

$\uparrow F_{sc}^c$   
 $\downarrow F_{Ec}^G$   
 $\Sigma F_x = F_{Ec}^G - F_{sc}^c = \Delta mg - k(x_{eq} - x_0)$   
 Translational eq =  $\Sigma F_x = 0$

$k = \frac{\Delta mg}{x}$

with your peers. It's ok to try hard and not succeed at first (only your effort is evaluated every problem. If you reach the Evaluate stage and find that your answer does not describe your thought process so you are prepared for a discussion with your team in class.

**Team/Reflect phase (in class):** On the due date of the problem set, you will work with your team to improve and/or correct your solutions, reflect on your work, and determine what you need to learn. During this stage, you may only use **red ink** to write on your problem sets (pens will be provided in class). In the final 45 minutes, your team will be provided with a solution set which you may use to confirm your answers. In the additional 45 minutes, your team must submit the marked-up problem sets together with your reflection sheets for the entire team and a team scoring sheet.

It is the team's responsibility to ensure that *all* team members hand-in complete answers and solutions together with a completed reflection sheet, because your team's submitted work will determine your team score. This means that if you do not put in adequate effort before the Team/Reflect phase, you will only receive your own score, but also that of your team members. Likewise, it is important to ensure that your team marks his/her work up correctly during the Team/Reflect phase.

**Important:** Writing on the problem set in class in any other color but red will be considered a violation of the rules.

with your peers. It's ok to try hard and not succeed at first (only your effort is evaluated every problem. If you reach the Evaluate stage and find that your answer does not describe your thought process so you are prepared for a discussion with your team in class

**Team/Reflect phase (in class):** On the due date of the problem set, you will work with your team to improve and/or correct your solutions, reflect on your work, and determine what you need to do next. At this stage, you may only use **red ink** to write on your problem sets (pens will be provided in class). During the 15 minutes, your team will be provided with a solution sheet which you may use to confirm your answers. After an additional 45 minutes, your team must submit the marked-up problem sets together with your reflection sheets for the entire team and a team scoring sheet.

**in class:**

**mark up/improve solutions**

**complete reflection sheet**

It is the team's responsibility to ensure that *all* team members hand-in complete and accurate solutions together with a completed reflection sheet because your team's score is based on the team score. This means that if you do not put in adequate effort before the Team/Reflect phase, you will only receive only your own score, but also that of your team members. Likewise, it is important to ensure that your team marks his/her work up correctly during the Team/Reflect phase.

**Important:** Writing on the problem set in class in any other color but red will be considered incorrect.

② continued.

c) Maximum transverse speed.

Use  $\lambda = \frac{v}{f}$ ; solve for v.

d) Length would have to be  $\lambda$  or  $1/2$  wavelength, etc.

Execute plan.

a)  $y = 0.2 \sin[\pi(0.5x - 100t)] = 0.5\pi(x - 200t)$

~~$x(t) = A \sin(\omega t + \phi)$~~   $y = A \sin[k(x - ct)]$

• amplitude = 0.2 cm

200 cm/s  
k = wave #  
c = wave speed  
A = amplitude

•  $\omega = \text{rotational speed} = 0.5\pi$

~~$0.5\pi = \frac{2\pi}{T} \Rightarrow T = 4 \text{ sec} = \text{period}$~~   $\frac{1}{50}$

$k = \frac{2\pi}{\lambda} \rightarrow \lambda = \frac{2\pi}{k}$

•  $f = \frac{1}{T} = 50 \text{ sec}^{-1} = \text{Hz}$   $0.02 \text{ sec}$

$\lambda = \frac{v}{f}$

•  $\lambda = \frac{v}{f} = \frac{200}{50} = 4 \text{ cm}$   $T = \frac{1}{f}$

$4 f = \frac{v}{\lambda}$

• wave number =  $\frac{2\pi}{\lambda} = \frac{1}{2} \pi = 0.5\pi$   $= \frac{200}{4} = 50$

(shifted right)  
 $y = 0.2 \sin[\pi(0.5x - 100(\frac{1}{200}))]$

$y = 0.2 \sin[\pi(0.5x - 100(0))]$

## Problem Set Reflection


Describe what you **learned** from working on this problem set before coming to class and reviewing it in class. (Do you think you would be able to take the concepts you explored in this problem set and transfer those concepts in a whole new context?) For example, would you be able to solve a problem involving the same physics concepts, but of a form you have never seen before?). You may complete this part before coming to class in blue or black ink.

Before coming to class, I learned a lot about waves in music and frequency. I feel really comfortable with concepts of wave speed, amplitude, frequency, and period. I understand beat frequency (although I made a clerical error by forgetting to use the speed of sound (twice)). I also feel like I now understand how decibels are calculated - before, I didn't know they were exponential! I know what the concept of intensity means and how to use it.

Based on your overall experience with this problem set, describe what you need to review.

I definitely need to review torque! I had no idea how to use that concept for #3 and I'll probably need to go over the solutions before I really understand it. Similarly with the damping coefficient estimation problem → I started off in the wrong direction and never really fixed where I went wrong. I also need to review some calculus. The last time I really understood calculus was high school and it's becoming an issue.





**“I was inspired and encouraged to do these problems on my own with the promise of collaborative work [the next day]”**



**“I felt less pressure to find the right answer  
and more freedom to explore”**

**1** design

**2** approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities  
Develop individual strategy  
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class  
Discuss with team, mark up  
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone  
Open book, open internet  
Part 2: solve with team





**1** design

**2** approach

A group of students in a classroom or computer lab, working on laptops and discussing their work. The scene is brightly lit with large windows in the background. Several students are seated at desks, some looking at their laptops, while others are engaged in conversation. The overall atmosphere is collaborative and focused.

**goal: formative assessment  
collaborative learning**

**1** design

**2** approach

## Session 389314

This is the individual round; work on these questions on your own.

Jump to ▼ 1 2 3 4 5

### expression question

What is the derivative of  $f(x) = 3x^2 - 6x$ ?

Enter an expression, e.g.,  $x^2$  for  $x^2$ ,  $\ln(y) - \sin(x)$  for  $\ln y - \sin x$ ,  $x/(y+1)$  for  $\frac{x}{y+1}$ ,  $(1/2)x$  for  $\frac{1}{2}x$ . Do not enter a complete equation.

Current team: **Blue team**  [Change team](#)  [Change seat](#)  [Send a message to the instructor](#)  [Join another](#)

This is the individual round;

**expression question**

What is the derivative of  $f(x) = 3x^2 - 6x$ ?

Submit response

Enter an expression, e.g.,  $x^2$  for  $x^2$ ,  $\ln(y) - \sin(x)$  for  $\ln y - \sin$

This is the individual round;

**expression question**

What is the derivative of  $f(x) = 3x^2 - 6x$ ?

