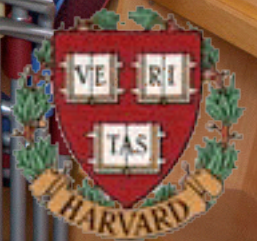


# Team Based Learning in Engineering Education



Universiteit Twente  
Enschede, Netherlands, 25 November 2015



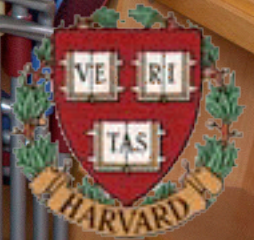


# Team Based Learning in Engineering Education

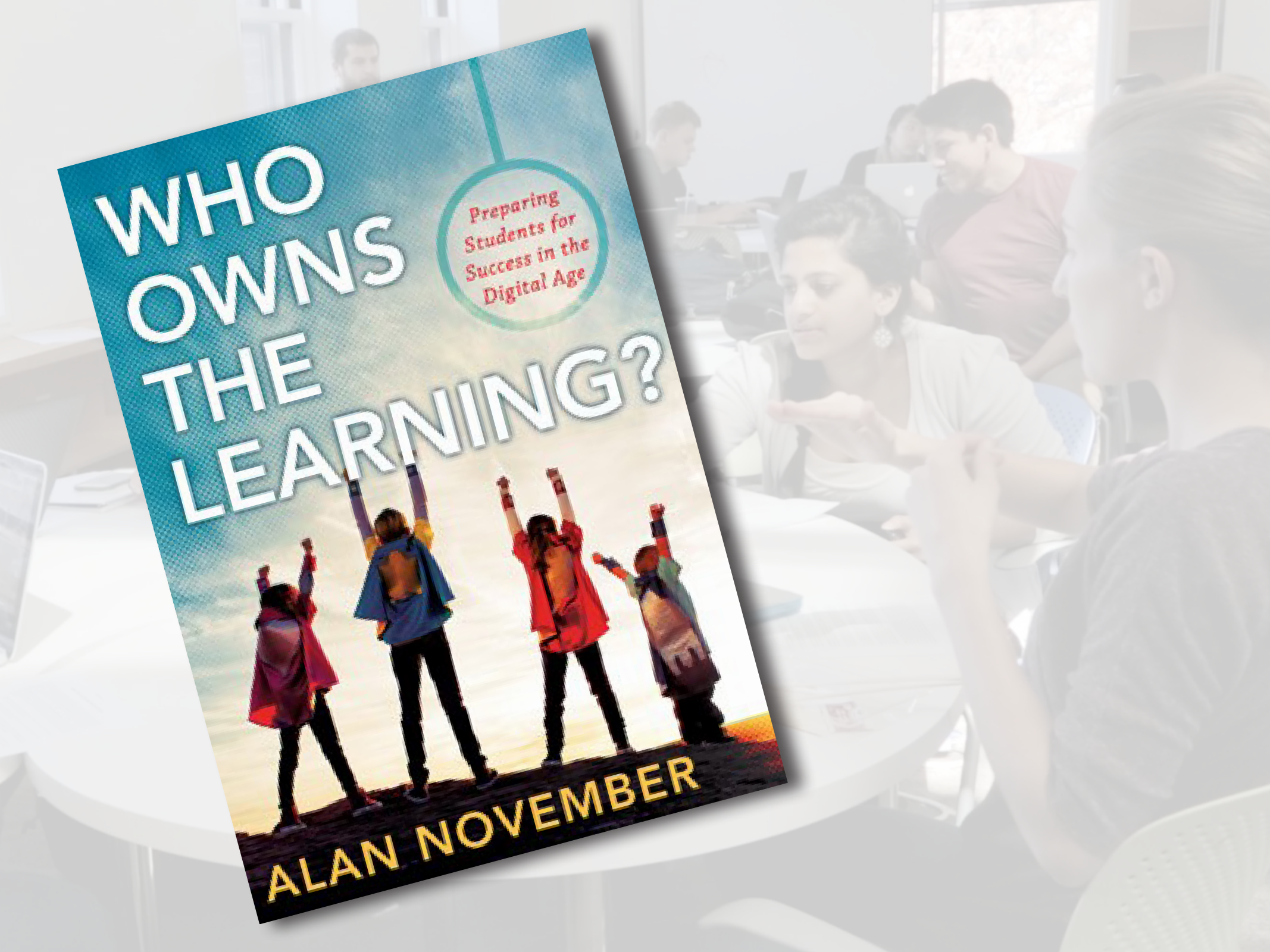
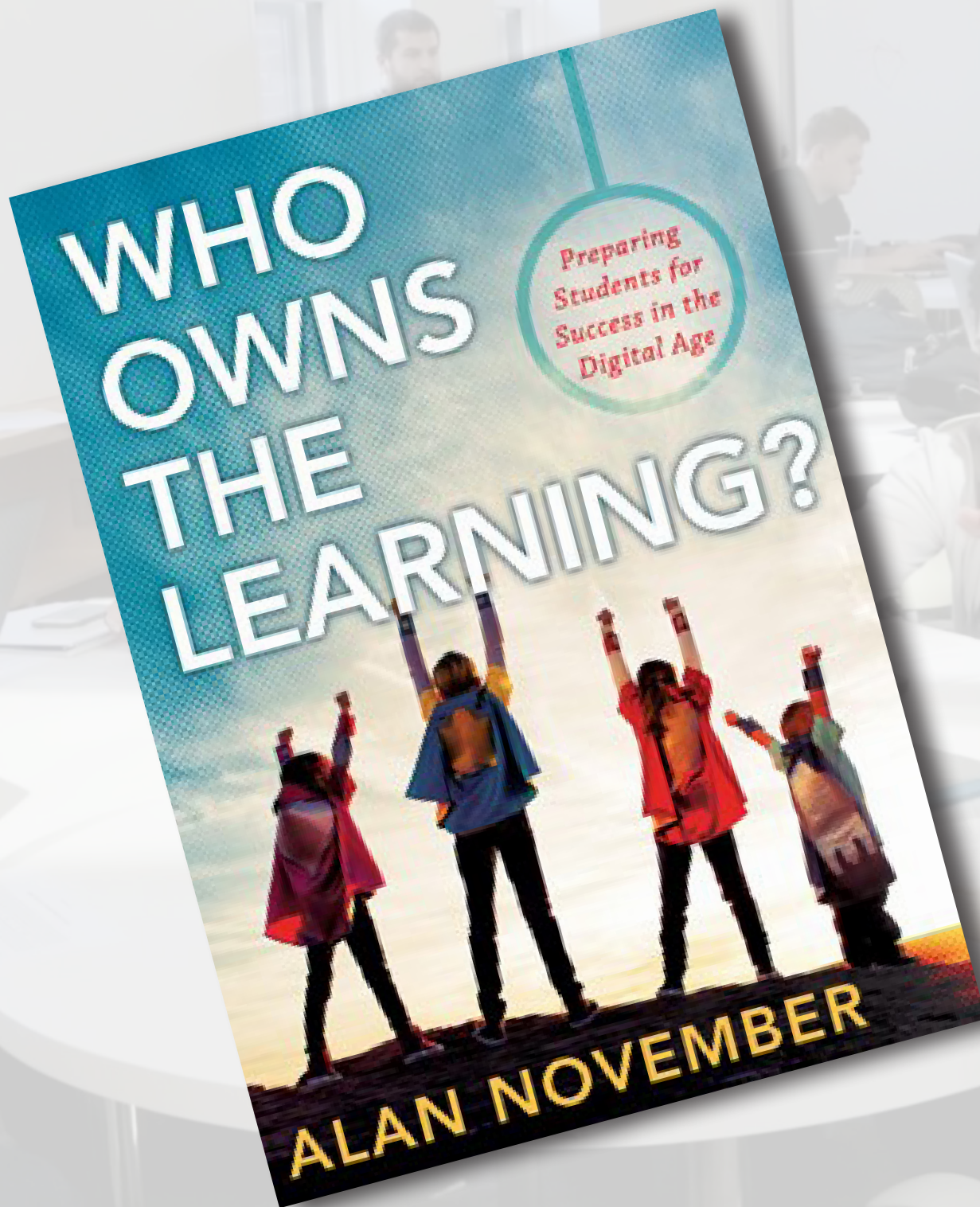


@eric\_mazur

Universiteit Twente  
Enschede, Netherlands, 25 November 2015





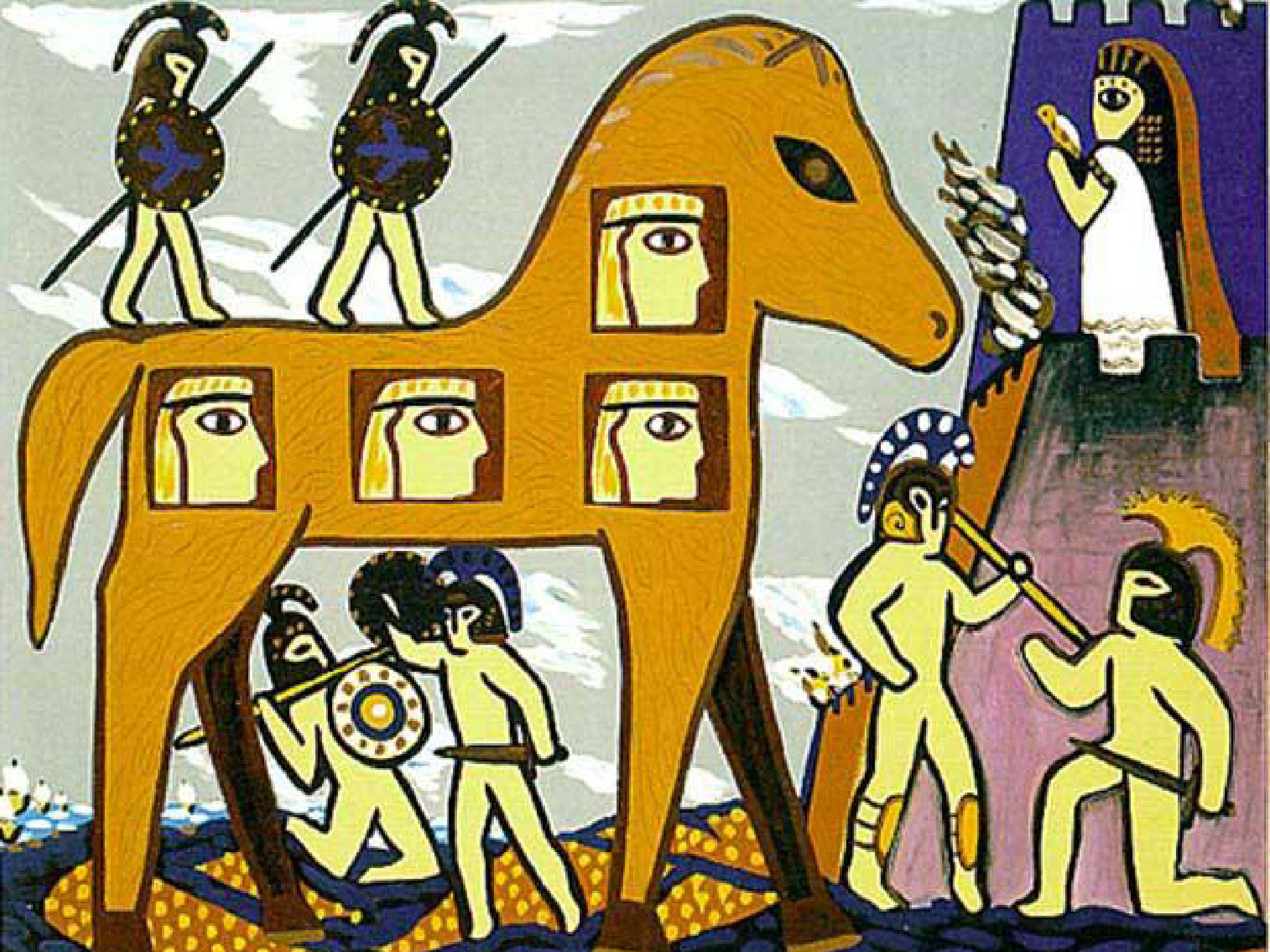




A group of students in a modern classroom setting, working on laptops and discussing physics. The students are seated around a white circular table, with laptops open in front of them. One student is pointing at a laptop screen, while others look on attentively. The background shows more students working at desks, suggesting a collaborative learning environment.

**Ownership of learning *physics*?**









**team & project-based approach**



A stylized illustration of a Trojan Horse, a large brown horse with a white mane and tail. The horse is decorated with several rectangular panels, each containing a different scene or figure. On the side of the horse, there are three panels showing a yellow face with a crown. Below these, there is a panel showing two yellow figures in a combat scene. On the back of the horse, there are two panels showing yellow figures with crowns and blue crosses on their chests. To the right of the horse, there is a panel showing a yellow figure in a white robe holding a staff. In the background, there are more yellow figures, some with crowns, and a purple structure that looks like a castle or a temple. The overall style is a mix of ancient Greek art and modern graphic design.

