

A group of people are seated around a white circular table in a meeting room. They are looking at laptops and documents. The room has large windows in the background. The text is overlaid on the image.

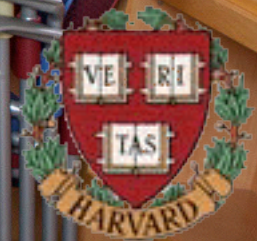
**Before we start, please sign on to Learning Catalytics using a web-enabled device (1 person/device):**

- 1. Go to [learningcatalytics.com/demo](https://learningcatalytics.com/demo)**
- 2. Enter info, click "Start"**
- 3. Join session 123456789**

# Flat space, deep learning



TU Delft  
Delft, Netherlands, 24 November 2015

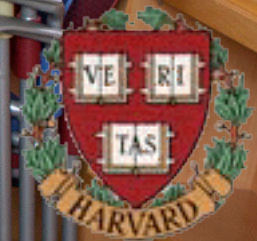


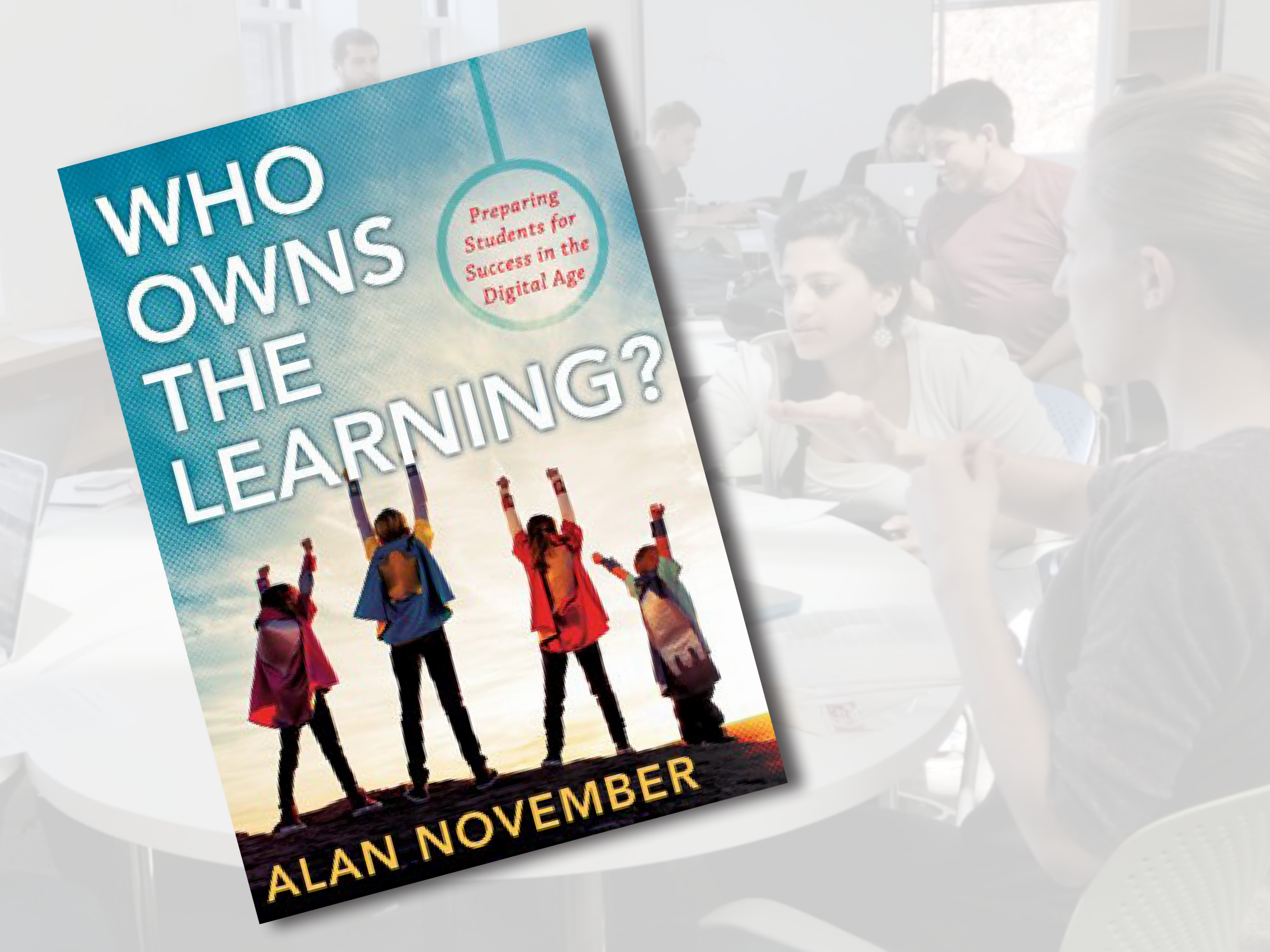
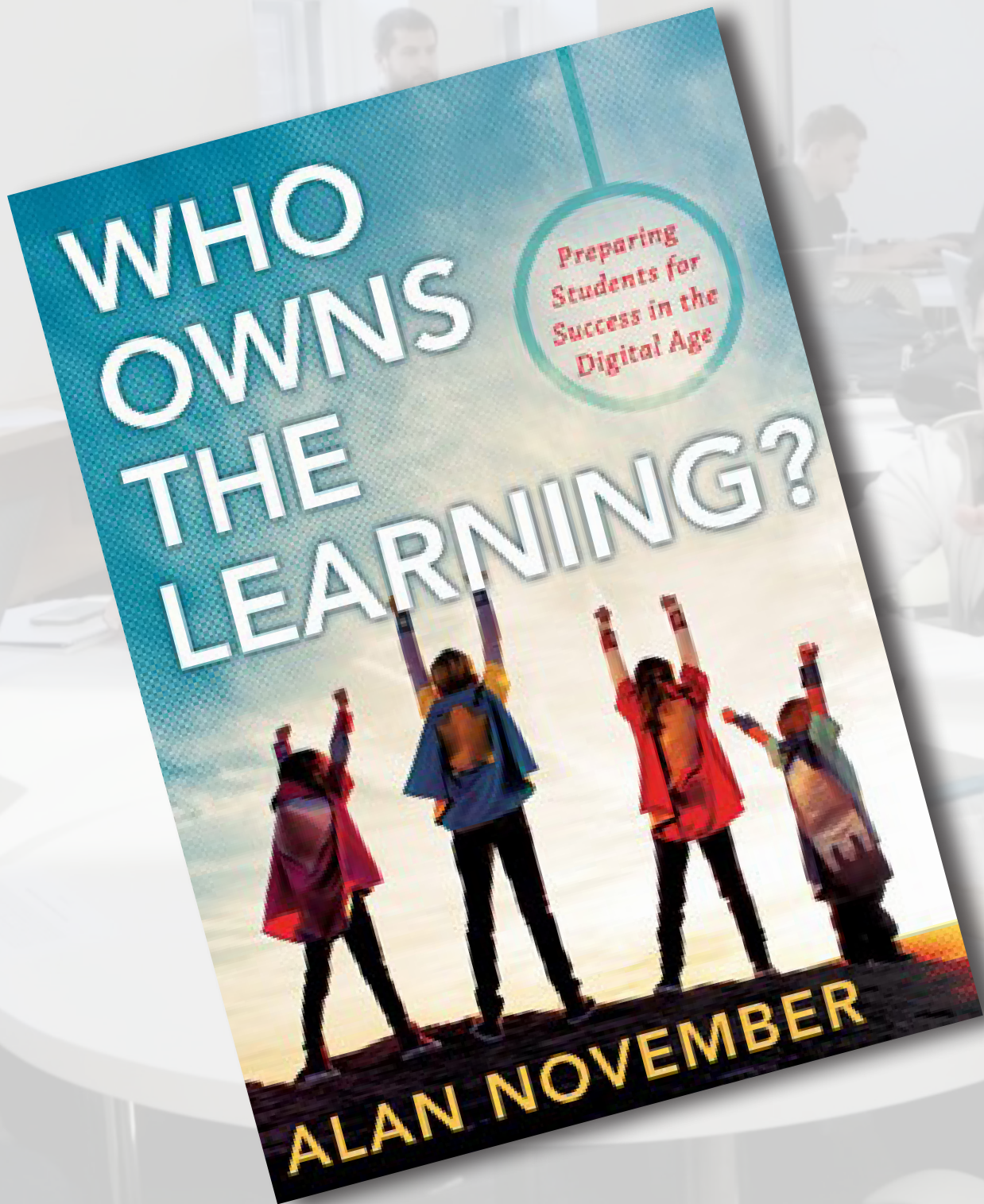
# Flat space, deep learning



A large white oval with a black border containing the Twitter logo and the handle "@eric\_mazur".

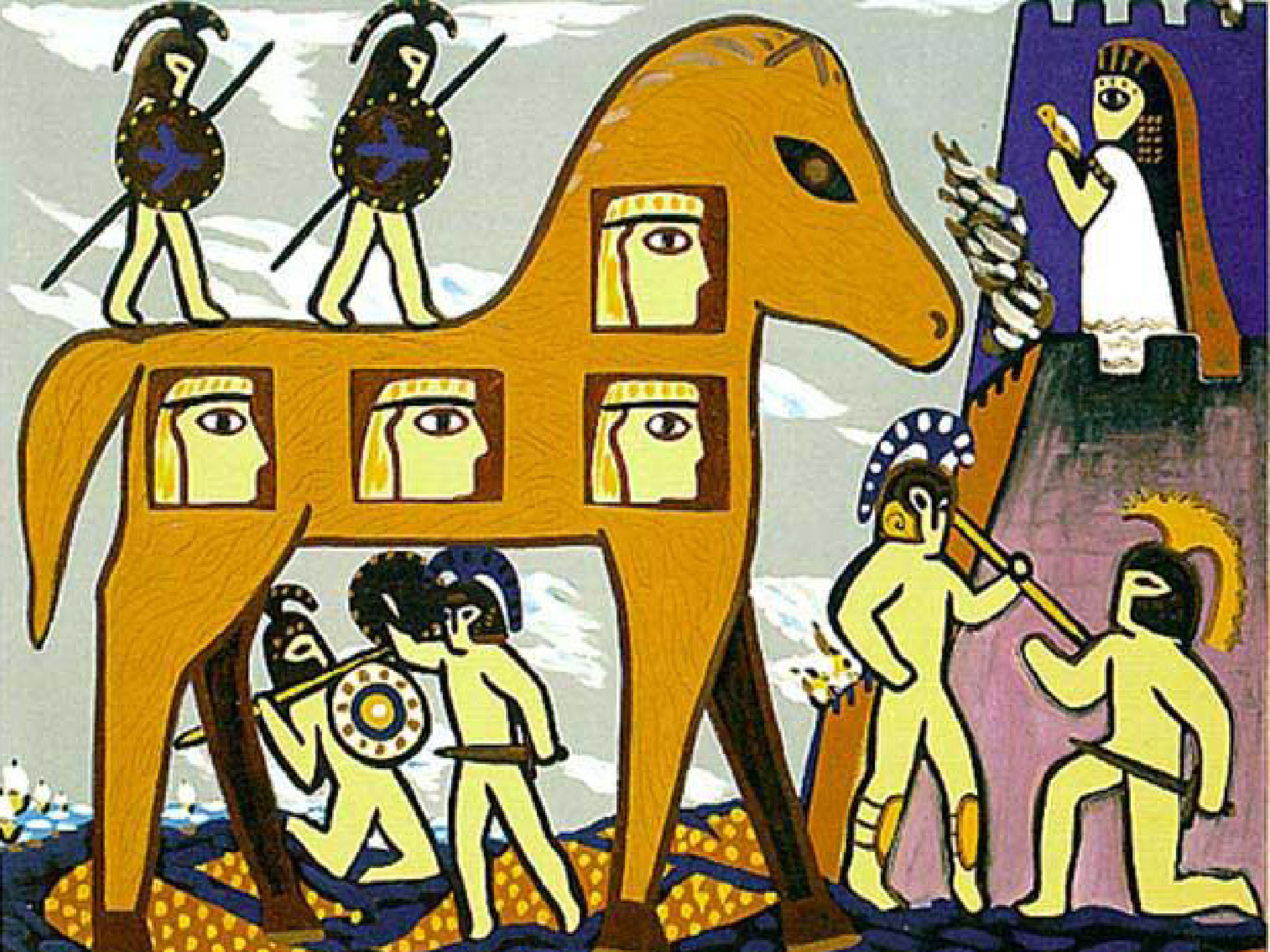
TU Delft  
Delft, Netherlands, 24 November 2015





A group of students in a classroom or lab setting, sitting around a table with laptops, engaged in a discussion. The scene is brightly lit, with large windows in the background. Several students are visible, some looking at laptops, others talking. The overall atmosphere is collaborative and focused.

**Ownership of learning *physics*?**





**team & project-based approach**

A stylized illustration of a brown horse with several human faces on its body, surrounded by various figures in a landscape. The horse is the central focus, with its body decorated with several rectangular panels, each containing a human face with a yellow complexion and a white headband. The horse's head is on the right, and its tail is on the left. In the background, there are two figures with dark skin and yellow clothing, each holding a long staff or spear. To the right of the horse, there is a figure with a white headband and a white garment, holding a staff. In the foreground, there are two more figures with dark skin and yellow clothing, one holding a staff and the other holding a shield. The background is a light blue and white landscape with a purple and blue sky. The overall style is reminiscent of ancient Egyptian art.