Submit response

Enter an expression, e.g.,  $x^2$  for  $x^2$ ,  $\ln(y) - \sin(x)$  for  $\ln y - \sin$



$6x - 6$

Brian Lukoff

$6x$

Brent Jones

$6x - 6$

Beth Sawyer

$6x^2 - 6$

Kip Harmon

### expression question

What is the derivative of  $f(x) = 3x^2 - 6x$ ?

Submit response

Enter an expression, e.g.,  $x^2$  for  $x^2$ ,  $\ln(y) - \sin(x)$  for  $\ln y - \sin$



1 design

2 approach

# Self, Peer, and Team assessment



**1** design

**2** approach

# Team, Peer, and Self assessment

## Self Assessment

Self Assessment (you!)		Never	Rarely	Sometimes	About half the time	Most of the time	All of the time
1.	I <b>participate fully</b> in team activities						
2.	I come to class <b>well-prepared</b> for all team activities						
3.	I <b>communicate effectively and respectfully</b> with team members: <ul style="list-style-type: none"> <li>• I express my opinions respectfully and with clarity</li> <li>• I listen respectfully to the perspectives and contributions of others</li> <li>• I collaborate effectively with team members to make decisions and resolve conflicts</li> </ul>						
4.	<b>Attendance:</b> <ul style="list-style-type: none"> <li>• I am present for team activities</li> <li>• I am on time/punctual</li> </ul>						
5.	I <b>take responsibility</b> for my own part of team work and decision-making						
6.	I am <b>open to change</b> and willing to re-evaluate my own position in light of new information from others						

7. Please describe one thing that you think you do well, that helps to make your team more effective

--	--

# Team, Peer, and Self assessment

## 4. Relative contributions

How much did each team member contribute to the overall goals? Please note that the **sum of all relative contributions must be zero** — if one person did more than his/her fair share, then others must have done less.

	RELATIVE CONTRIBUTION						
	Less than fair share			Fair share	More than fair share		
	Almost nothing	Much less	Somewhat less		Somewhat more	Much more	Almost everything
Self							
Member 1							
Member 2							
Member 3							
Member 4							

# Team, Peer, and Self assessment

## Assessment Report

You...	Avg. Assessment by Peers	Self Assessment
1. <b>Participate fully</b> in team activities		
2. Come to class <b>well-prepared</b> for all team activities		
3. <b>Communicate effectively and respectfully</b> with team members: <ul style="list-style-type: none"><li>• Express your opinions respectfully and with clarity</li><li>• Listen respectfully to the perspectives and contributions of others</li><li>• Collaborate effectively with team members to make decisions and resolve conflicts</li></ul>		
4. <b>Attendance:</b> <ul style="list-style-type: none"><li>• You are present for team activities</li><li>• On time/punctual</li></ul>		
5. <b>Take responsibility</b> for your own part of team work and decision-making		
6. Are <b>open to change</b> and willing to re-evaluate your own position in light of new information from others		

Scale: 0 = Never, 1 = Rarely, 2 = Sometimes, 3 = About half the time, 4 = Most of the time, 5 = All of the time

Your team members **praise you** for helping make your team more effective in the following ways (the quotes are in random order):

“quote 1”

“quote 2”

“quote 3”

“quote 4”

What you said you did to help make your team more effective:

“self quote”

Your team members have the following **suggestions** to help you become a more effective team member (the

# Team, Peer, and Self assessment

Relative contributions to team work	Average Peer Assessment	Self Assessment
You		
Team member 1		
Team member 2		
Team member 3		
Team member 4		

Scale: -3 = did almost nothing, -2 = did much less than fair share, -1 = somewhat less than fair share, 0 = fair share; +1 = somewhat more than fair share, +2 = much more than fair share, +3 = did almost everything

## Scores

Your **team work score**: 0-3 (based on peers' assessment of **your** relative contributions)

Your self and peer **assessment accuracy score**: 0-3

Scale: 3 = exceptional (very rarely given); 2 = meets expectations; 1 = needs improvement; 0 = deficient

# Assessment

- self-directed learning
- learning goals
- teamwork
- professionalism

1 design

2 approach



# Assessment

- self-directed learning — NB & problem sets
- learning goals
- teamwork
- professionalism

1 design

2 approach

# Assessment

- self-directed learning — NB & problem sets
- learning goals — RAA & project reports
- teamwork
- professionalism

1 design

2 approach

# Assessment

- self-directed learning — NB & problem sets
- learning goals — RAA & project reports
- teamwork — project & peer assessment
- professionalism

1 design

2 approach

# Assessment

- self-directed learning — NB & problem sets
- learning goals — RAA & project reports
- teamwork — project & peer assessment
- professionalism — participation, punctuality  
& ethics