# ProTeam Learning









**1** design

**2** approach



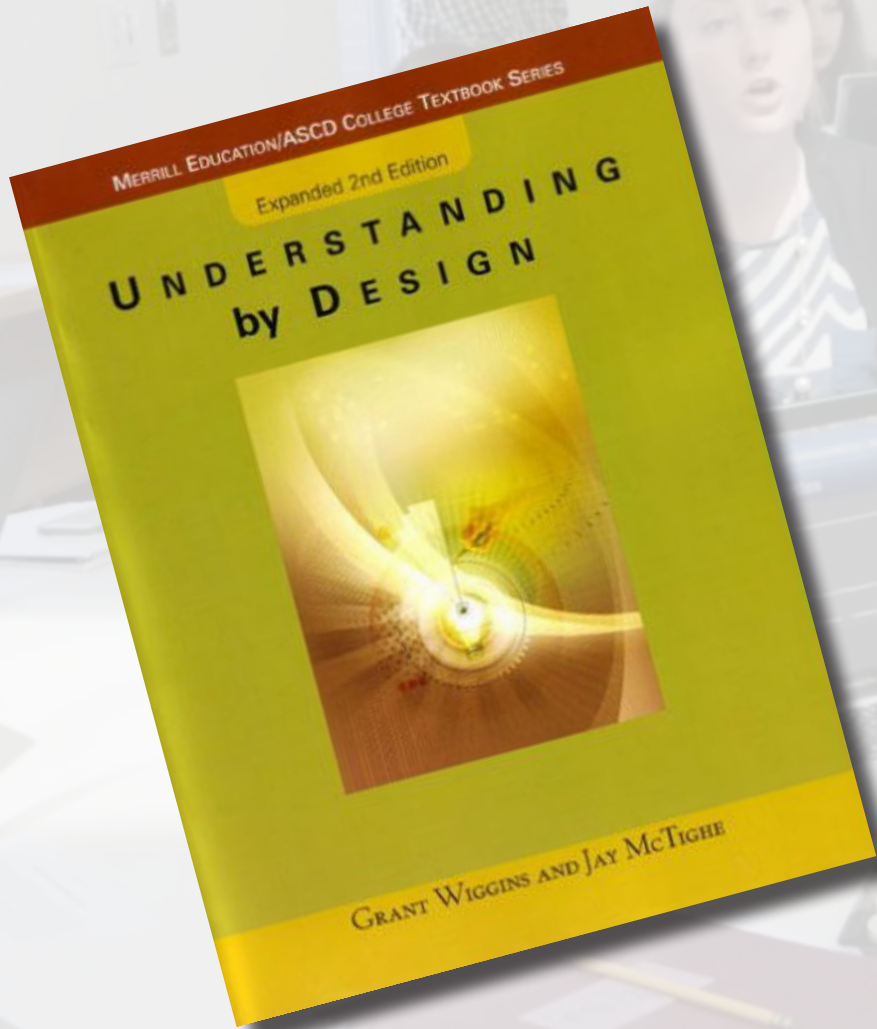
**1** design

**2** approach

**3** results

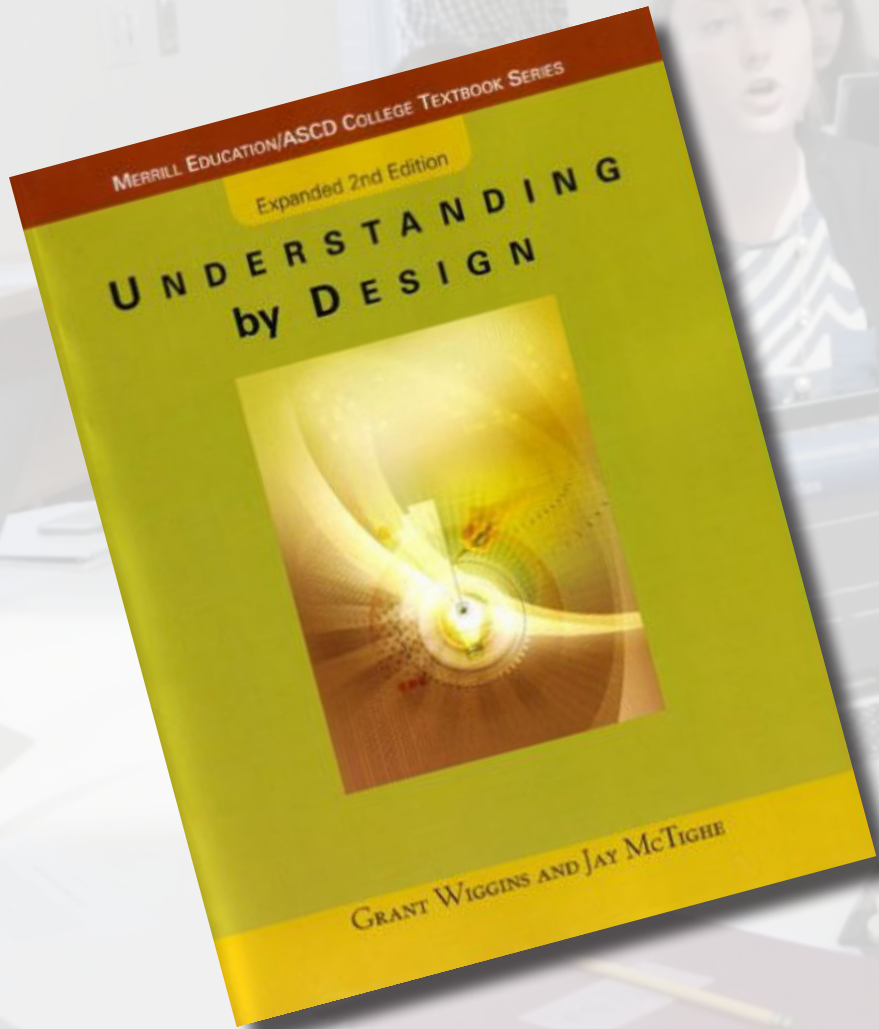


## Setting learning goals



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

## Backward design

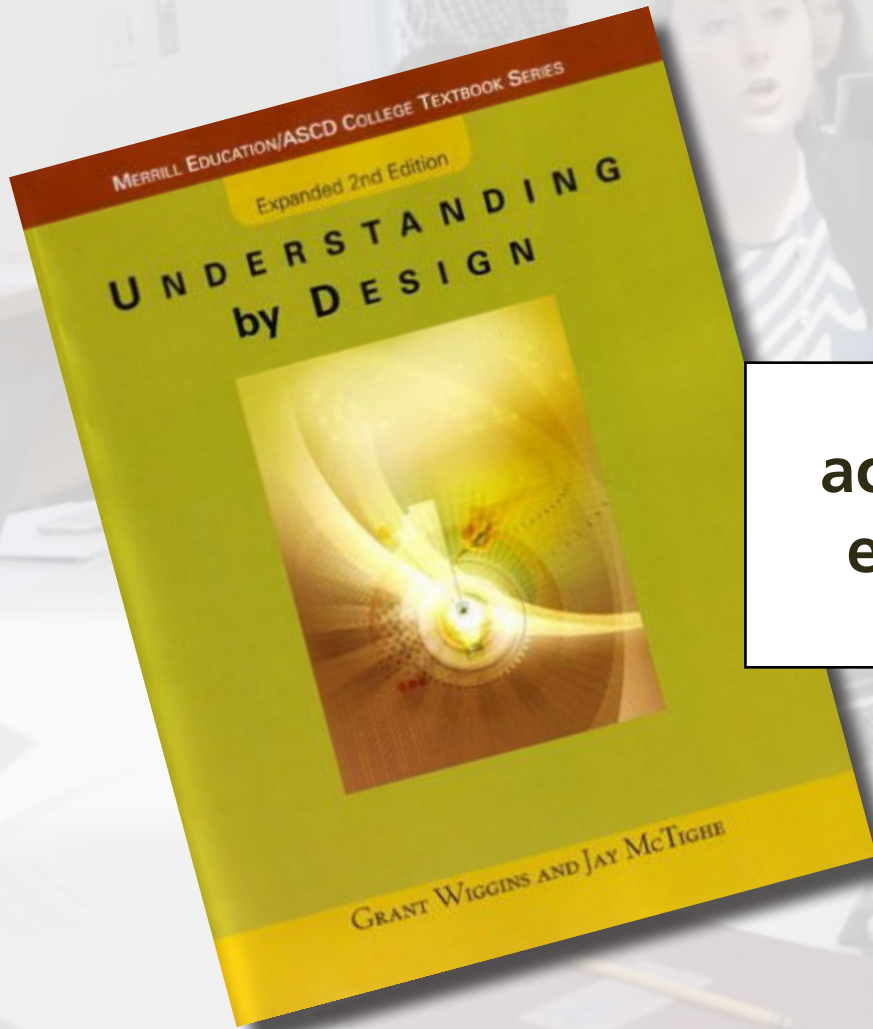


**desired  
outcomes**

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



## Backward design



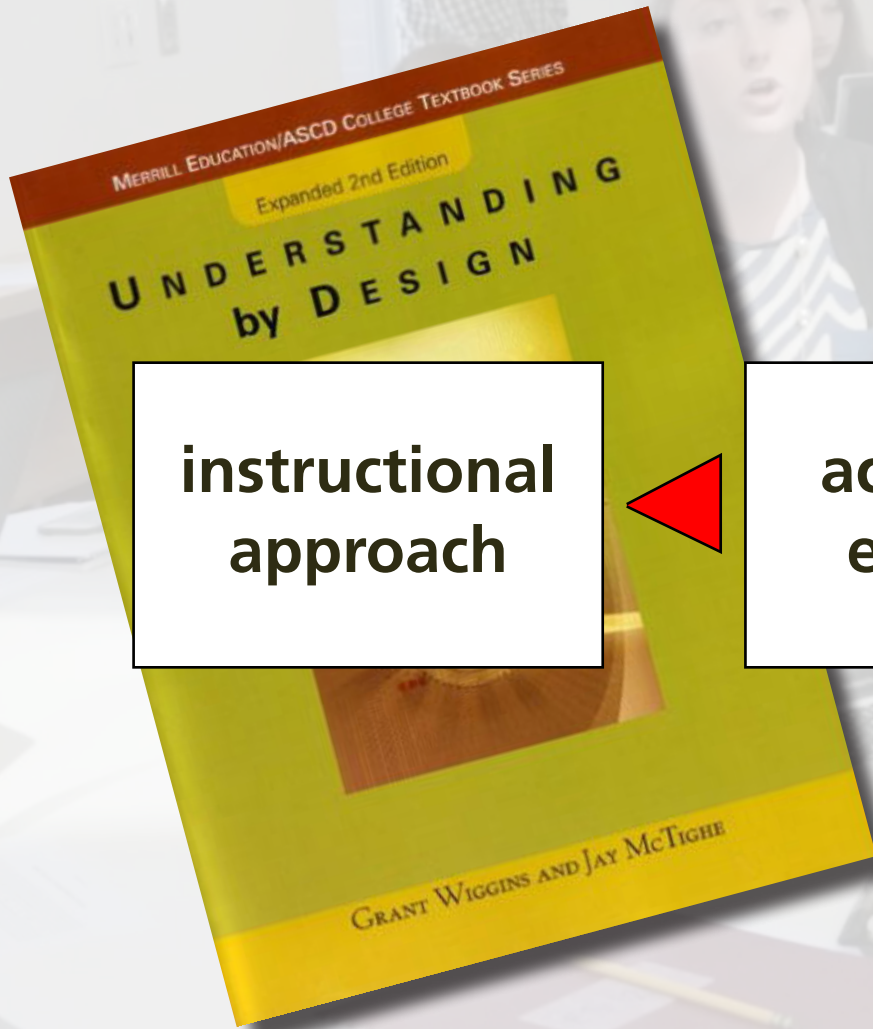
acceptable  
evidence



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

1. Engage in **self-directed learning** by:

- identifying and addressing your own educational needs in a changing
- personal attributes, fluency in use of information sources, planning
- using independent study and research to tackle problems, especial
- using a variety of techniques to get a handle on problems: repres
- perform order of magnitude estimates, use dimensional analysis
- symmetries, evaluate limits and/or relate the problem to cases
- explaining and justify any assumptions made
- “thinking critically,” both positively and negatively, about any
- evaluating the correctness of a solution

## course goals

2. Demonstrate **content mastery** by:

meeting the content learning goals specified in the project

knowledge of physics to solve problems

interpreting them



# COURSE GOALS

After successful completion of this course, you

1. Engage in **self-directed learning** by:

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- evaluating the correctness of a solution

2. Demonstrate **content mastery** by:

- meeting the content learning goals specified in the project
- using knowledge of physics to solve problems
- interpreting them

# content-specific goals



<http://bit.ly/ap50visitor>







**information transfer**

**faculty-centered**





A large, bright, open-plan classroom with a high ceiling and exposed wooden beams. Students are seated at round white tables, some using laptops. Whiteboards are visible in the background, and a few students are standing near them. The overall atmosphere is collaborative and modern.

**interaction**  
**student-centered**





**1** design

**2** approach





**CLASS**

1st exposure



**ROOM**

deeper understanding

**1** design

**2** approach



**CLASS**

1st exposure

**ROOM**

deeper understanding

**ROOM**

1st exposure

**CLASS**

deeper understanding





**no lectures**

**no exams**

**1 design**

**2 approach**





## **Three major components:**

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

PRINCIPLES & PRACTICE OF  
PHYSICS

ERIC MAZUR

PRINCIPLES & PRACTICE OF  
PHYSICS

ERIC MAZUR

1 design

2 approach

## 76 CHAPTER 4 MOMENTUM

In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover one of the most fundamental laws in physics—conservation of momentum.

## 4.1 Friction

Picture a block of wood sitting motionless on a smooth wooden surface. If you give the block a shove, it slides some distance but eventually comes to rest. Depending on the smoothness of the block and the smoothness of the wooden surface, this stopping may happen sooner or it may happen later. If the two surfaces in contact are very smooth and slippery, the block slides for a longer time interval than if the surfaces are rough. Notice that this is a very ordinary day experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval of motion, the velocity decreases over time. The velocity decreases over time on ice because there is very little friction between the block and the ice surfaces. The effect of friction is to slow down the block with respect to each other—in this case, the block and the surface it is sliding on. The longer it takes for the block to come to rest, the less friction there is between the block and the surface.

Figure 4.1 Velocity-versus-time graph for a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases.



Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.

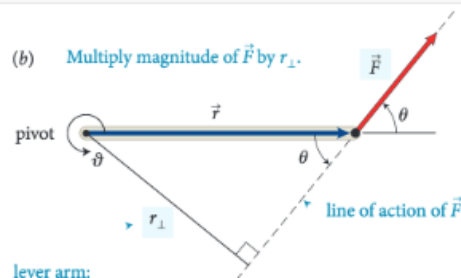


You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction surface—like a surface of air. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is some friction both for low-friction tracks and for wheeled carts, this friction is negligible during an experiment. For the carts shown in Figure 4.2 is horizontal, carts move without slowing down appreciably. In the absence of friction, the carts would keep moving without slowing down.

In the absence of friction, the carts would keep moving without slowing down.

Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



(b) Multiply magnitude of  $\vec{F}$  by  $r_{\perp}$ .

lever arm:  
perpendicular distance  
from line of action of force to rotation axis (pivot)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be written equivalently as  $rF_{\perp}$  and as  $r_{\perp}F$ .

Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing  $\vartheta$ . In Figure 12.4, for example, the torque caused by  $\vec{F}_1$  about the pivot tends to rotate the rod in the direction of increasing  $\vartheta$  and so is positive; the torque caused by  $\vec{F}_2$  is negative. The sum of the two torques about the pivot is then  $r_1F_1 + (-r_2F_2)$ . As we've seen, the two torques are equal in magnitude when the rod is balanced, and so the sum of the torques is zero. When the sum of the torques is not zero, the rod's rotational acceleration is nonzero, and so its rotational velocity and angular momentum change.

