

# Flat space, deep learning



Institute for Teaching and Learning Innovation Lecture  
The University of Queensland  
Brisbane, QLD, Australia 1 June 2015



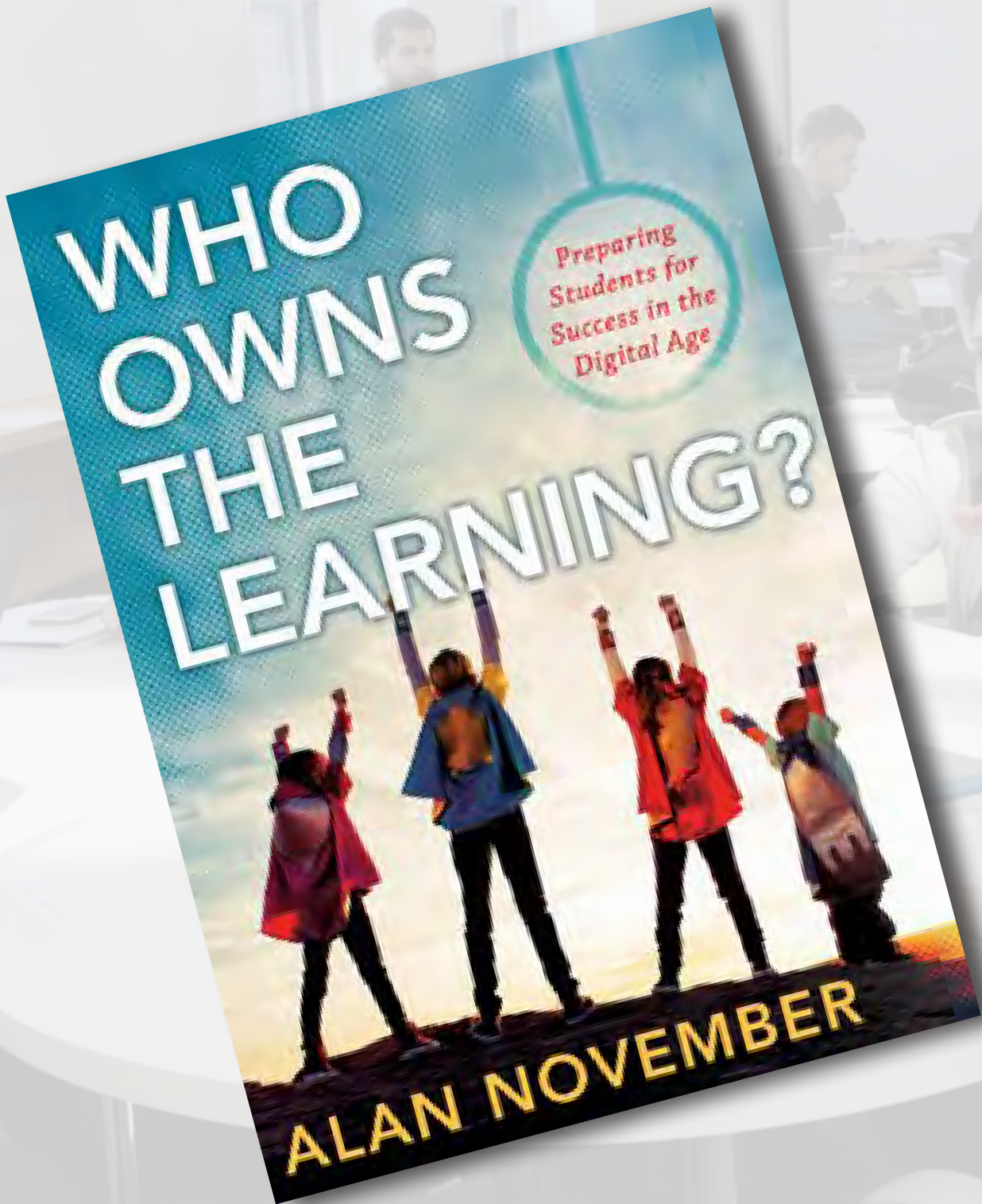
# Flat space, deep learning



**@eric\_mazur**

Institute for Teaching and Learning Innovation Lecture  
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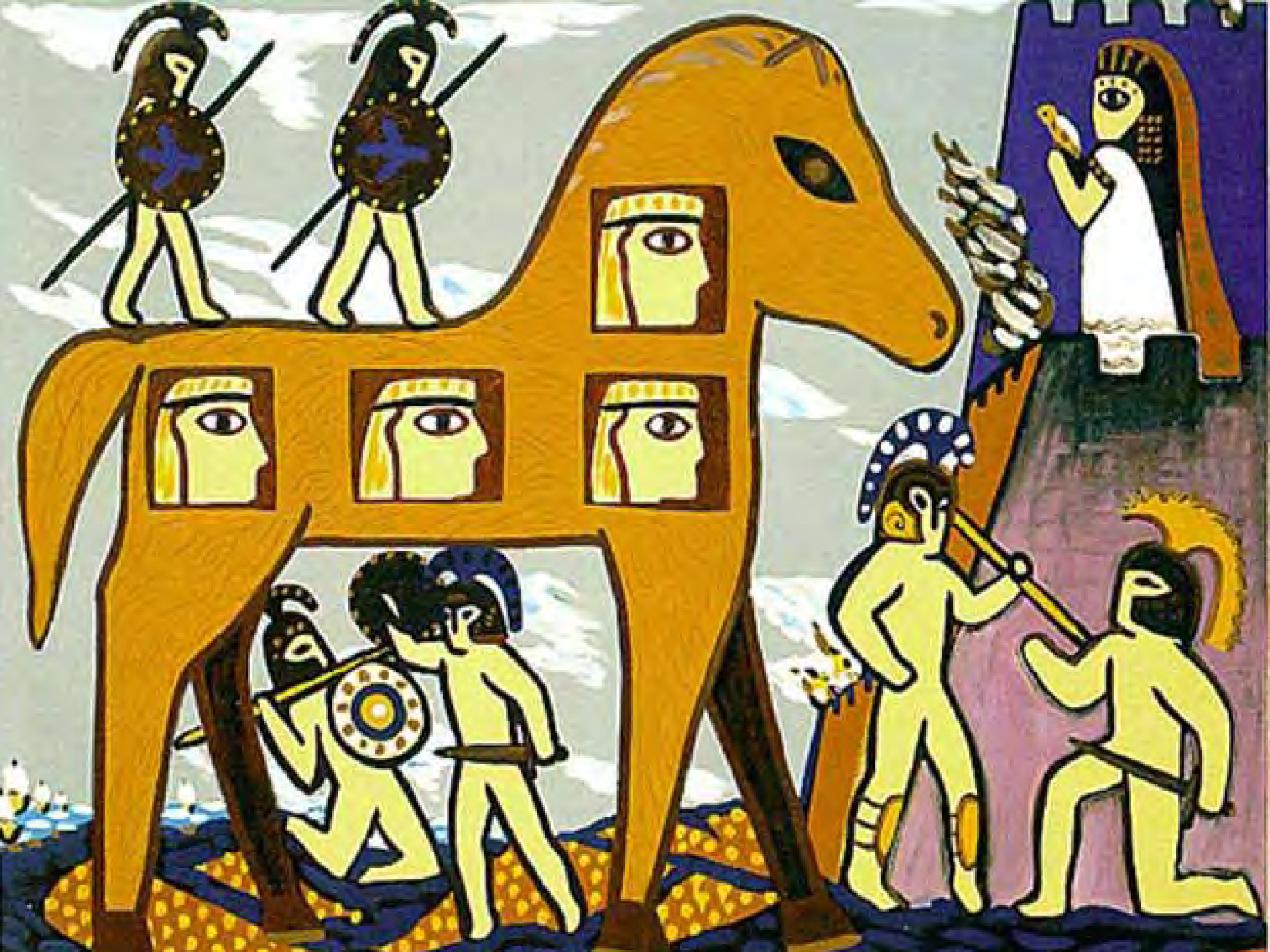
Preparing  
Students for  
Success in the  
Digital Age