# Assessment

self-directed learning

learning goals

team work

professionalism

# Assessment

Scale: 3-0

self-directed learning

learning goals

team work

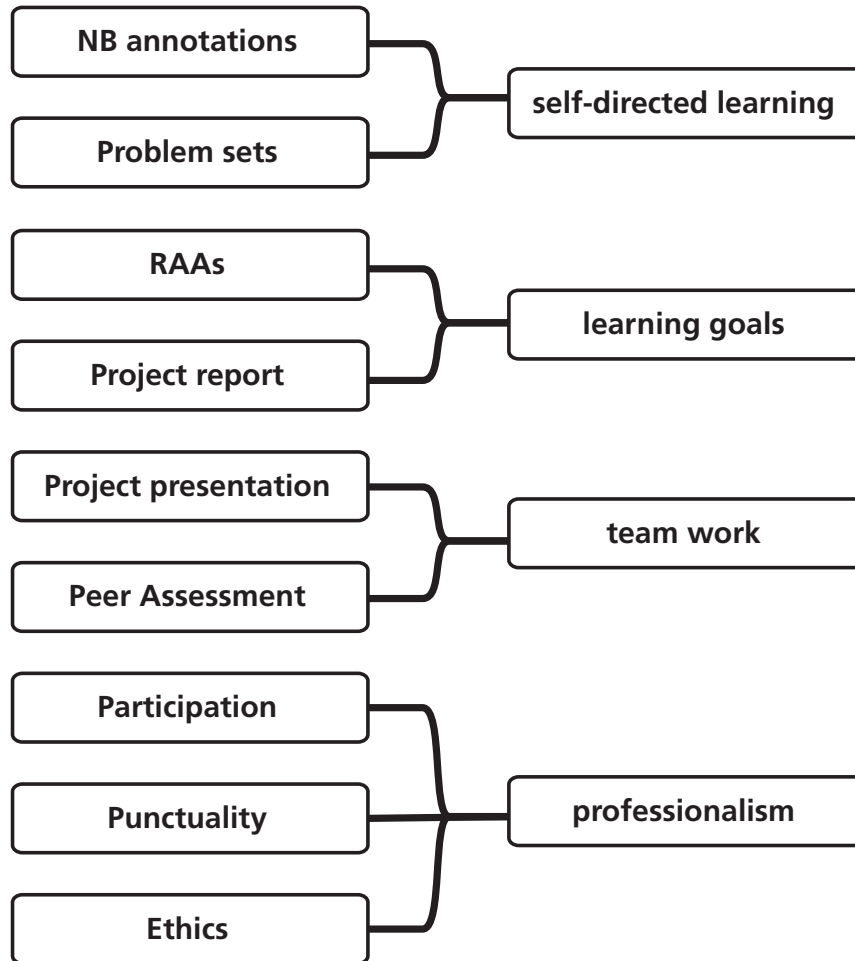
professionalism

**1** design

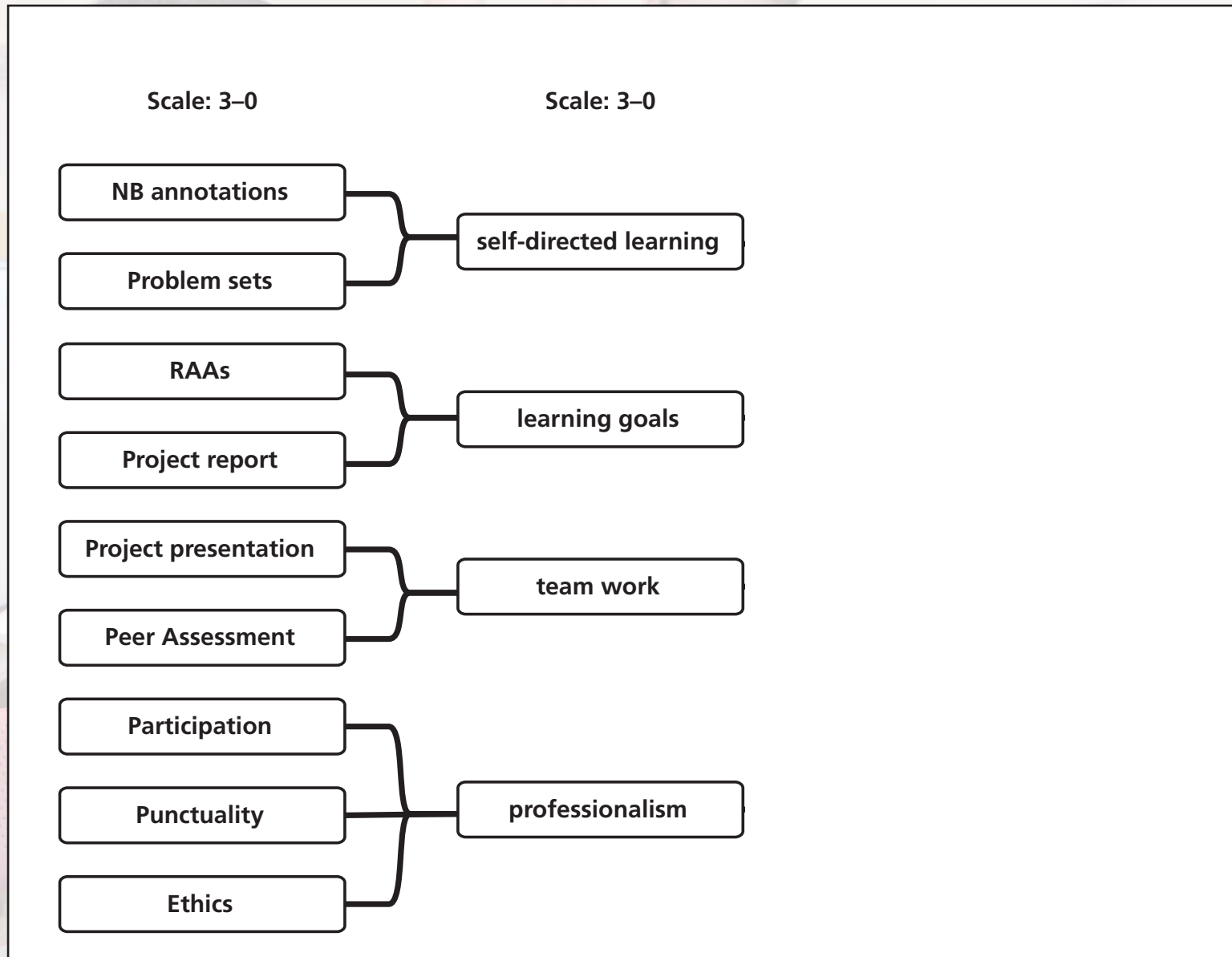
**2** approach

# Assessment

Scale: 3-0

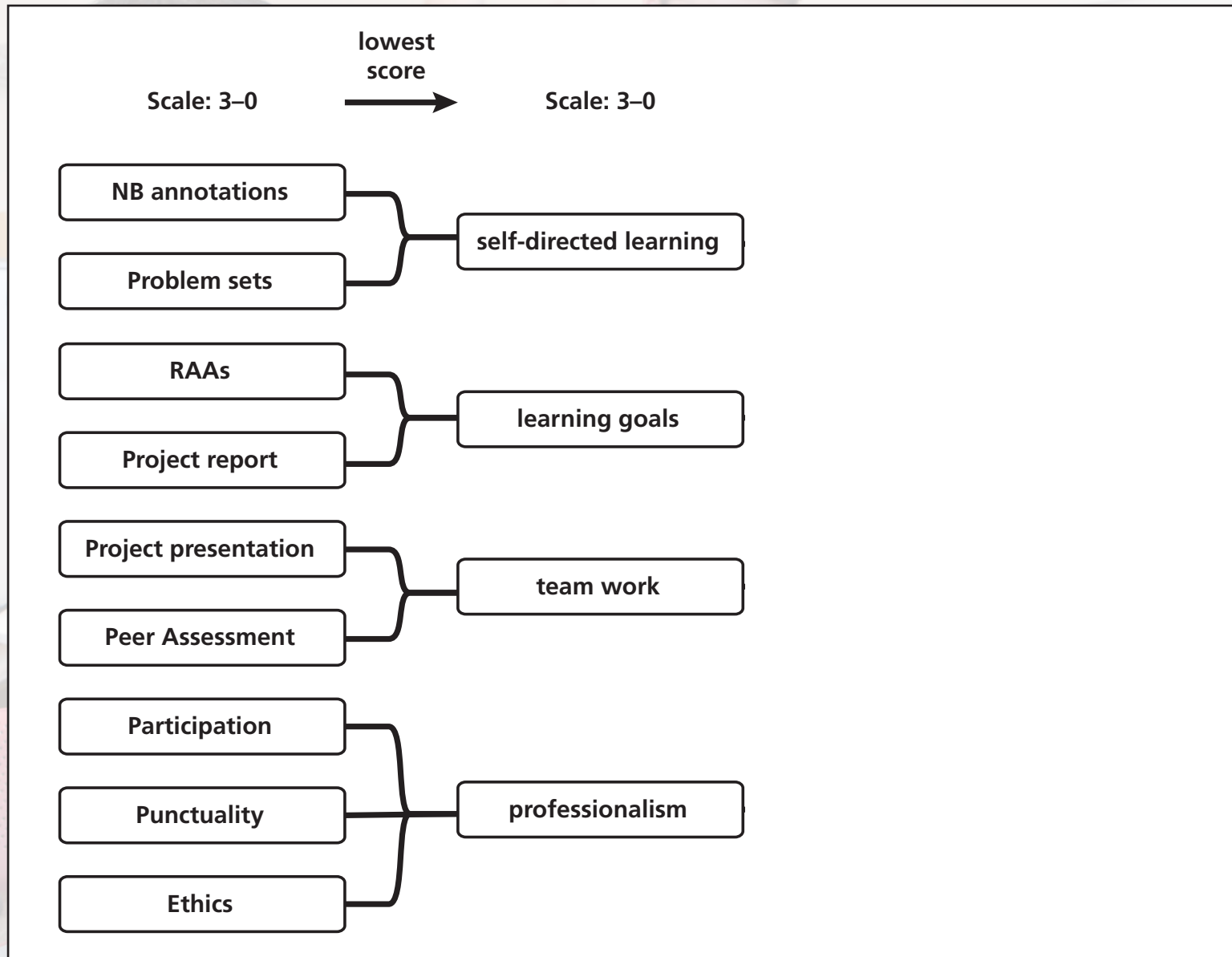


# Assessment

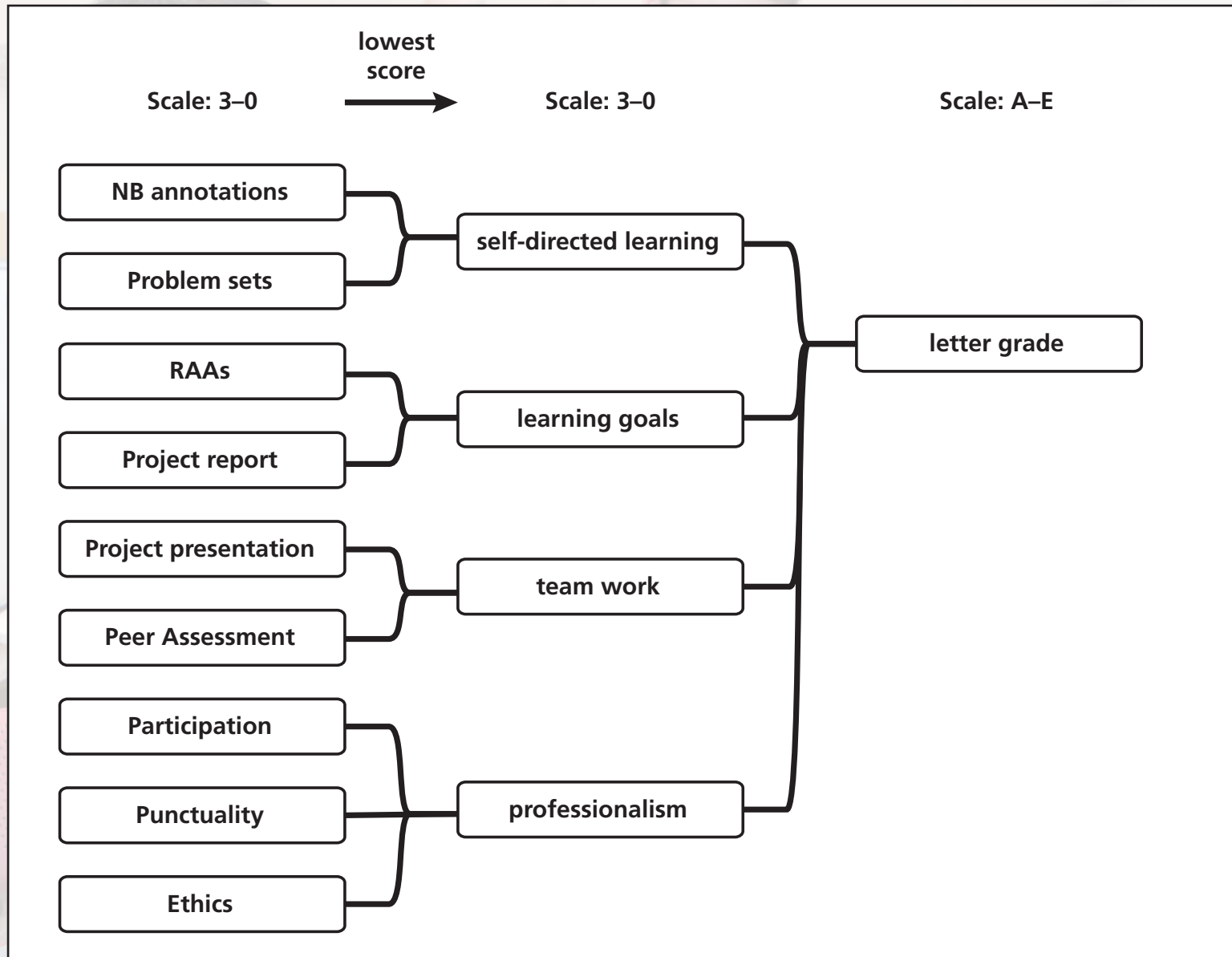




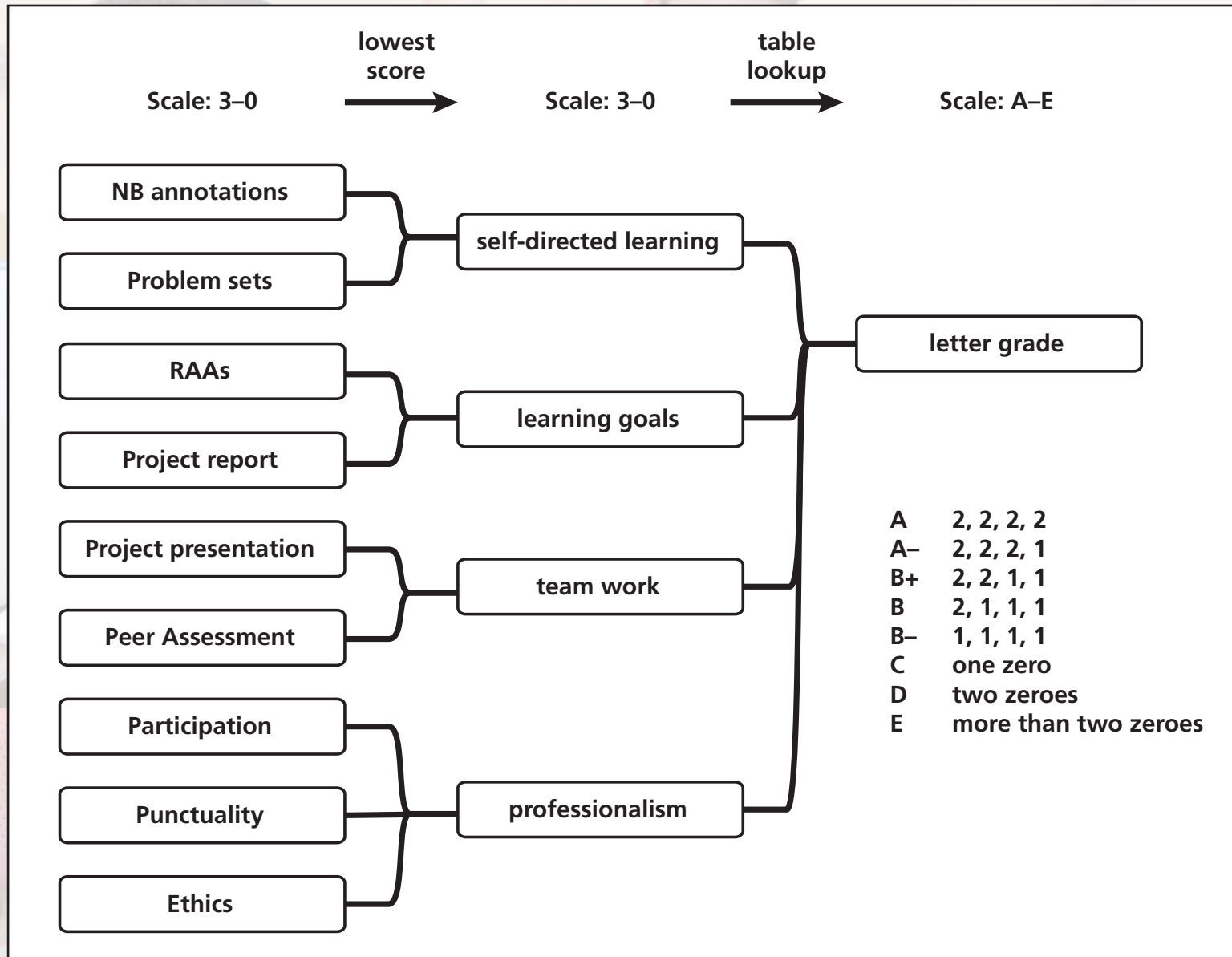
# Assessment



# Assessment



# Assessment





**1** design

**2** approach

**3** results

# Ownership



**1** design

**2** approach

**3** results

# Ownership

Course evaluation: 4.2/5

1 design

2 approach

3 results