In the situations depicted in Figures 12.4 and 12.5 we used the pivot to calculate the lever arm distances. This is a natural choice because that is the point about which the object under consideration is free to rotate. However, torques also play a role for stationary objects that are suspended or supported at several different points and that are not free to rotate—for example, a plank or bridge supported at either end. To determine what reference point to use in such cases, complete the following exercise.

#### Exercise 12.1 Reference point

Consider again the rod in Figure 12.4. Calculate the sum of the torques about the left end of the rod.

**SOLUTION:** I begin by making a sketch of the rod and the three

reference point

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force  $\vec{F}_1$  to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation,  $\vec{F}_2$  causes a negative torque about the left end of the rod; the force  $\vec{F}_{pr}$  exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of  $\vec{F}_2$  about the left end of the rod is  $r_1 + r_2$ ; that of  $\vec{F}_{pr}$  is  $r_1$ . Because the rod is at rest, the magnitude of the force exerted by the pivot is equal to the sum of the forces  $\vec{F}_1$  and  $\vec{F}_2$ . Taking into account the signs of the torques, we find that the sum of the torques about the left end of the rod is  $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$ . This is the same result we obtained for the torques about the pivot, and so the sum of the torques about the left end is zero. ✓

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. You can repeat the calculation for the torques about the right end of the rod or any other point, and each time you will find that the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

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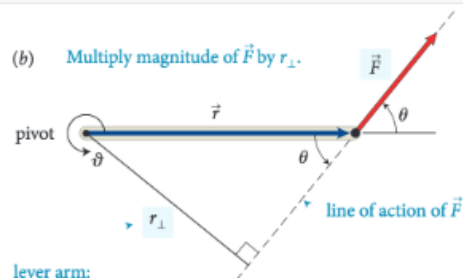
For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of application of a force, we can eliminate that force from the calculation.



**12.2** In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

#### Example 12.2 Torques on lever

Three forces are exerted on the lever of Figure 12.7. Forces  $\vec{F}_1$  and  $\vec{F}_3$  are equal in magnitude, and the magnitude of  $\vec{F}_2$  is half as great. Force  $\vec{F}_1$  is horizontal,  $\vec{F}_2$  and  $\vec{F}_3$  are vertical, and the lever

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# Information transfer

Perusall AP50 Fall 2015 » Chapter 12 Page 284 Eric Mazur

reference point

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1 design

2 approach

# Information transfer

over 20,000 annotations!

1 design

2 approach



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 (thoughtful reading & interpretation)
- Quantity (10)
- Timeliness (before class)
- Distributed



reference point

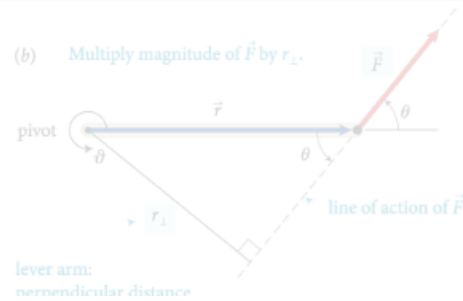
## READING SCHEDULE

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

# Information transfer

(b) Multiply magnitude of  $\vec{F}$  by  $r_{\perp}$ .



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## chapter deadline

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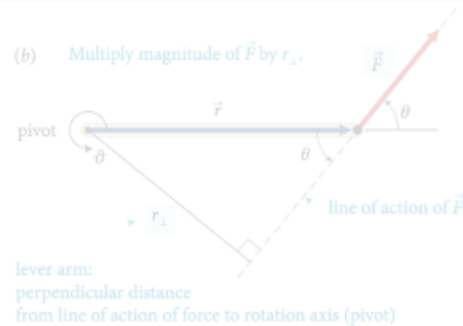
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1 design

2 approach

# Information transfer

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# virtually all students complete all readings!

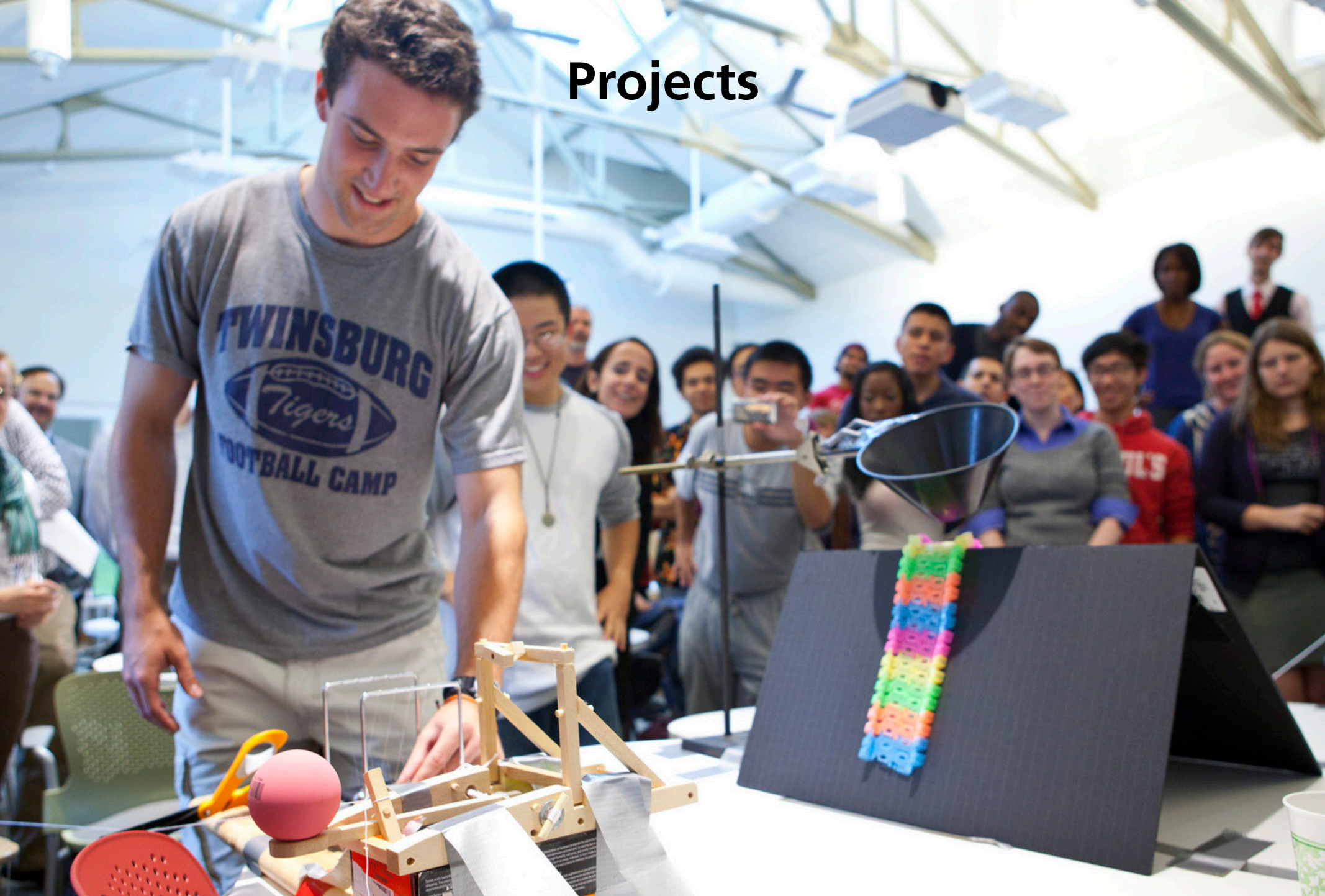
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# Projects



1 design

2 approach



# Projects

- 1 project/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

## 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

---

**Fall**

**Drag Race**

**Rube Goldberg**

**Symphosium**

---

**Spring**

**Ecotricity**

**Crack-a-Thon**

**inSPECT Fair**

---

**1 design**

**2 approach**





**AP50 FALL 2014**

**Project Brief**

**Drag**

**Rube G**

**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:

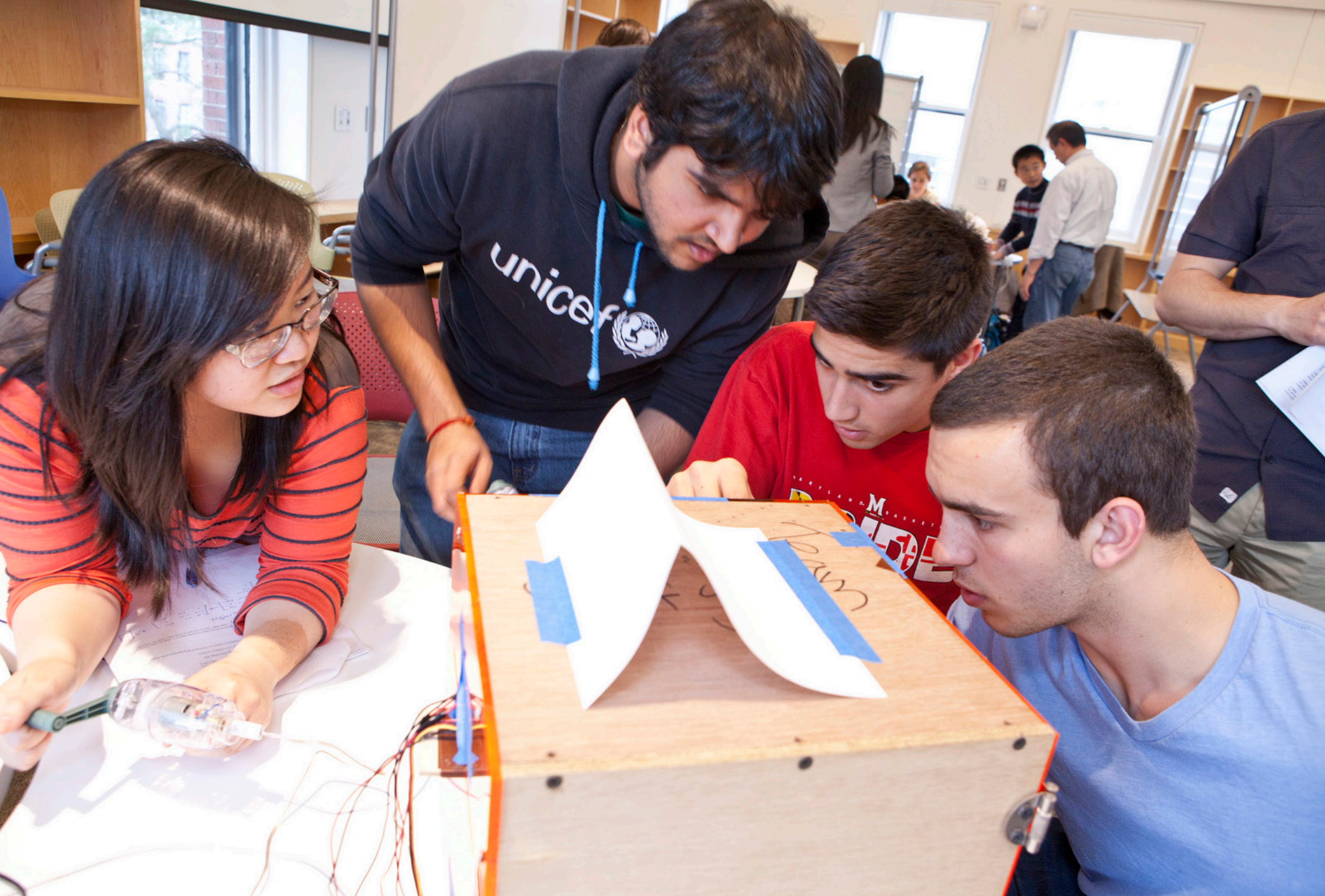
- team contract (at beginning)
- proposal (+1 week)
- fair (+3 weeks)
- report (+1 week +3 days for revision)
- team, peer, and self assessment (at end)





**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 grey hoodie with 'unicef' 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 on the left, holding a small electronic device. Two other male students are on the right, looking at the project. The project appears to be a white paper structure, possibly a model or a prototype, mounted on a wooden board. Wires and other components are visible on the table. The background shows other students and classroom furniture.