# WHO OWNS THE LEARNING?

ALAN NOVEMBER



**Ownership of learning *physics*?**





**team & project-based approach**



# ProTeam Learning







**1** design

**2** approach

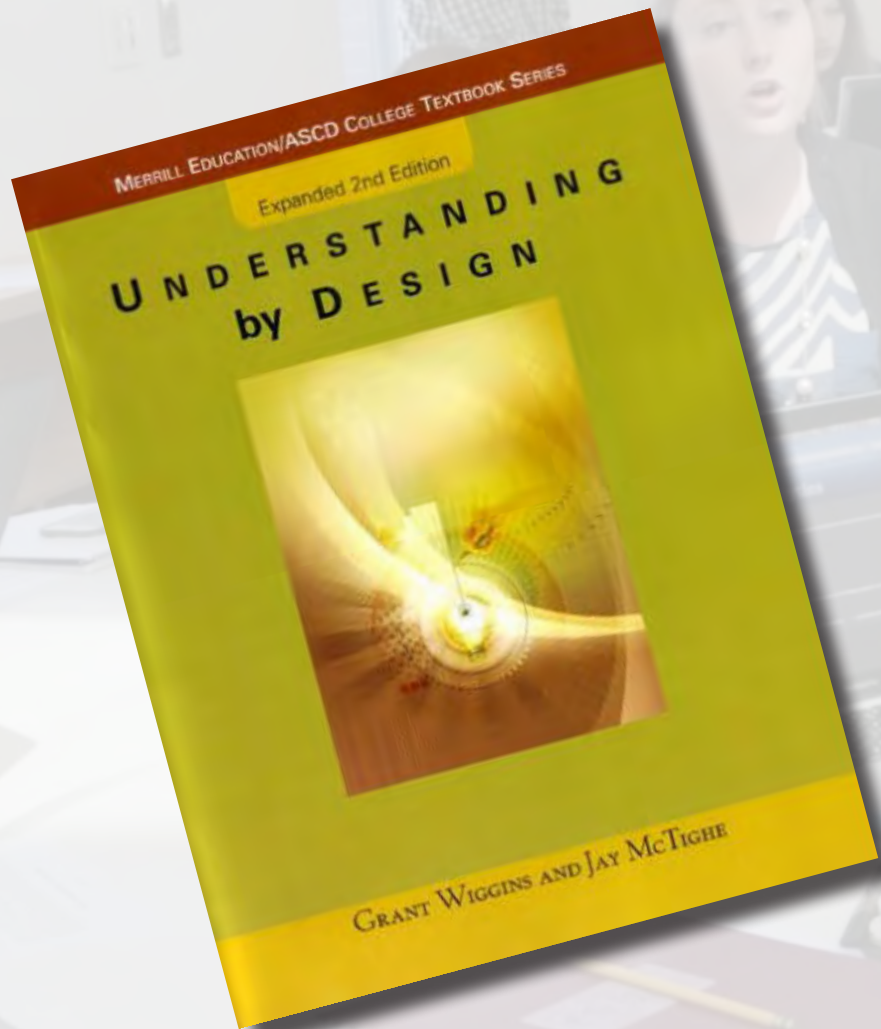


**1** design

**2** approach

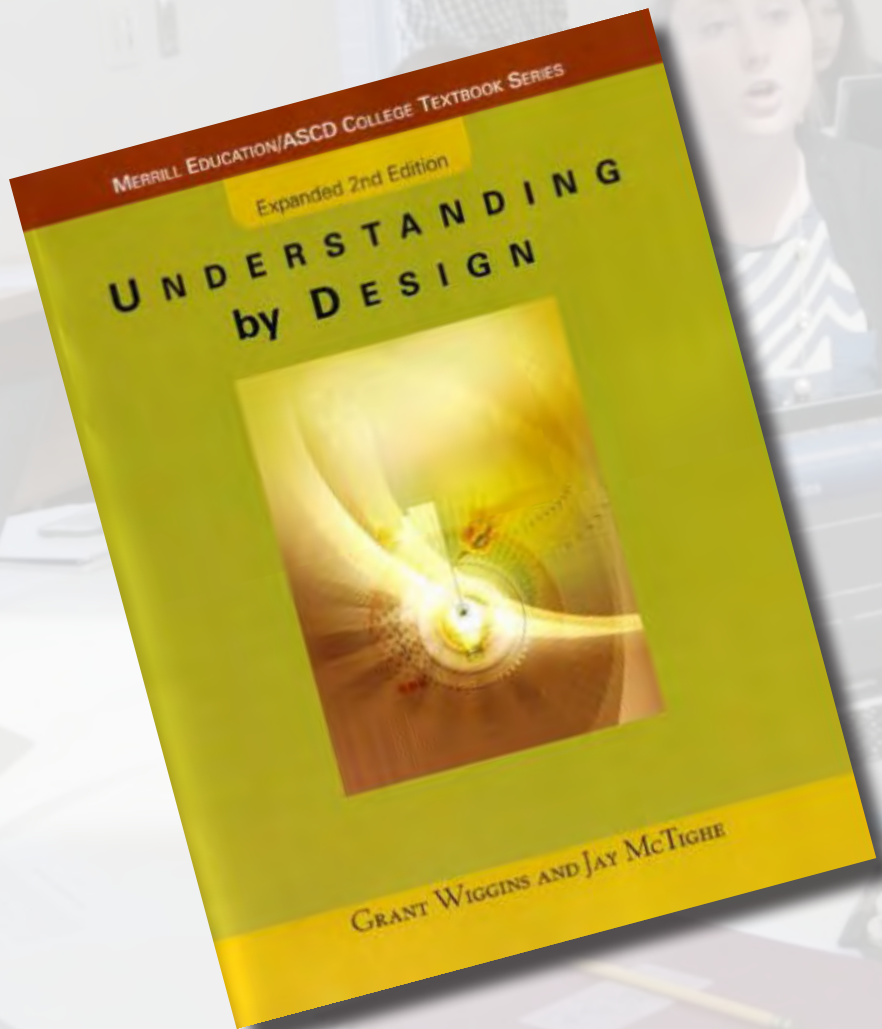
**3** results

## Setting learning goals



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

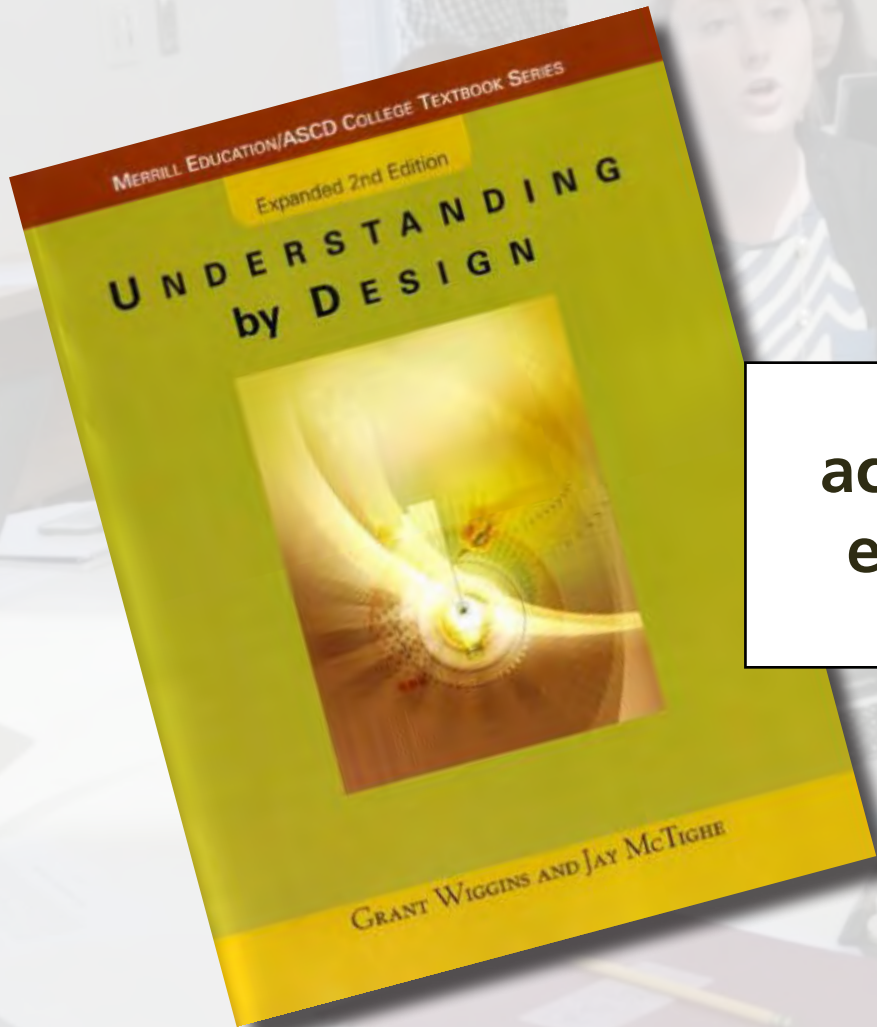
## Backward design



**desired  
outcomes**

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

## Backward design



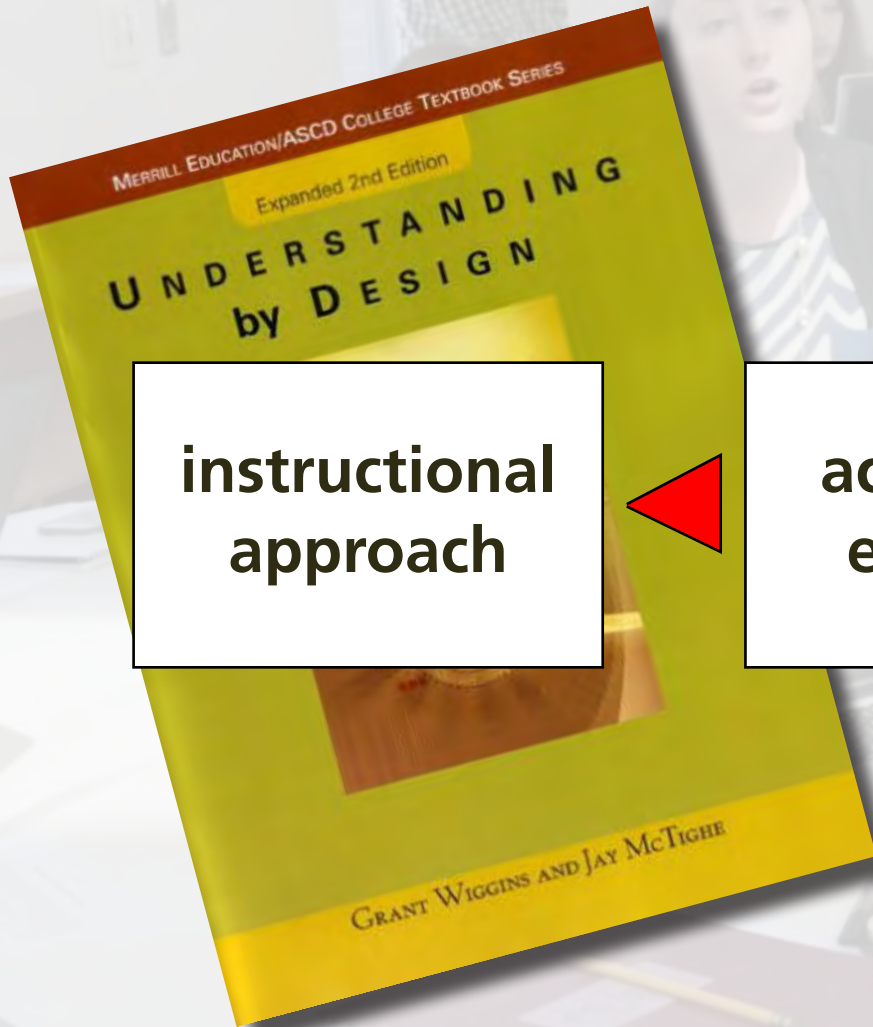
acceptable  
evidence



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)

# 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
- ts 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)**
- **projects**
- **in-class activities**

**1** design

**2** approach

PRINCIPLES & PRACTICE OF  
PHYSICS

ERIC MAZUR

PRINCIPLES & PRACTICE OF  
PHYSICS

ERIC MAZUR

1 design

2 approach

# Information transfer

## social document annotation system

1 design

2 approach

# Information transfer

Files Nav Home Practice Exam Midterm 2 6

6/34 105%

## CHAPTER 29 Changing magnetic fields

any relative motion between the magnet and the coil 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.

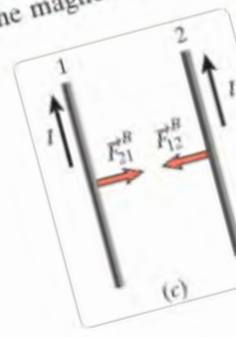
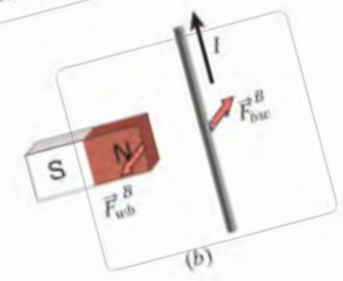
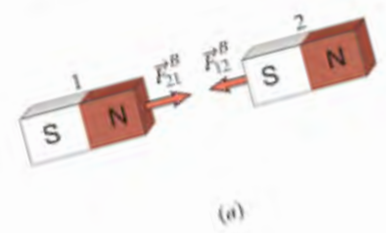
### 28.1 Source of the magnetic field

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

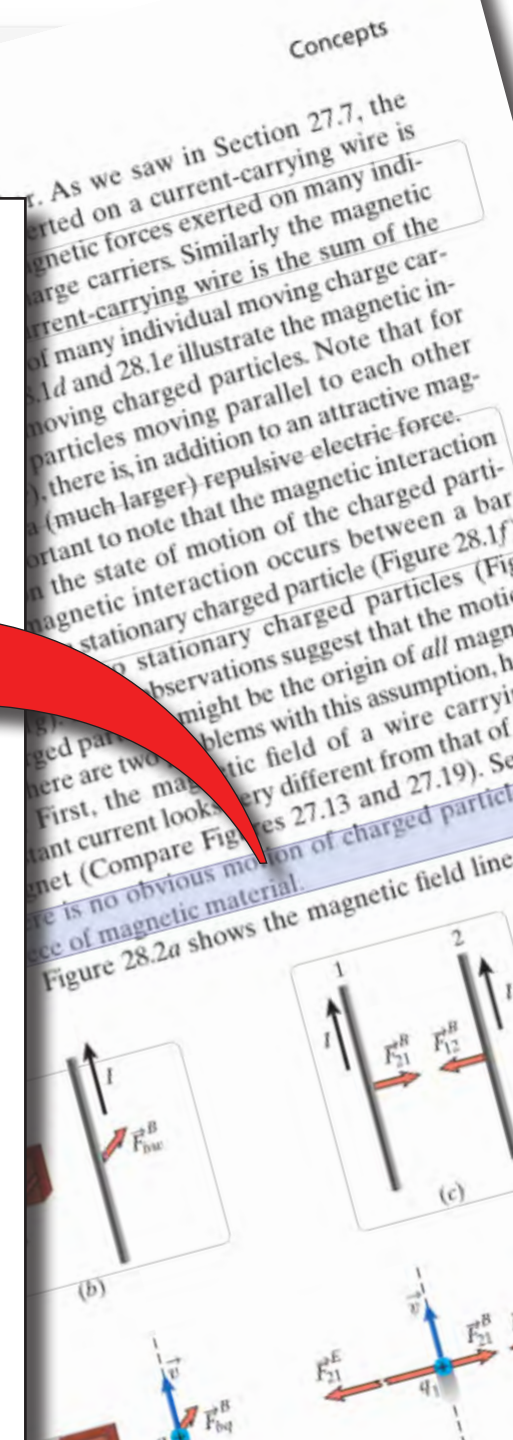
I agree that the motion is not "obvious" in that it is not visible to the naked eye. The cause must be atomic.

## 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, for example?). How does this reconcile?

**Student 2 – 26 Feb, 11:21AM**

Maybe they're trying to say that there is no *obvious* motion, but they are in fact moving in a way that 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.

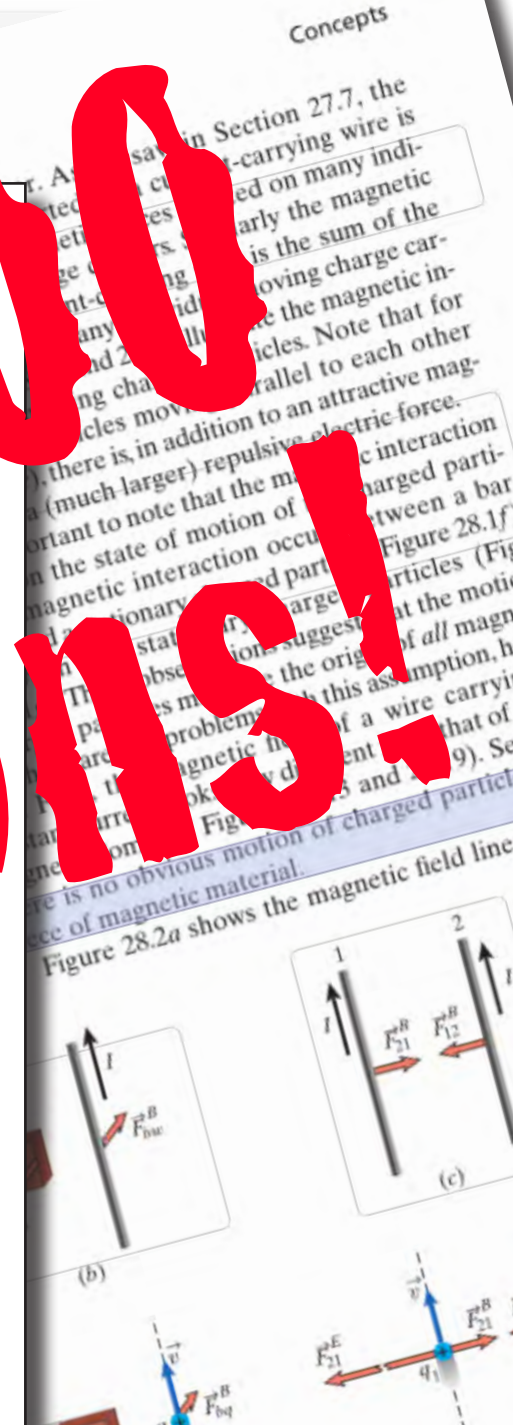
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**Student 4 – 4 Mar, 01:05PM**

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

Over 20,000 annotations!





# 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.

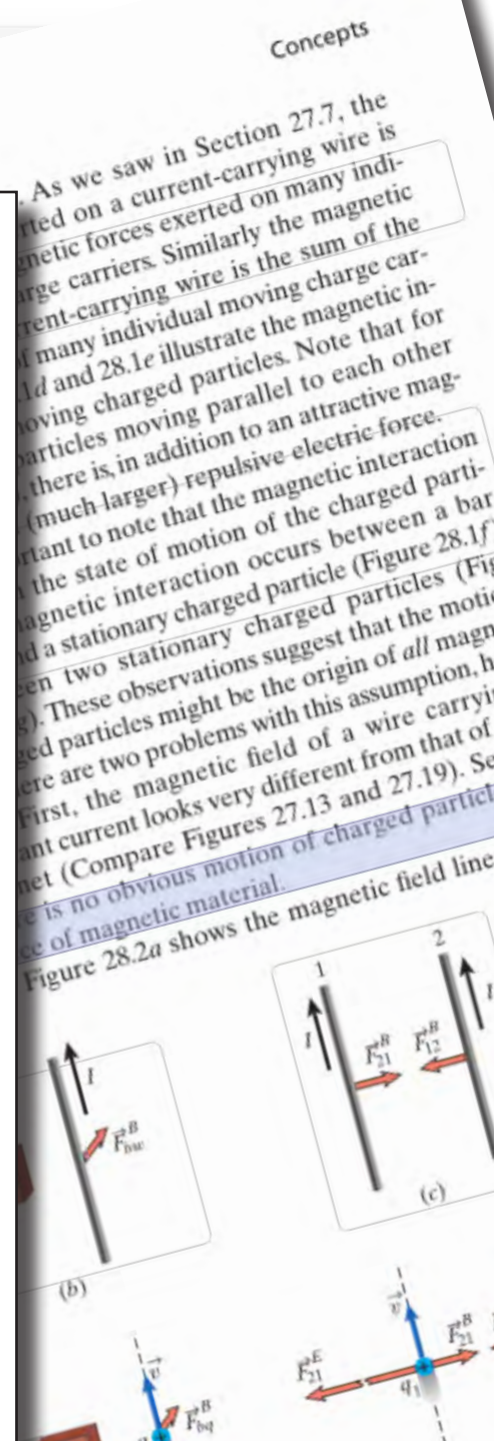
- 2 = Demonstrates thorough and thoughtful reading AND insightful interpretation of the chapter
- 1 = Demonstrates reading, but no (or only superficial) interpretation of the chapter
- 0 = Does not demonstrate any thoughtful reading of the chapter

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.