# ProTeam Learning







**1** design

**2** approach

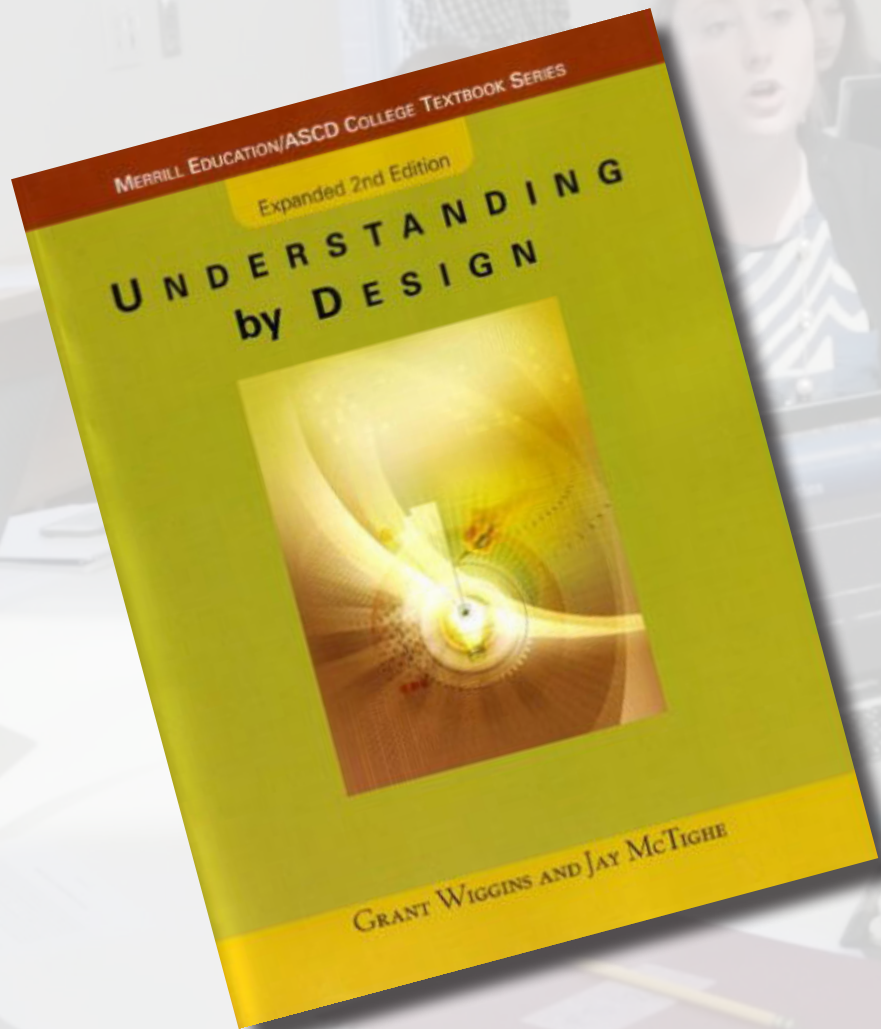


**1** design

**2** approach

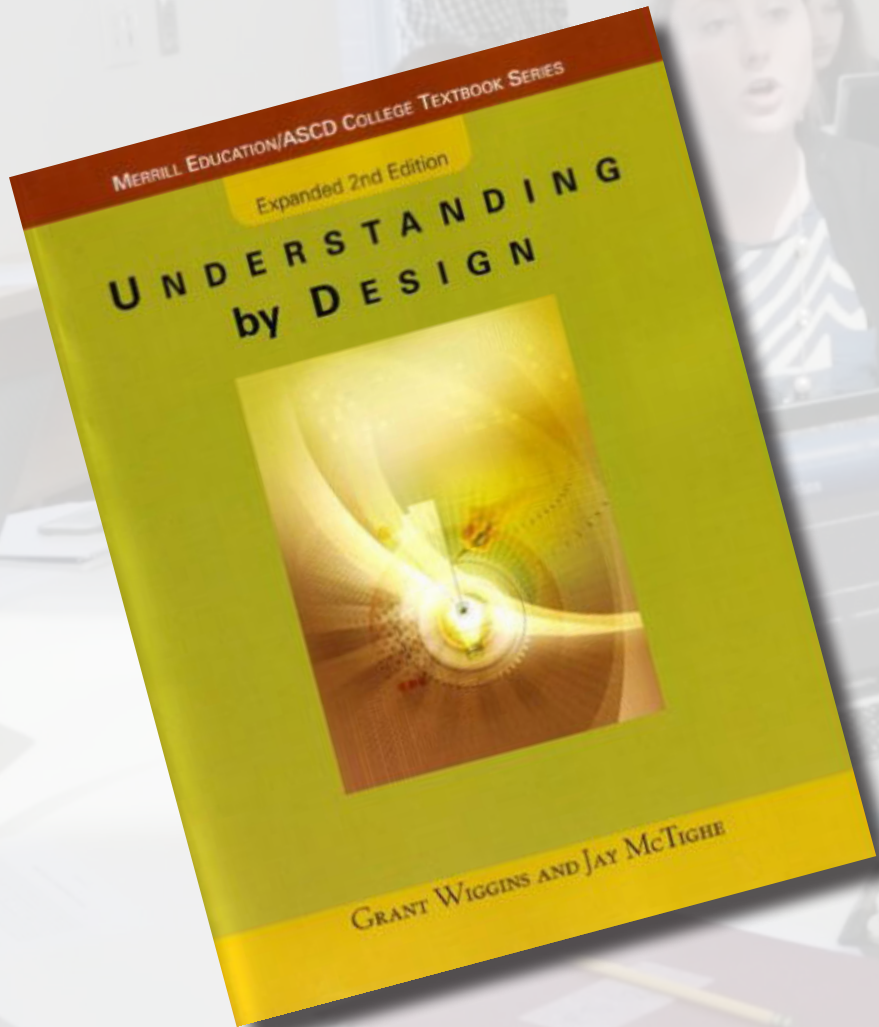
**3** results

## Setting learning goals



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

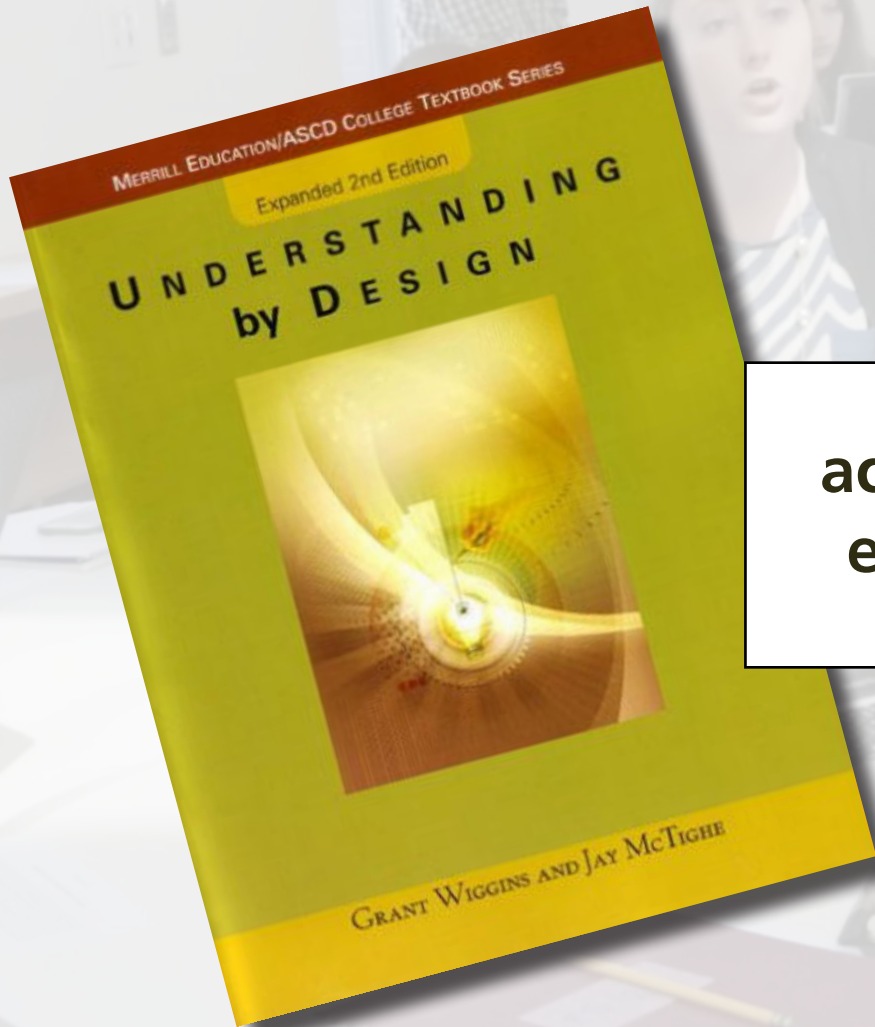
## Backward design



**desired  
outcomes**

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

## Backward design



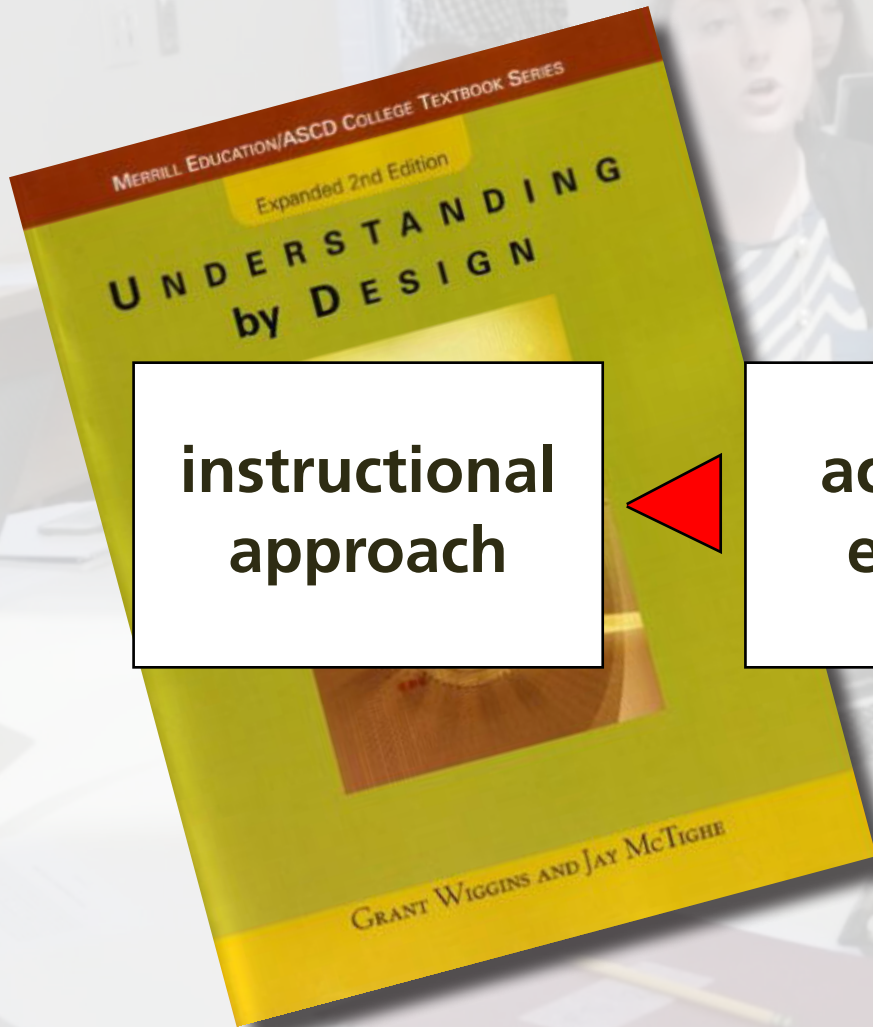
acceptable  
evidence



desired  
outcomes

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

## Backward design



**instructional  
approach**

**acceptable  
evidence**

**desired  
outcomes**



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

also designed to

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

# 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
  - using knowledge of physics to solve problems
  - interpreting them

# 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 world
- using personal attributes and research to tackle problems, especially using a variety of information sources, planning, and performing order of magnitude estimates, use dimensional analysis, symmetries, evaluate limits, and/or relate the problem to cases
- “thinking critically,” both positively and negatively, about any
- 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**





**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**

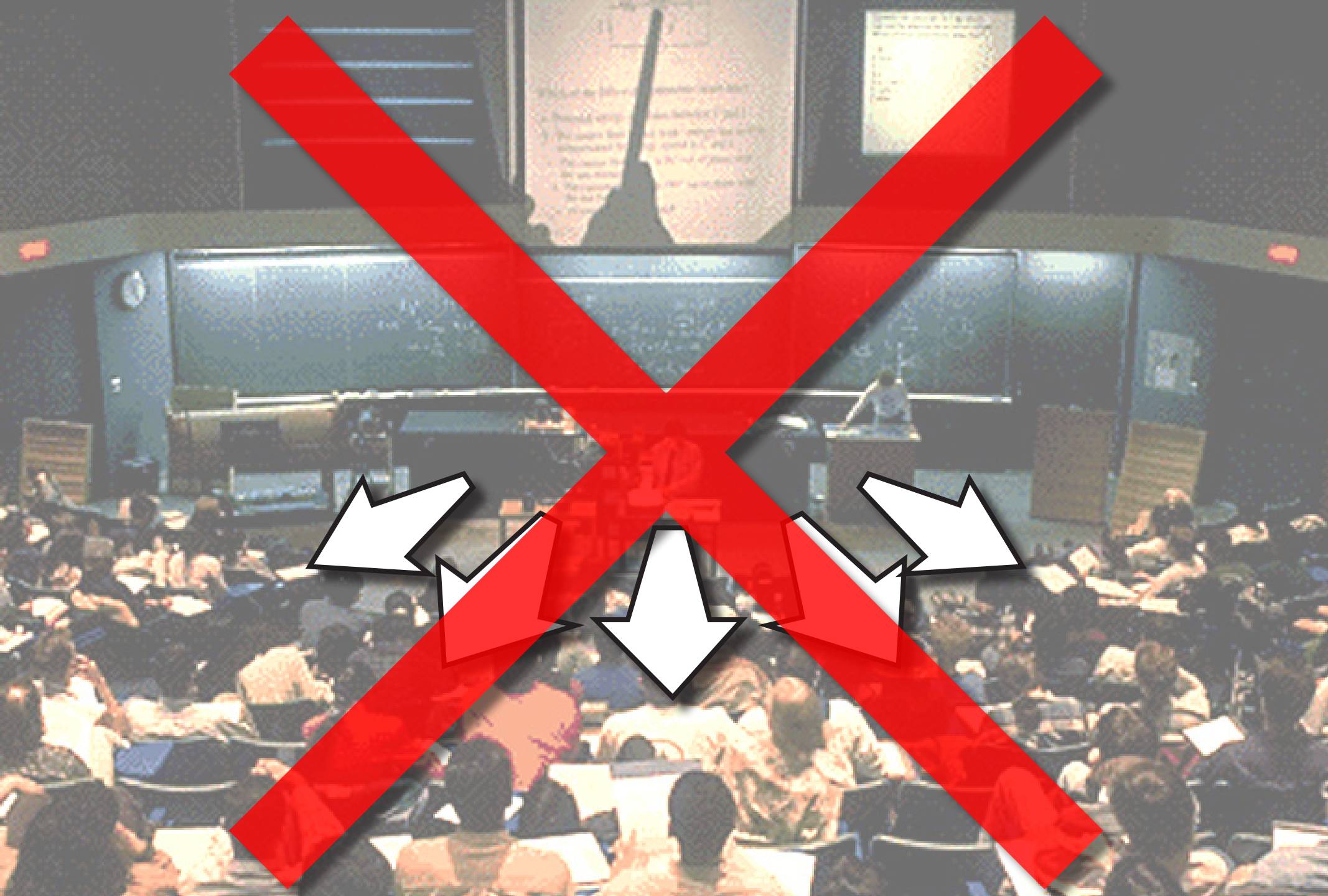


**Three major components:**

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

**1 design**

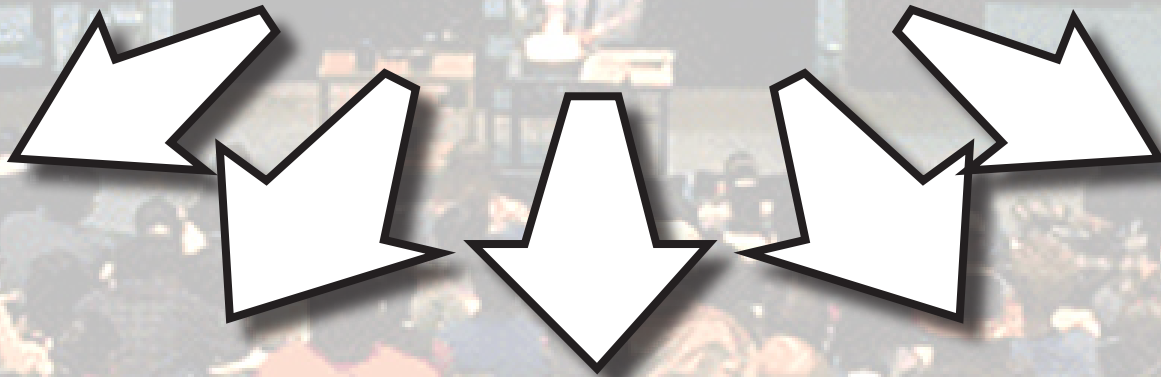
**2 approach**



1 design

2 approach

how to effectively transfer information outside classroom?



**1** design

**2** approach



1 design

2 approach



A person is holding a tablet computer. The screen shows a man in a light blue shirt and tie, seen from the side, writing on a green chalkboard. He is holding a piece of chalk and is in the process of drawing a square with a diagonal line. The word "but..." is written in large, bold, black letters across the middle of the screen. In the background of the tablet screen, there are some faint mathematical formulas and diagrams. The tablet is being held over a desk with an open book, a green apple, and a piece of graph paper. The overall scene is brightly lit and has a soft, warm tone.

**but...**

**1** design

**2** approach

- 
- transfer pace set by video
  - viewer passive
  - viewing/attention tanks as time passes
  - isolated/individual experience



**we're simply moving this outside classroom!**

**1** design

**2** approach



**1** design

**2** approach

PRINCIPLES & PRACTICE OF  
PHYSICS

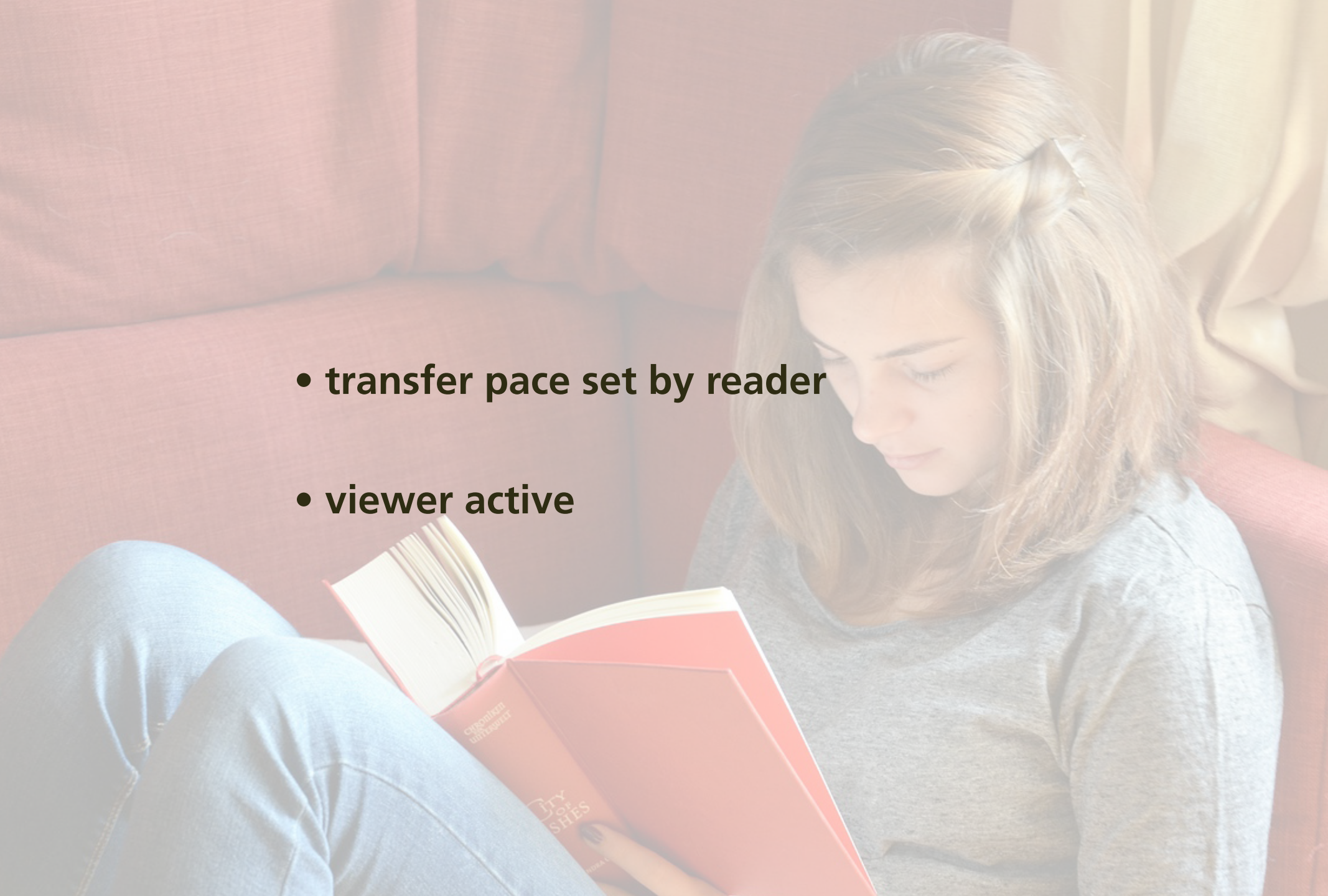
ERIC MAZUR

PRINCIPLES & PRACTICE OF  
PHYSICS

ERIC MAZUR

1 design

2 approach

- 
- transfer pace set by reader
  - viewer active

**1** design

**2** approach



but...

**1** design

**2** approach



**isolated/individual experience &  
no real accountability**

**1** design

**2** approach





**want:**

***every student prepared for every class***

**1 design**

**2 approach**



**want:**  
***every student prepared for every class***  
**(without additional instructor effort)**

**1** design

**2** approach



**Solution**

**turn out-of-class component  
also into a social interaction!**

**1** design

**2** approach

# Perusal

every student prepared for every class

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. An interesting everyday 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 covered by the velocity-versus-time graph, the velocity decrease as the block slides over ice is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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 an air hockey table. The air that flows through the table 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 still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

**In the absence of friction, objects moving along a horizontal track 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.

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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. Given any amount of shove, the distance the block slides depends on the smoothness of the 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 or sticky. This you know from everyday 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 velocity decreases due to friction—the resistance to motion that an object encounters when it moves across a surface. Notice that, during the interval of time shown in the velocity-versus-time graph, the velocity decreases more rapidly on the rougher surface. The velocity of the block over ice is hardly observable. The velocity of the block over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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, would move forever. There is no such thing as a 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 track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, separating the object and the track all but eliminating friction. You can also use wheeled carts with low-friction wheels on a very smooth surface. Figure 4.2 shows low-friction tracks and carts that are commonly encountered in your lab or class. Although there is still some friction both for the track and the carts, this friction is so small that it can be ignored during an experiment. For the track shown in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

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log in through social network



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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 covered by the velocity-versus-time graph, the velocity decrease as the block slides over ice is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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 track—a track whose surface is dotted with little holes through which pressurized air blows. 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 still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

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#### 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 wood, this distance can vary. If the surface is particularly slippery, the block slides for a longer time interval than if the surfaces are rough or sticky. This you know from everyday 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 covered by the velocity-versus-time graph, the velocity decreases as the block slides over ice; it hardly decreases as the block slides over a smooth surface; and it decreases rapidly as the block slides over a rough surface. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*. The rougher the surface, the more quickly the object encounters friction. In the graph, the velocity decreases as the block slides over ice, which is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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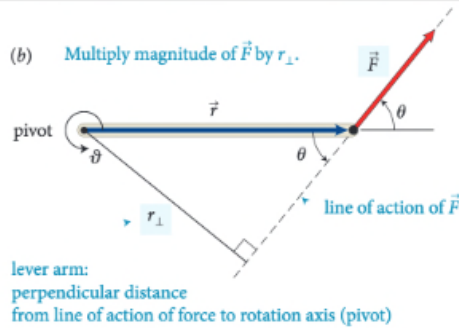
...opens chat window

? No friction at all seems impossible. Isn't there always some friction in any real case. Nov 1 4:41 pm

Enter your comment or question and press Enter

1 design

2 approach



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  $\vec{F}_{pr}^c$  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  $\vec{F}_{pr}^c$  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:

**For a stationary object, the sum of the torques is zero.**

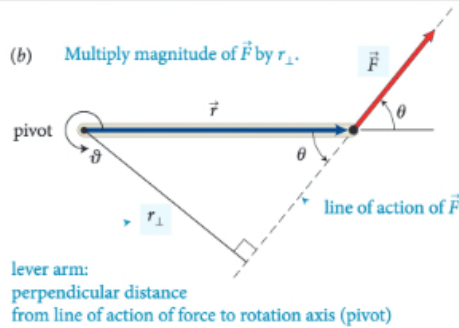
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CONCEPTS



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1 design

2 approach

# email notifications

Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

21 minutes ago, you asked this question on Perusall:

No friction at all seems impossible. Isn't there always some friction in any real case?

Brian Lukoff just responded to the question by saying:

Right - I think there will always be some friction due to the second law of thermodynamics.

If this helps your understanding, click the button below. If you want to respond, simply reply to this email to post to Perusall.

[View conversation](#)

[This comment helps my understanding](#)

1 design

2 approach

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

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

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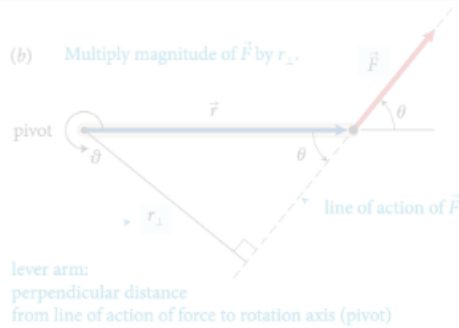
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# use combination of

# intrinsic and extrinsic motivation drivers

1 design

2 approach



# rubric-based assessment

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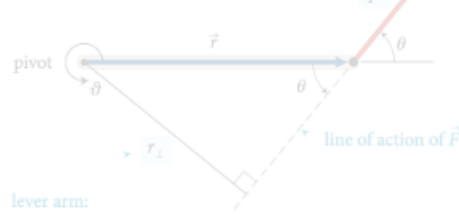
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lever arm:  
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from line of action of force to rotation axis (pivot)

- quality (thoughtful reading & interpretation)

- quantity (minimum 10)

- timeliness (before class)

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I don't understand how... factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able... think about the... direction separately. So... distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.