**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





# In-class activities

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	16	21	23	28	
intro	6	T 6	6	6	7	7	7	ECOTRICITY	T 8	8	8	8	9	9	9			CRACKATHON	T 10	10	10	10	10	inSPECT FAIR	
	6	6	6	7	7				8	9	8	9P	9						10	10		P			
				P																					

1 design

2 approach

# In-class activities

## one project

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	16	21	23	28	
intro	6	T 6	6	6	7	7	7	ECOTRICITY	T 8	8	8	8	9	9	9	CRACKATHON			T 10	10	10	10	10	inSPECT FAIR	
	6	6	6	7	7				8	9	8	9P	9						10	10		P			

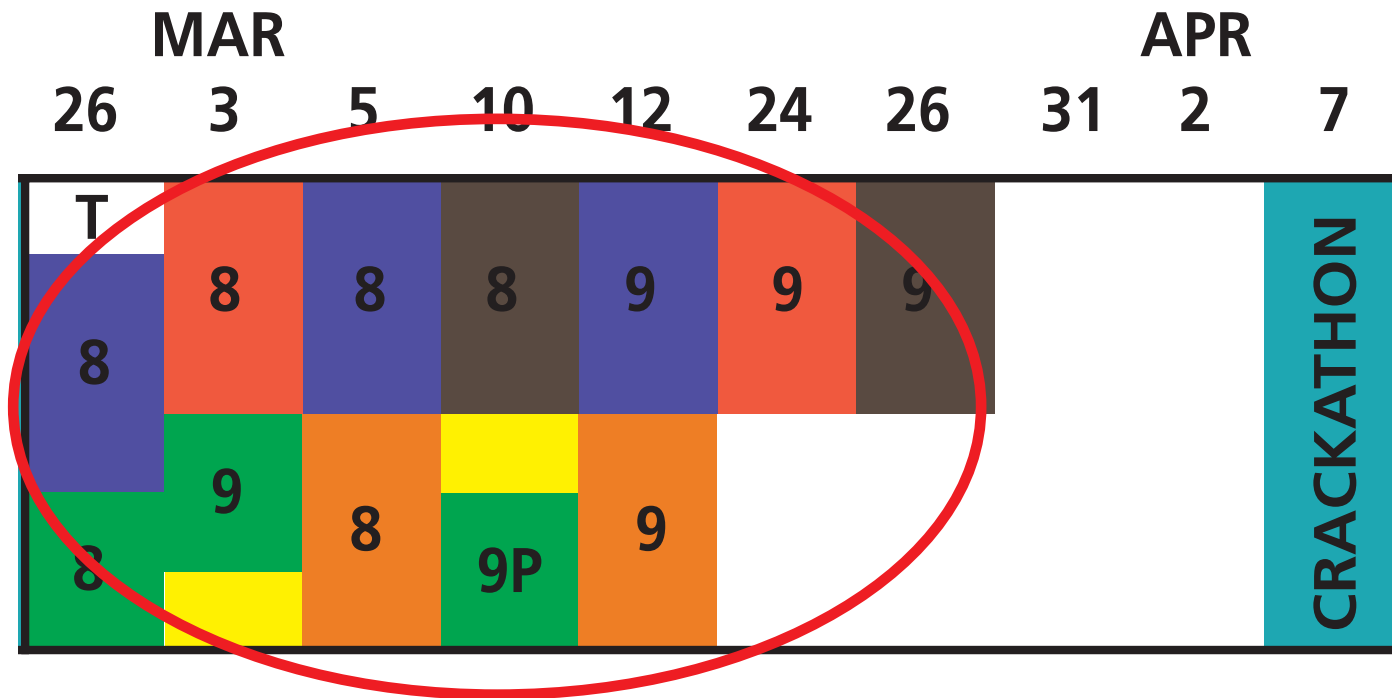
1 design

2 approach

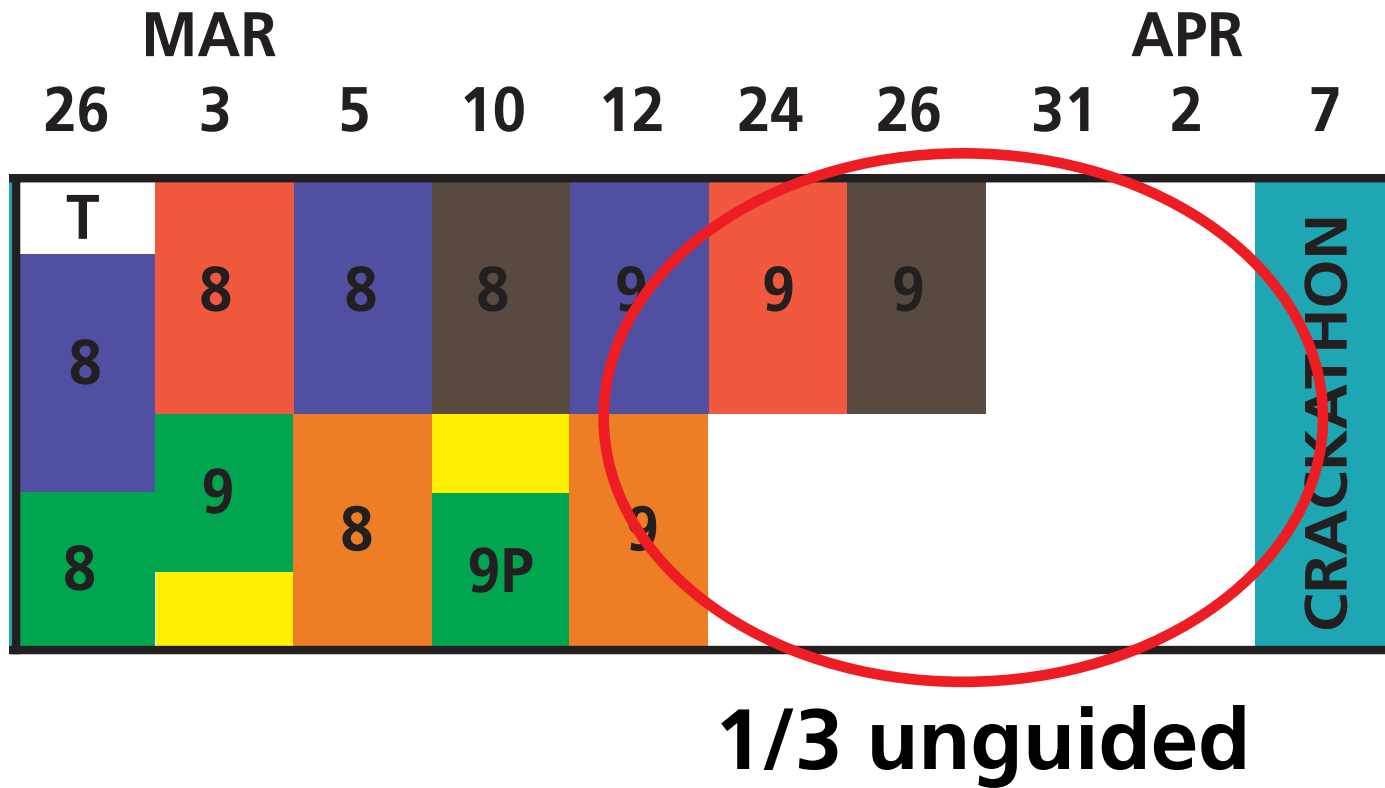


# In-class activities

2/3 scaffolded, guided



# In-class activities





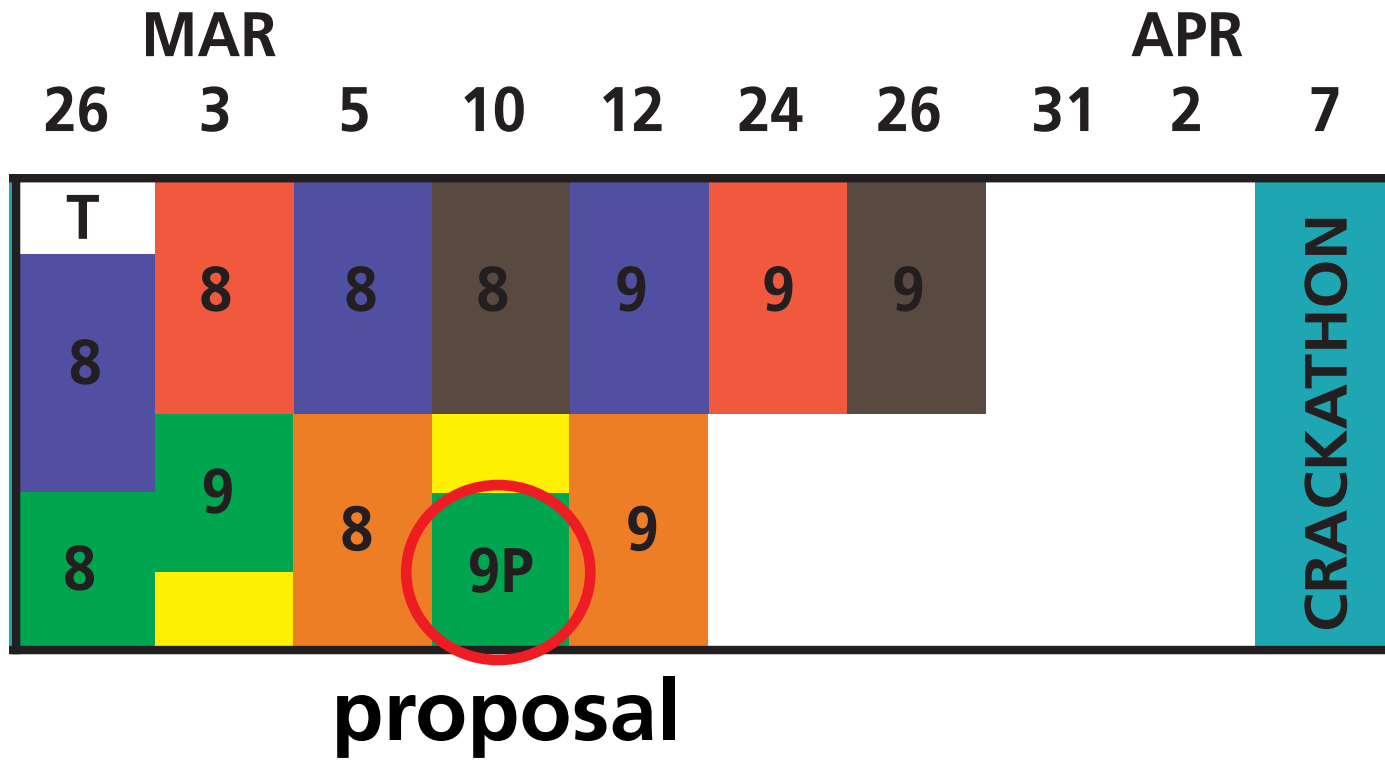
# team intro



# 1 design

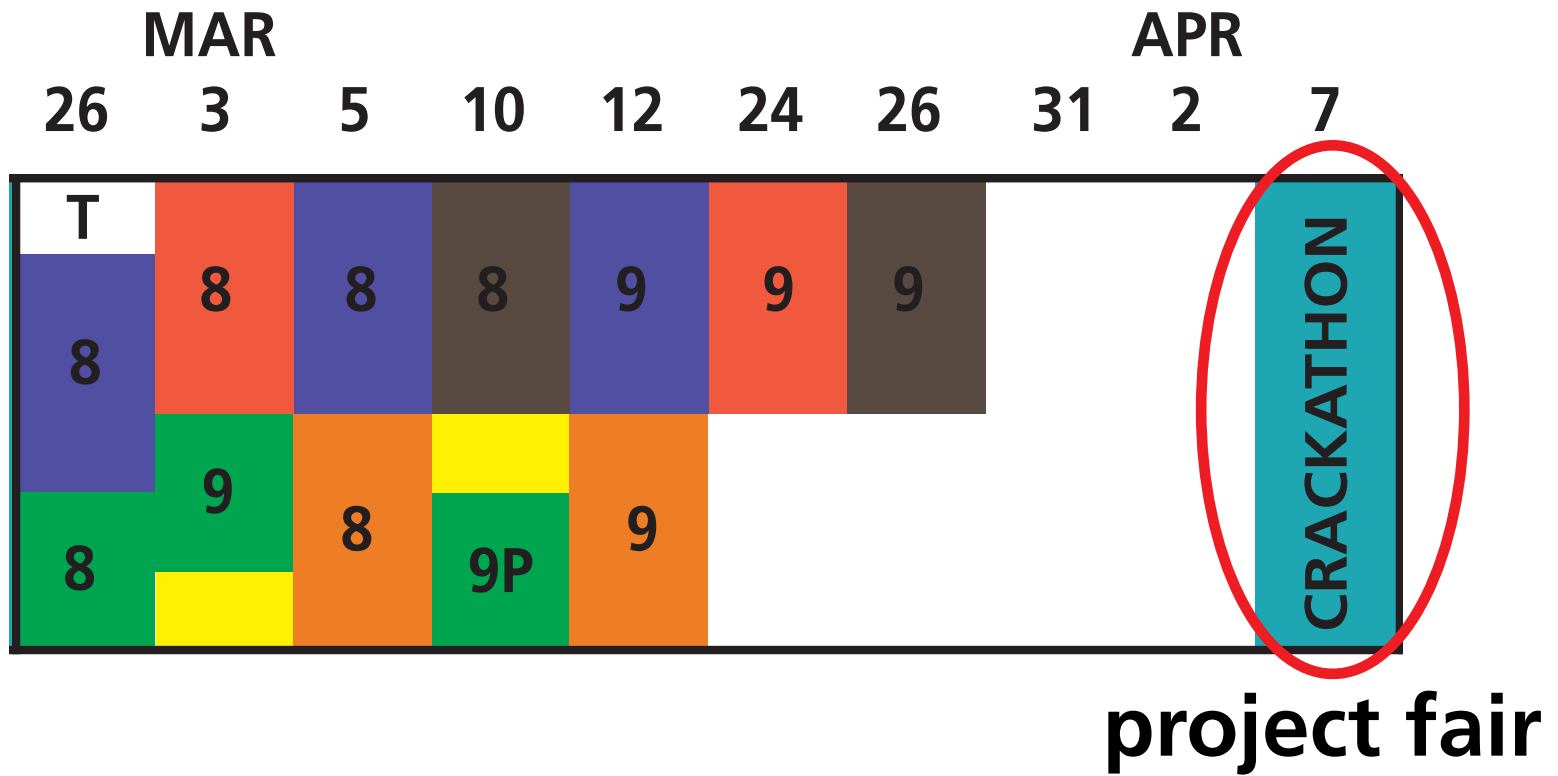
## 2 approach

# In-class activities





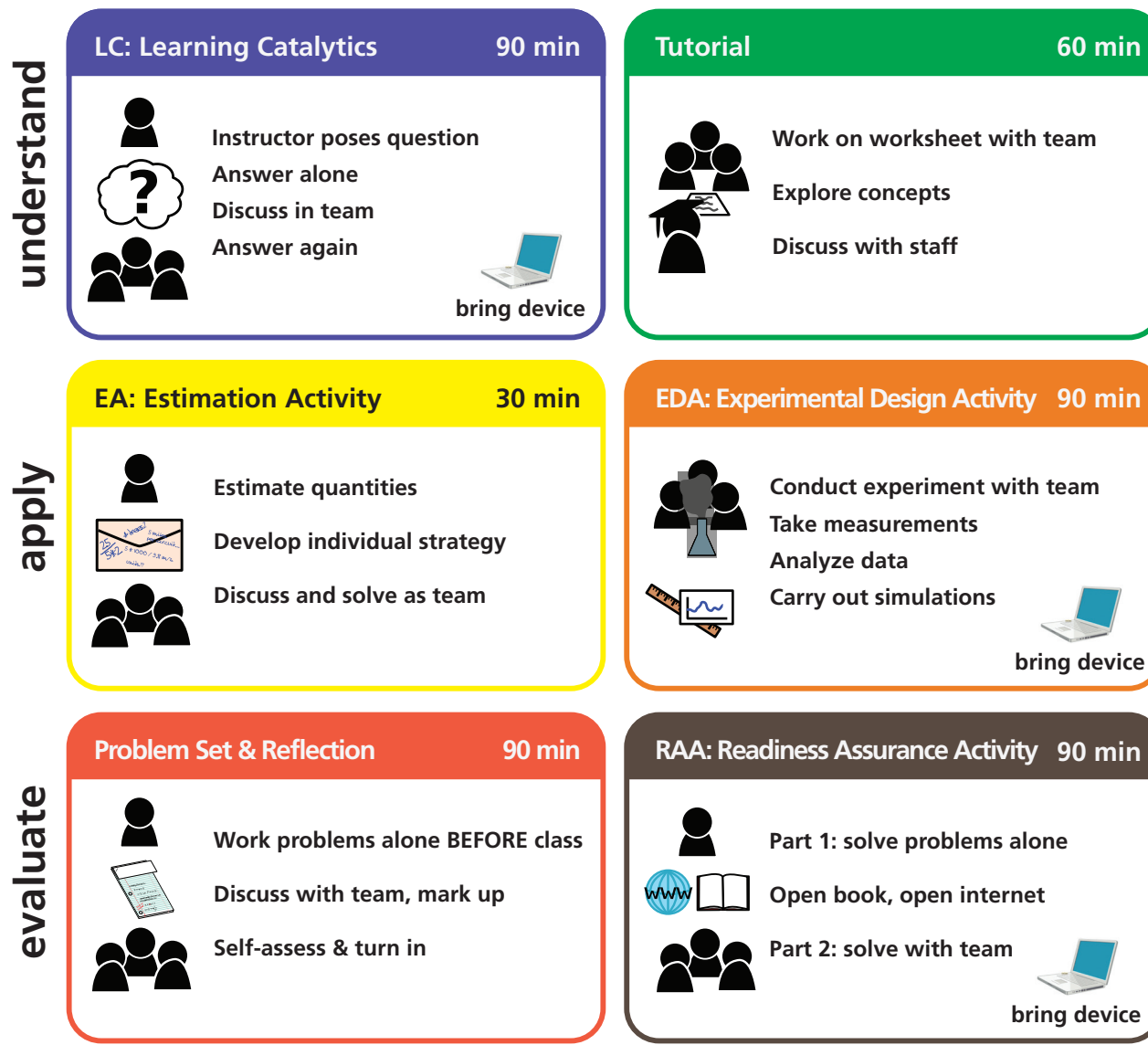
# In-class activities



1 design

2 approach

# In-class activities





# 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  
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90 min



Work problems alone BEFORE class  
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RAA: Readiness Assurance Activity

90 min



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



AP50b Fall 2013

## Problem Set 1

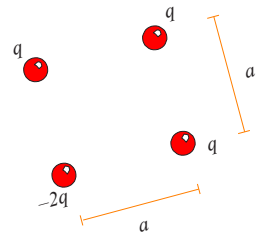
due W Feb 6 in class

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?





AP50b Fall 2013

## Problem Set 1

due W Feb 6 in class

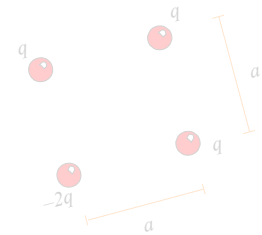
Instructions: We need to quickly scan your work so we can return it before the end of class, please:

- use a pen or pencil
- 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 nozzle that gives each drop a positive charge by removing some electrons. The drops then pass between parallel deflecting plates where there is a uniform vertical electric field (see 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?

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AP50b Fall 2013

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- no dog ears or torn corners
- dark ink (no light pencils)
- no staples
- single-sided writing (no back)
- leave margins blank

phase

goal

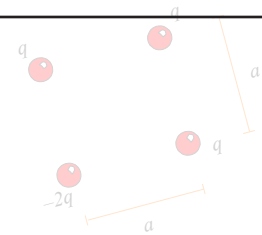
solve (at home/individual)

skills development

reflect (in class/team)

metacognition

2. **Levitation.** In an inkjet printer, letters are formed by starting drops of ink at a piece of paper and directing them 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 and the upper plate is at a uniform vertical electric field (see chapter 23). Estimate the number of atoms in a single drop 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. During this stage, you may only use **red ink** to write on your problem sets (pens will be provided in class to review. During additional 45 minutes, your team will be provided with a solution set which you may use to review. During the last 45 minutes, your team must submit the marked-up problem sets to the teaching staff. You will receive your team's score 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 team's responsibility to ensure that all team members understand the 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 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.