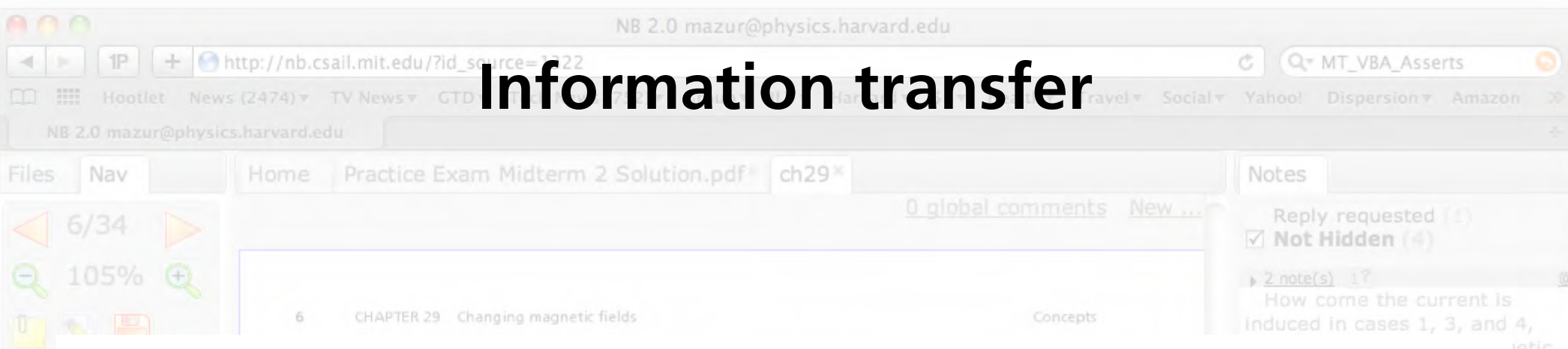


# Information transfer

## 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

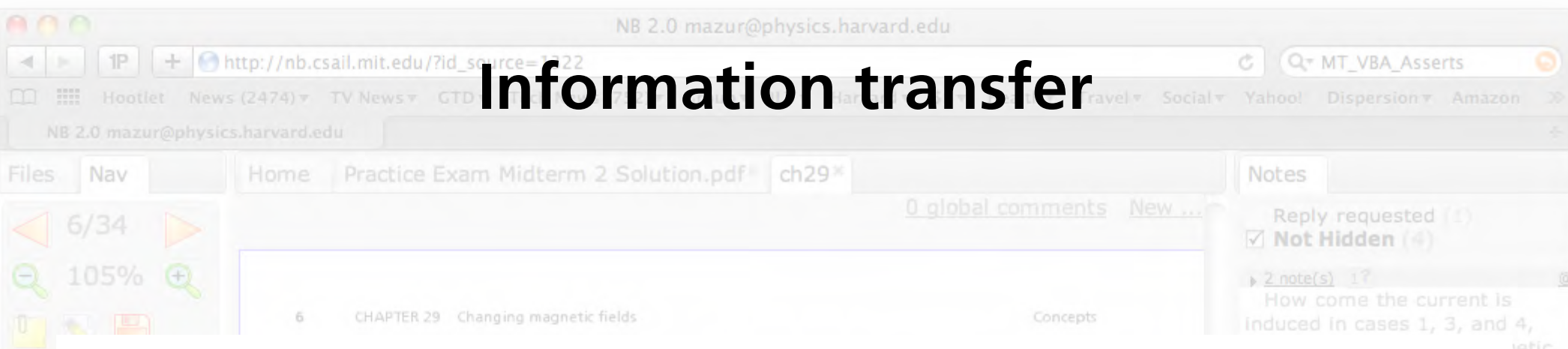
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The potential difference that develops between the ends of the rod shown in Figure 29.10 is the same as that which would develop if the magnetic field were stationary and the rod were moving to the right (recall Figure 29.1). Any relative motion of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

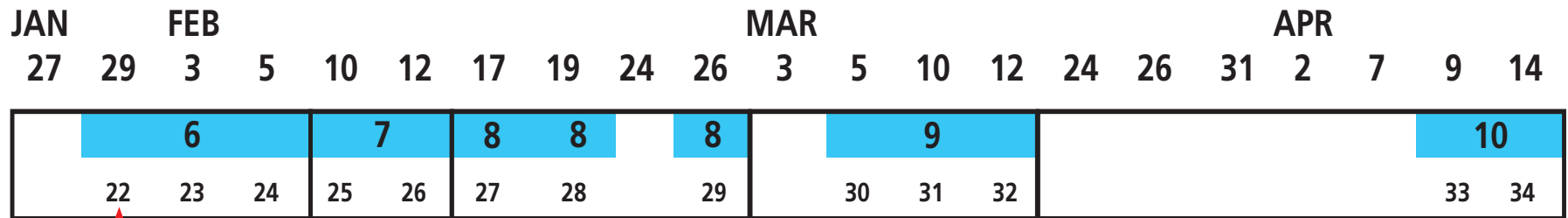
*A changing magnetic field is accompanied by an electric field.*

**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

# Information transfer



READING  
SCHEDULE



sections 27.4 and 27.8 optional

chapter deadline

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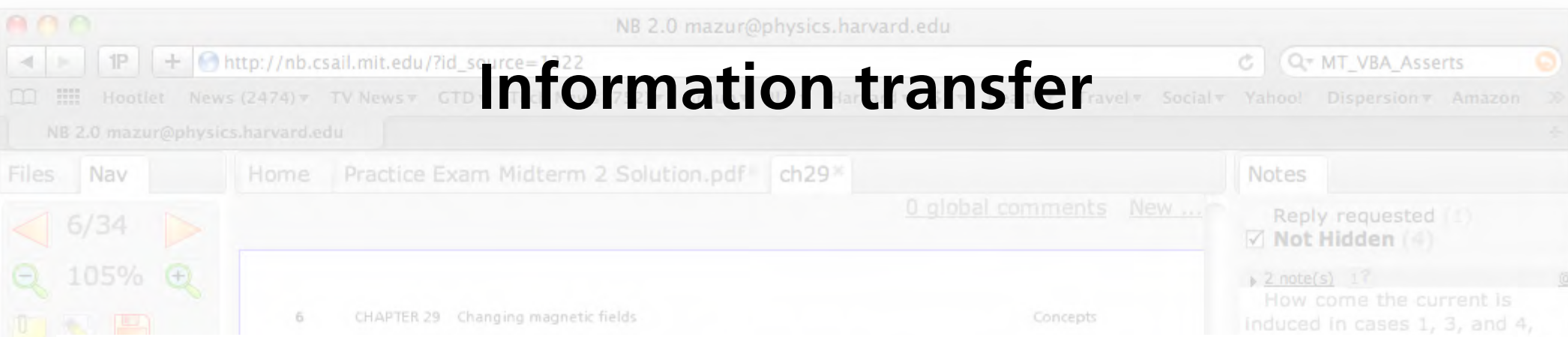


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1 design

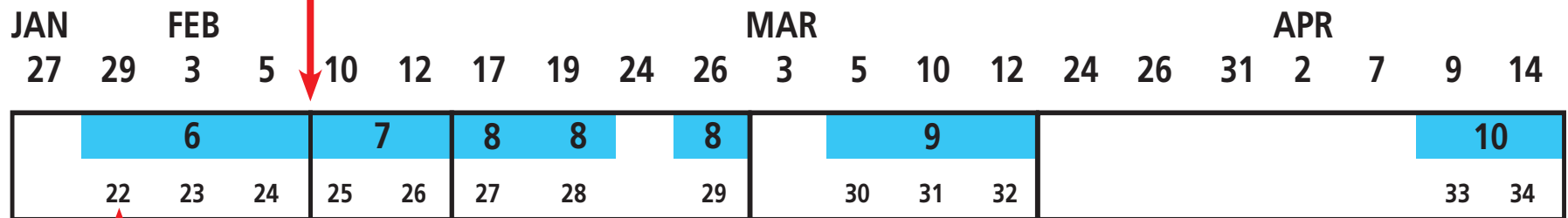
2 approach

# Information transfer



## unit deadline

READING SCHEDULE



sections 27.4 and 27.8 optional

## chapter deadline

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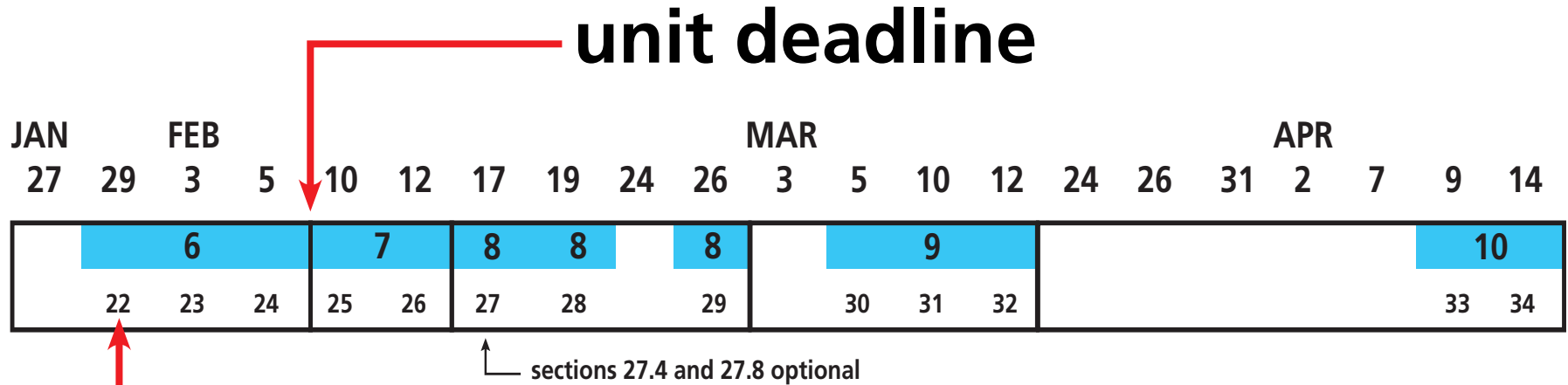
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1 design