This is a great question. To further explore on this... can think of this in terms of... torque is  $\tau = r \times F$ , with  $r$  being the level arm distance and  $F$  being force. We know that force is a vector vector from previous chapters, and in regards to "r" it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

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 sign of the torques, we find  $r_1(F_1 + F_2) - (r_1 + r_2)F_2 = r_1F_1 - r_2F_2$ . 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:

For any stationary object, the sum of the torques is zero.

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 where a force is applied, 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  $\vec{F}_2$  are equal in magnitude, and the magnitude of  $\vec{F}_3$  is half as great. Forces  $\vec{F}_1$  and  $\vec{F}_2$  are perpendicular to the lever.

- On the very left, we see th...
- It's interesting that the white ...
- Is the reference frame i... 2
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- In this class, we always emp...
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- How small is small? As ... 3
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- (a) The change in rotationa...
- As we saw earlier in the chap...

# rubric-based assessment

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 or sticky. This you know from everyday 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 covered by the velocity-versus-time graph, the velocity decrease as the block slides over ice is hardly observable. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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.

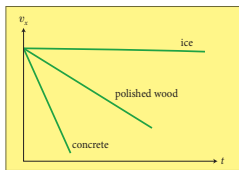
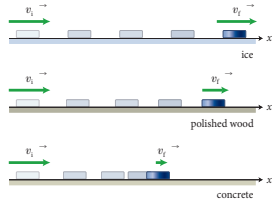


Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.



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 track—a track whose surface is dotted with little holes through which pressurized air blows. 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 still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track 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.

4.1 (a) Are the accelerations of the motions shown in Figure 4.1 constant? (b) For which surface is the acceleration largest in magnitude?

## 4.2 Inertia

We can discover one of the most fundamental principles of physics by studying how the velocities of two low-friction carts change when the carts collide. Let's first see what happens with two identical carts. We call these standard carts because we'll use them as a standard against which to compare the motion of other carts. First we put one standard cart on the low-friction track and make sure it doesn't move. Next we place the second cart on the track some distance from the first one and give the second cart a shove toward the first. The two carts collide, and the collision alters the velocities of both.

### ANNOTATION

**Alan:** I remember, in high school, being amazed at how quickly carts could travel on these tracks - air would blow up through these tiny holes evenly distributed along the length of the track and the cart would essentially float on the air and consequently - the cart would move very quickly with the slightest push.

**Bob:** Although there is no way to create frictionless surfaces, I find it interesting that we consider experiments "in the absence of friction." In a way, this relates back to Chapter 1.5 where we talked about the importance of having too little or too much information in our representations. In some cases, the friction is so insignificant that we ignore it (simplifying our representation).

**Claire:** Does this only apply to solid surfaces? I feel as if a substance that floats on water either has negligible or very little friction.

**Alan:** Why is this? I don't get it.

**David:** believe this applies to almost every surface, although I'm not sure if water would count more as resistance than friction. Anyways, the best example I could think of would be a surf board. If people who were paddling in the same direction as the waves experienced no resistance, they would continually speed up, and eventually reach very high speeds. However, in reality if they were two stop paddling they'd slow down and only the waves would slowly push them to shore.

**Alan:** Is it possible to have a surface, in real life, that inflicts NO friction at all?

**Erica:** Doesn't air resistance factor into this at all? It seems that it is not enough for there to be only an absence of friction for something to keep moving without slowing down. What about some other opposing force - like air resistance? Or is air resistance just another example of friction?

**Bob:** The key word is "appreciably". In the absence of friction, the cart does not slow down appreciably but still would a little due to air resistance

**Alan:** a) yes b) concrete has the acceleration of greatest magnitude

**Erica:** I would think that they are not constant because if we think of the formula  $F=ma$ , the force of friction is different in every case so that would change the acceleration value (where mass would stay the same since it's assumed that the object is the same in each situation).

**Claire:** As a theoretical question about inertia, if an object in motion will stay in motion, but is being affected by friction, will it slow down perpetually but remain in motion, or will it eventually stop completely due to the friction? Just curious.

**Alan:** With friction everything slows down to a half at one point or another. It is only if an outside force acts on the object if that object will maintain motion after the effects of inertia.

**Claire:** Standard carts: identical carts in mass, shape, etc. I like this notion of standard carts, it provides a good baseline to compare other motion and to understand the concepts before building on it.

**Alan:** Great visual representation of friction! It is interesting how this compares the velocity of things on different surfaces

**Bob:** The rougher the surface, the more friction between the surface and the wooden block, and thus acceleration will be greater.

### EVALUATION

No substance. Does not demonstrate any thoughtful interpretation of the text. **0**

Annotation interprets the text and demonstrates understanding of concepts through analogy and synthesis of multiple concepts. **2**

Possibly insightful question but does not elaborate on thought process, nor demonstrate thoughtful reading of the text. **1**

Question does not explicitly identify point of confusion nor demonstrates thoughtful reading or interpretation of the text. **0**

Response demonstrates a thoughtful explanation with a claim substantiated with a concrete example **2**

Question exhibits superficial reading, but does not exhibit any interpretation of the textbook. **1**

Demonstrates thoughtful interpretation of the text by refuting a statement through a counter example. **2**

Responds to the question by thoughtfully interpreting the text **2**

Annotation not backed up by any reasoning or theoretical assumptions. No evidence of thoughtful reading of text. **0**

Response backed up with reasoning that demonstrates an interpretation of the text and applies understanding of concepts **2**

Profound question that goes beyond the material covered in the textbook. **2**

Demonstrates some thought but does not really address Claire's question **1**

No substance. Does not demonstrate any thoughtful reading. **0**

No substance. Does not demonstrate any thoughtful reading. **0**

Interprets the graph and applies understanding of both the concept of friction, how a v-t graph corresponds to acceleration and the relationship between the force of friction and acceleration **2**

CONCEPTS

## ANNOTATION

## EVALUATION

**Alan:** I remember, in high school, being amazed at how quickly carts could travel on these tracks - air would blow up through these tiny holes evenly distributed along the length of the track and the cart would essentially float on the air and consequently - the cart would move very quickly with the slightest push.

No substance. Does not demonstrate any thoughtful interpretation of the text.

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**Bob:** Although there is no way to create frictionless surfaces, I find it interesting that we consider experiments "in the absence of friction." In a way, this relates back to Chapter 1.5 where we talked about the importance of having too little or too much information in our representations. In some cases, the friction is so insignificant that we ignore it (simplifying our representation).

Annotation interprets the text and demonstrates understanding of concepts through analogy and synthesis of multiple concepts.

2

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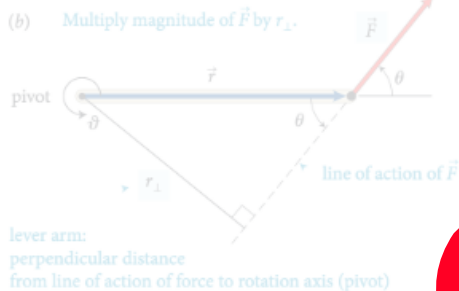
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Response demonstrates a thoughtful explanation with a claim substantiated with a concrete example

2

# rubric-based assessment



- quality (thoughtfulness & in-depth reasoning)

**over 20,000 annotations!**

1 design

2 approach

# rubric-based assessment

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



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

- quality (thoughtful reading & interpretation)

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

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 net torque 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. This result is important to the study of statics. In general, for any stationary object, 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:

For a stationary object, the sum of the torques is zero.

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 where a force is exerted, 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  $\vec{F}_2$  are equal in magnitude, and the magnitude of  $\vec{F}_3$  is half as great. Forces  $\vec{F}_1$  and  $\vec{F}_2$  are perpendicular to the lever.

# how do you process all of that??

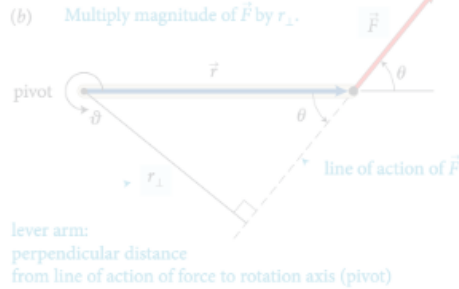
- quantity (minimum)
- timeliness (before class)
- distribution (not clustered)

1 design

2 approach



# rubric-based assessment



- quality (though future re-evaluation/interpretation)

**fully automated**

**you process all of that??**

**assessment**

- timeliness (before class)

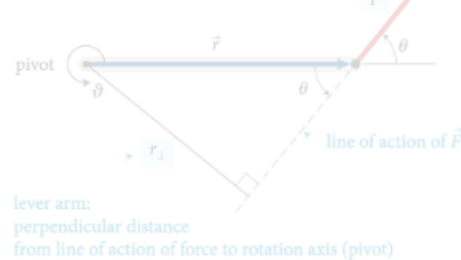
- distribution (not clustered)

1 design

2 approach

# fully automated assessment

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



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

- specialized machine learning algorithm

- assesses intellectual content

- exceeds intercoder reliability

I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like you would just know some sort of direction from the force vector.

I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. For example, in a graph, you can explain how to choose the sign.

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is  $\tau = r \times F$ , with  $r$  being the level arm distance and  $F$  being force. We know that force is a vector vector from previous chapters, and in regards to " $r$ " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force.

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 any point 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. This result is true for any rod that is not rotating about any point, and so the sum of the torques must be zero about any point. In general we can say:

For a stationary object, the sum of the torques is zero.

For a stationary object we can choose any reference point to calculate the torques. We can choose a reference point that is not on the object. For example, 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?

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- Is the reference frame i... 2
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- As we saw earlier in the chap...

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[blurred]		3	3	

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1 design

2 approach

# gradebook

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Total number of annotations **16**

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Total number of annotations submitted on time **11**

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Average quality of top 10 annotations submitted on time **1.80**  
2 = demonstrates thorough and thoughtful reading and insightful interpretation of the reading, 1 = demonstrates reading, but no (or only superficial) interpretation of the reading, 0 = does not demonstrate any thoughtful reading or interpretation

---

Distribution of annotations **3.8**  
0 = clustered, 5 = evenly distributed throughout assignment

---

Assignment score **1**  
scores range from 0 to 3

1 design

2 approach

Perusall AP50 Fall 2015 » Chapter 12 Group 1's comments Page 284 Eric Mazur

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

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

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# connect pre-class and in-class activities

- lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.
- I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction.
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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. This is not surprising, because the rod is in equilibrium and the sum of the torques must be zero about any point. In general we can say:

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- While I believe I underst...
- (a) The change in rotationa...
- As we saw earlier in the chap...

1 design

2 approach

## Confusion report for Chapter 24

## right hand rule (11 questions)

- JB Can someone in simpler terms explain the right- hand rule? +1
- WJ Is there another way, besides the right hand rule, to find the direction of the magnetic field with a current? 2
- SB Using the right hand rule, I believe the answer is D. Is that correct? 3  
Show more...

## direction magnetic field (8 questions)

- CP Why is it that the magnet field points away from the north pole and towards the south pole? When on the previous page it stated that the direction of the magnetic field is the direction that the north pole of a compass needle points. +2
- AB How can you determine which direction the magnetic field will point towards? +1
- KH So whichever way the north pole faces is the direction of the magnetic field but that doesn't always mean its pointing true north? +1  
Show more...

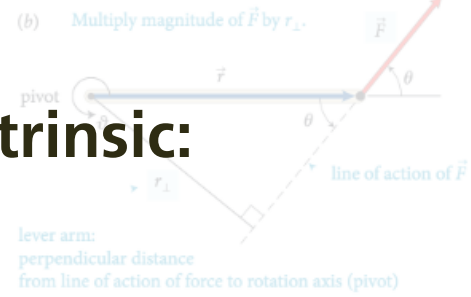
## earth magnetic field (6 questions)

- CP Does that mean that the compass will be distracted from the Earth's magnetic field and use the magnetic field that the current of the wire gives off? 2
- AK Can someone explain why this type of bacteria knows what direction the earth's magnetic fields are facing? 3
- J Does the circular loop of current have any similarities with the look of the earths magnetic field? They kind of look similar to me. 3  
Show more...

# motivating factors

## Intrinsic:

- social interaction



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### Example 12.2 Torques on lever

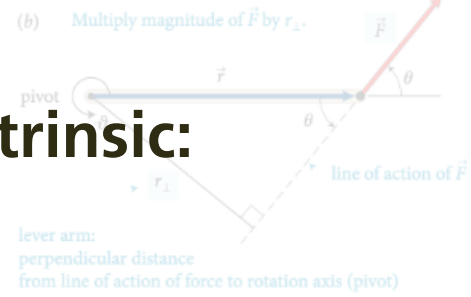
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# motivating factors

## Intrinsic:

- social interaction
- tie-in to in-class activity



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# motivating factors

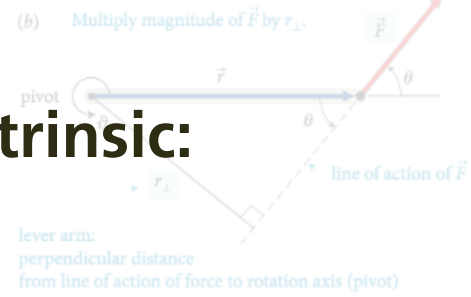
## Intrinsic:

- social interaction

- tie-in to in-class activity

## Extrinsic:

- assessment (fully automated)



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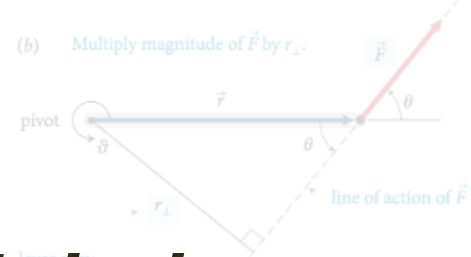
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# motivating factors



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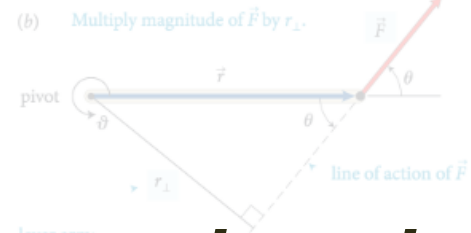
**"I think the Perusall app and annotation system is way better than just reading a textbook normally... I've been reading for almost four hours now and haven't gotten bored"**

**Harvard student**

**1 design**

**2 approach**

# motivating factors



*"It makes the book fun to read..."*

*All the other students on my floor are disap-*

*pointed their Prof isn't using Perusall because*

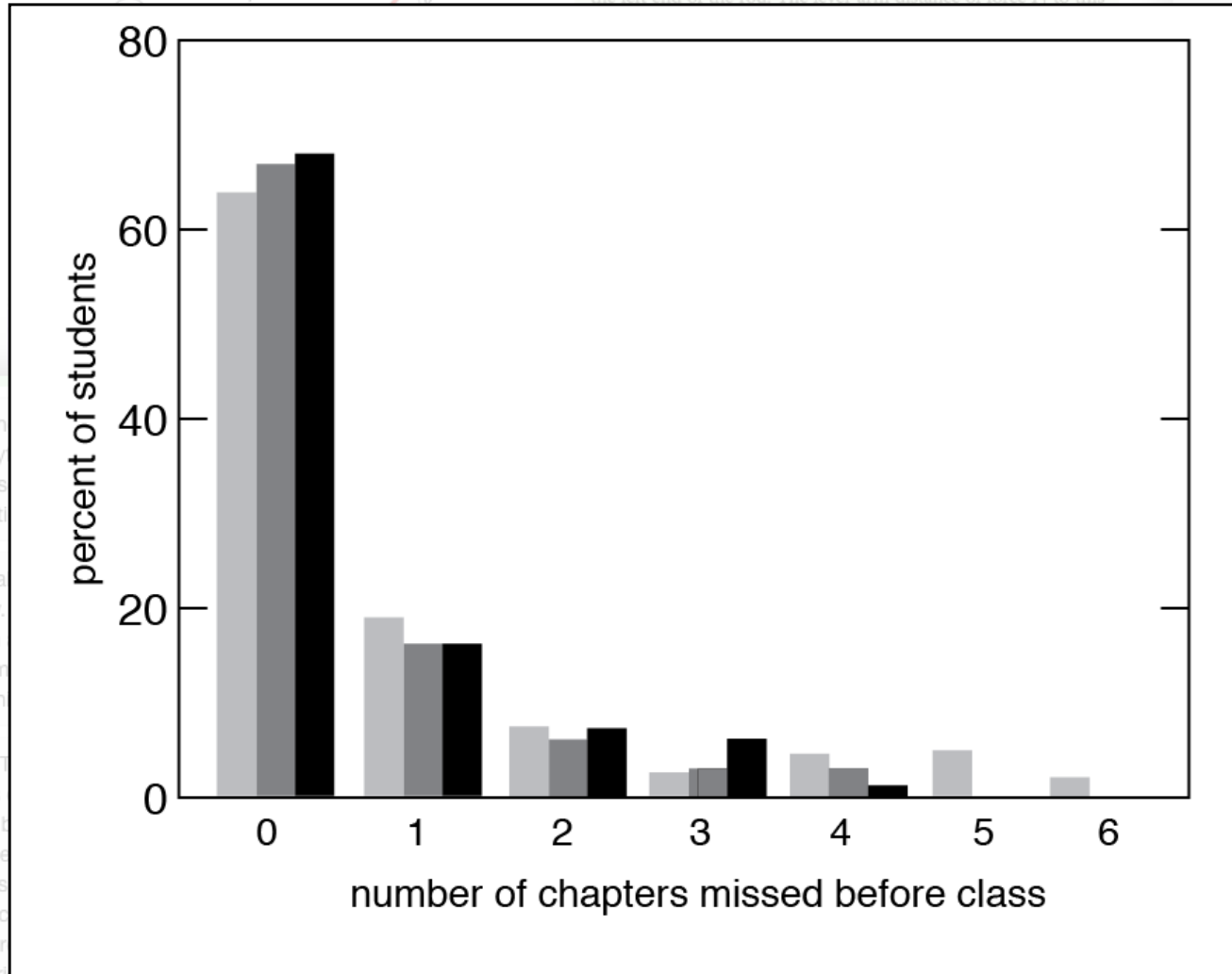
*they don't read the book."*

**Ohio State student**

**1 design**

**2 approach**

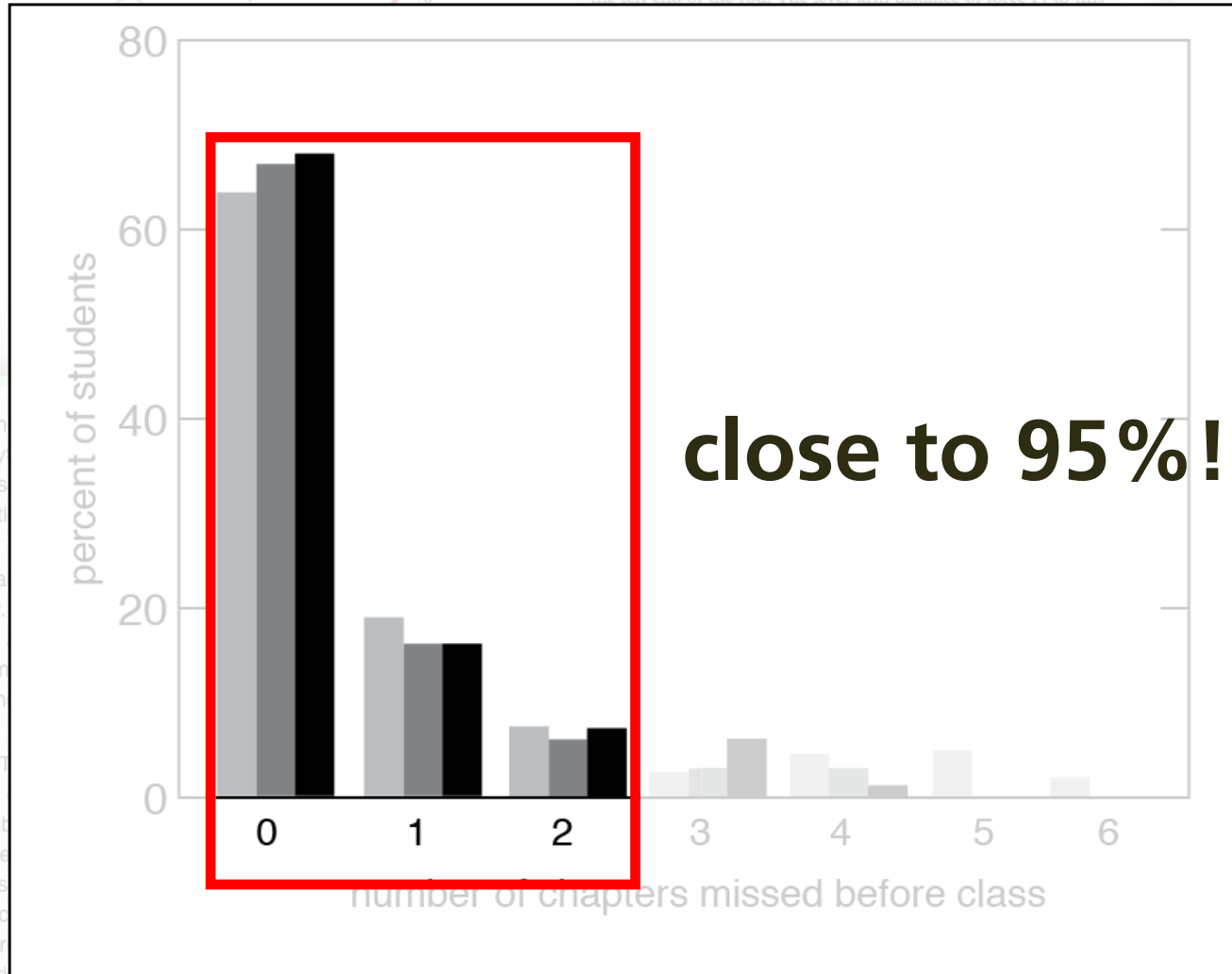
# participation



1 design

2 approach

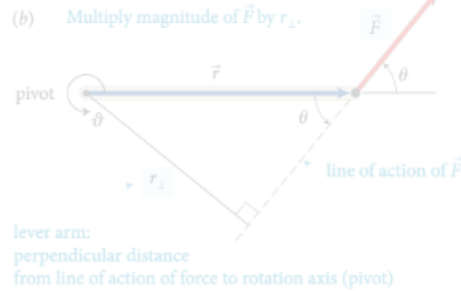
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1 design