# Ownership

**“The structure of the class made what was my least-favorite subject into one of my favorites.”**

**1 design**

**2 approach**

**3 results**

# Ownership

**“The structure of the class made what was my least-favorite subject into one of my favorites. I was worried that people, including myself, would just slack off and do the bare minimum, but you really need to be on top of your readings and concepts in order to contribute to your team. GREAT CLASS!!!!!!”**

**1 design**

**2 approach**

**3 results**



# Ownership

**“Dear Harvard students, this class will be unlike any class you’ve taken at Harvard, and it will, hopefully, shift the entire foundation upon which you’ve based your education. I truly believe everyone should take this course; prepare to take full ownership of your learning.”**

**1 design**

**2 approach**

**3 results**

# Ownership

**Attendance: 94% (AP50a), 97% (AP50b)**

**1 design**

**2 approach**

**3 results**

# Ownership

**Attendance: 94% (AP50a), 97% (AP50b)**

**3 hours and they don't *leave!***

**1 design**

**2 approach**

**3 results**

# Ownership

**"I don't think I am well enough to make it through class. I feel terrible because I don't want to let my team down by not being there, but I don't think I'd be very helpful in my current state."**

**(via email)**

**1 design**

**2 approach**

**3 results**

# Self-efficacy

**1** design

**2** approach

**3** results

# Self-efficacy

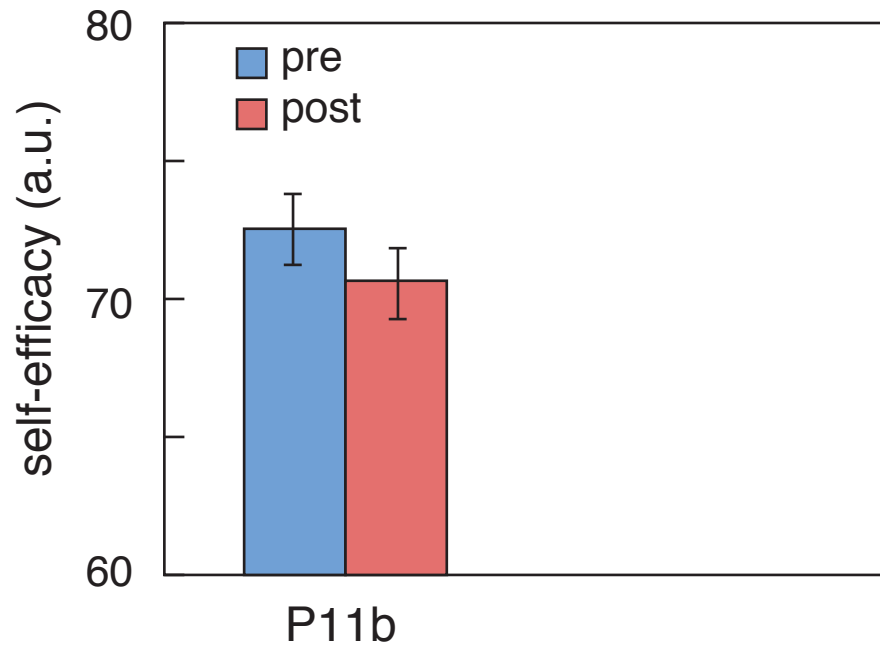
(students' belief in their ability to succeed)