2 approach

# Information transfer

READING  
SCHEDULE



three extra days for answers to questions

1 design

2 approach

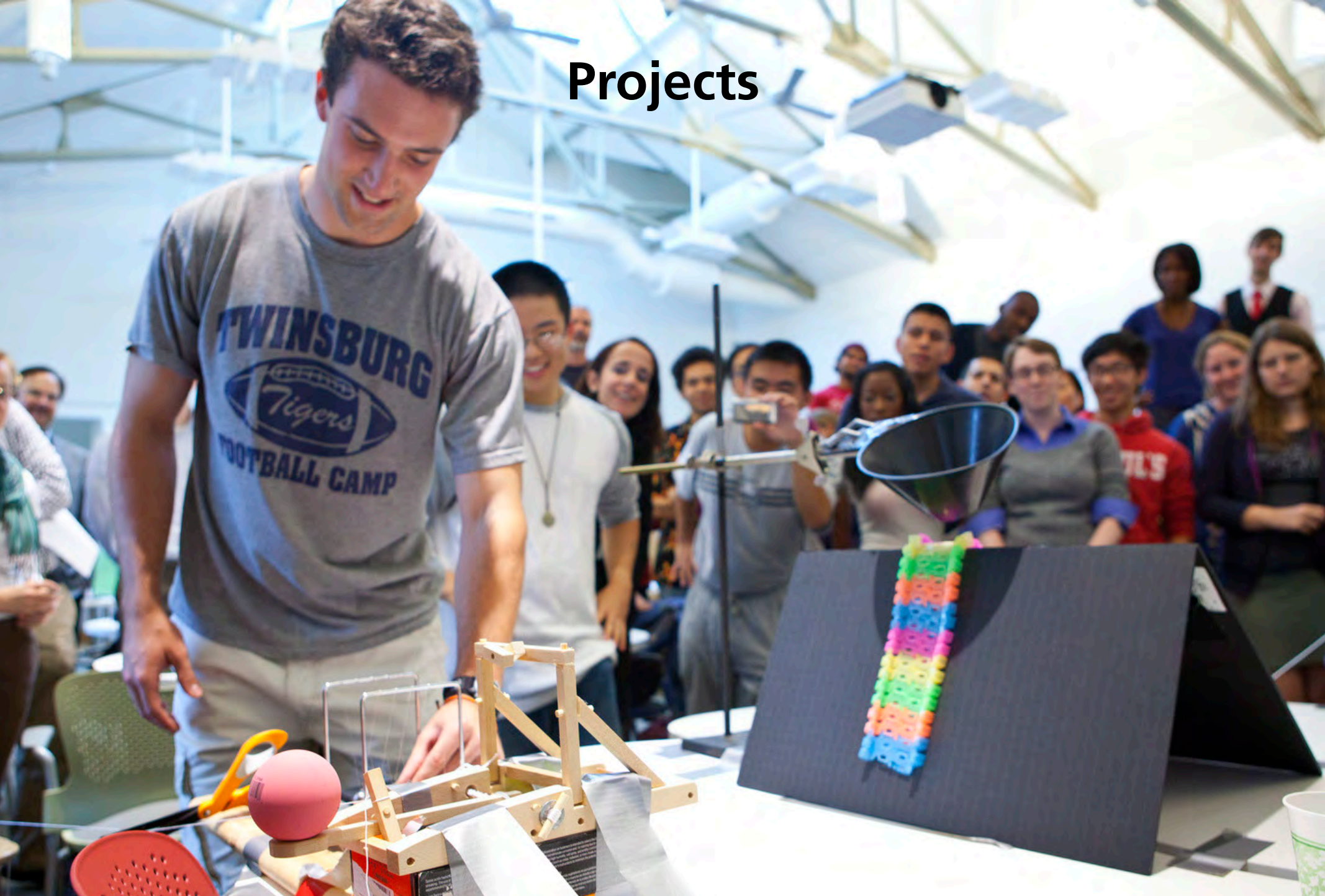
# Information transfer

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

**To be successful, the projects must**

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

# Projects

---

**Fall**

**Rube Goldberg**

**Mission to Mars**

**Symphosium**

---

**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

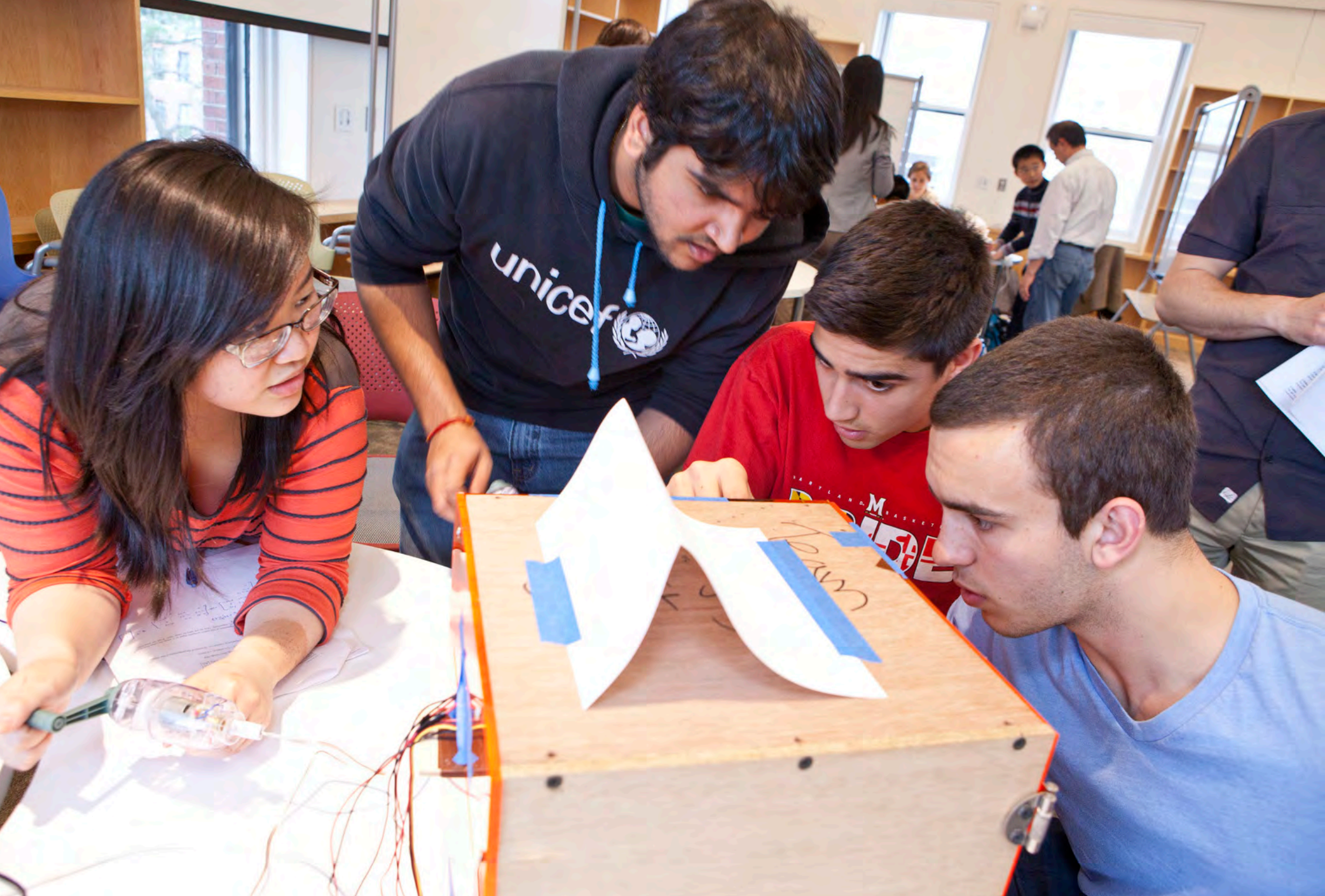
## Milestones:

- **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 wooden table in a classroom, working on a project. A young man in a black hoodie with 'unicef' written on it is leaning over the table, looking at a white paper structure. A young woman with glasses and a red and orange striped shirt is using a soldering iron on a circuit board. Another young man in a red shirt is looking at the project, and a young man in a blue shirt is looking at the camera. The background shows other students and a whiteboard.