2 approach

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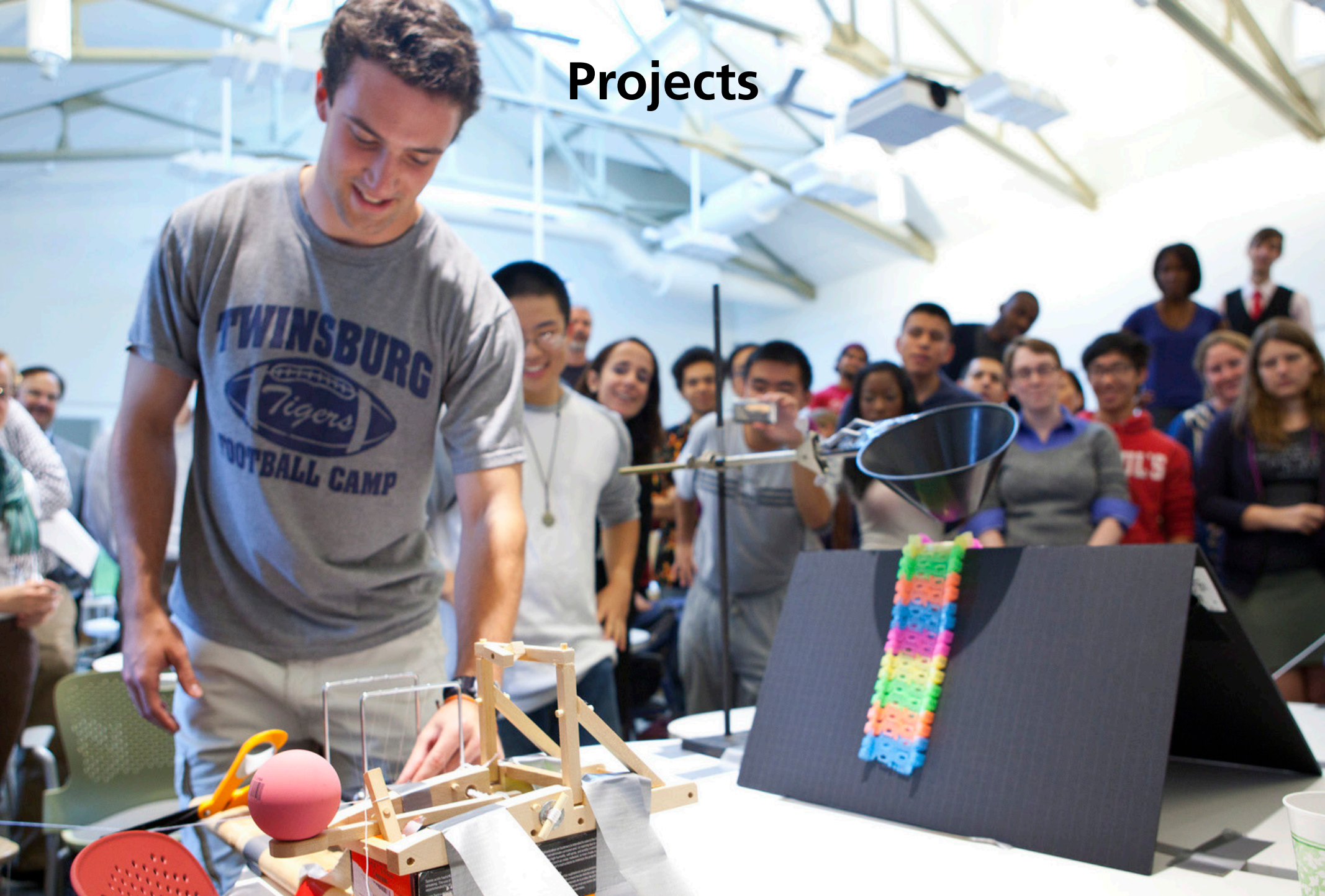
# every student prepared for every class

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1 design

2 approach

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

# Projects

## Milestones:

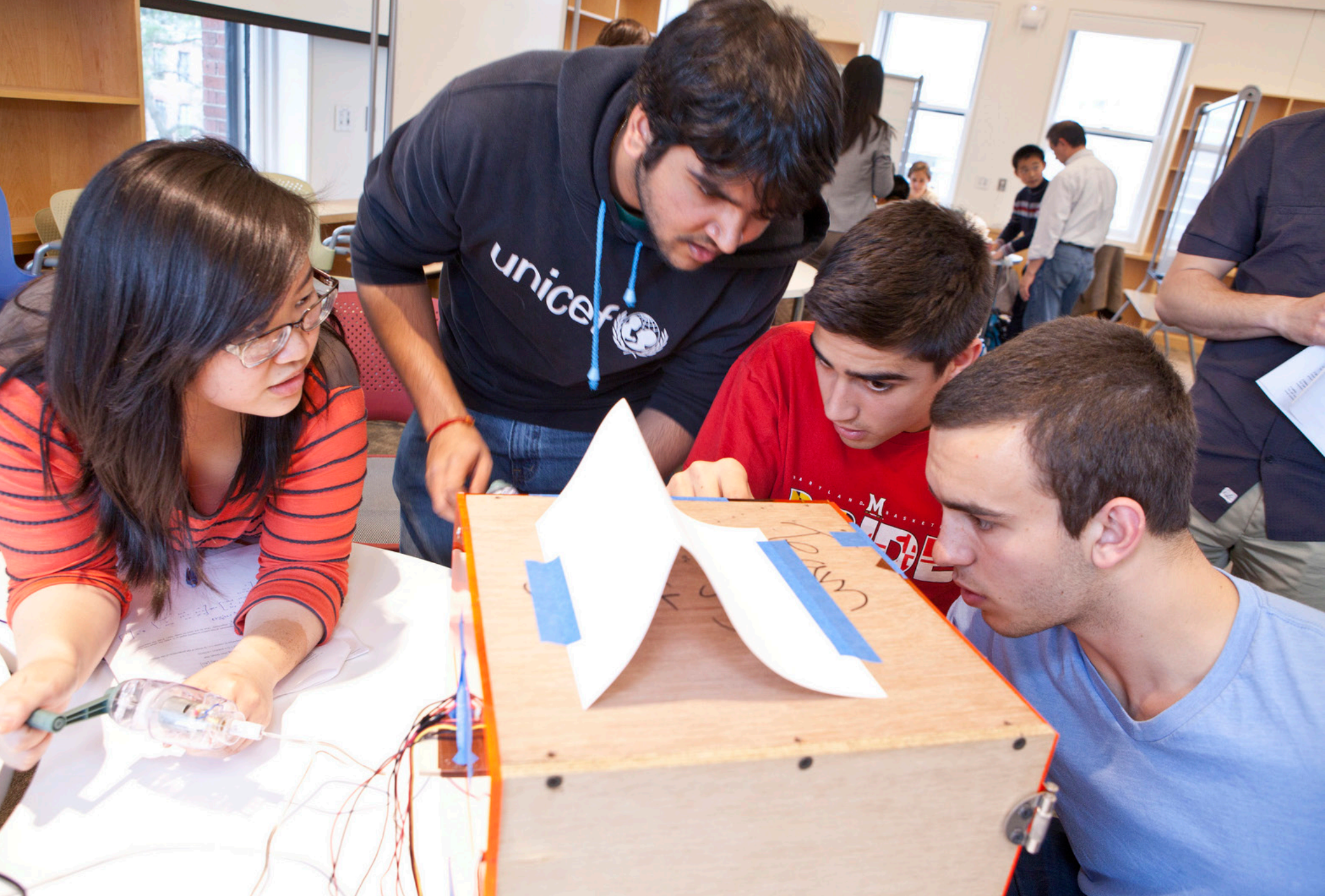
- **team contract (at beginning)**
- **proposal (+1 week)**
- **fair (+3 weeks)**
- **report (+1 week +3 days for revision)**
- **team, peer, and self assessment (at end)**



**1** design

**2** approach





**1** design

**2** approach

A group of students are gathered around a table in a classroom, working on a project. A male student in a black hoodie with 'unicef' written on it is leaning over the table, looking at a white paper structure. A female student with glasses is on the left, and a male student in a blue shirt is on the right. They are all focused on their work. The background shows other students and classroom windows.