1 design

2 approach

3 results

# Self-efficacy

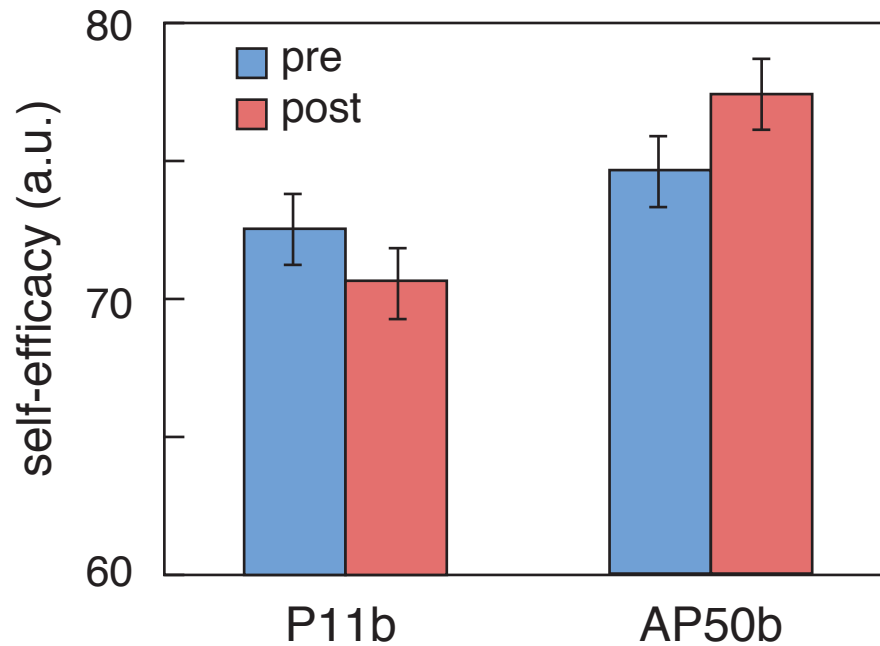


1 design

2 approach

3 results

# Self-efficacy



1 design

2 approach

3 results



# Self-directed learning

**1** design

**2** approach

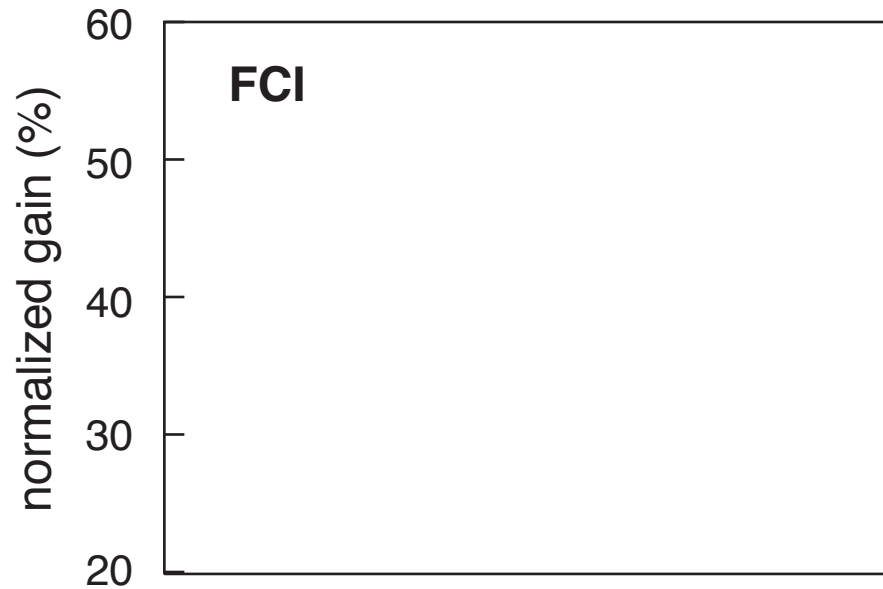
**3** results

# Self-directed learning

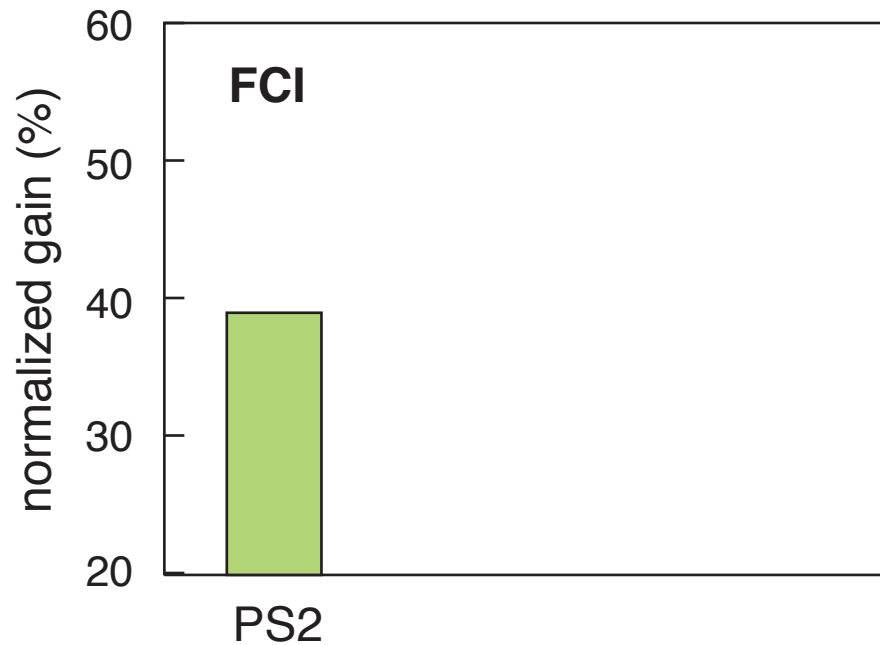
**NB data shows:**

- **student spend on average 2.3 hrs/chapter**
- **600–700 annotations/chapter (8–10/stu)**