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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 correctness. You may only use **blue or black ink** and you must attempt to solve each problem. **Implement 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. Consider why a particular approach can or cannot 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, or check the magnitude of an answer.

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

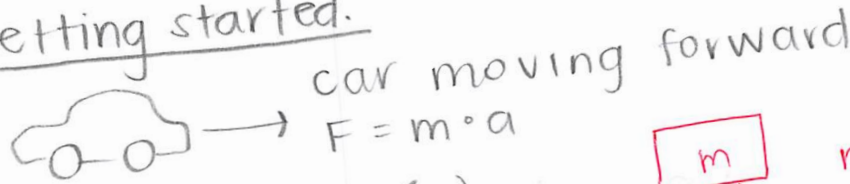
**1 design**

**2 approach**

# Applied Physics 50a

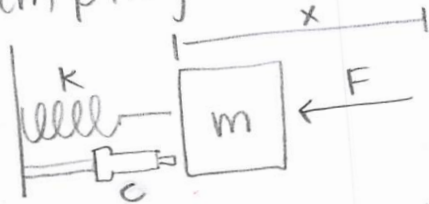
① Estimate damping coeff. for a shock absorber on a midsize car.

Getting started.



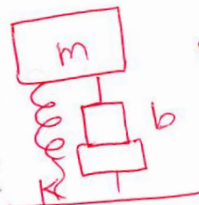
$$F = m \cdot a$$

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

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

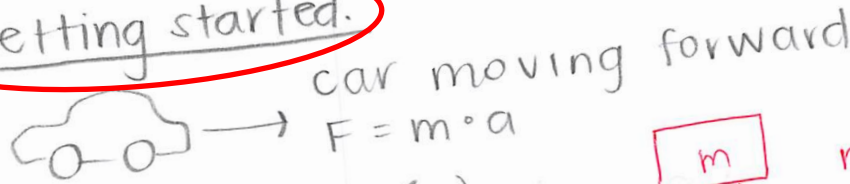
$$k = \frac{\Delta mg}{x}$$



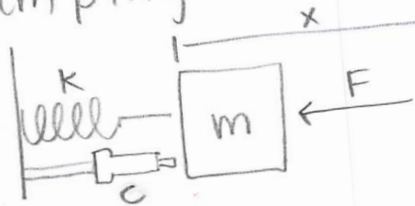
# Applied Physics 50a

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

Getting started.

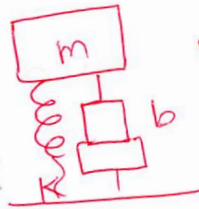


Damping coeff (c)



$$F_s = -kx$$

$$F_d = -cV$$



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



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

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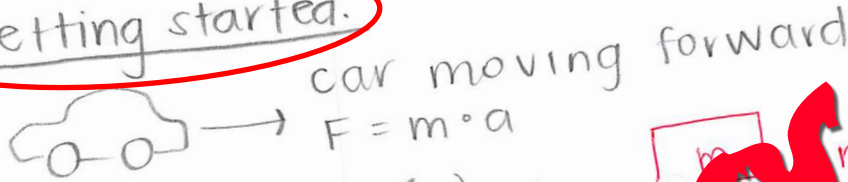
$$\begin{aligned} \uparrow F_{sc}^c \quad \Sigma F_x &= F_{Ec}^G - F_{sc}^c = \Delta mg - k(x_{eq} - x_0) \\ \downarrow F_{Ec}^G \quad \text{Translational eq} &= \Sigma F_x = 0 \end{aligned}$$

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

## 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

Diagram showing forces on a mass:  $F_{sc}^c$  (up) and  $F_{Ec}^G$  (down).

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

Translational eq =  $\sum F_x = 0$

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



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 have your own score, but also that of your team members. Likewise, it is important to ensure that each team member 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.

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## **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 correct 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 a violation of the rules.



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 =  $\frac{2\pi}{\lambda} = \frac{1}{2}\pi = 0.5\pi$

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

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

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

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

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

(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 was, but I didn'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”**

# 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 modern classroom setting, working on laptops and discussing their work. The students are seated around a large white table, with several laptops open. One student in the foreground is looking at a laptop screen, while others are engaged in conversation. The background shows more students working at desks, creating a collaborative learning environment.