**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

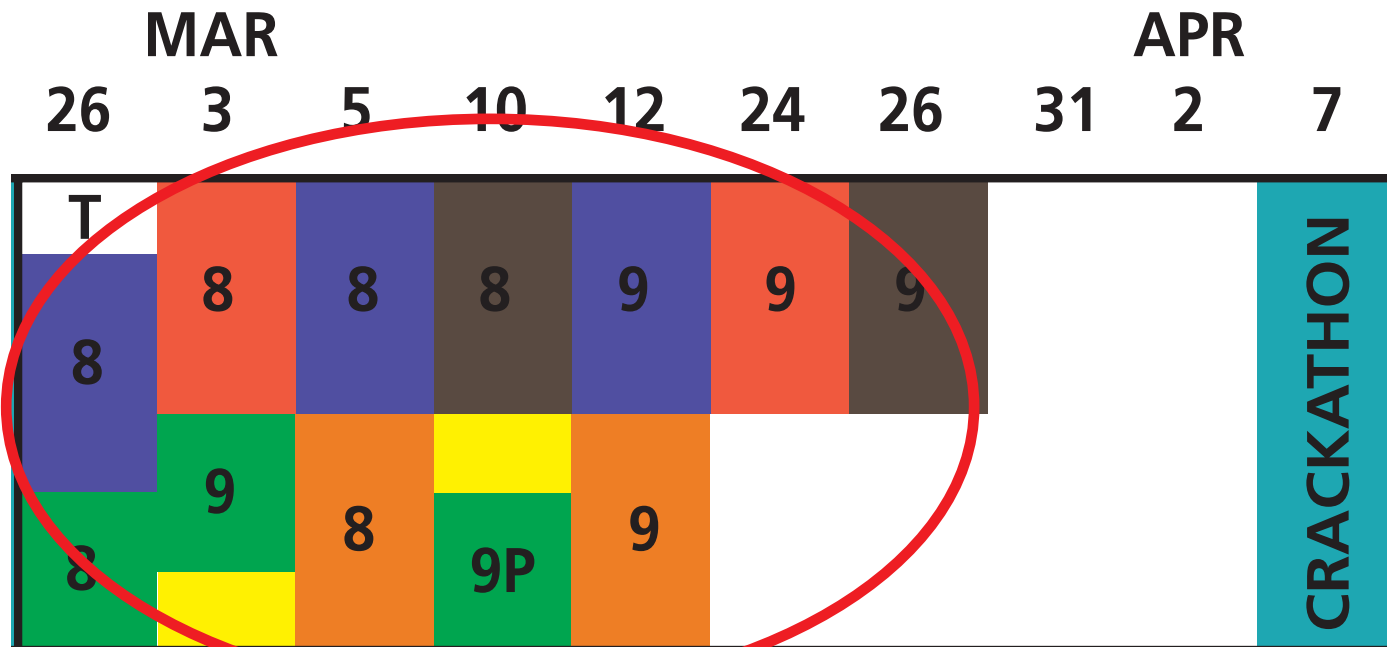




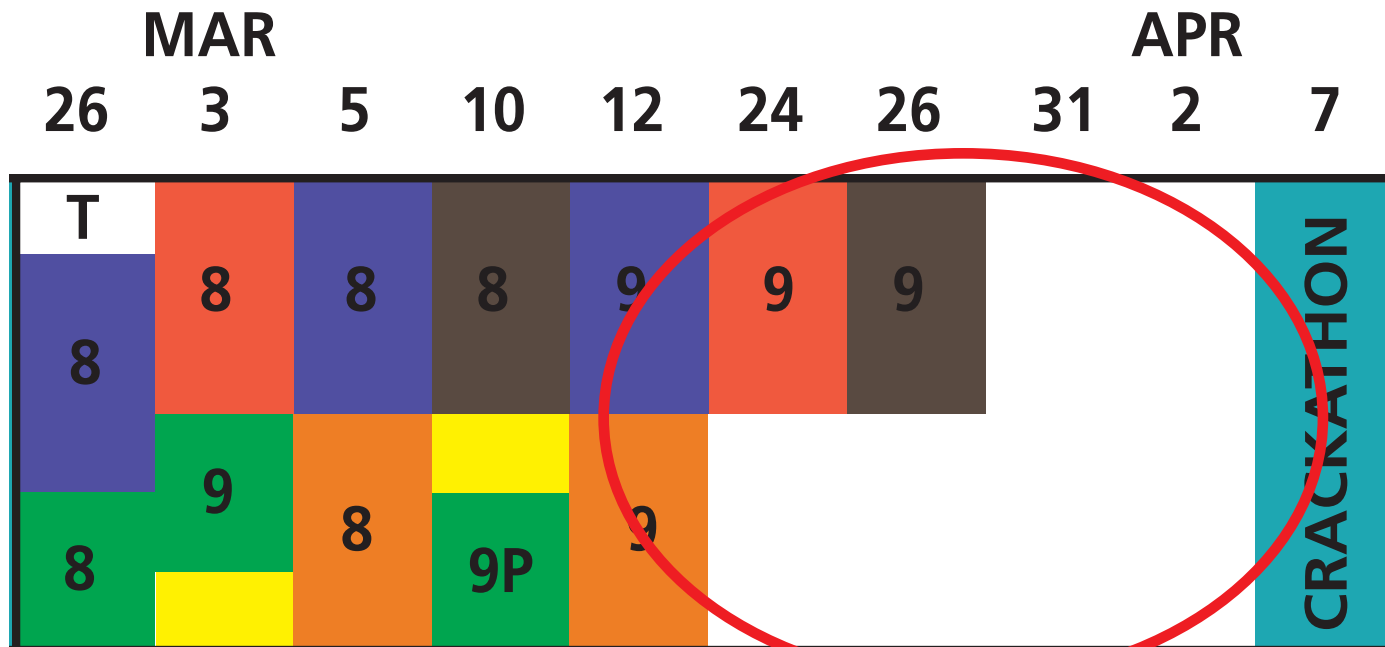


# In-class activities

2/3 scaffolded, guided



# In-class activities



1/3 unguided

1 design

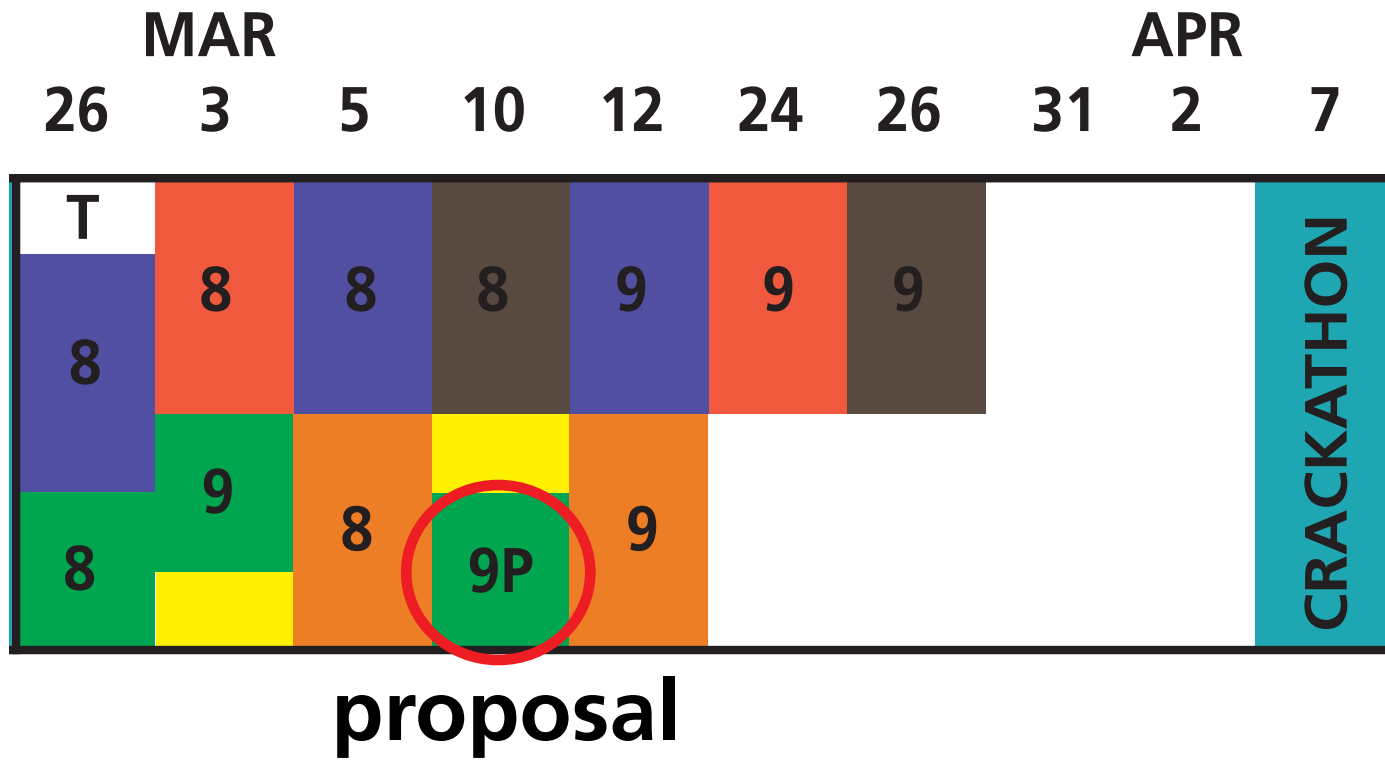
2 approach

# In-class activities

## team intro



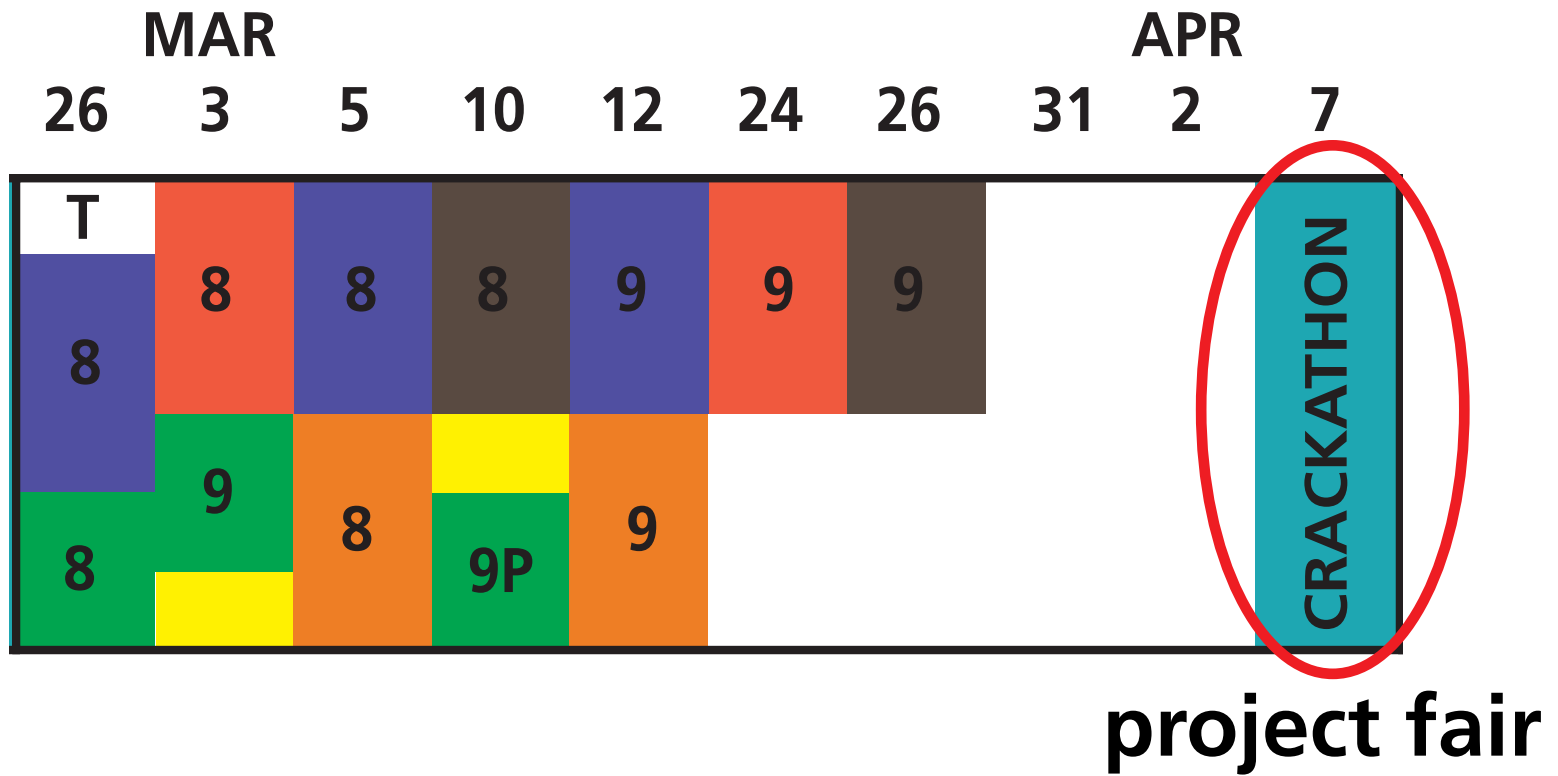
# In-class activities



1 design

2 approach

# In-class activities



1 design

2 approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



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  
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bring device

# In-class activities

understand

LC: Learning Catalytics 90 min



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Answer alone  
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Answer again



bring device

Tutorial 60 min



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bring device

1 design

2 approach

## learning | catalytics

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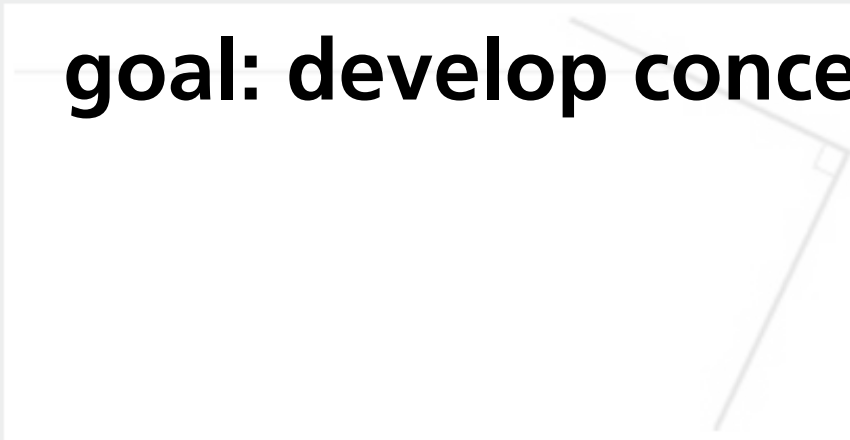
13

14

15



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

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

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



feedback &amp; support

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



A group of people are seated around a white circular table in a meeting room. They are looking at laptops and documents. The room has large windows in the background. The text is overlaid on the image.

**Before we start, please sign on to Learning Catalytics using a web-enabled device (1 person/device):**

- 1. Go to [learningcatalytics.com/demo](https://learningcatalytics.com/demo)**
- 2. Enter info, click "Start"**
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optics i

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

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



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



feedback & support

1 design

2 approach

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6 7 8 9 10 11 12 13 14 15

perpendicular mirrors as shown below.

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[feedback & support](#)



1 design

2 approach

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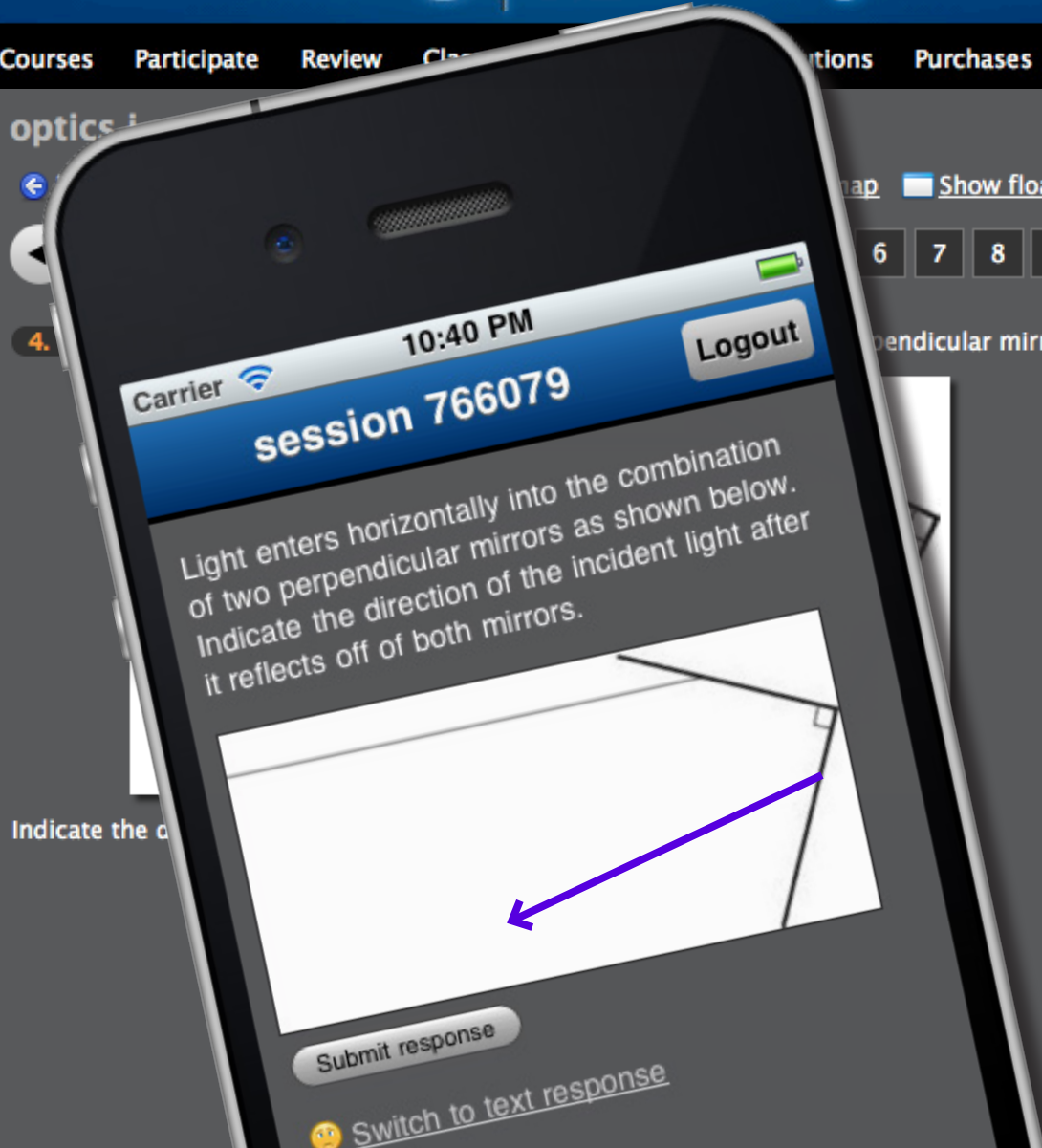
[Map](#)  [Show floating session ID](#) [Edit](#) [Delete](#)

6 7 8 9 10 11 12 13 14 15

perpendicular mirrors as shown below.

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[feedback & support](#)



1 design

2 approach

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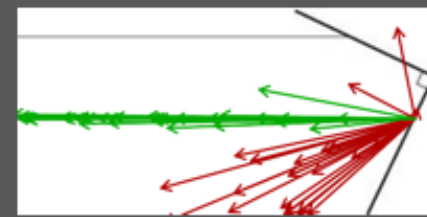
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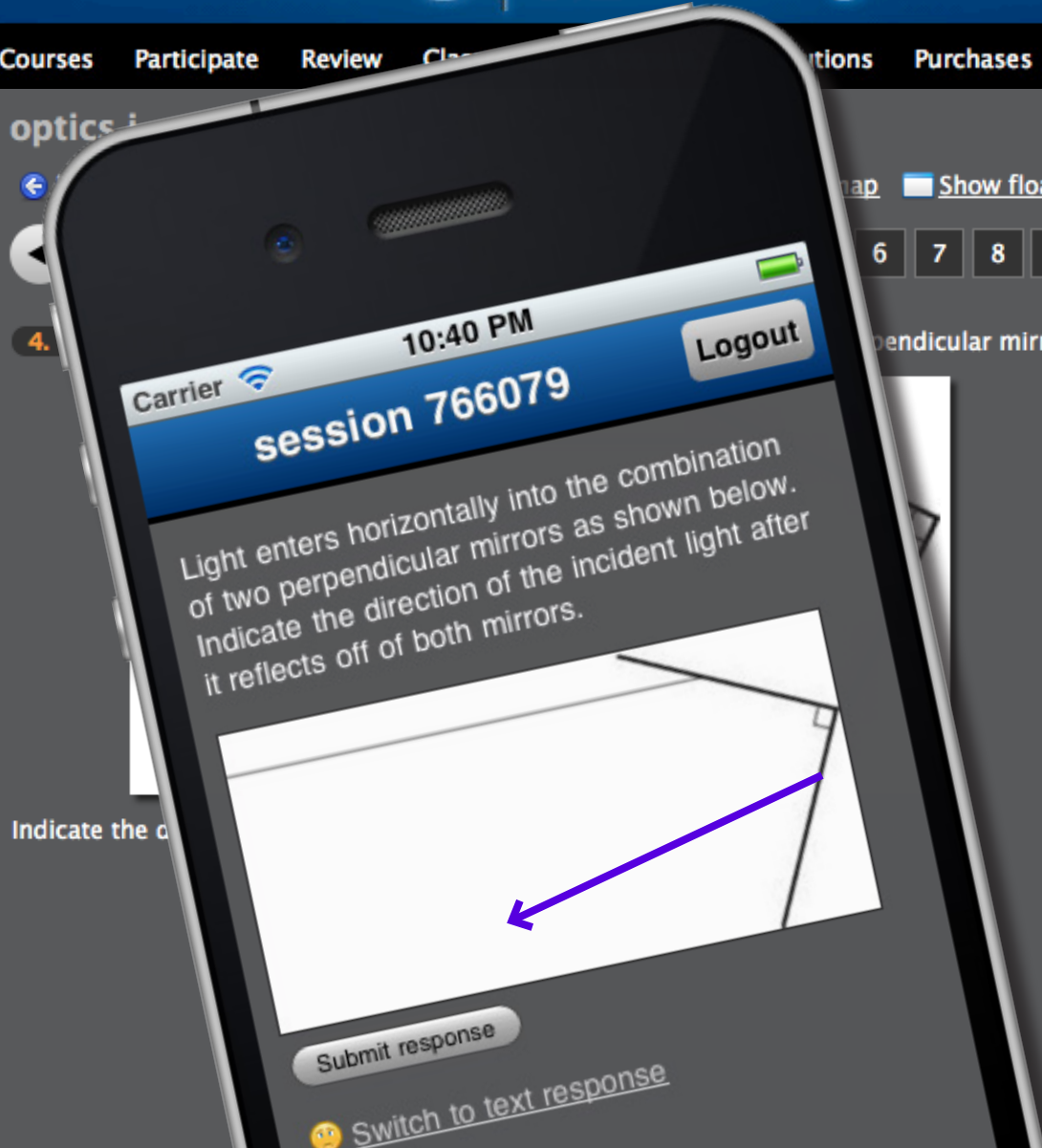
[Deliver](#) [Show all results](#)

Round 1 ✖  

57 responses, 58% correct



 [feedback & support](#)



**1** design

**2** approach

# learning | catalytics

Courses Participate Review Classifications Purchases Users Tour Help

current session: **766079** | 69 students

map  Show floating session ID Edit Delete

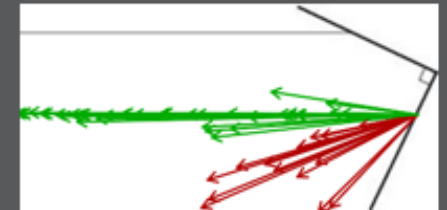
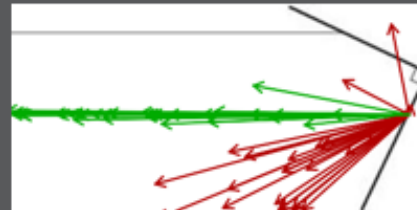
6 7 8 9 10 11 12 13 14 15

perpendicular mirrors as shown below.

Deliver Show all results

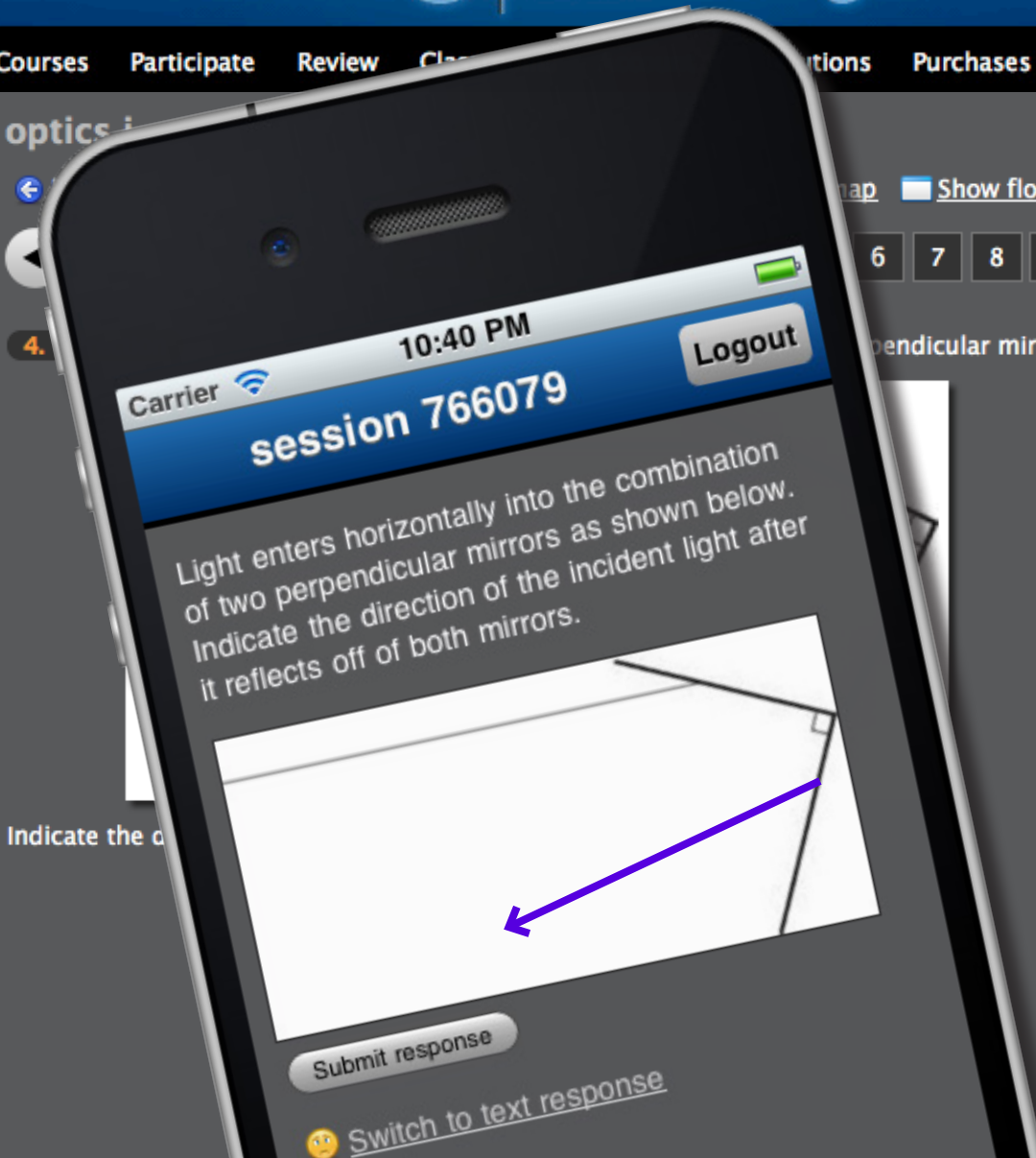
Round 1   
● 57 responses, 58% correct

Round 2   
● 51 responses, 73% correct



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

feedback & support



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

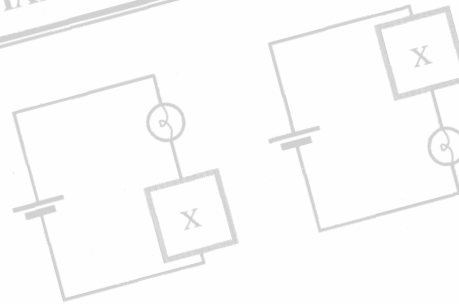


bring device

# A MODEL FOR CIRCUITS PART 2: POTENTIAL DIFFERENCE

## I. Current and resistance

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



How do the bulbs compare in brightness? Explain.