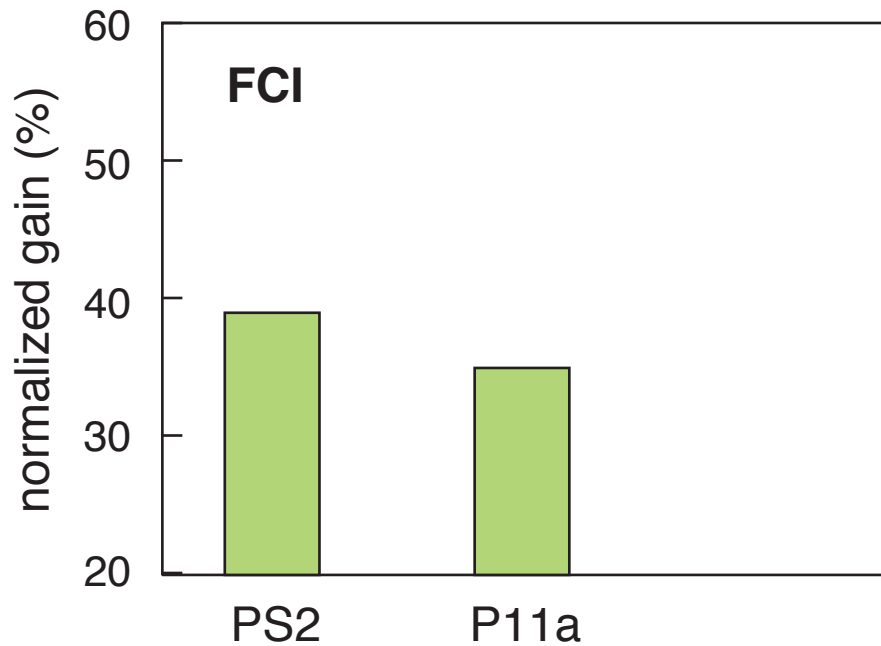
# Conceptual Mastery



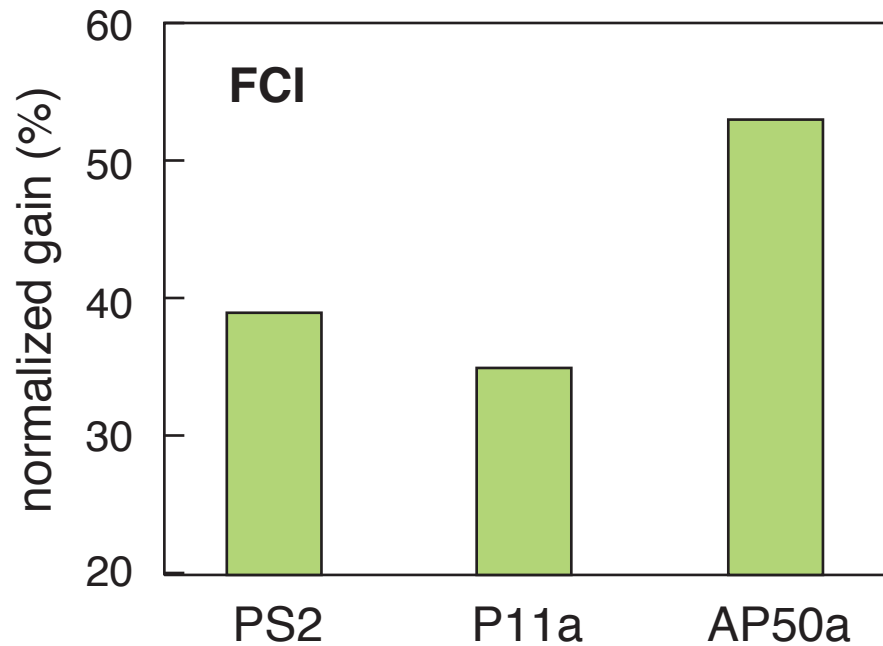
# Conceptual Mastery



# Conceptual Mastery



# Conceptual Mastery

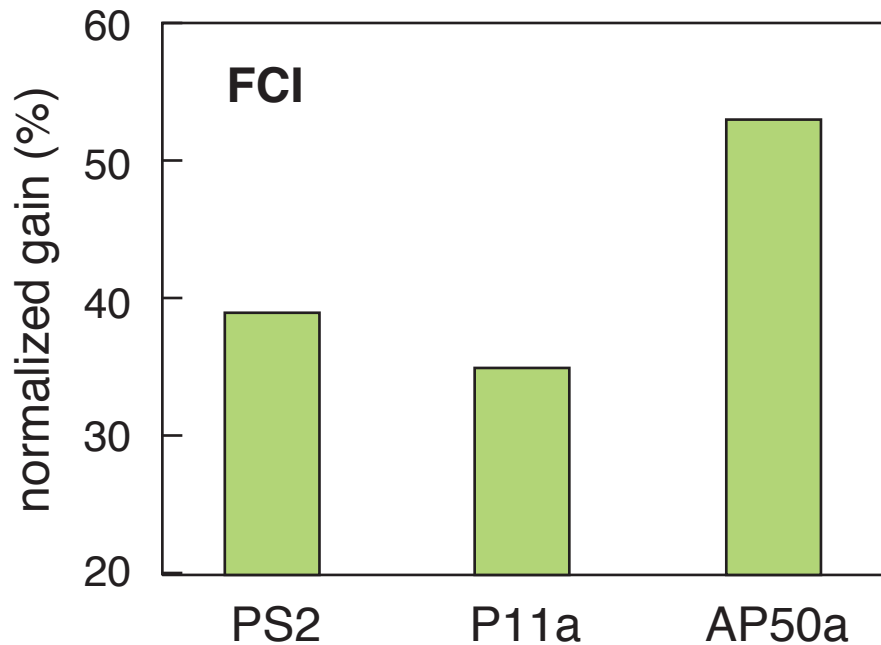


1 design

2 approach

3 results

# Conceptual Mastery



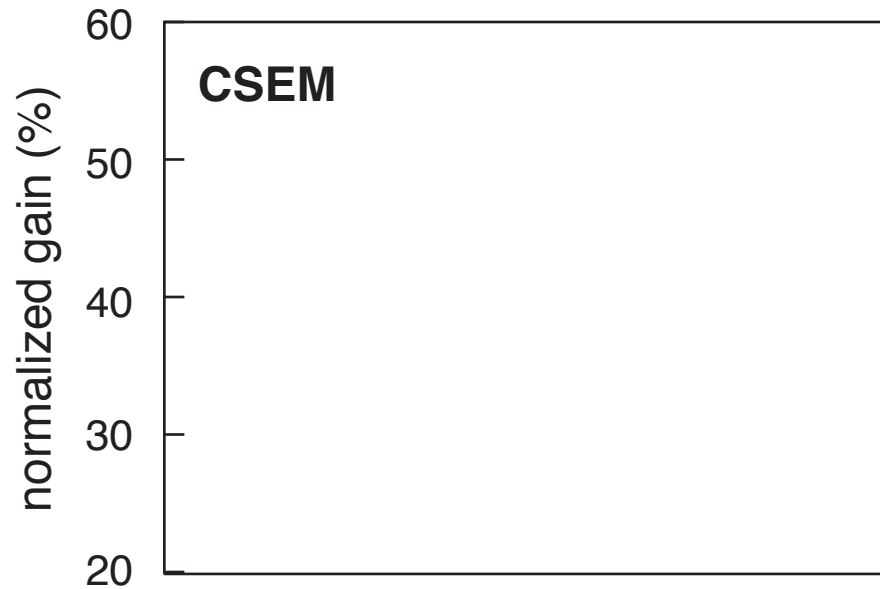
**largest conceptual gain in *any* course past 6 yrs!**