**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

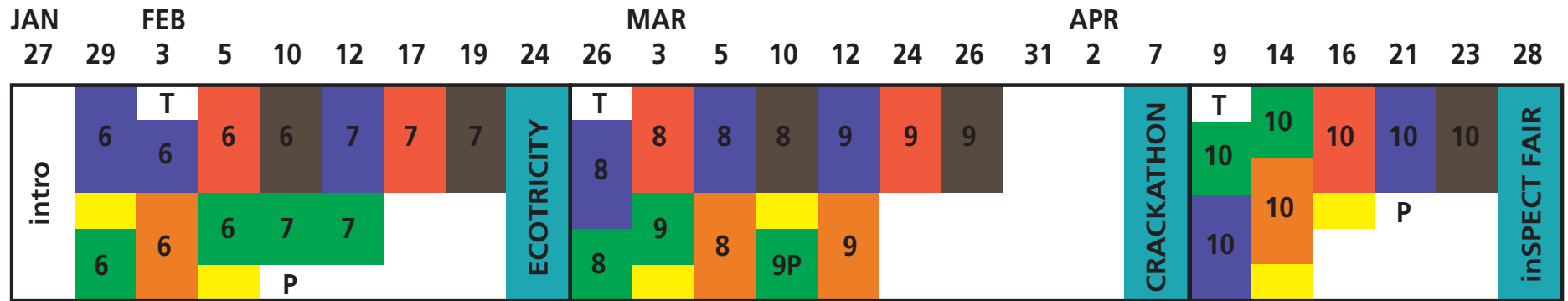


bring device

1 design

2 approach

# In-class activities

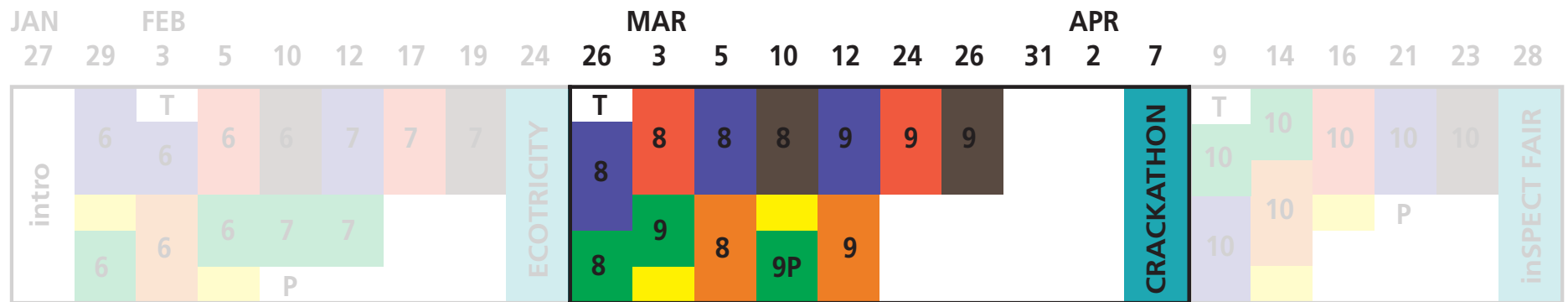


1 design

2 approach

# In-class activities

## one project

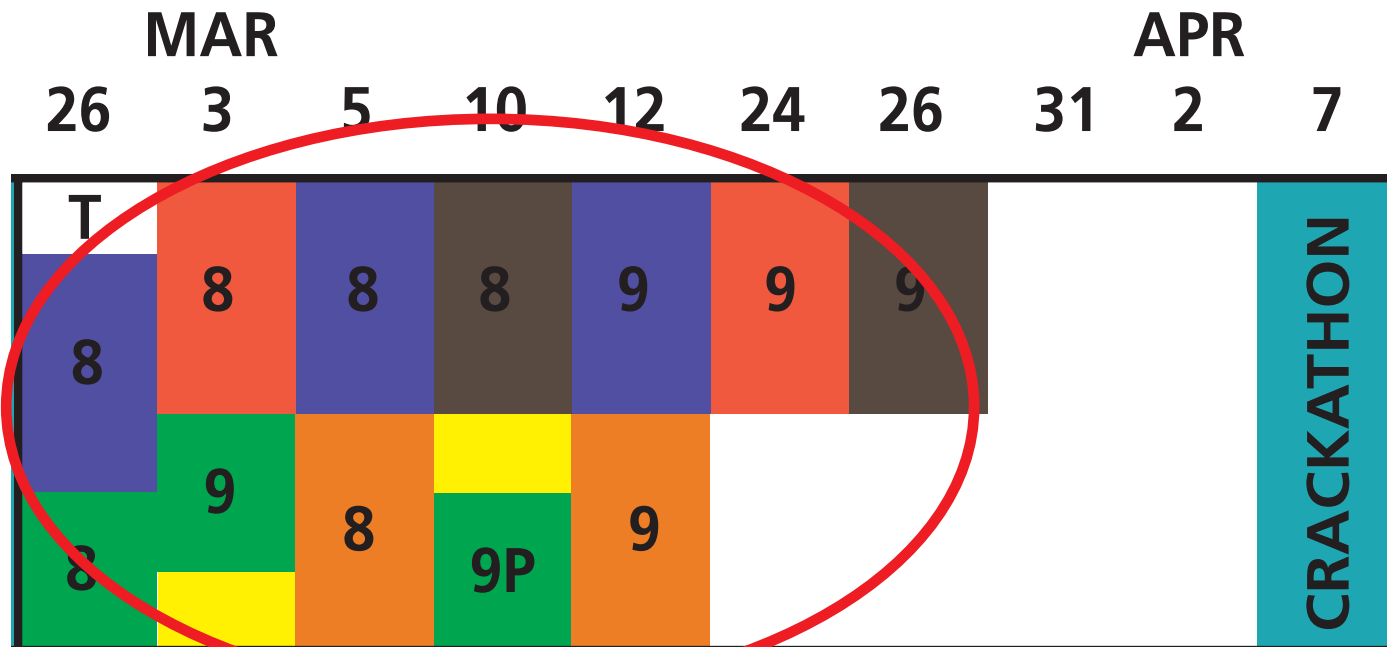


1 design

2 approach

# In-class activities

2/3 scaffolded, guided

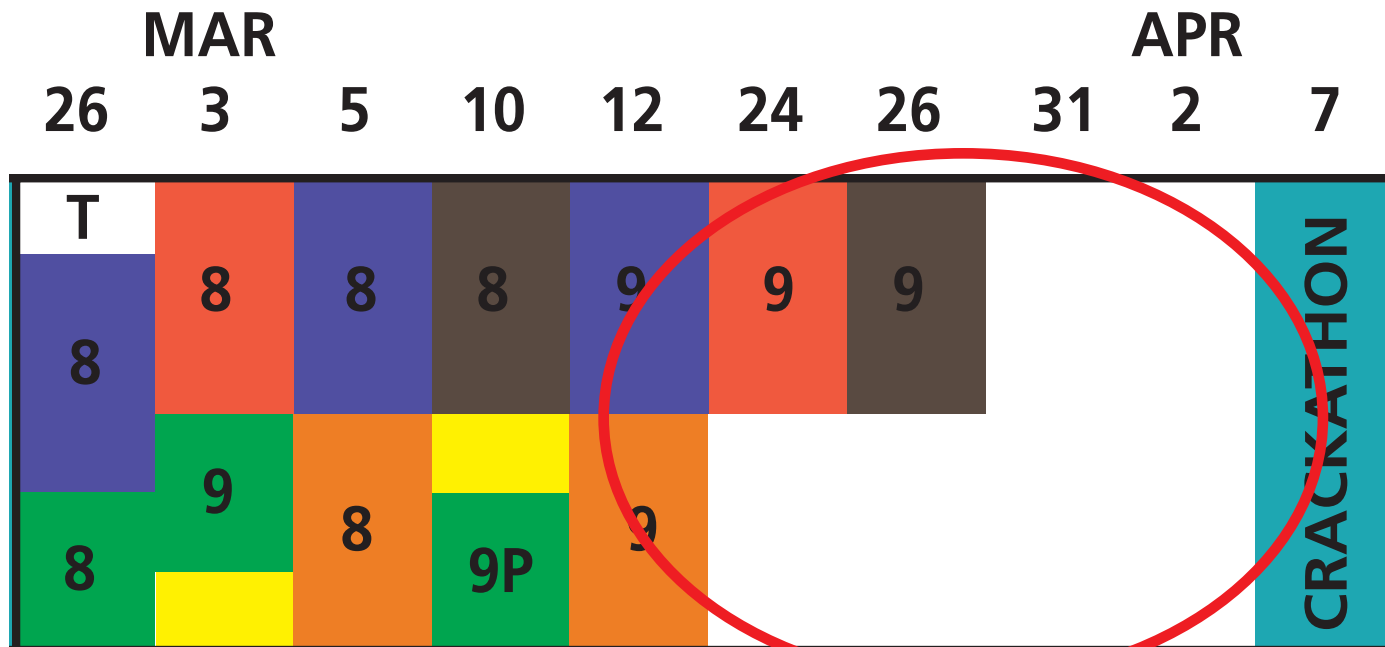


1 design

2 approach



# In-class activities



1/3 unguided

1 design

2 approach

# In-class activities

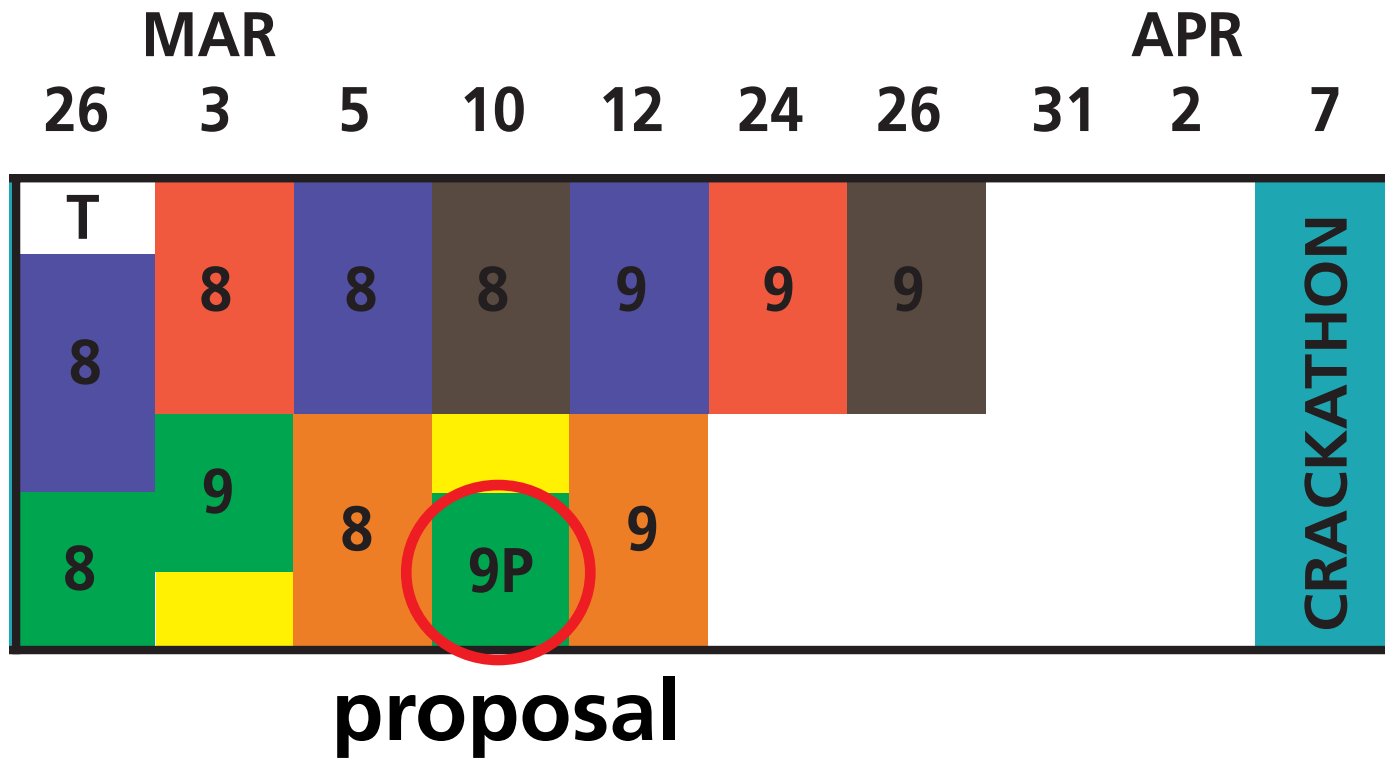
## team intro



1 design

2 approach

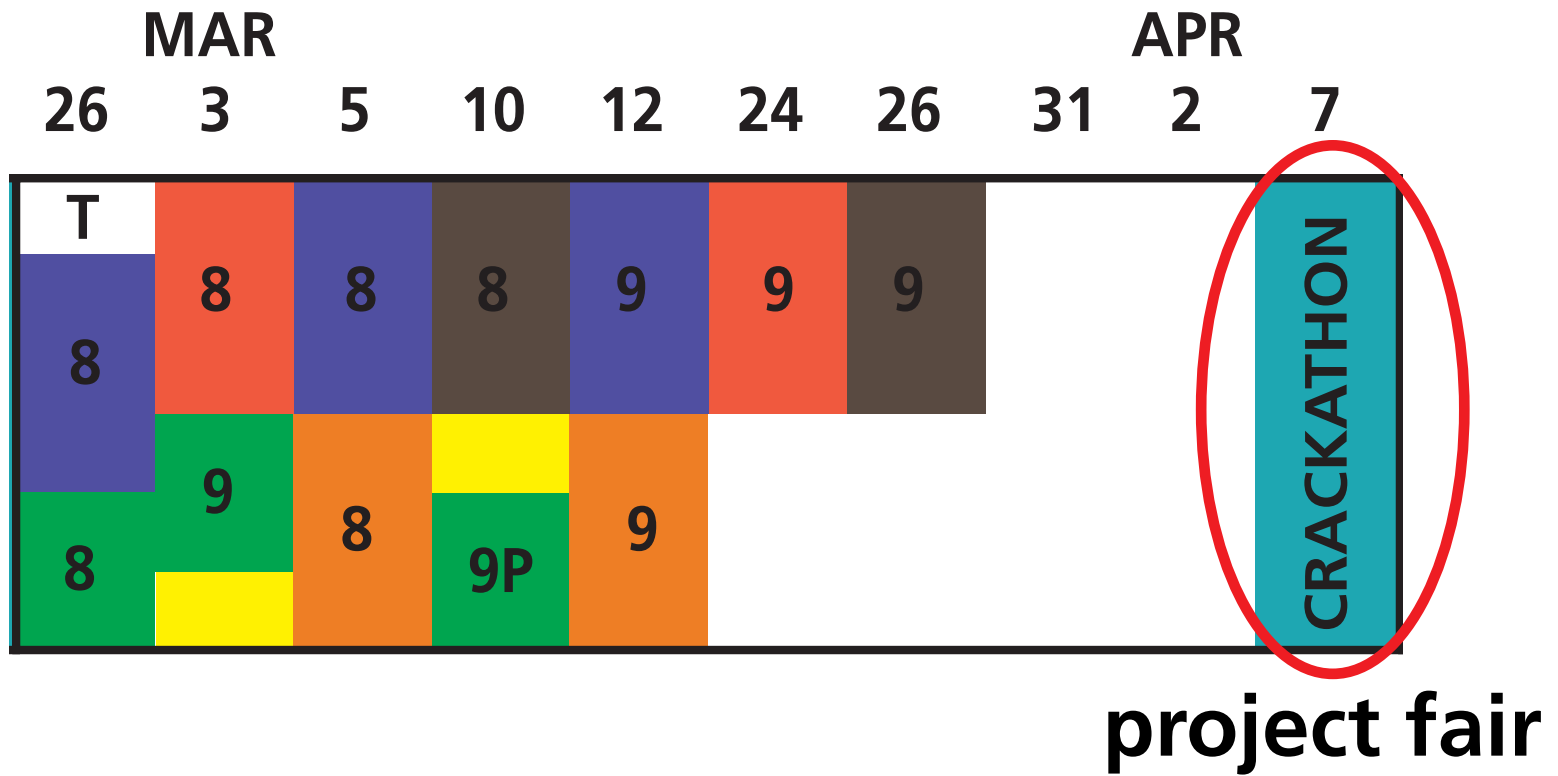
# In-class activities



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



bring device

Tutorial

60 min

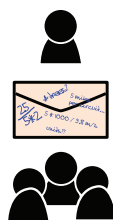


Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity

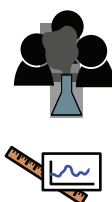
30 min



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



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

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
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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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Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
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Carry out simulations



evaluate

Problem Set & Reflection 90 min



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# In-class activities

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Answer again



Tutorial 60 min



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apply

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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  
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



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AP50b Fall 2013

## Problem Set 1

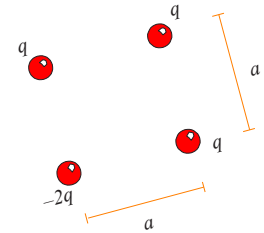
due W Feb 6 in class

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  $\rho$ . They are electrically neutral, free of other external forces, and levitationally. Now suppose that both particles are made of  $n$  that would prevent them from being neutral.

AP50b Fall 2013

## Problem Set 1

due W Feb 6 in class

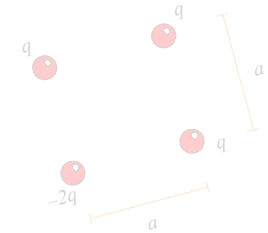
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- use a pen or pencil
- no-dog ears or tabs
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- no staples
- name on each page
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- leave margins

# goal: develop problem solving and metacognitive skills

- 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. Estimate the number of atoms present in a droplet of ink.
- 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?

- 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 masses are vastly different. To illustrate this, consider the following spherical dust grains,  $50 \mu\text{m}$  in diameter, with mass density  $\rho = 2000 \text{ kg/m}^3$ . The grains are electrically neutral, free of other external forces, and are held together by their own gravitational attraction. Now suppose that both grains are made of a material with a positive charge density  $\rho_c$  that would prevent them from touching.

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 in. paper
- no-dog ears or torn corners
- dark ink (no light pencils)
- no staples
- one problem per page
- single-sided writing (no back)
- leave margins blank

**phase**

**goal**

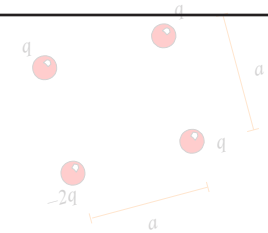
**solve (at home/individual)**

**skills development**

**reflect (in class/team)**

**metacognition**

2. **Levitation.** In an inkjet printer, letters are formed by spraying drops of ink at a piece of paper. 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 two parallel deflection plates that are fixed on a vertical pole 0.5 m apart. The lower plate is grounded. The upper plate is a uniform vertical electric field (see Chapter 23). Estimate the number of atoms in a 100- $\mu\text{m}$ -diameter 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 understand the solutions together with a team score. This is the only way to ensure that the team score is accurate.

**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 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.

**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 for help.

**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**

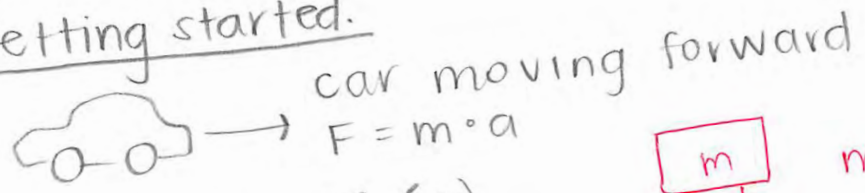
**2 approach**



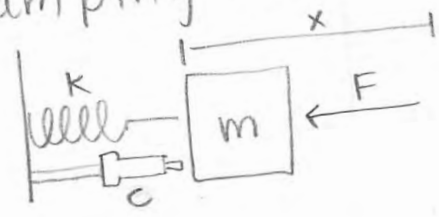
Applied Physics 50a

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

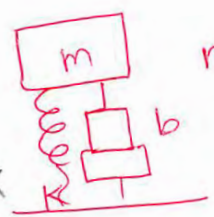
Getting started.



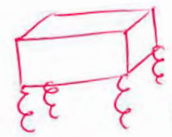
Damping coeff (c)



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



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



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

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.

$F = m \cdot a$

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

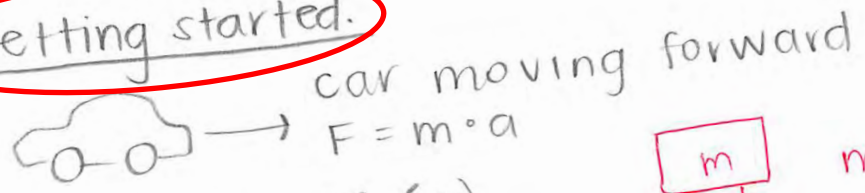
- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s

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

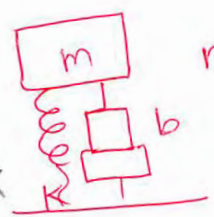
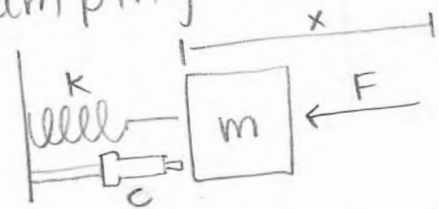
Applied Physics 50a

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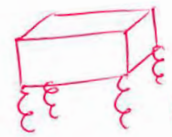
Getting started.



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
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Execute plan.

$$F = m \cdot a$$

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

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

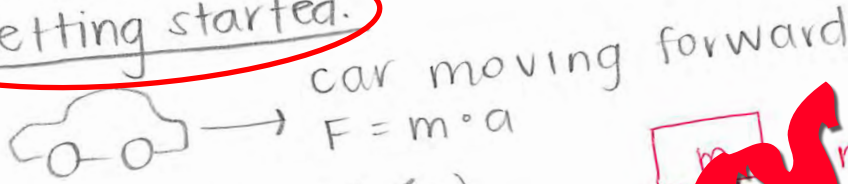
Translational eq =  $\sum F_x = 0$

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

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

$F_{sc}^c$   $\Sigma F_x = F_{Ec}^G - F_{sc}^c = \Delta mg - k(x_{eq} - x_0)$   
 $F_{Ec}^G$  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 15 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 unacceptable.

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. 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 unacceptable.

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

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

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

•  $f = \frac{1}{T} = \frac{1}{4} \text{ cycles/second} = \text{frequency}$

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

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

$k = \text{wave \#}$   
 $c = \text{wave speed}$   
 $A = \text{amplitude}$

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

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

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

$= \frac{200}{4} = 50$

(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.

## 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). I also feel like I now understand how decibels are calculated - before, I didn't know they were exponential! I know what the concept is, but I don't know how to use it.

**phase**

**credit**

**solve (at home/individual)**

**50%**


**reflect (in class/team)**

**50%**

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

I definitely need to review torque! I had a hard time with that concept for #3 and I'll probably need to go back to my notes 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

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Answer again



Tutorial 60 min



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Open book, open internet  
Part 2: solve with team





**1** design

**2** approach



**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  $f(x) = 3x^2 - 6x$ ?

Submit response

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;

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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  $\ln y - \sin x$



$6x - 6$

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

A background image of a classroom. On the left, a student in a dark shirt stands by a whiteboard with a circuit diagram and equations. In the center, a student in a white shirt has their back to the camera. On the right, a student in a blue hoodie points towards the whiteboard. In the background, another student is seated at a desk with a laptop. The scene is overlaid with a semi-transparent blue filter.