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

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



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

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

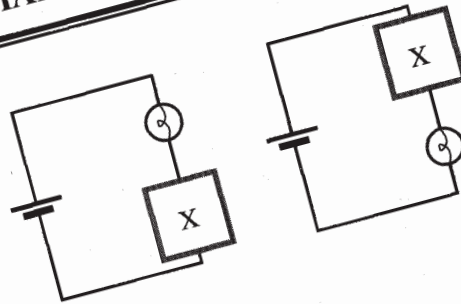
McDermott et al., *Tutorials in Introductory Physics* (Prentice Hall, 2002)



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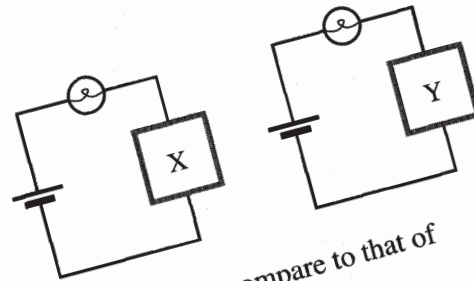
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McDermott et al., *Tutorials in Introductory Physics* (Prentice Hall, 2002)

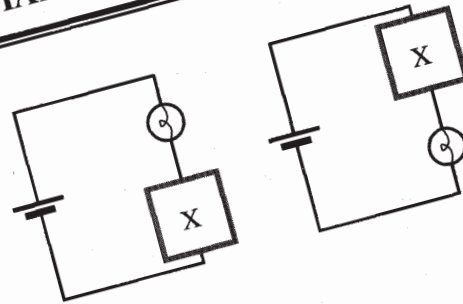


brightness

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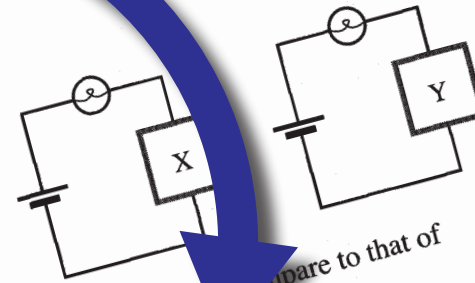
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McDermott et al., *Tutorials in Introductory Physics* (Prentice Hall, 2002)



brightness

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities  
Develop individual strategy  
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



evaluate

Problem Set & Reflection 90 min



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

RAA: Readiness Assurance Activity 90 min



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



AP50 Fall 2014

## Estimation Activity

Th Oct 9

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

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

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

# goal: develop qualitative reasoning skills

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

1 design

2 approach

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AP50 Fall 2014

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

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# In-class activities

understand

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Answer alone  
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Answer again



Tutorial 60 min



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apply

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evaluate

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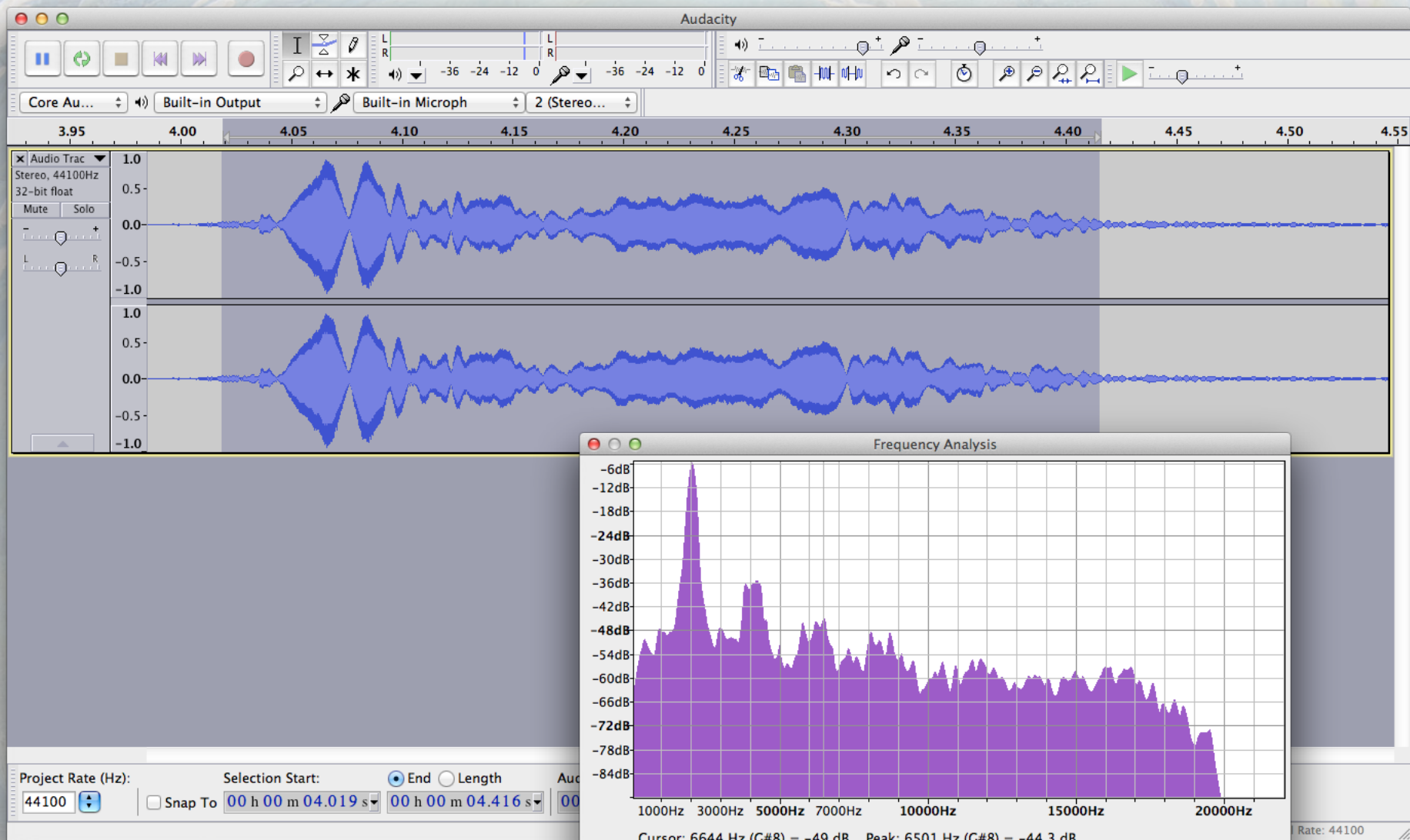


**goal: develop experimental skills**

**1** design

**2** approach





1 design

2 approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



bring device

Tutorial 60 min



Work on worksheet with team  
Explore concepts  
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bring device

evaluate

Problem Set & Reflection 90 min



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RAA: Readiness Assurance Activity 90 min



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bring device

1 design

2 approach

AP50b Fall 2013

## Problem Set 1

due W Feb 6 in class

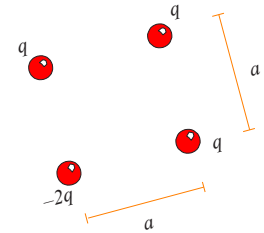
Instructions: as we need to quickly scan your work so we can return it before the end of class, please:

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

1. **Ink-Jet Printing.** In an inkjet printer, letters are built up by squirting drops of ink at a piece of paper from a rapidly moving nozzle. The ink drops leave a nozzle and travel toward the paper, passing through a charging unit that gives each drop a positive charge by removing some electrons from it. The drops then pass between parallel deflecting plates where there is a uniform vertical electric field (to be discussed in Chapter 23). Estimate the number of atoms present in a droplet of ink.

2. **Levitation.** One possible way of levitating an object might be to use the forces associated with charged objects. For example, you have two charged particles that are fixed on a vertical pole 0.5 m apart. The lower one has a fixed charge of  $-3.0 \mu\text{C}$ . The upper one has a charge  $q_A$  that can be adjusted. A 30-mg particle with a charge of  $+8.0 \mu\text{C}$  can move freely on the pole below the other two. You wish to levitate (i.e., float) this particle at a distance of 1.0 m below the lower fixed charge. What should the adjustable charge  $q_A$  be to achieve this feat?

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



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

AP50b Fall 2013

## Problem Set 1

due W Feb 6 in class

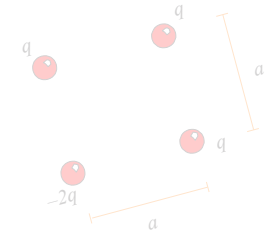
Instructions: We need to quickly scan your work so we can return it before the end of class, please:

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- 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

- 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 a small amount of ink. The drops then pass between parallel deflecting plates where there is a uniform vertical electric field. The drops then pass between two parallel plates (Chapter 23). 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?

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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  $\rho$ . 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 mass density  $\rho$  that would prevent them from being held together by their own gravitational attraction.



## 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 only for the team's benefit.

**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.

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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 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.

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**1 design**

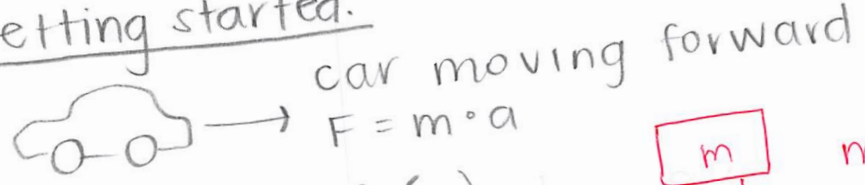
**2 approach**



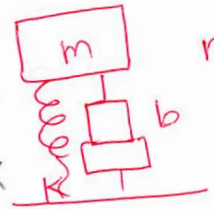
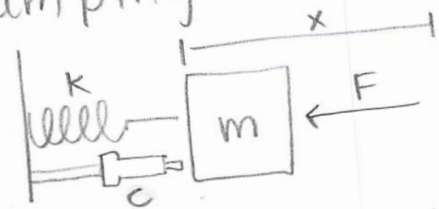
# Applied Physics 50a

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

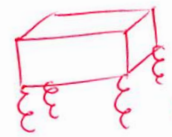
Getting started.



Damping coeff (c)



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



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

Create a plan.

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

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

Execute plan.

$$F = m \cdot a$$

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

Translational eq =  $\sum F_x = 0$

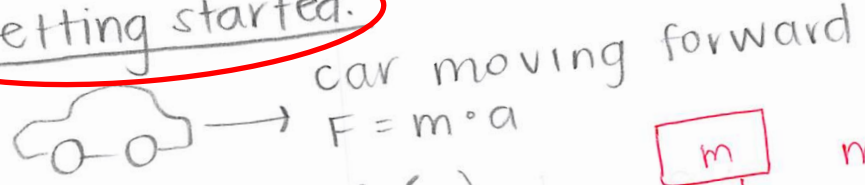
- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s

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

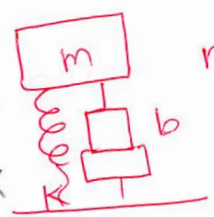
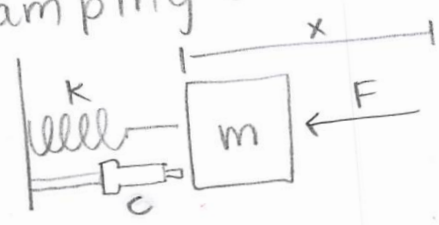
Applied Physics 50a

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

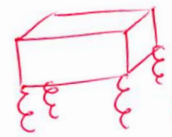
Getting started.



Damping coeff (c)



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



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

Create a plan.

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

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

Execute plan.

$$F = m \cdot a$$

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

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

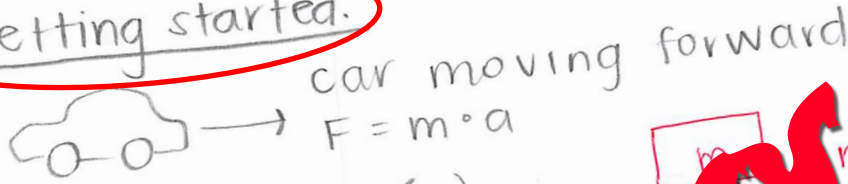
Translational eq =  $\sum F_x = 0$

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

# 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 =  $490.5 \text{ N/m}$   
 $x$  (distance compressed) =  $0.1 \text{ m}$

Execute plan.

$$F = m \cdot a$$

- Estimate mass of mid-size car =  $1500 \text{ kg}$
- Est. accel. of midsize car:  $5 \text{ m/s}^2$

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

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

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). After 15 minutes, your team will be provided with a solution set 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.

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 next 15 minutes, your team will be provided with a solution sheet 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.

**in class:**

**mark up/improve solutions**

**complete reflection sheet**

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

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

② continued.

c) Maximum transverse speed.

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

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

Execute plan.

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

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

• amplitude = 0.2 cm

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

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

~~$0.5\pi = \frac{2\pi}{T} \Rightarrow T = 4 \text{ sec} = \text{period}$~~   $\frac{1}{50}$   
 $50 \text{ sec}^{-1} = \text{Hz}$   $0.02 \text{ sec}$

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

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

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

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

$T = \frac{1}{f}$

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

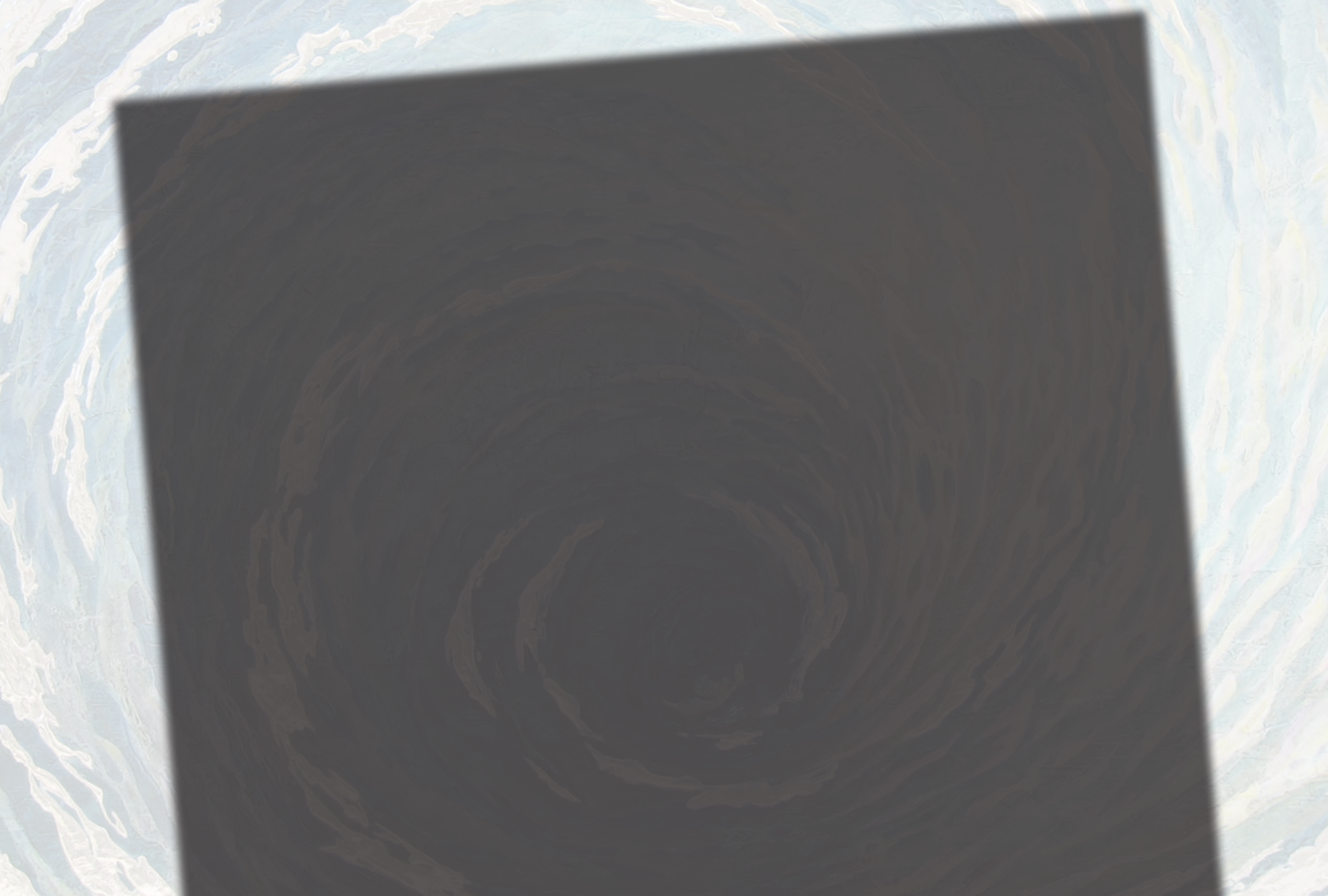
• wave number =  $\frac{2\pi}{\lambda} = \frac{1}{2} \pi = 0.5\pi$

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

(shifted right)

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

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



**1** design

**2** approach

## 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 the conditions before I really understand it. Similarly with the damping coefficient estimation problem - I started off in the wrong direction and never really fixed where I went wrong. I also need to review some calculus. The last time I really understood calculus was high school and it's becoming an issue.





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



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

**1** design

**2** approach

# In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question  
Answer alone  
Discuss in team  
Answer again



Tutorial 60 min



Work on worksheet with team  
Explore concepts  
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities  
Develop individual strategy  
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team  
Take measurements  
Analyze data  
Carry out simulations



evaluate

Problem Set & Reflection 90 min



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

RAA: Readiness Assurance Activity 90 min



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





**1** design

**2** approach

A group of students in a classroom setting, some working on laptops and others in discussion. The image is overlaid with a semi-transparent white filter.

**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;

**expression question**

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

Submit response

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



$6x - 6$

Brian Lukoff

$6x$

Brent Jones

$6x - 6$

Beth Sawyer

$6x^2 - 6$

Kip Harmon

### expression question

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

Submit response

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

**1 design**

**2 approach**

A photograph of a classroom with several students. In the foreground, a student in a white shirt is seen from behind, looking towards a whiteboard. To the right, a student in a blue jacket is pointing towards the whiteboard. In the background, another student is sitting at a desk with a laptop. The whiteboards contain technical diagrams and equations, including a circuit diagram with a 17V source and a 4Ω resistor, and several equations like  $-5(I_1) = 0$ ,  $4I_1 + I_2(3) = 0$ ,  $(I_1) - I_2 = 0$ ,  $-2I_1 - 18I_2 - 4I_3 = 0$ ,  $-20 - 11I_2 = 0 \rightarrow (I_2) = -20/11$ , and  $4 - I_2 = 4 - (20/11)$ .

---

**round**

**credit**

---

**individual**

**50%**

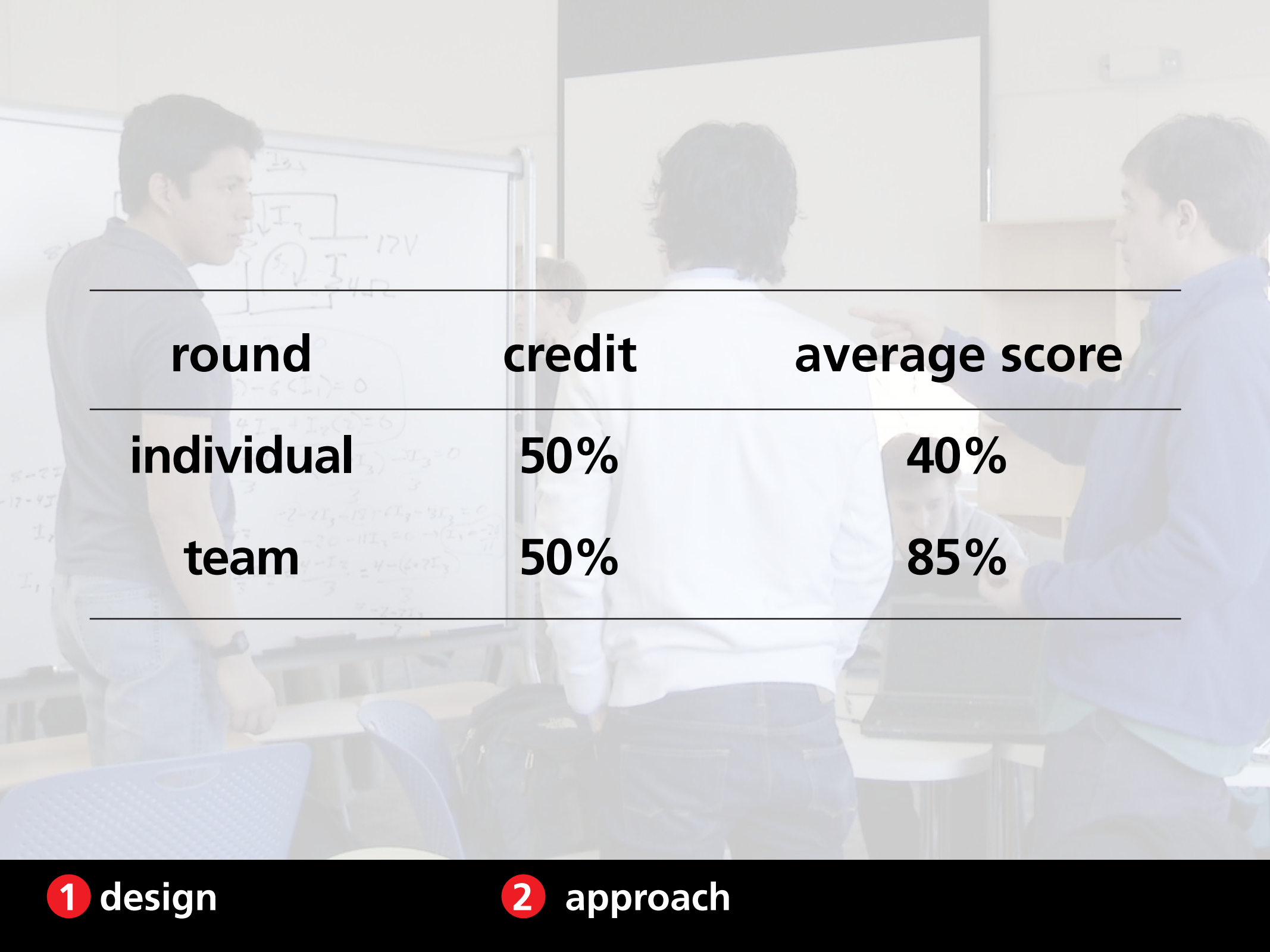
**team**

**50%**

---

**1 design**

**2 approach**



---

**round**

**credit**

**average score**

---

**individual**

**50%**

**40%**

**team**

**50%**

**85%**

---

**1 design**

**2 approach**

# Self, Peer, and Team assessment



1 design

2 approach

# Team, Peer, and Self assessment

## Self Assessment

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

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

--	--

# Team, Peer, and Self assessment

## 4. Relative contributions

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

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

# Team, Peer, and Self assessment

## Assessment Report

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		

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
1. Participate fully in team activities	4.67	4
2. Come to class prepared for team activities	4.67	4
3. Communicate effectively and respectfully with team members	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