**1** design

**2** approach

**3** results

# Conceptual Mastery



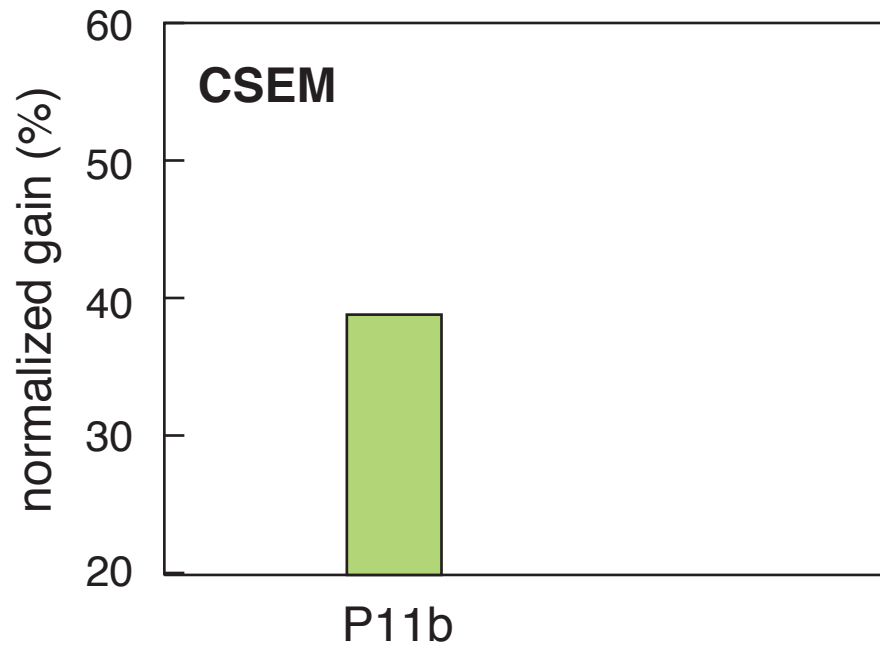
1 design

2 approach

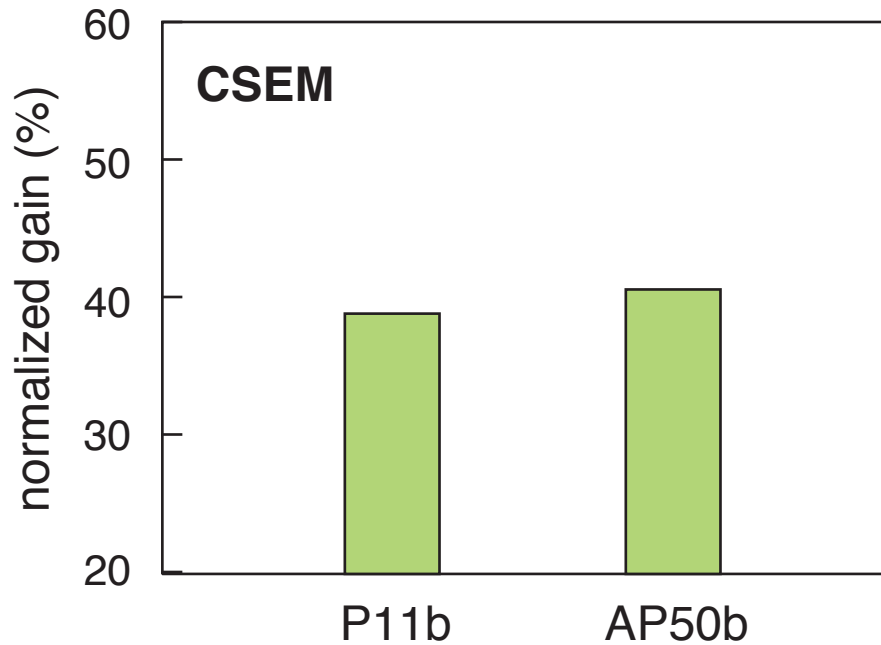
3 results



# Conceptual Mastery



# Conceptual Mastery

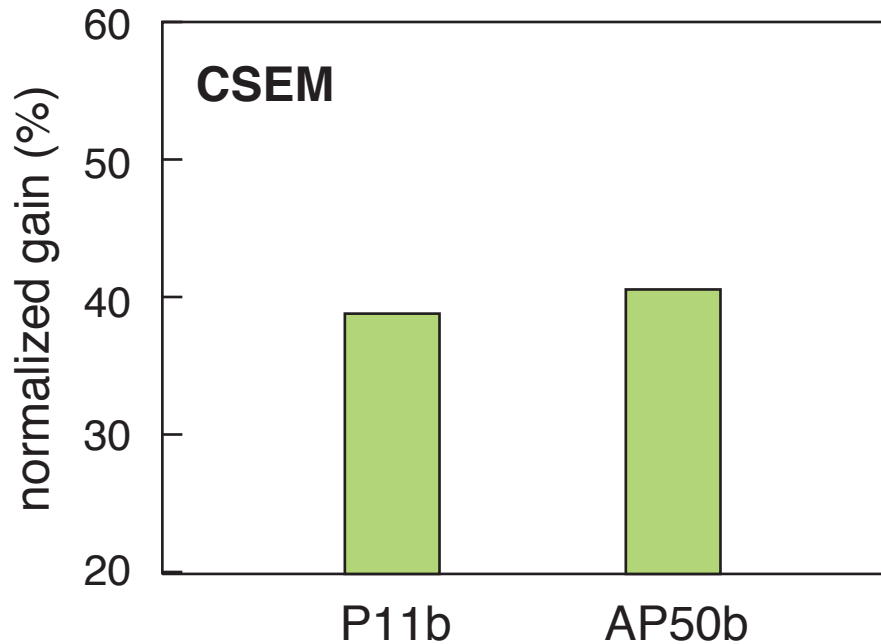


1 design

2 approach

3 results

# Conceptual Mastery



**as good as when I do my best teaching!**

**1 design**

**2 approach**

**3 results**



**1** design

**2** approach

**3** results

A photograph of four students in a physics laboratory. A woman with glasses is leaning over a wooden box containing a circuit board with many small lights. She is holding a white cup and pouring liquid into it. Two other women and one man are looking on with interest and smiles. The man is wearing a plaid shirt and yellow pants. The woman in the foreground is wearing a maroon hoodie. The background shows a typical lab setting with whiteboards and equipment.

***Can create ownership of learning physics!***

**1** design

**2** approach

**3** results



**Can create ownership of learning physics!**

**1 design**

**2 approach**

**3 results**




**“you come out with so much knowledge and experience and fun”**

**1** design

**2** approach

**3** results

A group of four students in a laboratory setting are gathered around a wooden box containing electronic equipment. One student is using a pipette to transfer liquid into a cup. They are all smiling and looking at the equipment. The background shows a typical lab environment with whiteboards and lab benches.

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**1** design

**2** approach

**3** results