---

**round**

**credit**

---

**individual**

**50%**

**team**

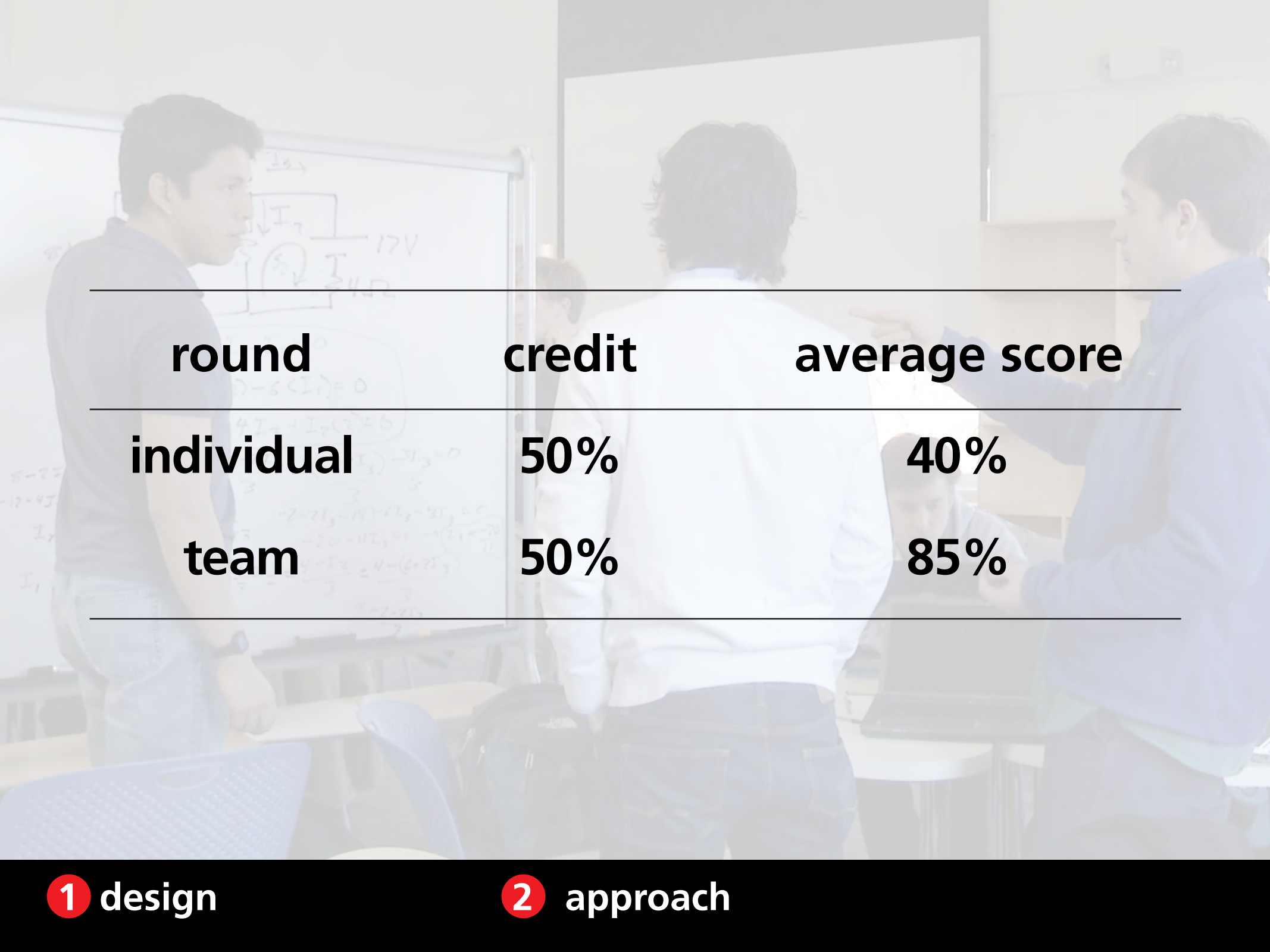
---

**50%**

---

**1** design

**2** approach



---

**round**

**credit**

**average score**

---

**individual**

**50%**

**40%**

**team**

**50%**

**85%**

---

**1 design**

**2 approach**

# Assessment

self-directed learning

learning goals

team work

professionalism

# Assessment

Scale: 3-0

self-directed learning