**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  $\ln y - \sin x$



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  $\ln y - \sin x$

$$6x - 6$$

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  $\ln y - \sin x$





1 design

2 approach



**round**

**credit**

**individual**

**50%**

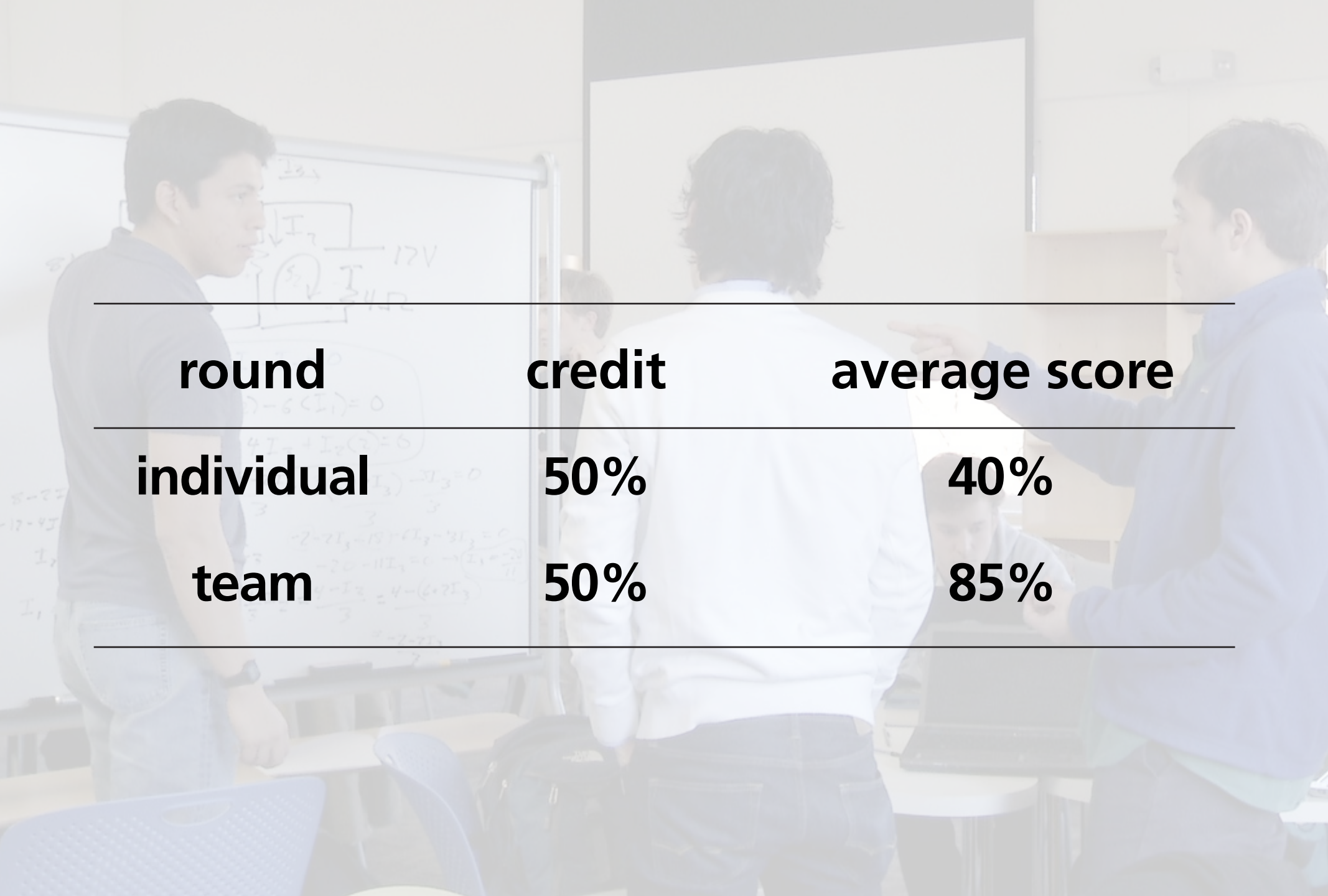
**team**

**50%**

**1 design**

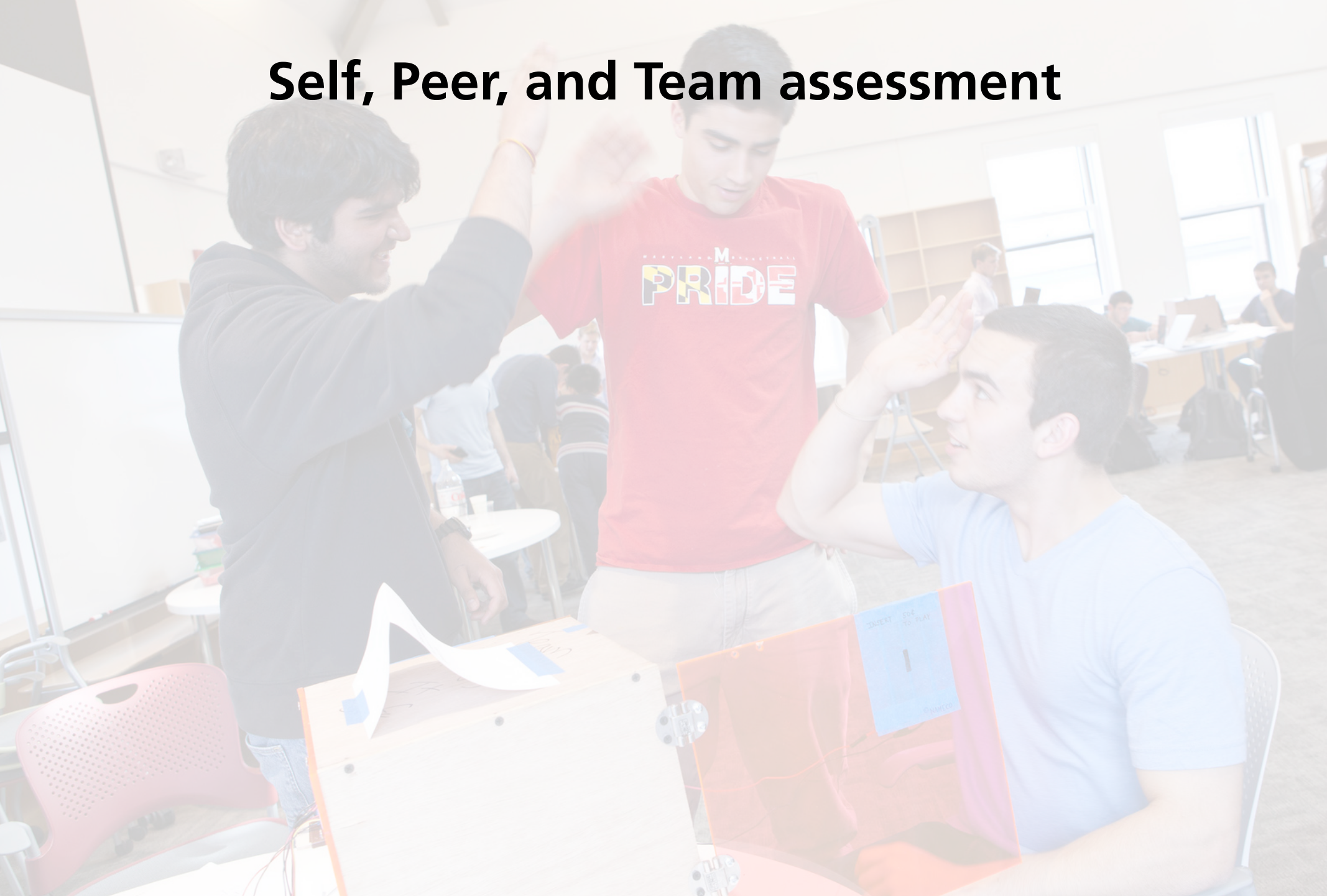
**2 approach**





round	credit	average score
individual	50%	40%
team	50%	85%

# 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		
1. Participate fully in team activities	4.67	4
2. Come to class well-prepared for all team activities	4.67	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	4
4. Attendance: <ul style="list-style-type: none"> <li>You are present for team activities</li> <li>On time/punctual</li> </ul>	4.83	5
5. Take responsibility for your own part of team work and decision-making	4.83	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	
2. Come to class with prepared team activities		4
3. Communicate effectively and respectfully with team members	4.83	
• Express your opinions respectfully and with clarity		
• Listen respectfully to the perspectives and contributions of others		
• Collaborate effectively with team members to make decisions		
4. Attendance:	4.83	5
• 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 effectively and respectfully with team members	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