# 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

# Assessment

self-directed learning

learning goals

team work

professionalism

# Assessment

Scale: 3-0

self-directed learning

learning goals

team work

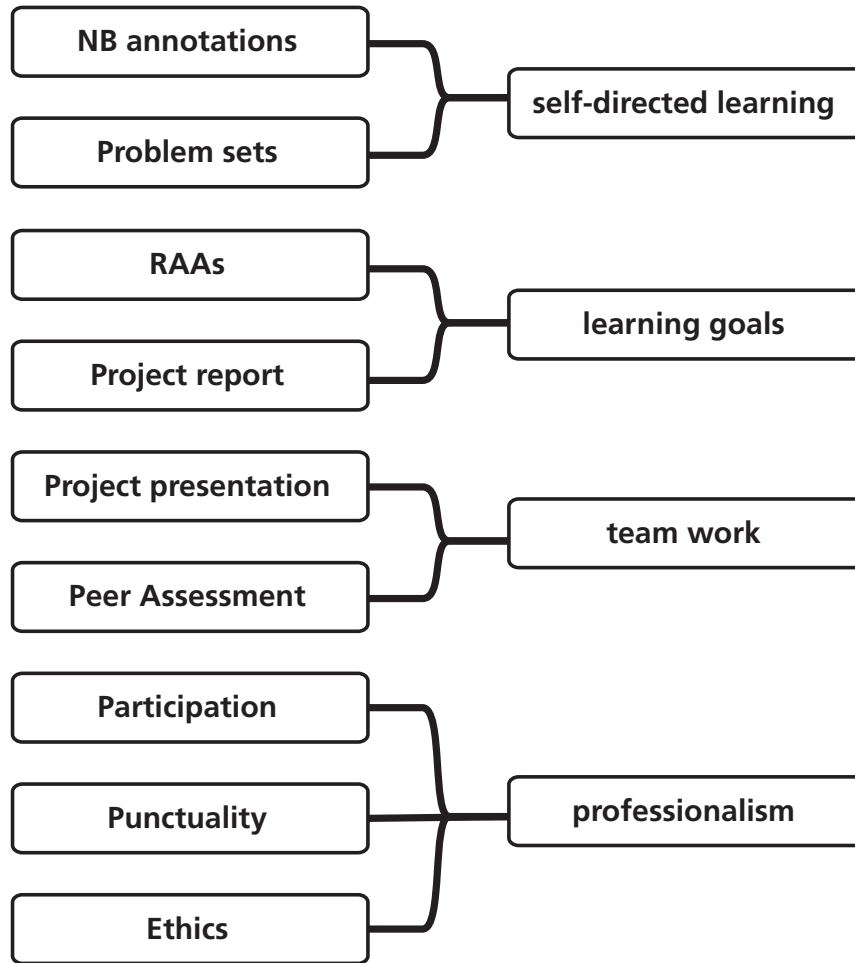
professionalism

**1** design

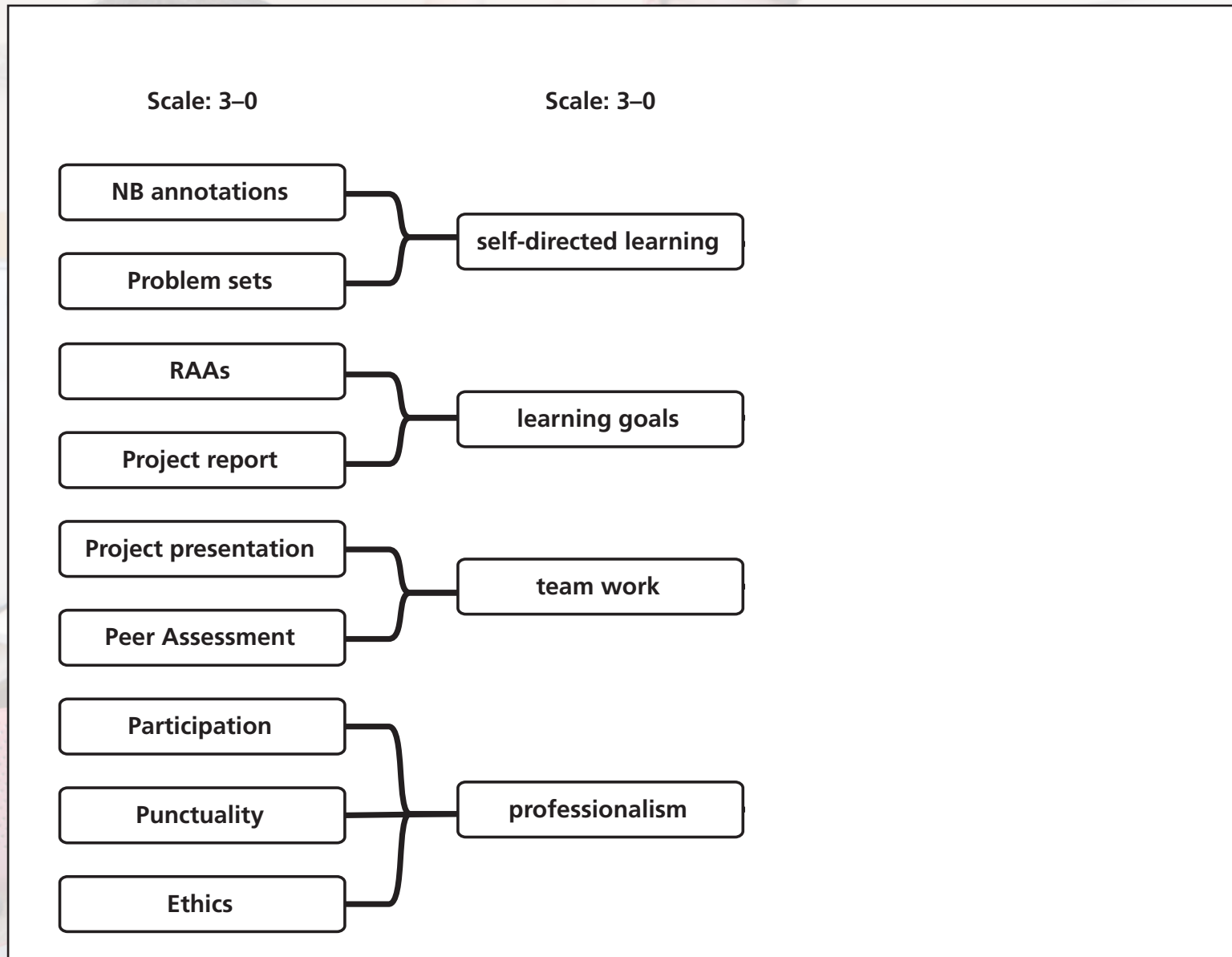
**2** approach

# Assessment

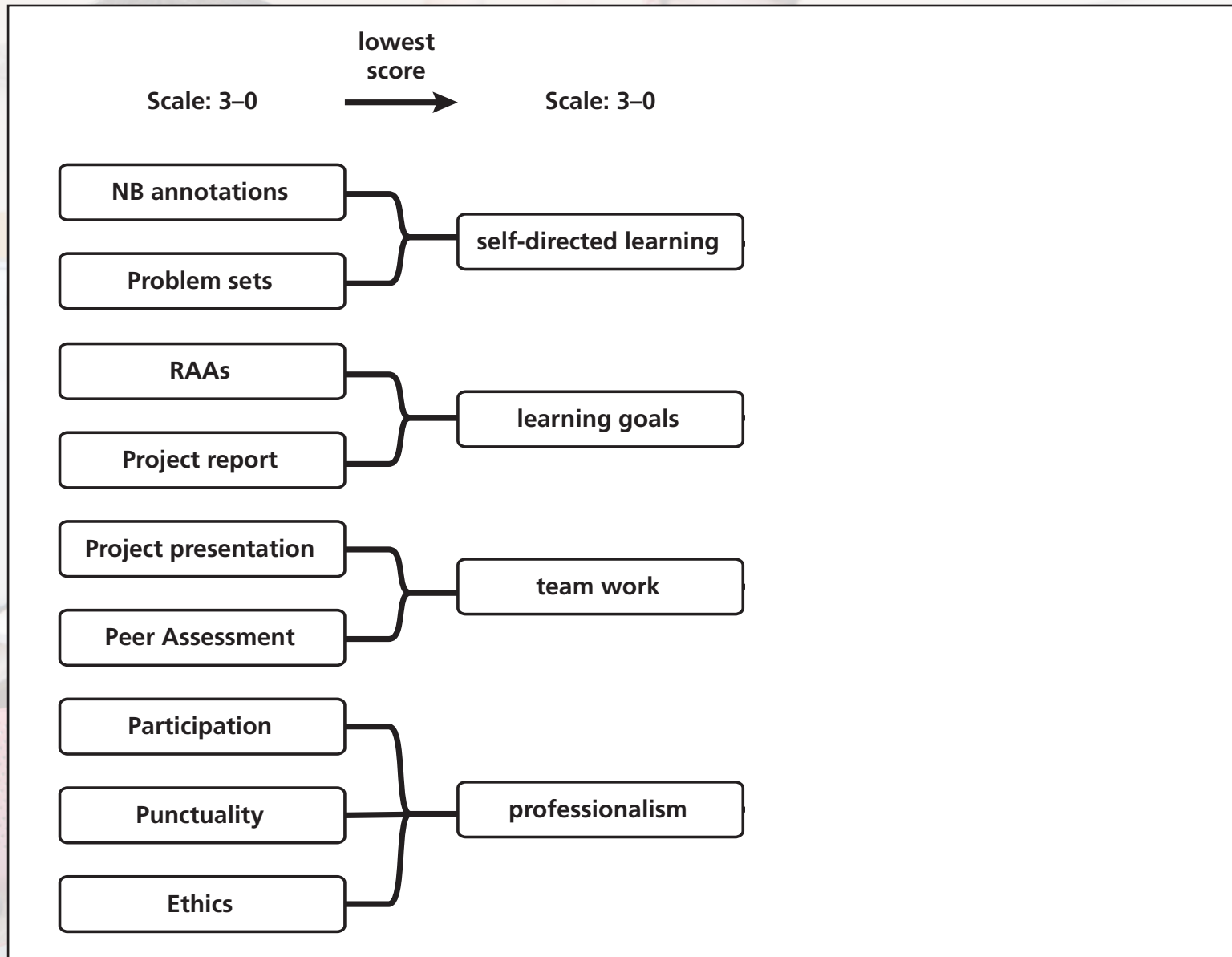
Scale: 3-0



# Assessment

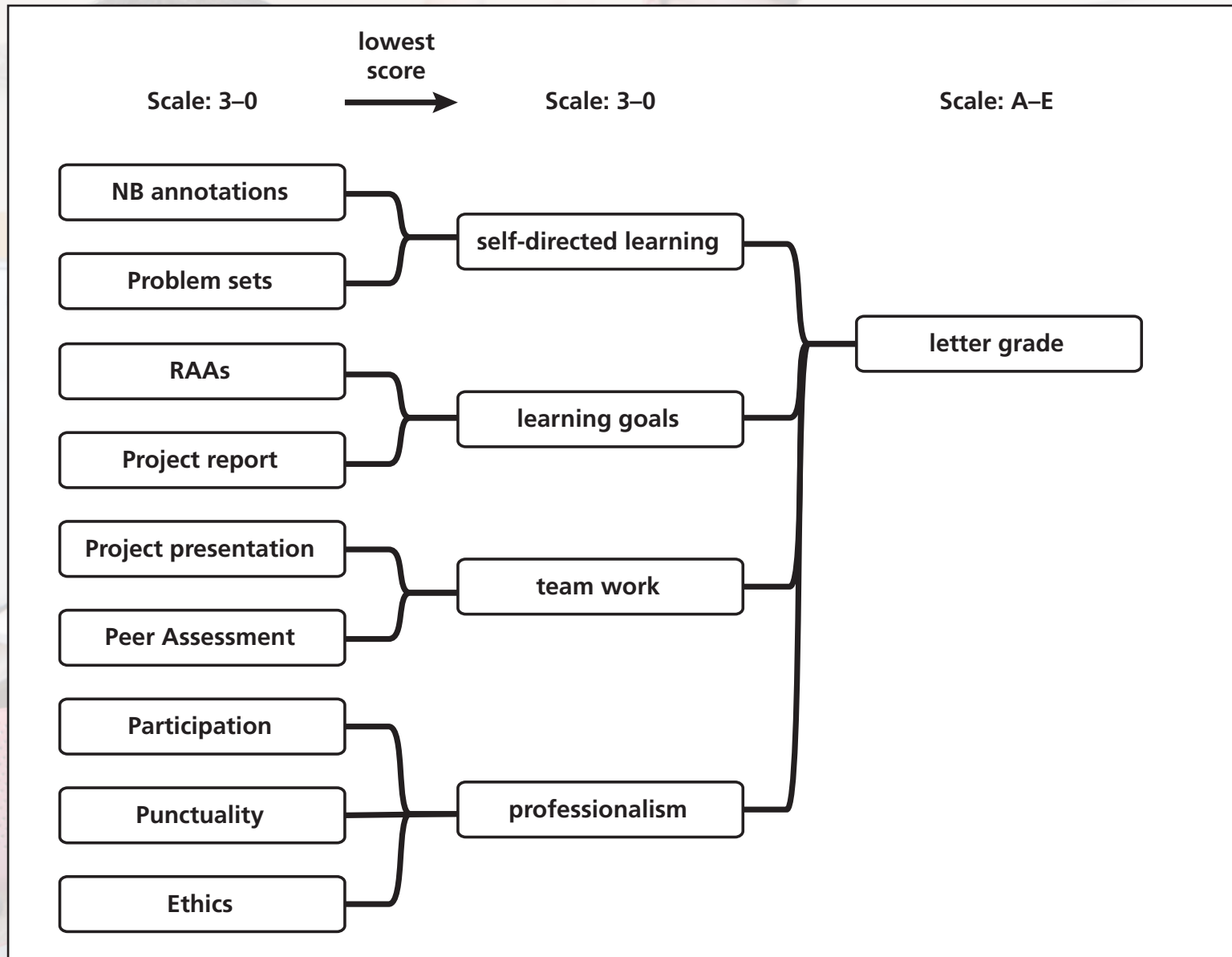


# Assessment

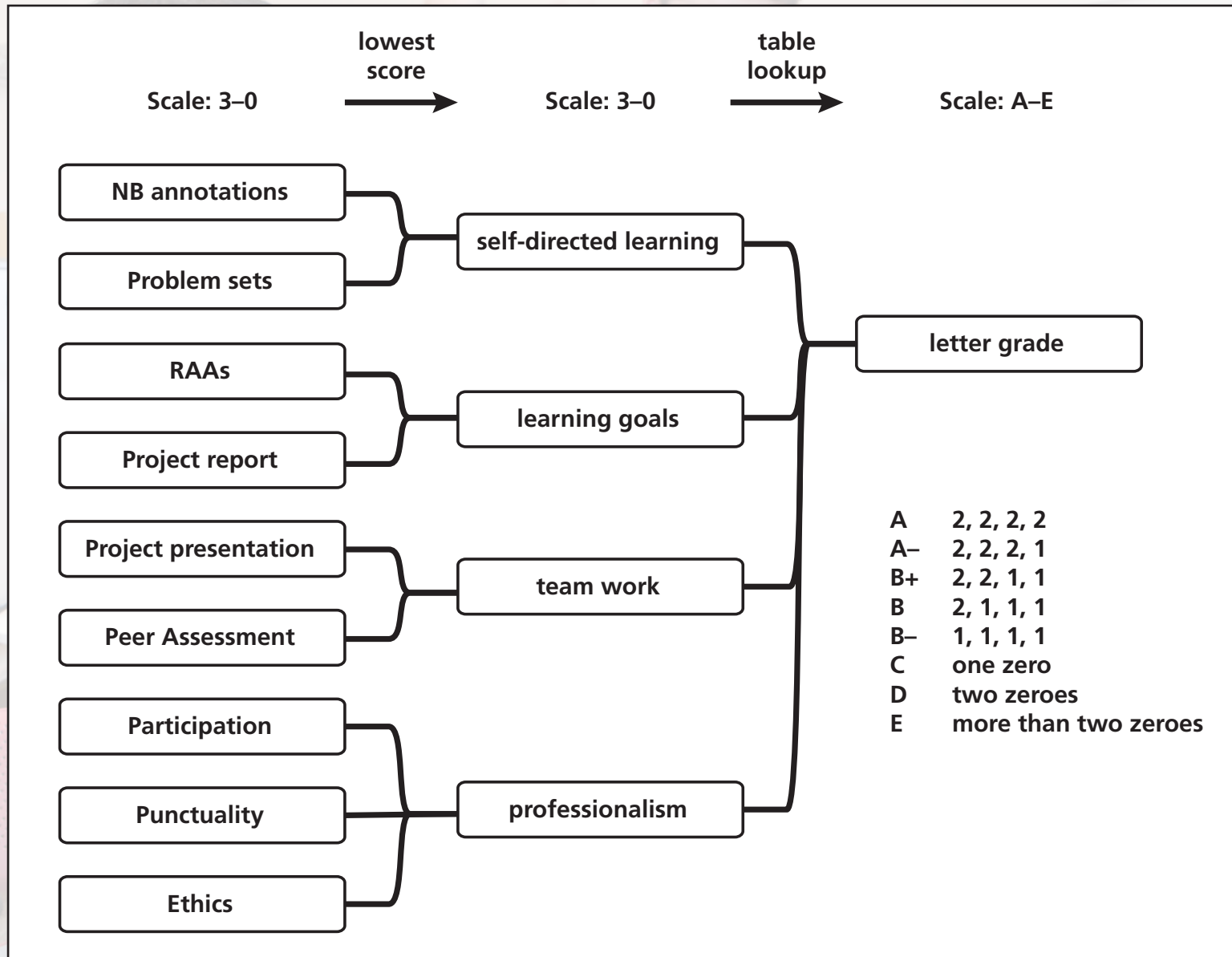




# Assessment



# Assessment





**1** design

**2** approach

**3** results



# Ownership

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

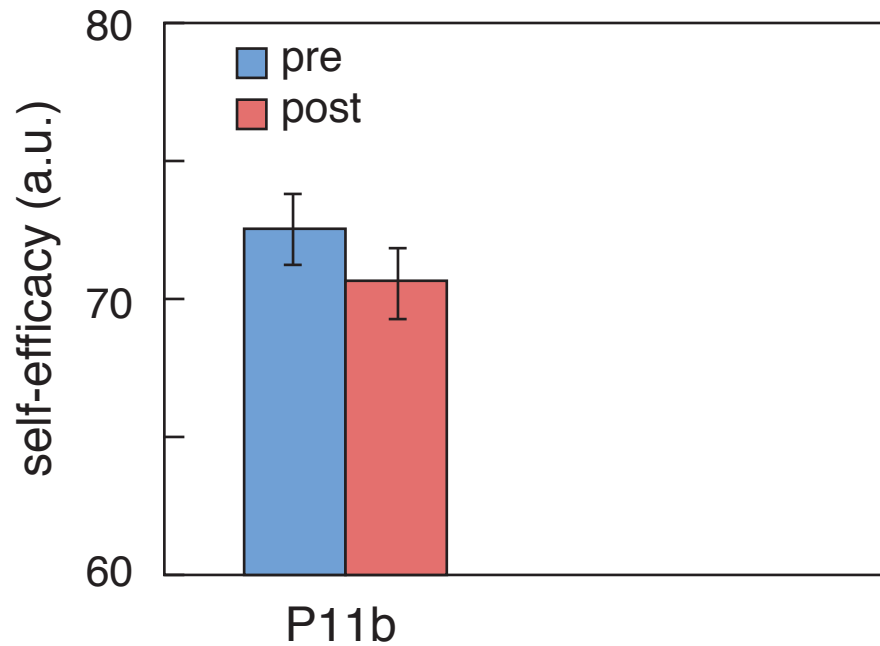
(students' belief in their ability to succeed)