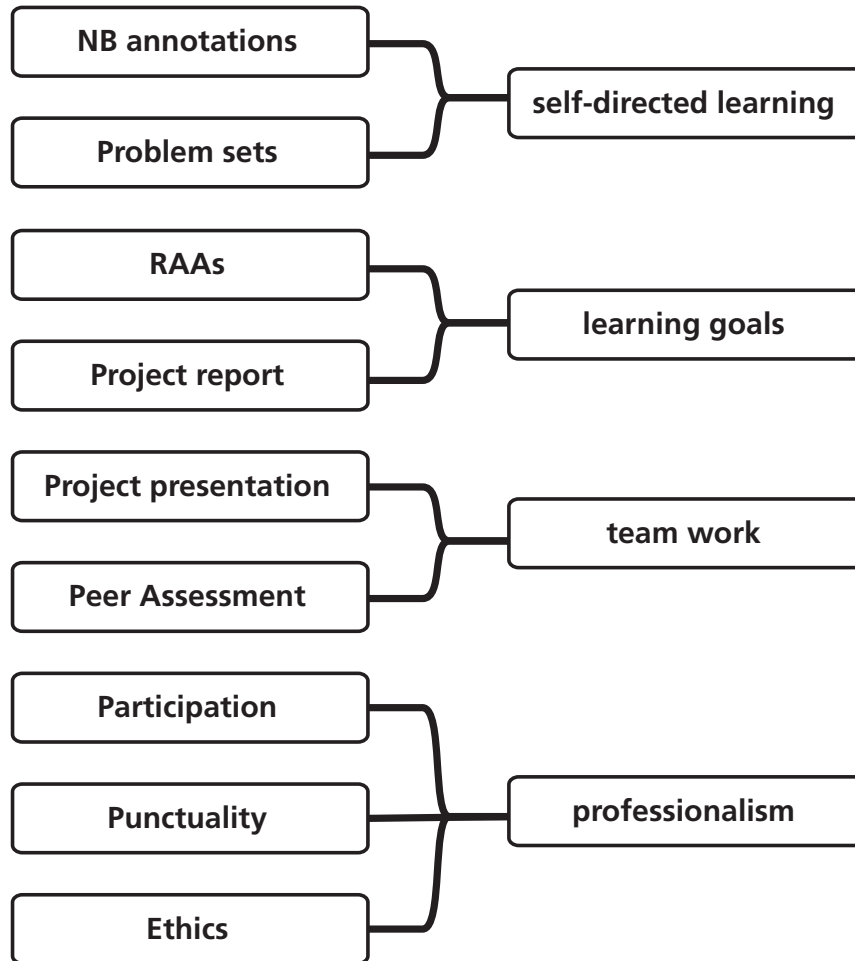
learning goals

team work

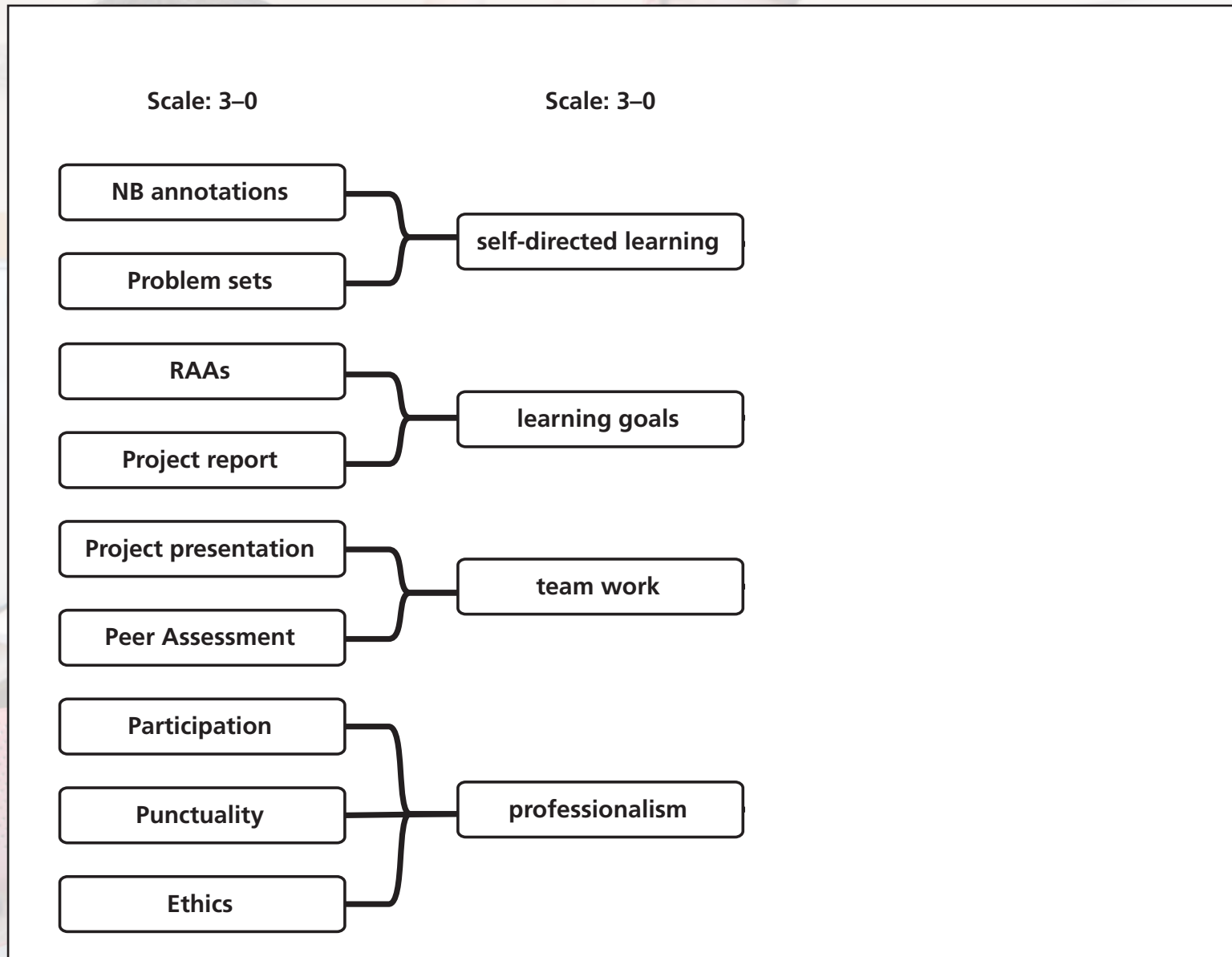
professionalism

# Assessment

Scale: 3-0

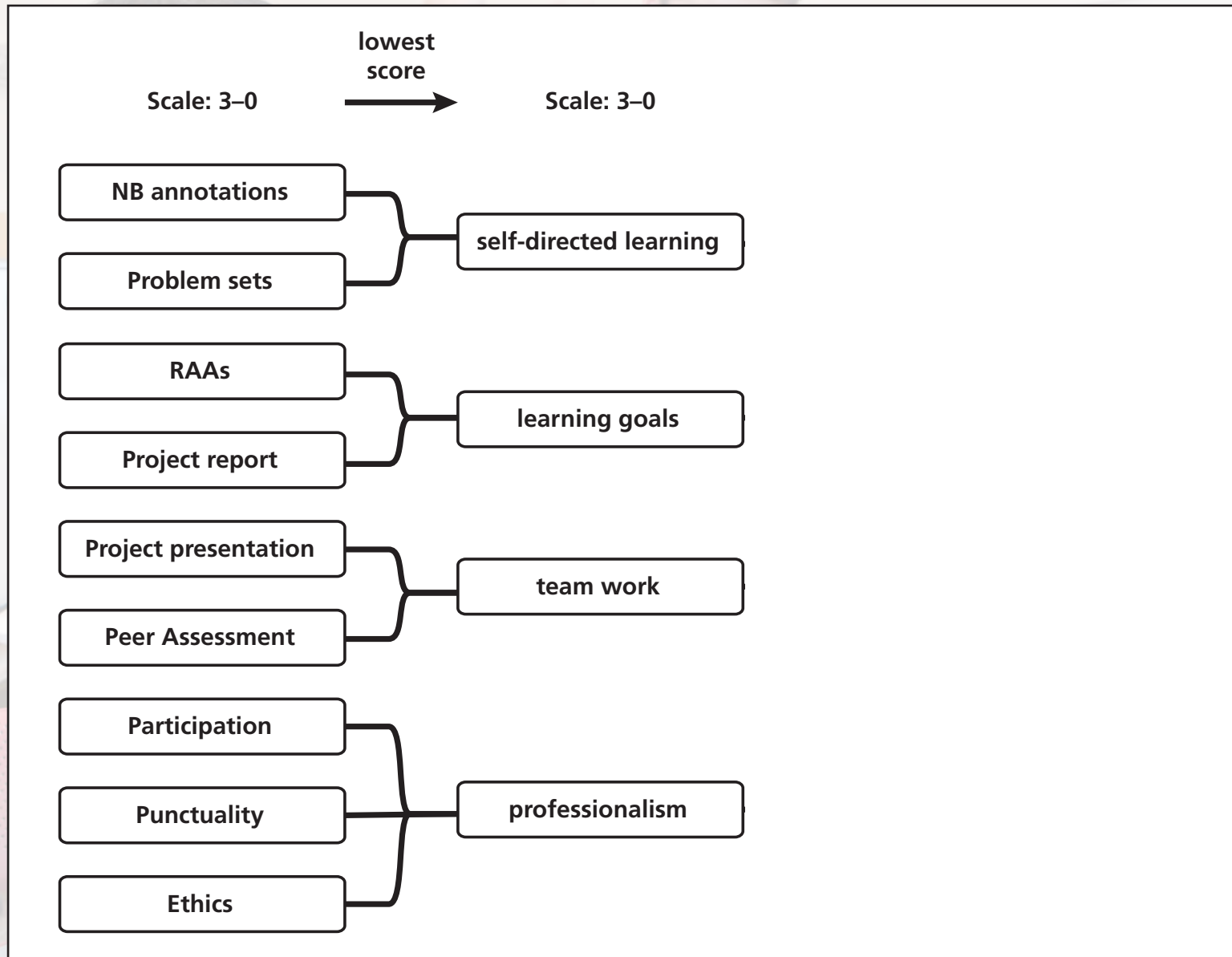


# Assessment

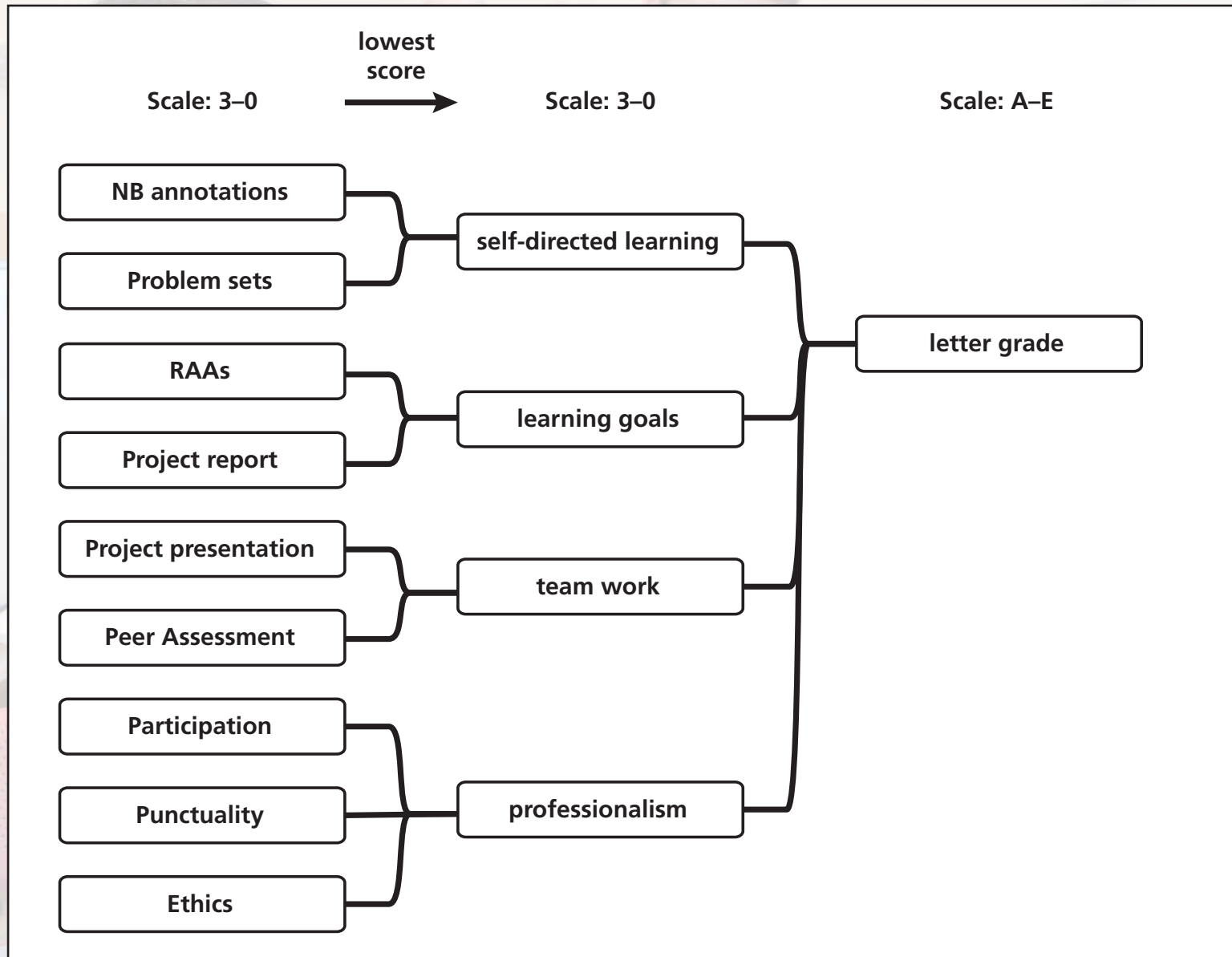




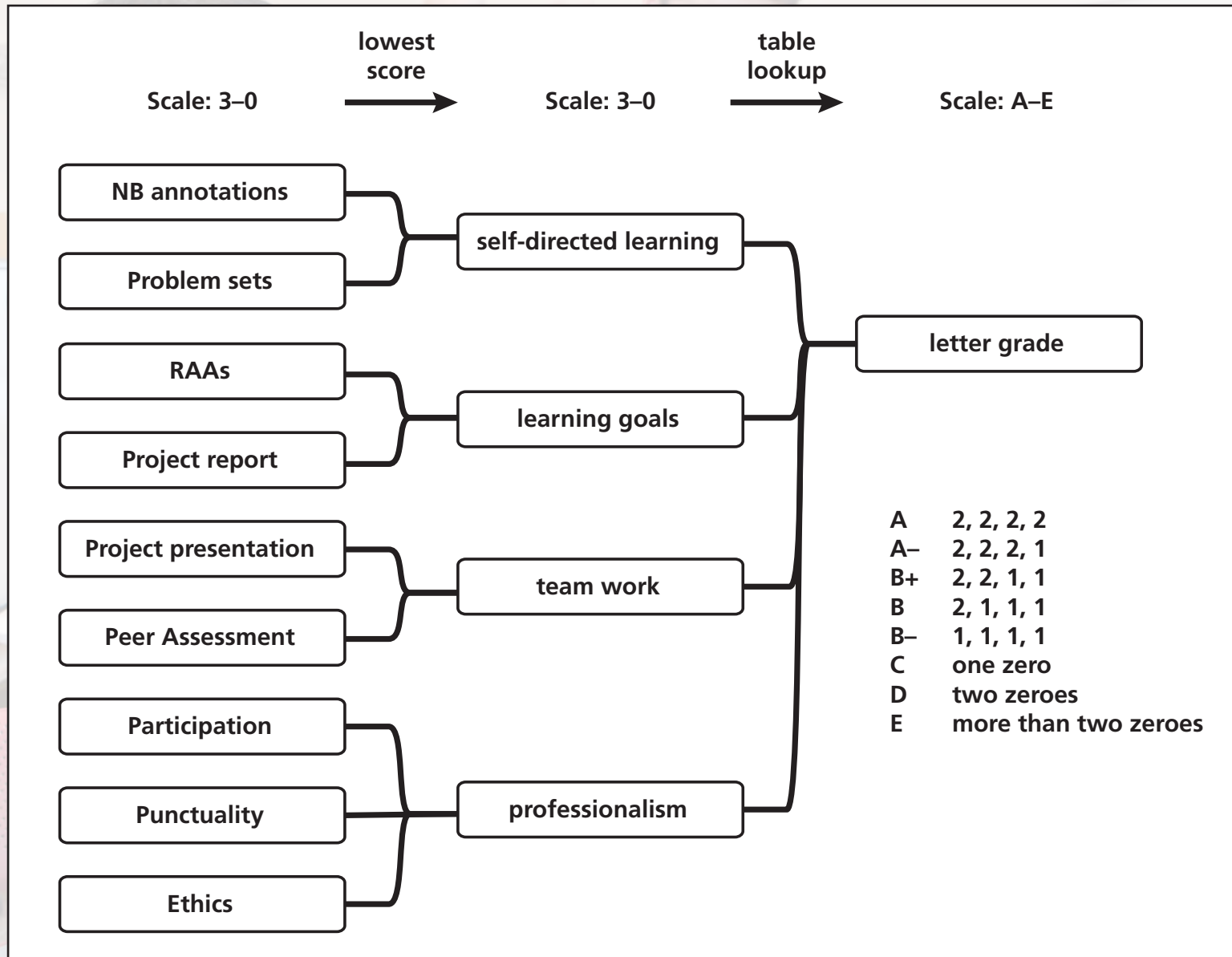
# Assessment



# 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

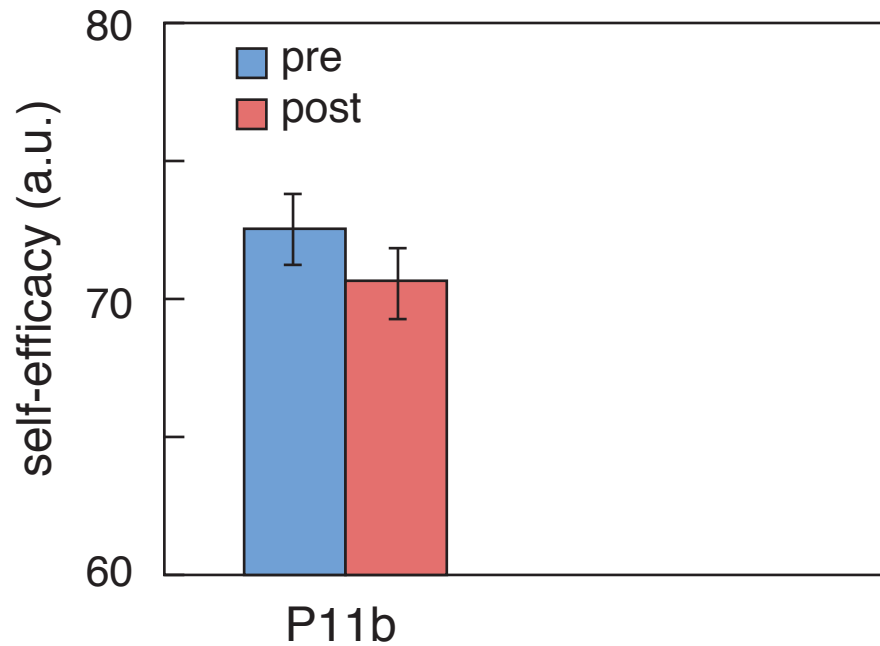
(students' belief in their ability to succeed)