# Assessment

self-directed learning

learning goals

team work

professionalism

# Assessment

Scale: 3–0

self-directed learning

learning goals

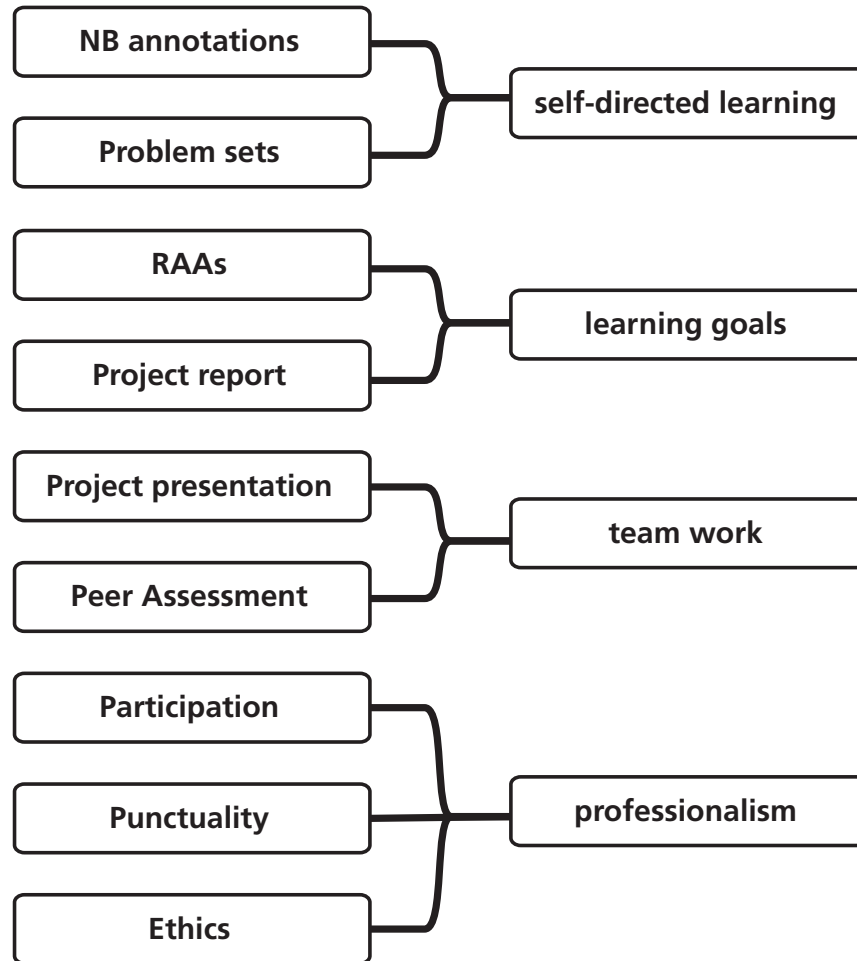
team work

professionalism

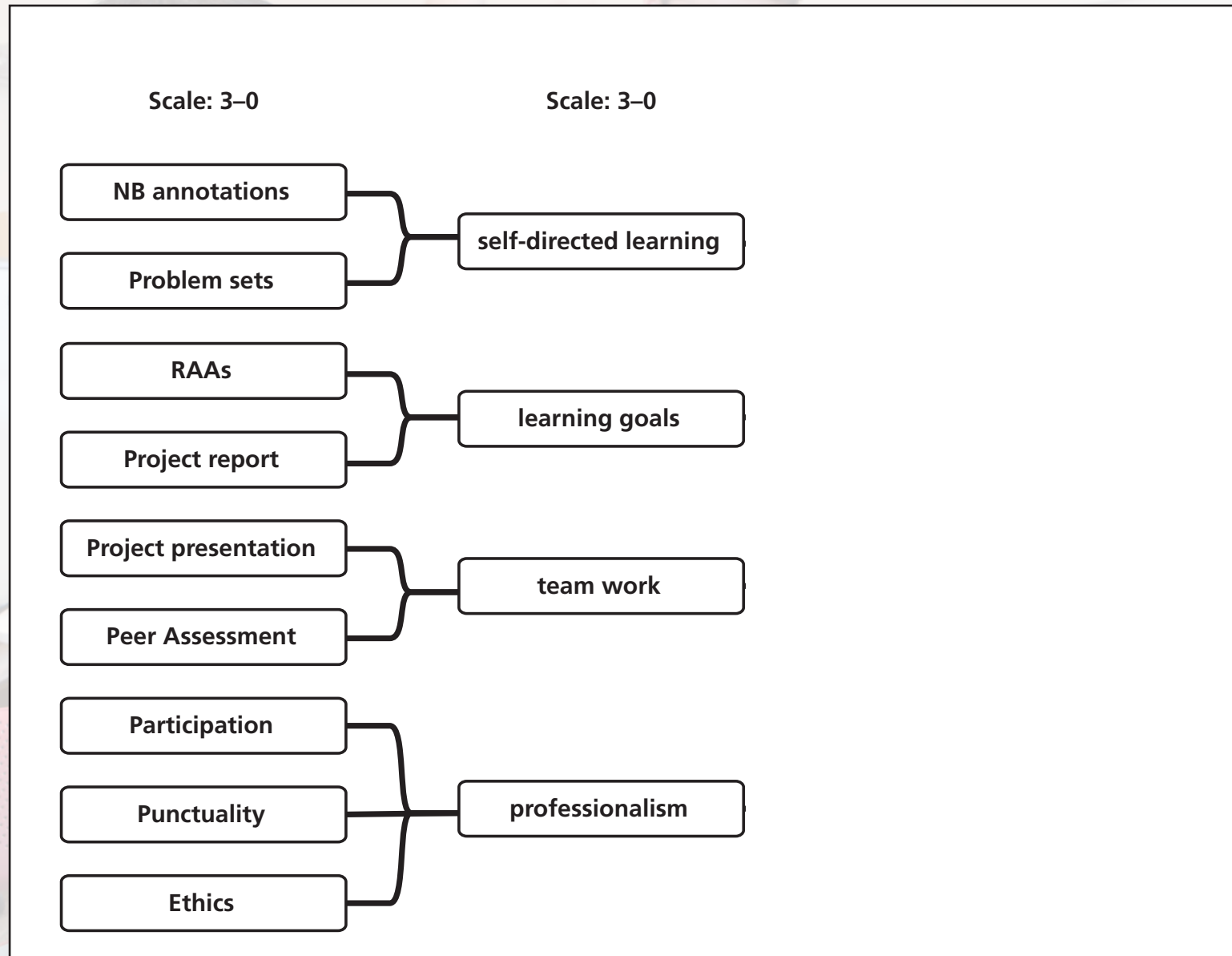


# Assessment

Scale: 3-0

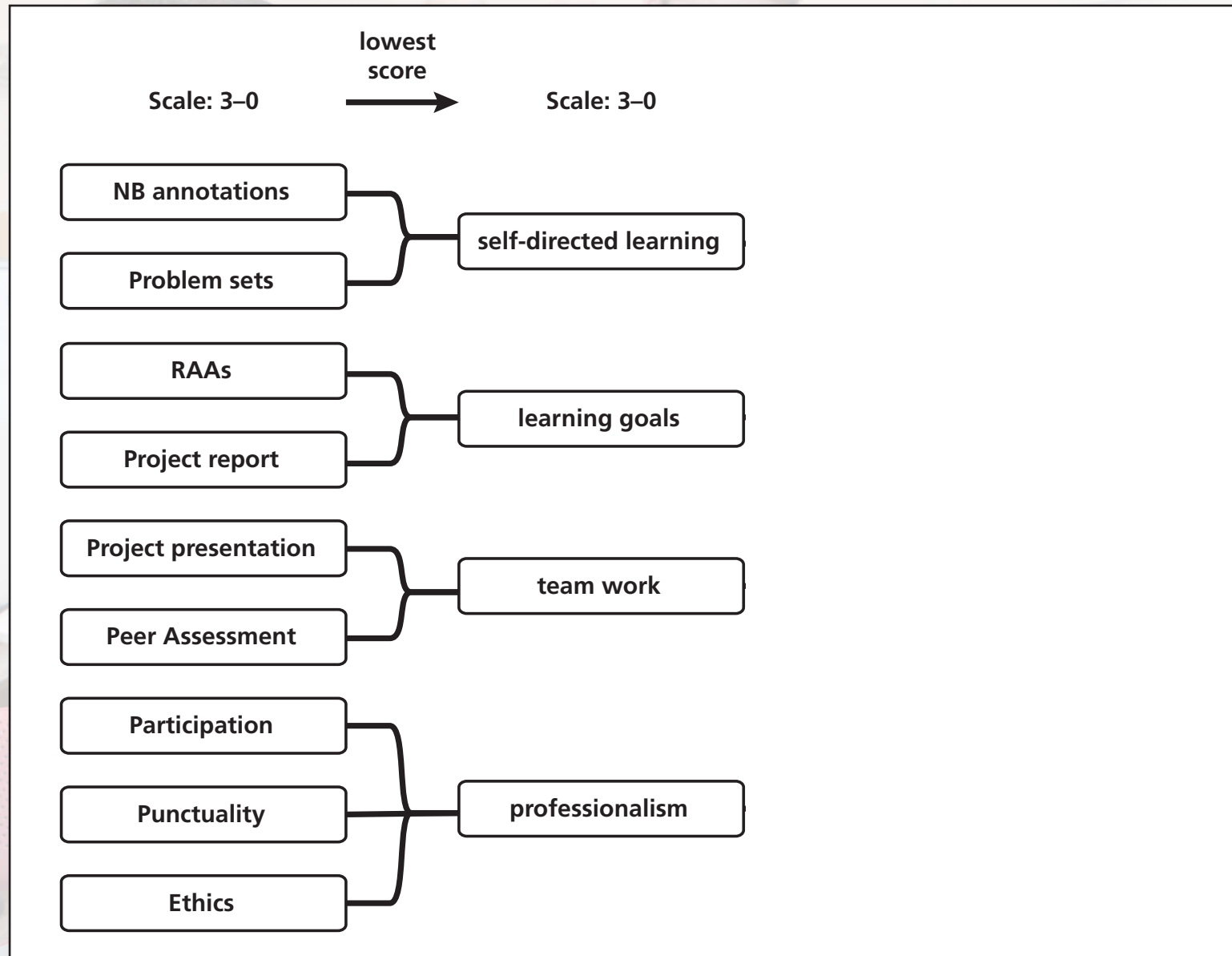


# Assessment

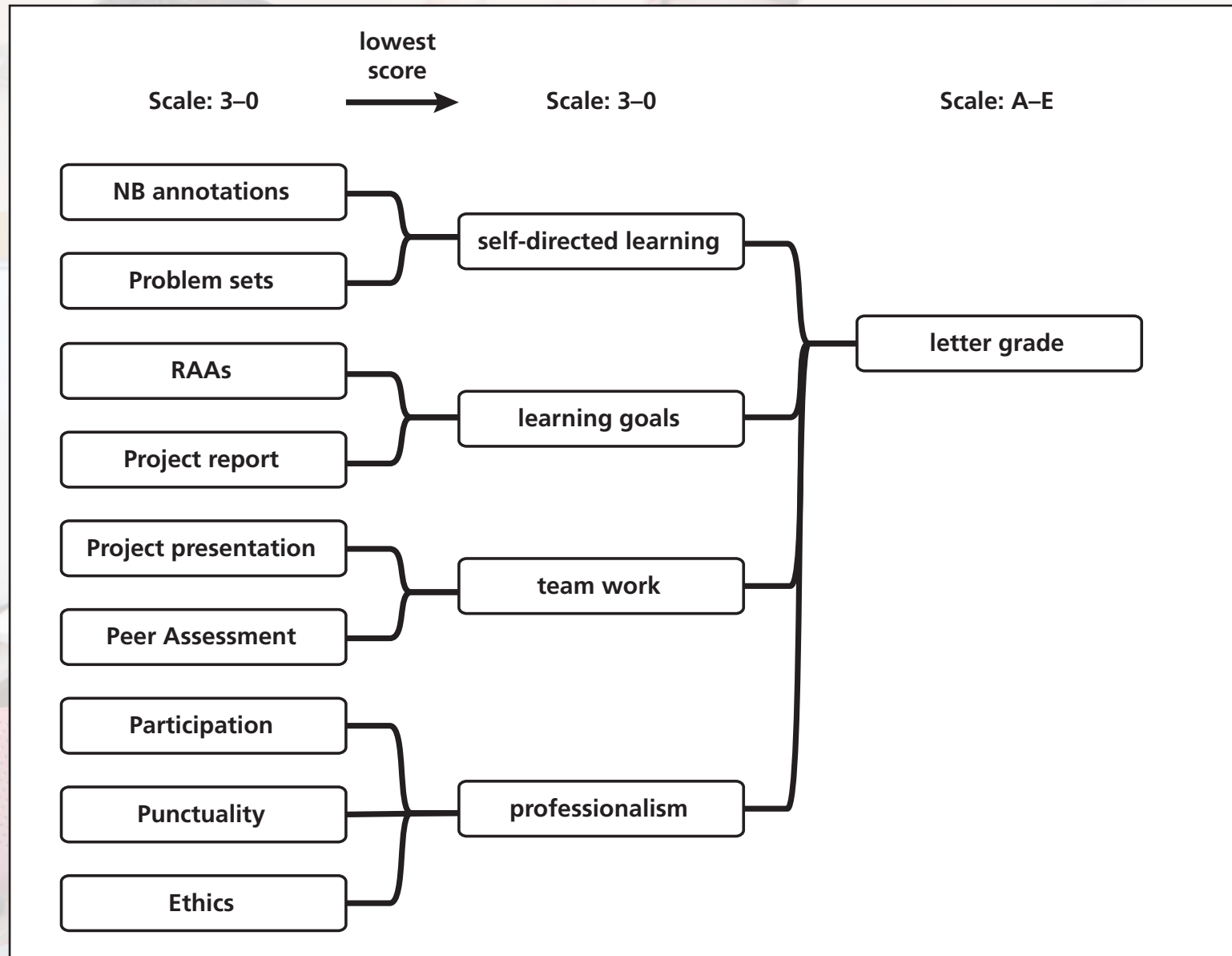




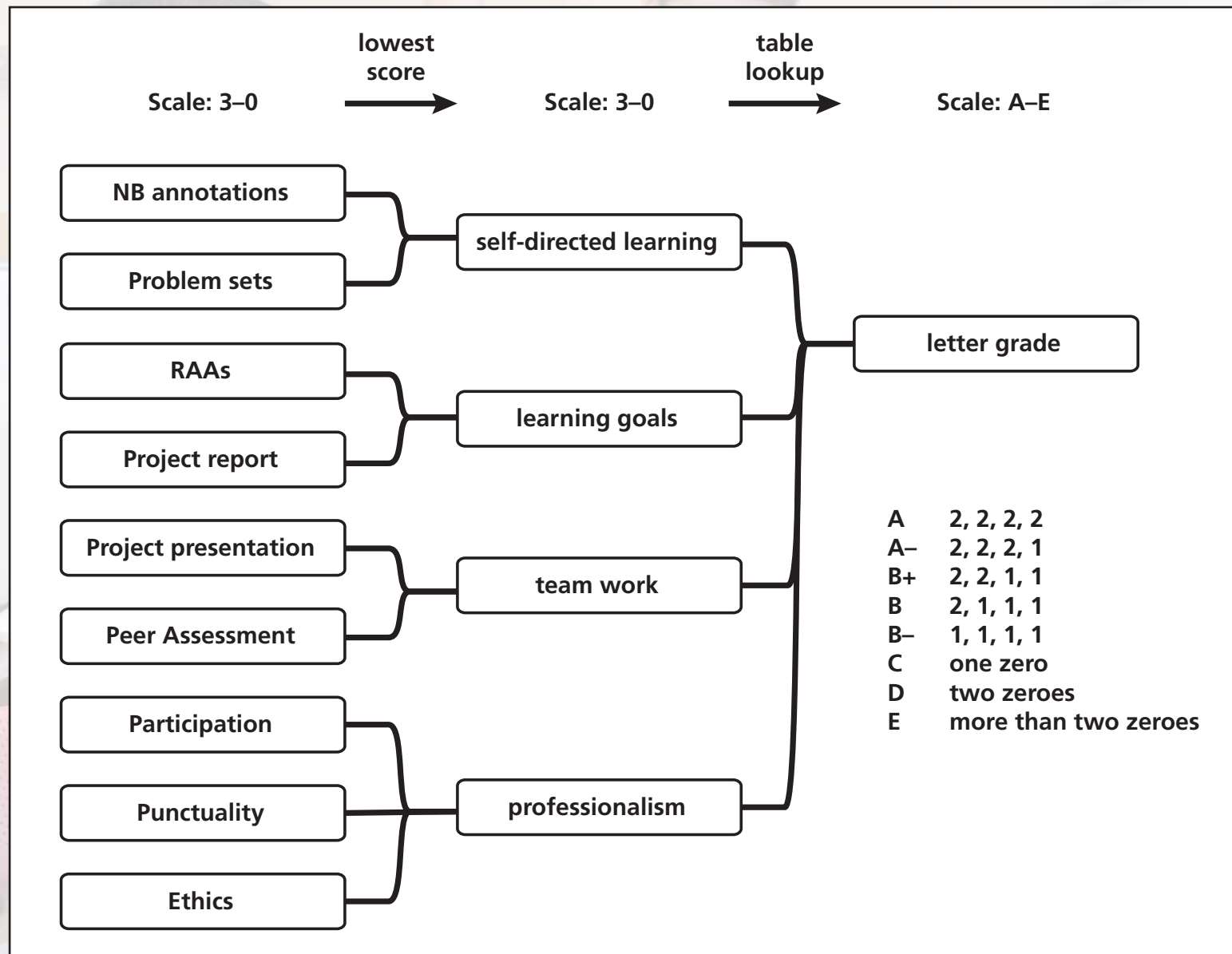
# Assessment



# 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!!!!!!”**

# 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.”**





# 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)**



# Self-efficacy



**1** design

**2** approach

**3** results



# Self-efficacy

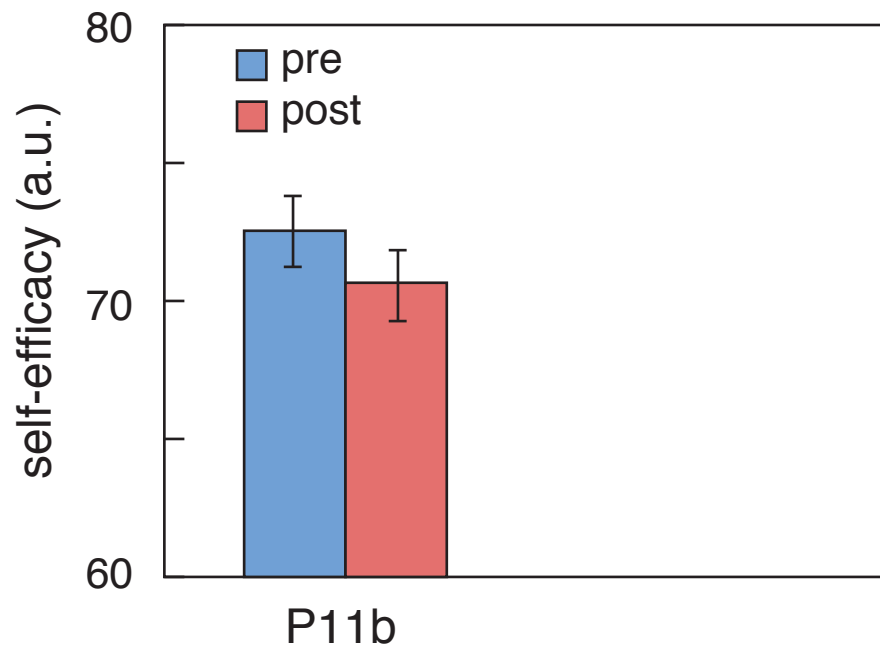
**(students' belief in their ability to succeed)**