1 design

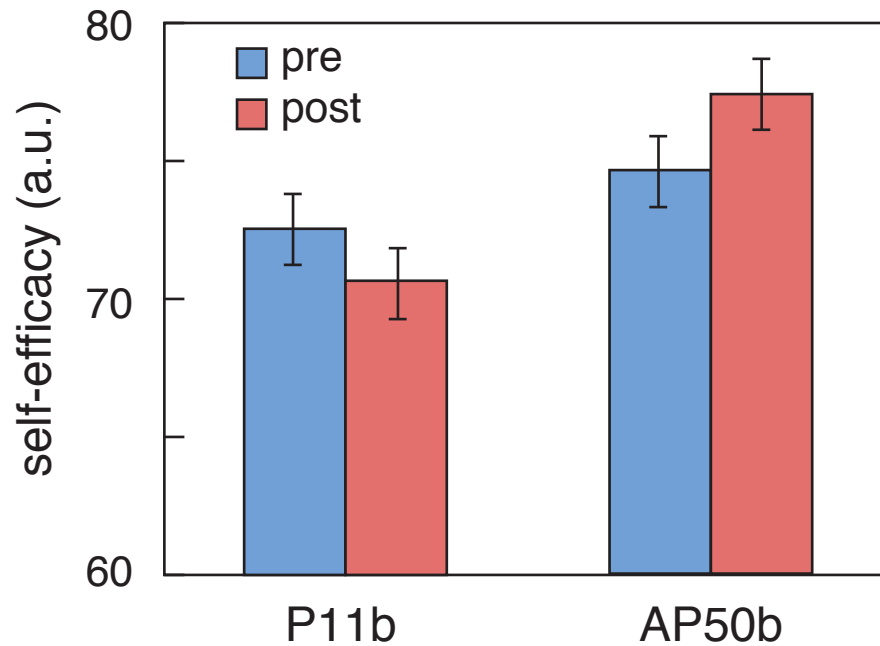
2 approach

3 results

# Self-efficacy



# Self-efficacy



1 design

2 approach

3 results

# Self-directed learning

**1** design

**2** approach

**3** results

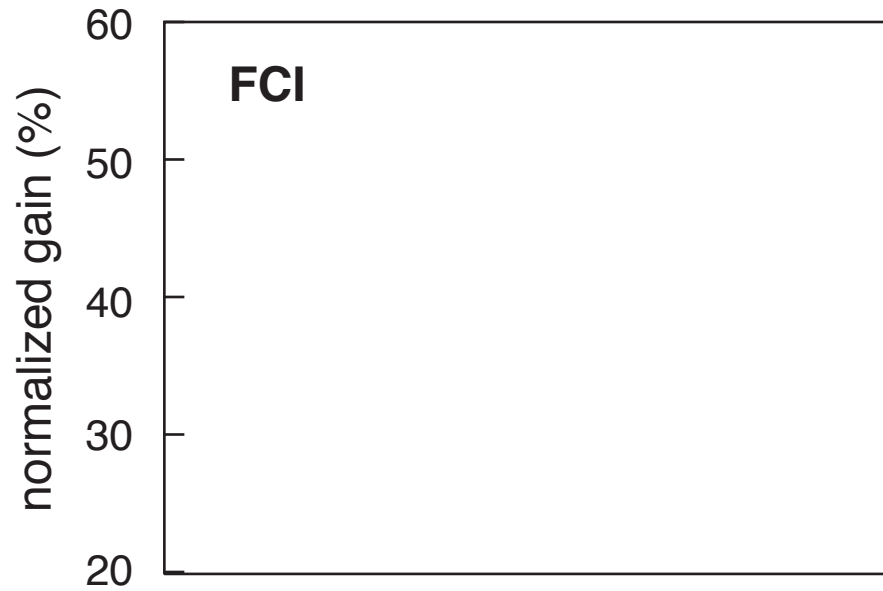


# Self-directed learning

**NB data shows:**

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

# Conceptual Mastery

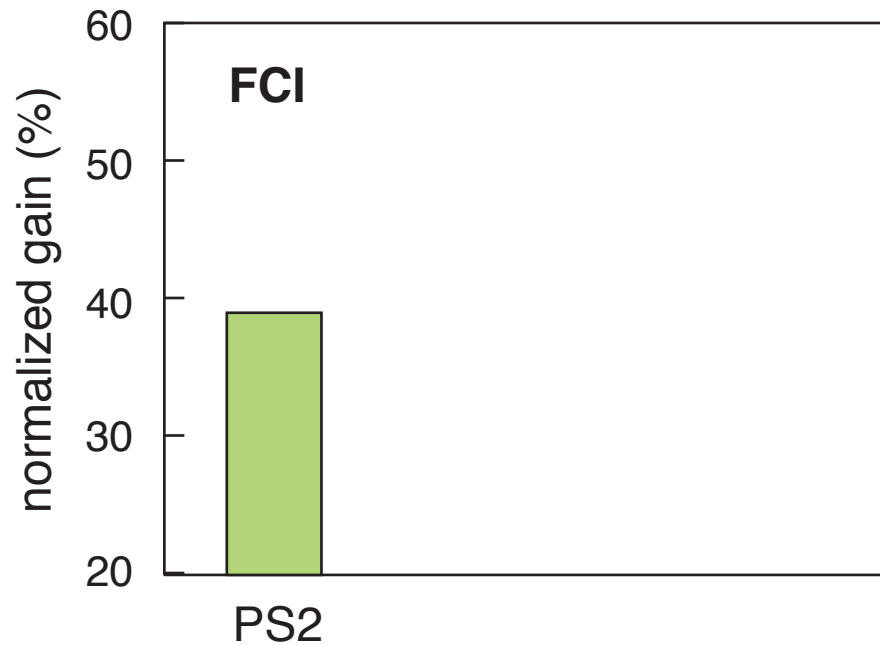


1 design

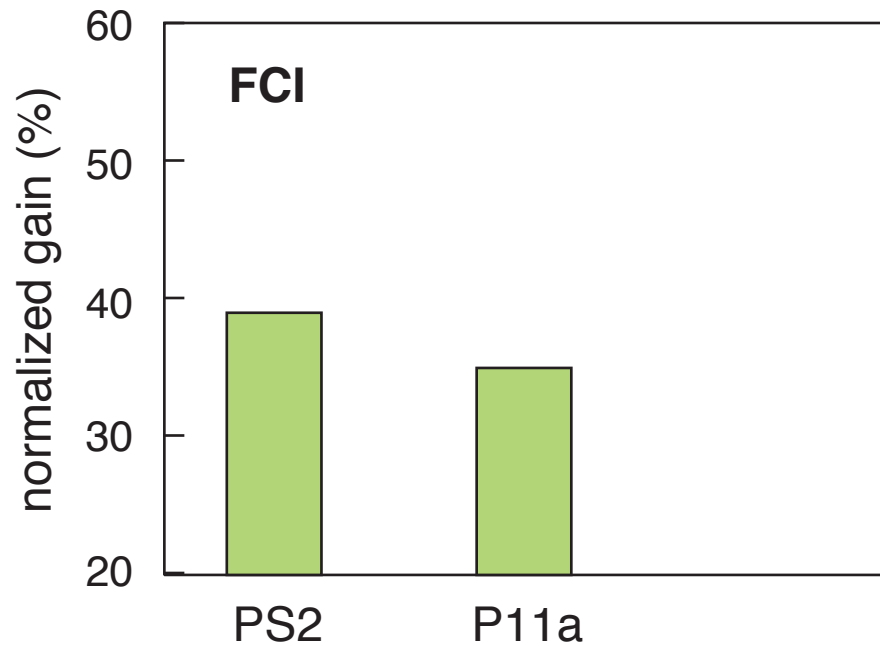
2 approach

3 results

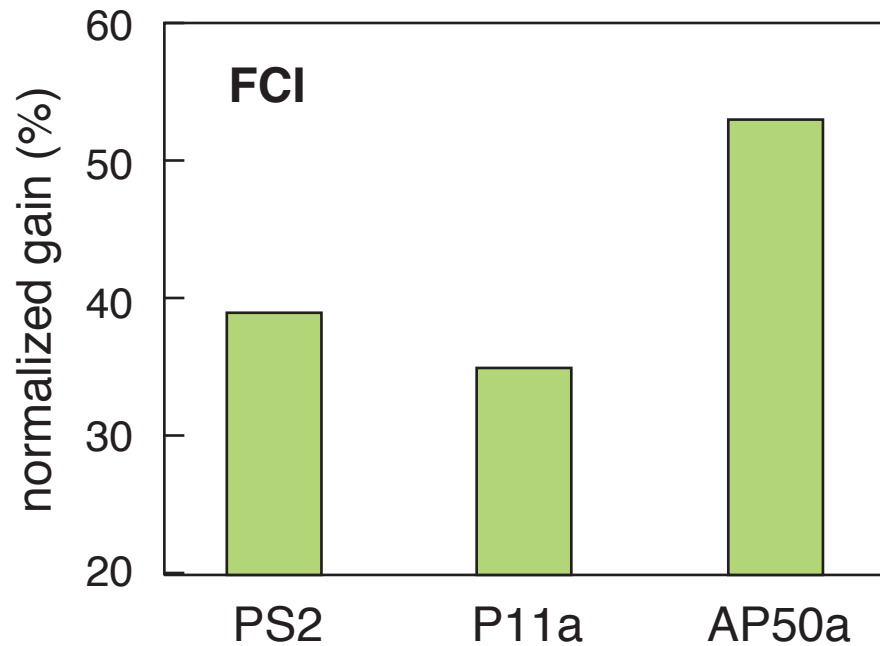
# Conceptual Mastery



# Conceptual Mastery



# Conceptual Mastery

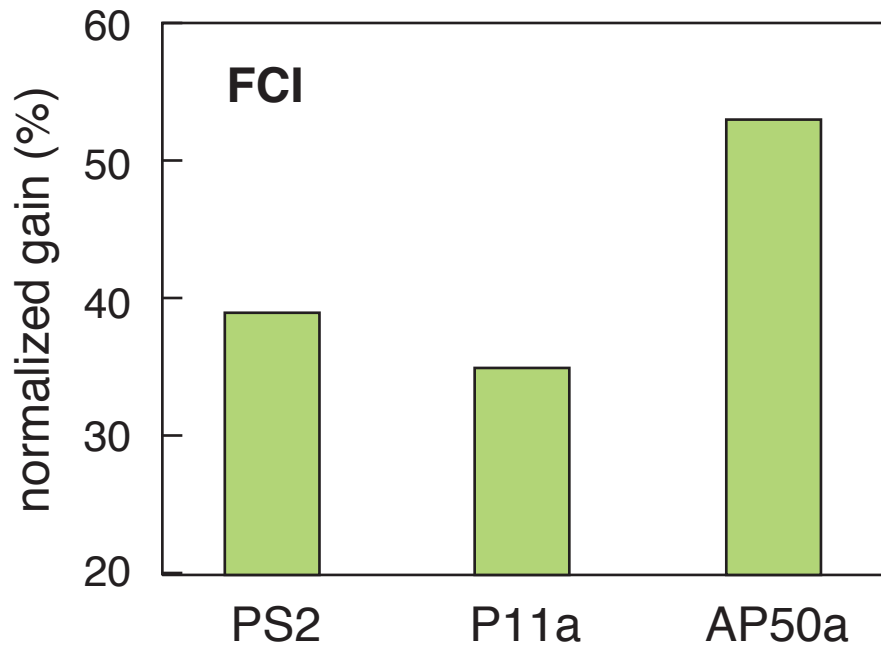


1 design

2 approach

3 results

# Conceptual Mastery



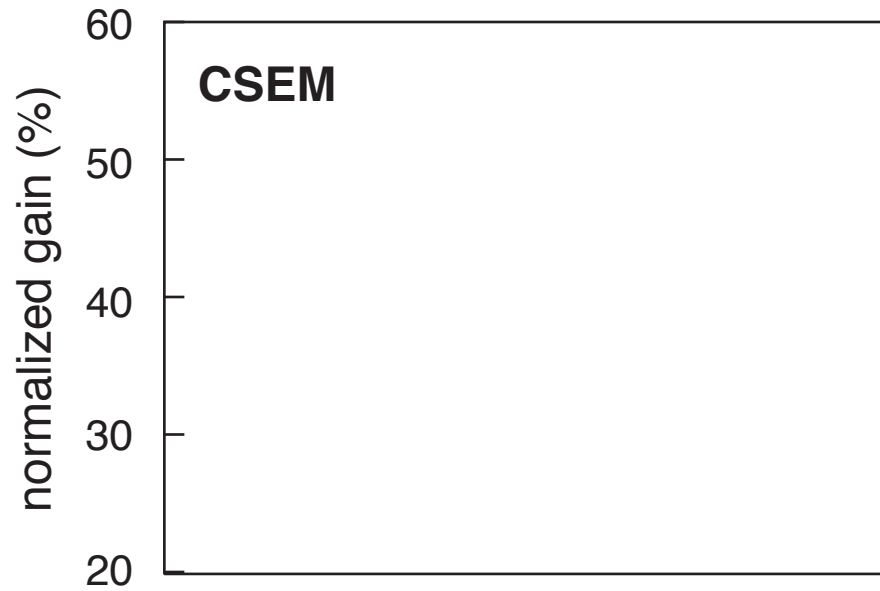
**largest conceptual gain in *any* course past 6 yrs!**

**1** design

**2** approach

**3** results

# Conceptual Mastery

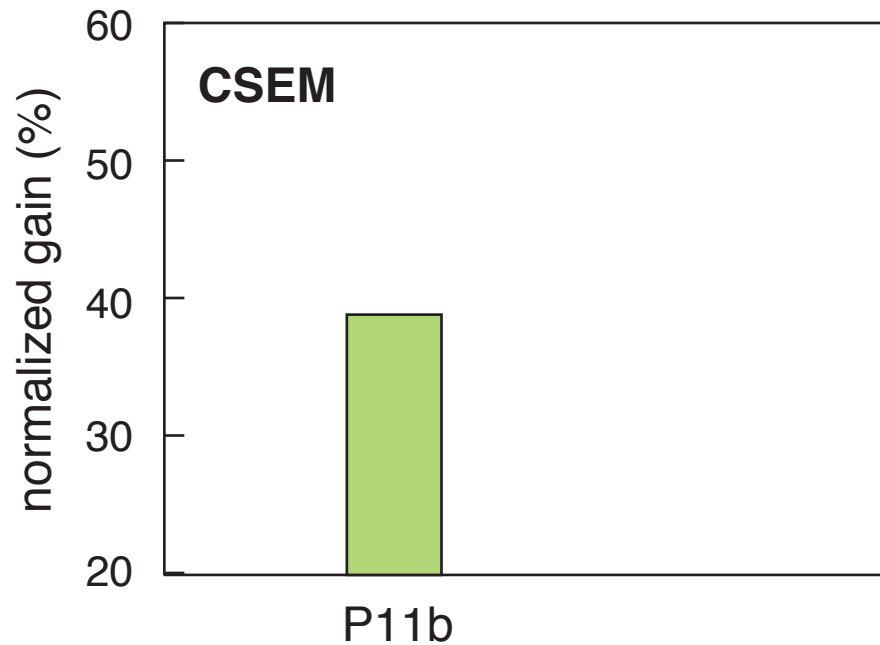


1 design

2 approach

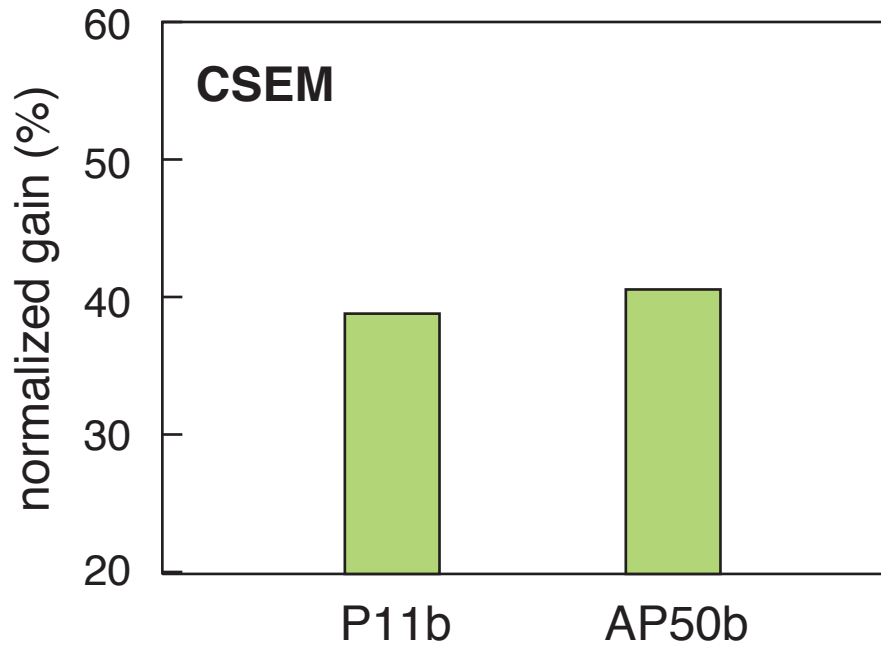
3 results

# Conceptual Mastery

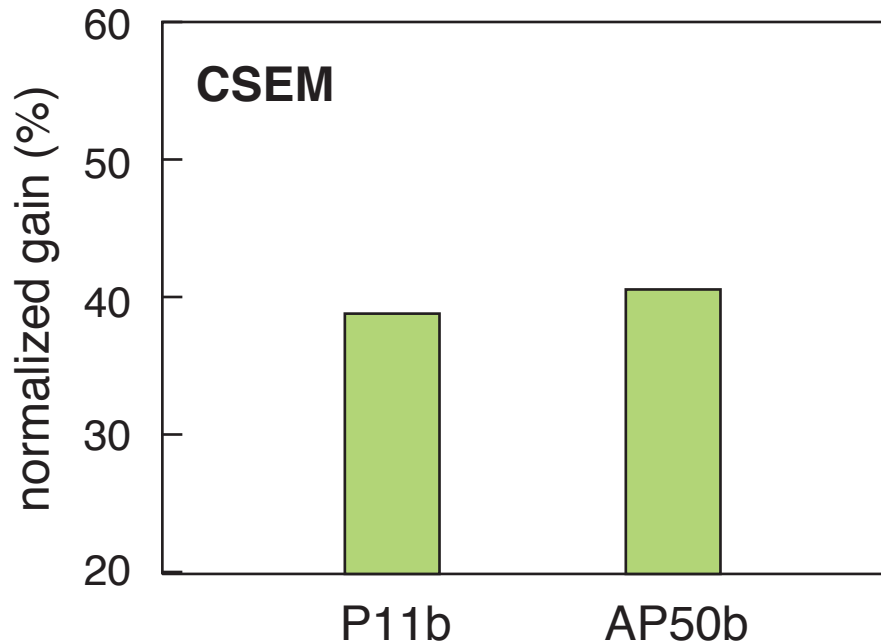




# Conceptual Mastery



# 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

A group of four students in a laboratory or classroom setting. A woman with glasses is leaning over a wooden box containing electronic equipment, pointing at it. A man in a plaid shirt stands to the right, smiling. Two other women are looking at the equipment. The scene is brightly lit with windows in the background.

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**1** design

**2** approach

**3** results