1 design

2 approach

3 results

# Self-efficacy

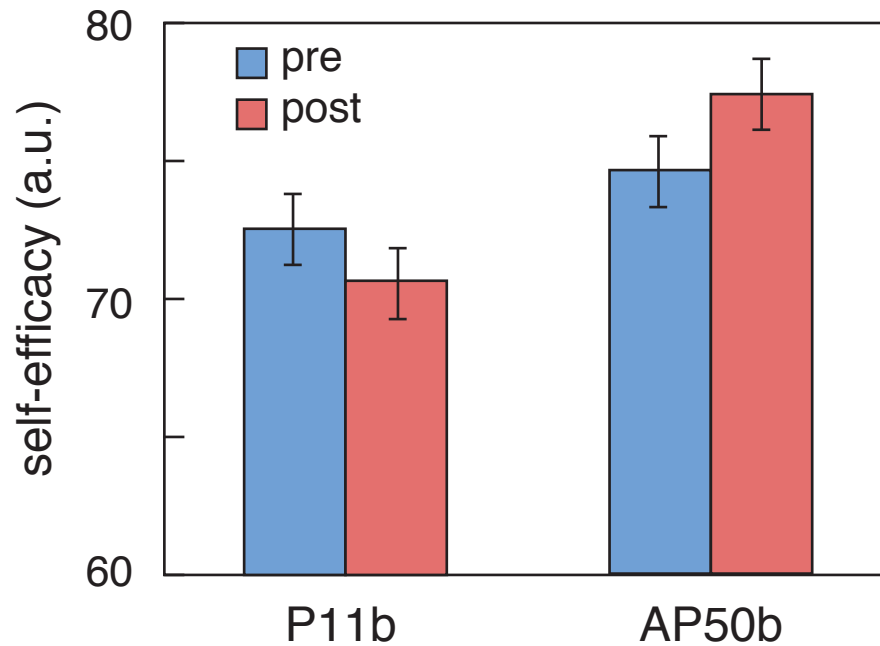


1 design

2 approach

3 results

# Self-efficacy



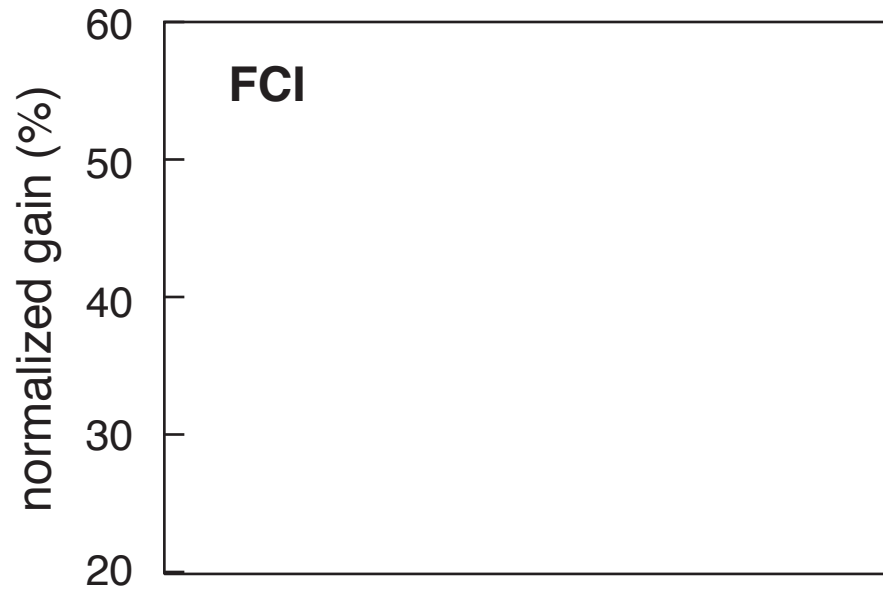
1 design

2 approach

3 results



# Conceptual Mastery

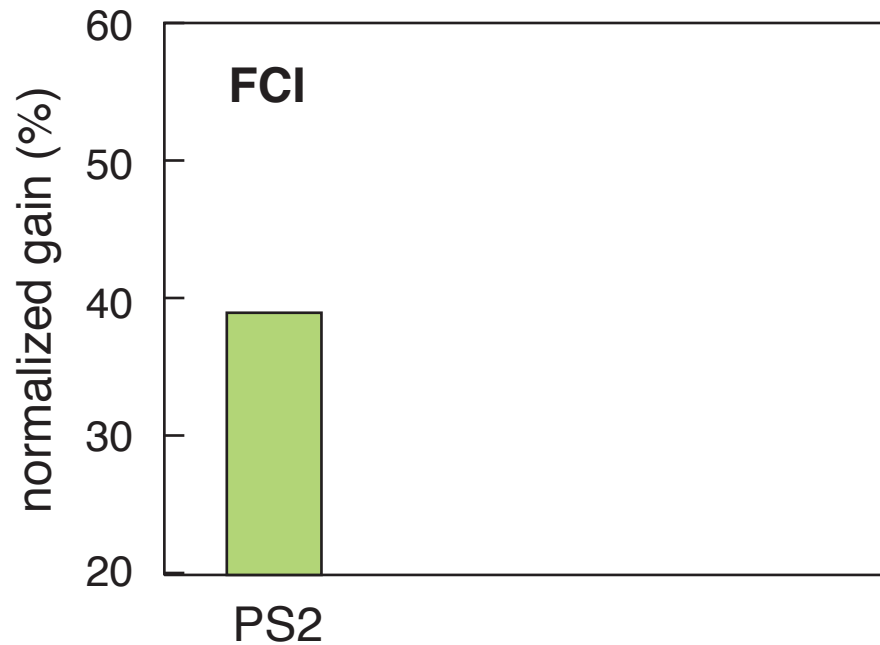


1 design

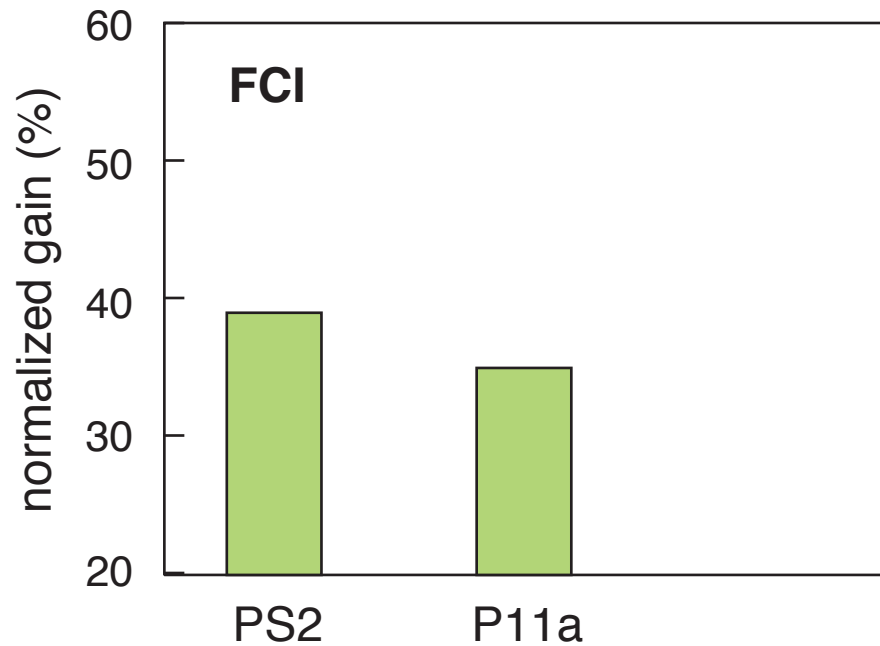
2 approach

3 results

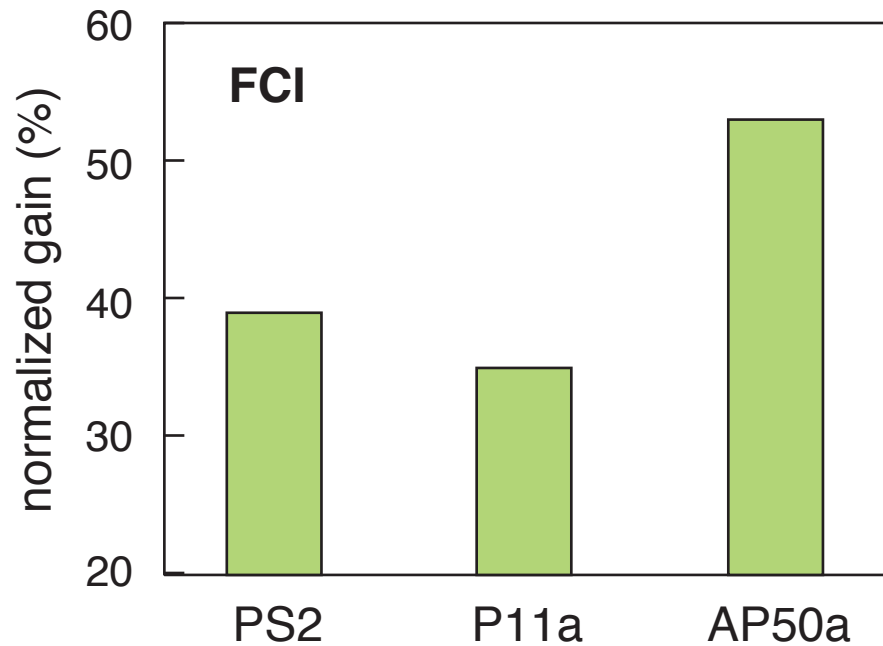
# Conceptual Mastery



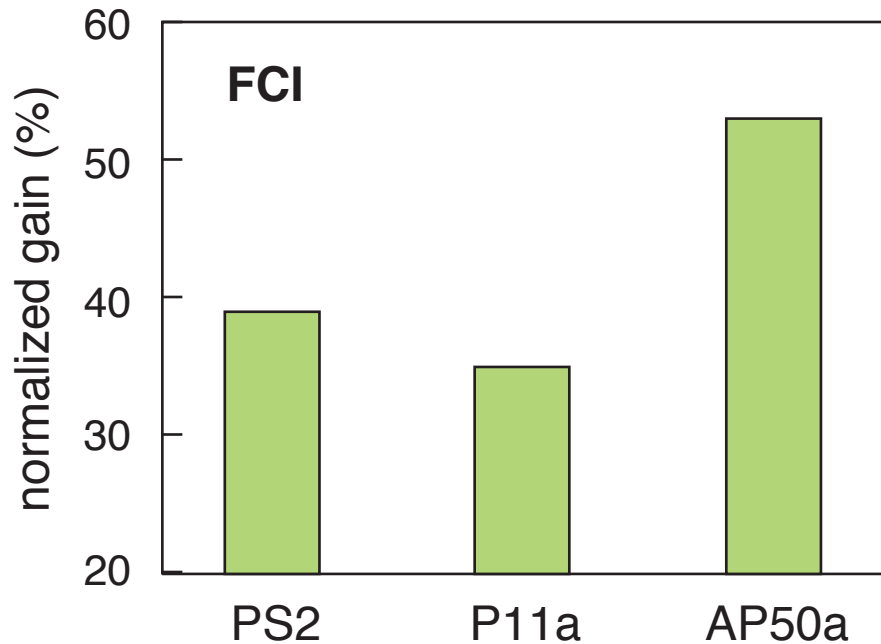
# Conceptual Mastery



# Conceptual Mastery



# Conceptual Mastery



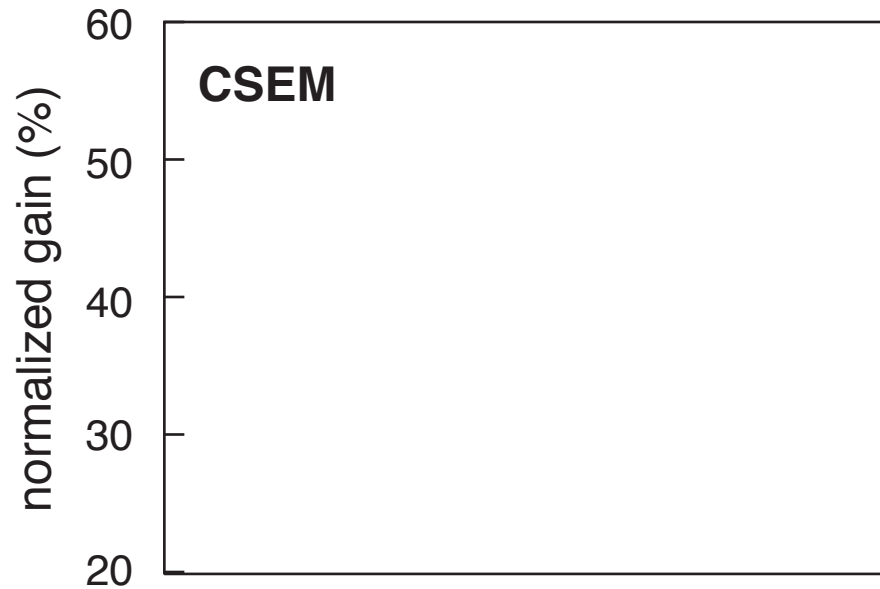
**largest conceptual gain in *any* course past 6 yrs!**

**1** design

**2** approach

**3** results

# Conceptual Mastery

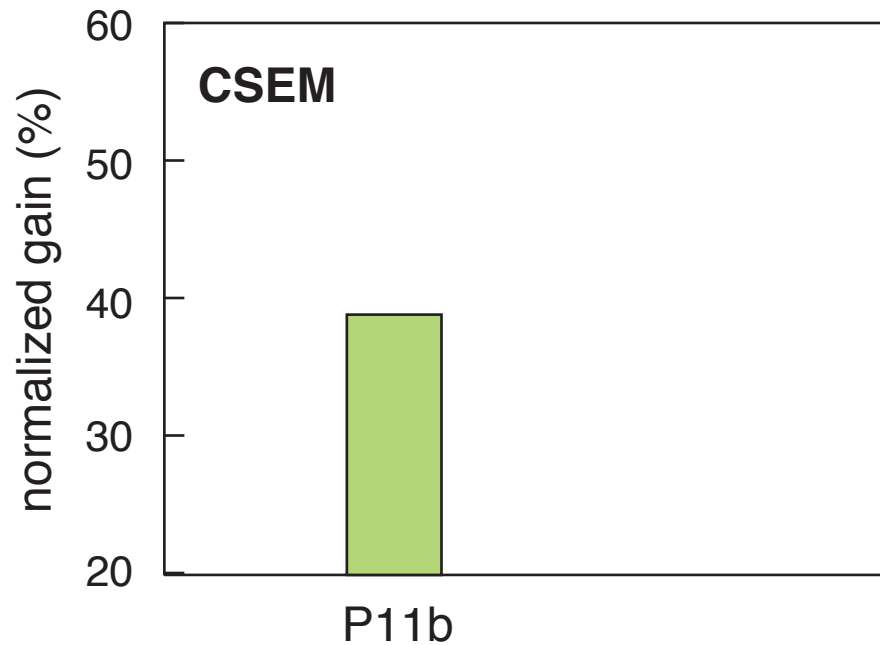


1 design

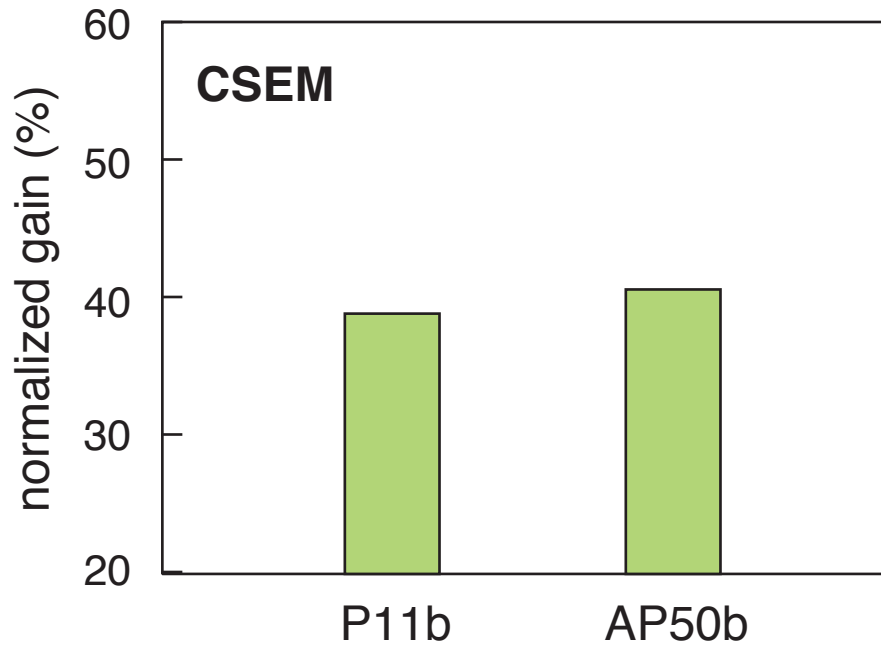
2 approach

3 results

# Conceptual Mastery

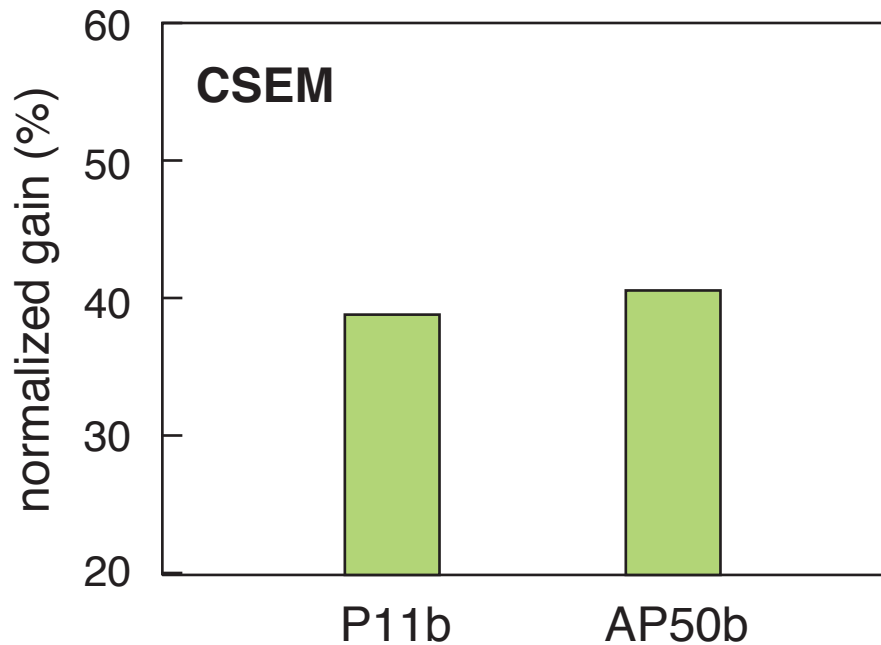


# Conceptual Mastery





# Conceptual Mastery



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

**1 design**

**2 approach**

**3 results**



**1** design

**2** approach

**3** results



**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

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**1** design

**2** approach

**3** results

# 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

Assessment of You	Average Peer Assessment	Self Assessment
You	4.67	4
1. Participate fully in team activities	4.67	4
2. Come to class well-prepared for all team activities	4.83	4
3. Communicate effectively and respectfully 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>	4.83	5
4. Attendance: <ul style="list-style-type: none"> <li>You are present for team activities</li> <li>On time/punctual</li> </ul>	4.83	4
5. Take responsibility for your own part of team work and decision-making	4.67	4
6. Are open to change and willing to re-evaluate your own position in light of new information from others	4.67	4

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

helping make your team more effective in the following ways (the quotes

# Team, Peer, and Self assessment

- You were great to work with and a true team player!
- Your ideas were a great contribution to our team
- You come up with good ideas
- You were really easy to work with and had a contagious enthusiasm

## Assessment Report

Assessment of You	Average Peer	Self Assessment
You	4.67	4
1. Participate fully in team activities	4.67	4
2. Come to class prepared for team activities	4.83	4
3. Communicate effectively and respectfully with team members	4.83	5
4. Attendance: • You are present for team activities • On time/punctual	4.83	4
5. Take responsibility for your own part of team work and decision-making	4.67	4
6. Are open to change 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

...being make your team more effective in the following ways (the quotes

# Team, Peer, and Self assessment

- You were great to work with and a true team player!
- Your ideas were a great contribution to our team
- You come up with good ideas
- You were really easy to work with and had a contagious enthusiasm

**“I felt as if I was able to effectively communicate my ideas, even though they may have been wrong... (still good for discussion, right?)”**

# Team, Peer, and Self assessment

- I would suggest being more responsive throughout the project process.
- Sometimes you're not engaged in activities
- It was hard to understand what you actually thought about an idea or project
- You could be more reasonable about what is actually feasible and what isn't

## Assessment Report

Assessment of You	Average Peer	Self Assessment
You	4.67	4
1. Participate fully in team activities	4.67	4
2. Come to class with prepared work	4.83	4
3. Express your opinion and with clarity	4.83	5
4. Listen respectfully to the perspectives of others	4.83	4
5. Take responsibility for your own work and decision-making	4.67	4
6. Are open to change 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