**1 design**

**2 approach**

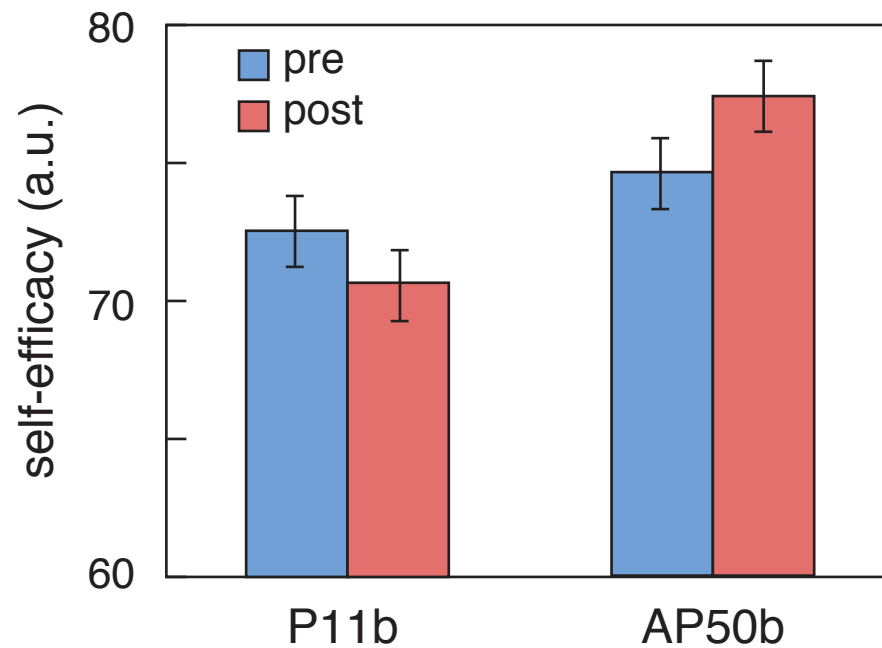
**3 results**

# Self-efficacy





# Self-efficacy





# Self-directed learning

### 3 results

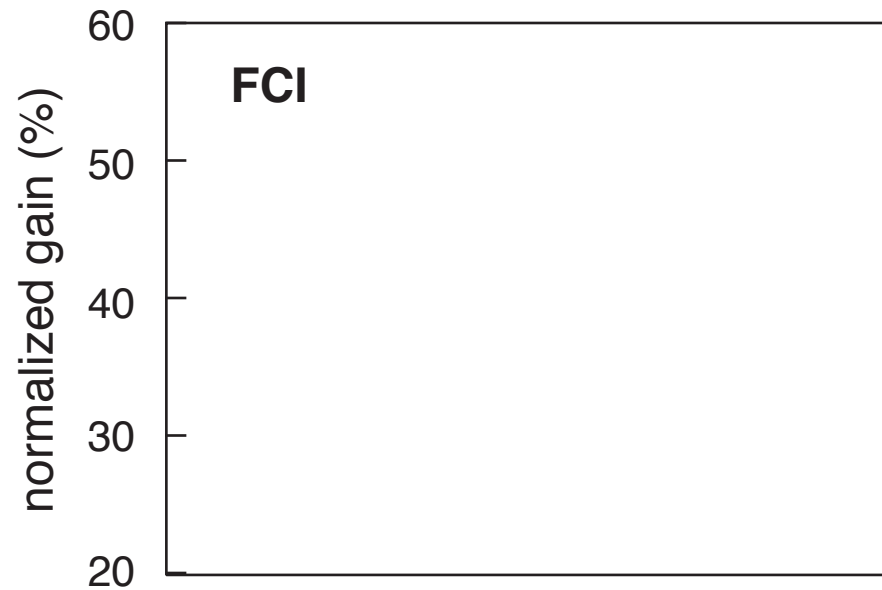
# Self-directed learning

**NB data shows:**

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



# Conceptual Mastery

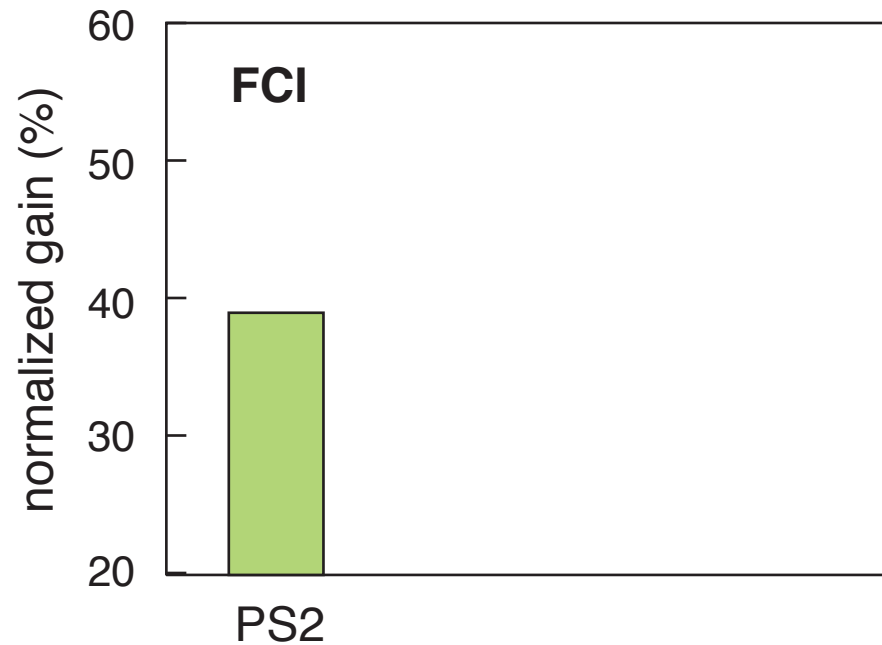


1 design

2 approach

3 results

# Conceptual Mastery

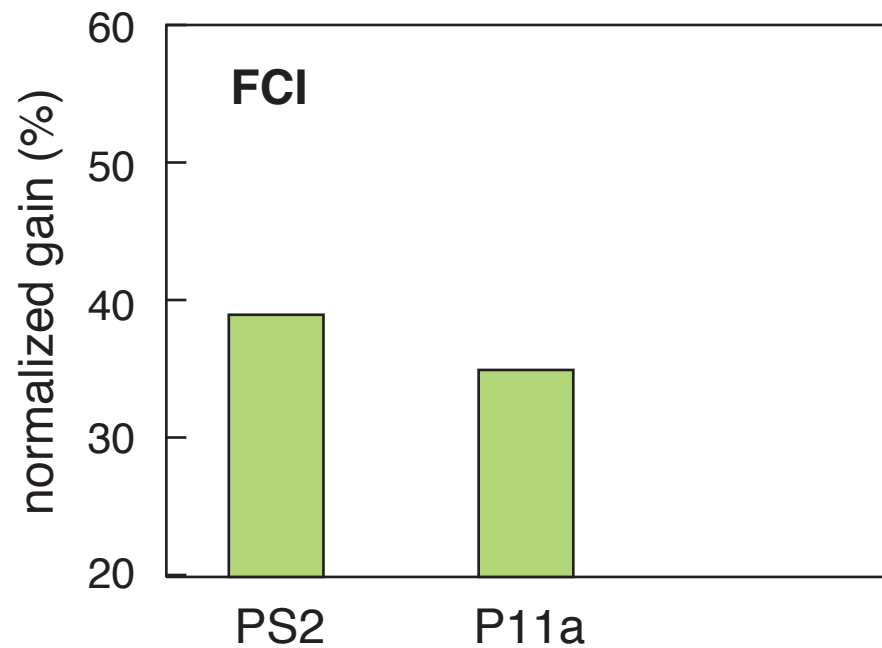


1 design

2 approach

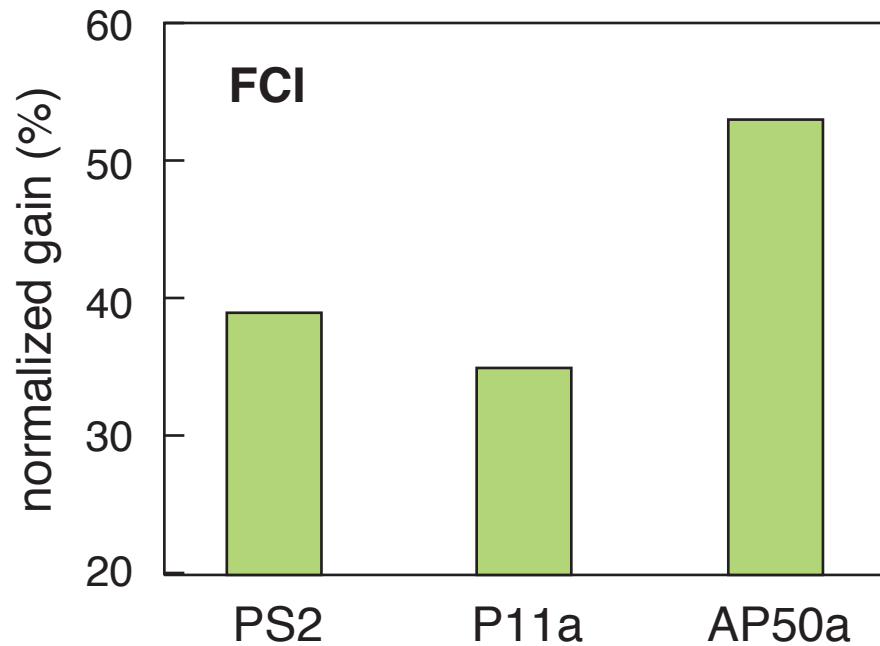
3 results

# Conceptual Mastery

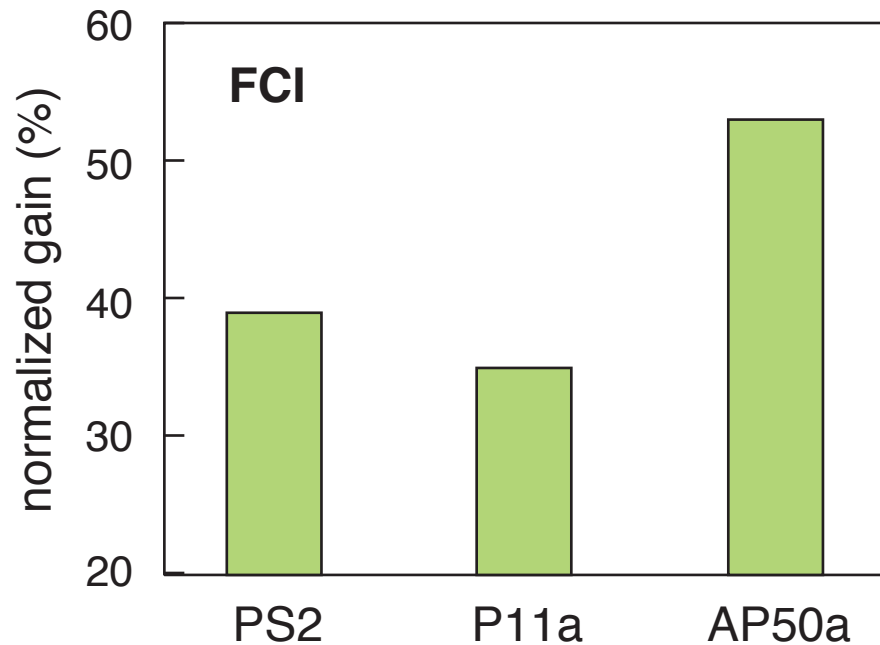




# Conceptual Mastery



# Conceptual Mastery



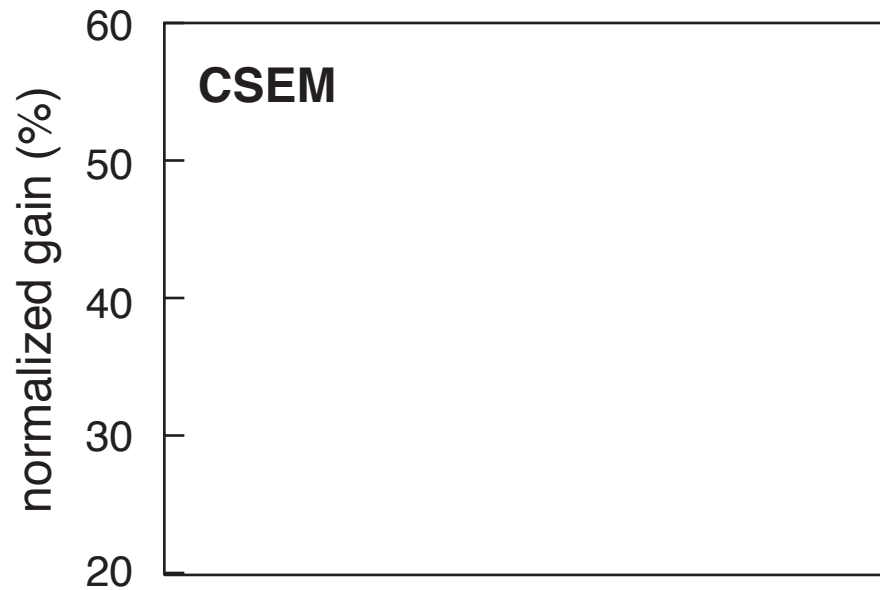
**largest conceptual gain in *any* course past 6 yrs!**

**1** design

**2** approach

**3** results

# Conceptual Mastery



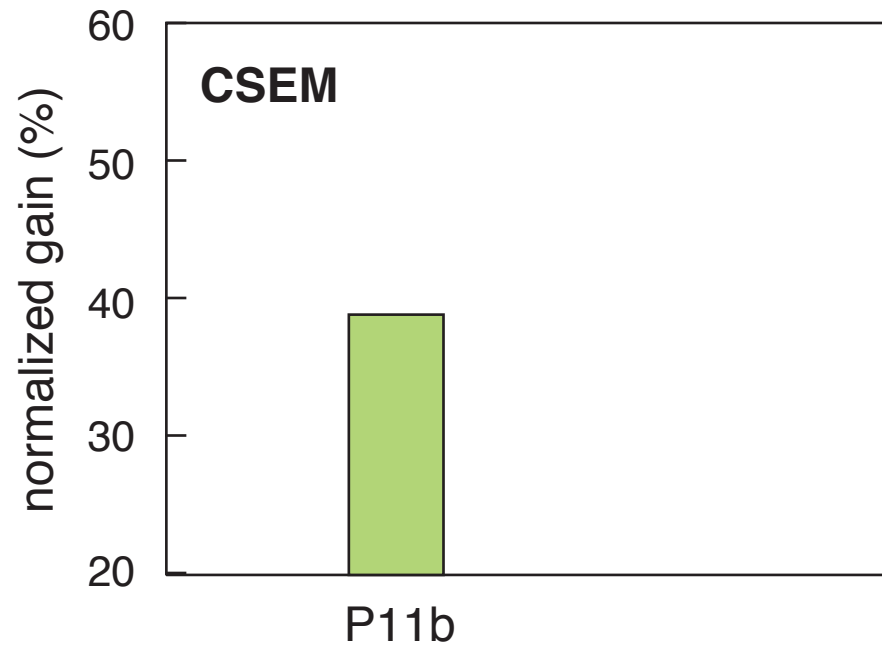
1 design

2 approach

3 results



# Conceptual Mastery

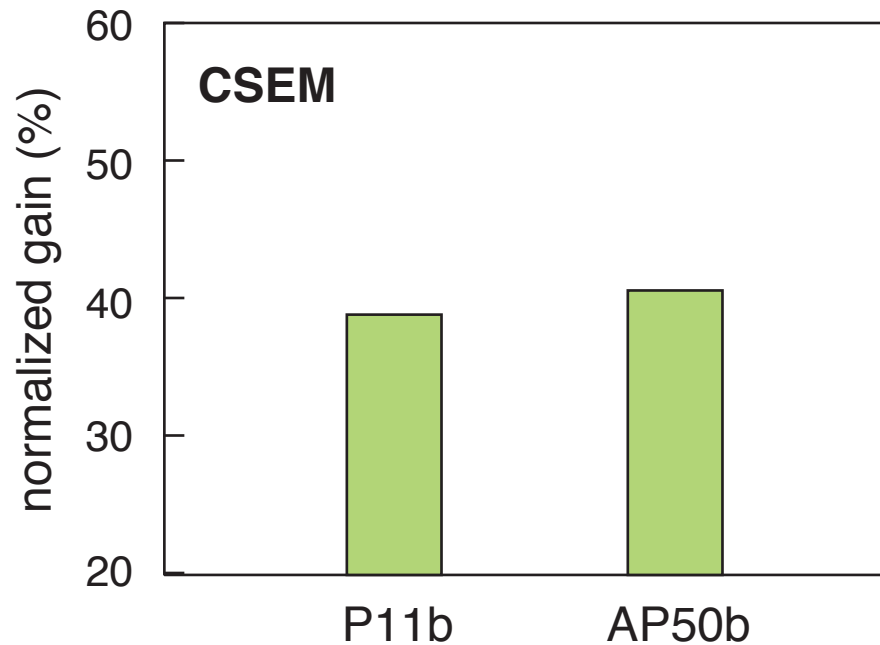


1 design

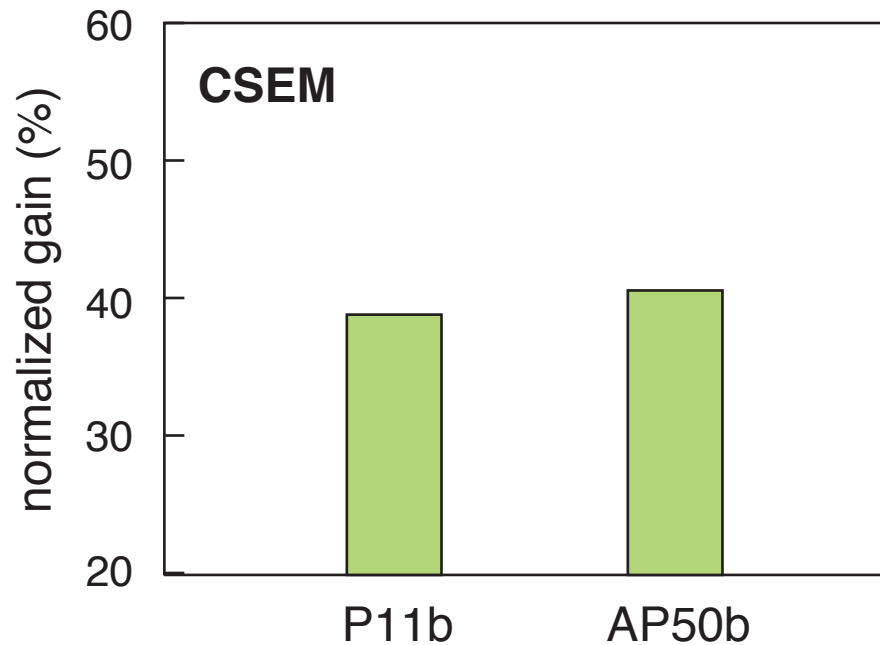
2 approach

3 results

# 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



A group of four students are gathered around a wooden box containing a physics experiment. A female student with glasses is pouring liquid from a white cup into a container inside the box. Another female student is smiling and looking at the experiment. A male student in a plaid shirt is standing and smiling. A female student in a maroon hoodie is sitting and looking at the experiment. The box contains various components, including a circuit board with many small lights, a blue bowl, and other electronic parts. The background shows a classroom or lab setting with a whiteboard and other equipment.

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

**1** design

**2** approach

**3** results



A group of four students are gathered around a table in a classroom or lab, working on a project. A female student with glasses is pointing at a circuit board on the table. A male student is smiling and looking at the project. Another female student is also smiling. A male student in a plaid shirt is standing and looking on. The table is covered with various electronic components, wires, and a breadboard. The background shows a typical classroom setting with a whiteboard and other students.

**Can create ownership of learning physics!**

**1 design**

**2 approach**

**3 results**



A group of four students are gathered around a wooden box containing electronic components. A female student with glasses is using a soldering iron on a circuit board. Another female student is smiling and looking at the work. A male student in a plaid shirt is standing and smiling. A female student in a maroon hoodie is sitting and looking at the work. The background shows a classroom or lab setting with whiteboards and other equipment.


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

**1 design**

**2 approach**

**3 results**



A group of four students are gathered around a wooden box containing electronic components. One student is using a soldering iron on a circuit board. The others are looking on with interest and excitement. The background shows a classroom or workshop setting with whiteboards and other equipment.

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**1** design

**2** approach

**3** results