

Flat space, deep learning



Pontificia Universidad Católica de Chile
Santiago, Chile, 15 January 2016



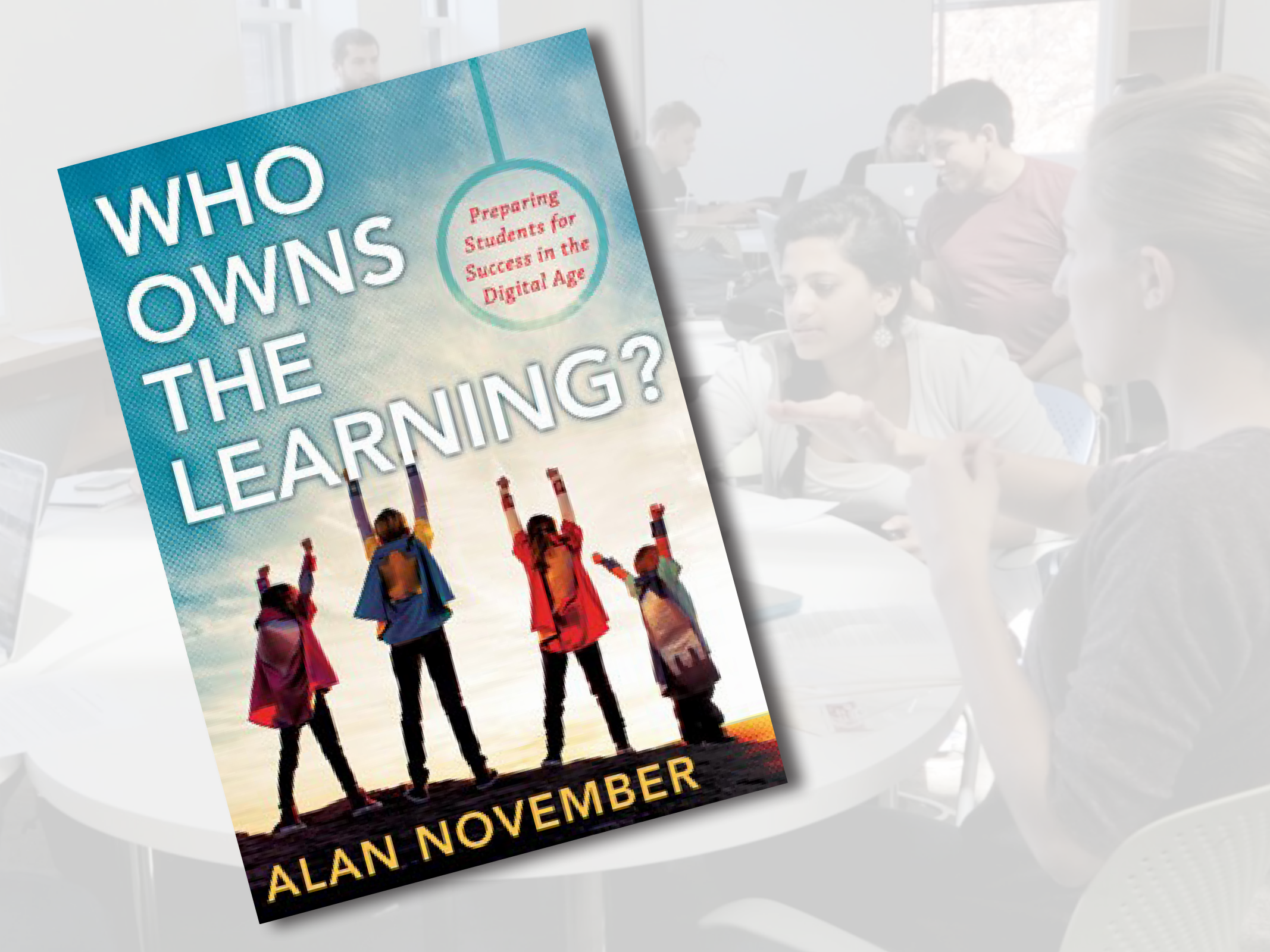
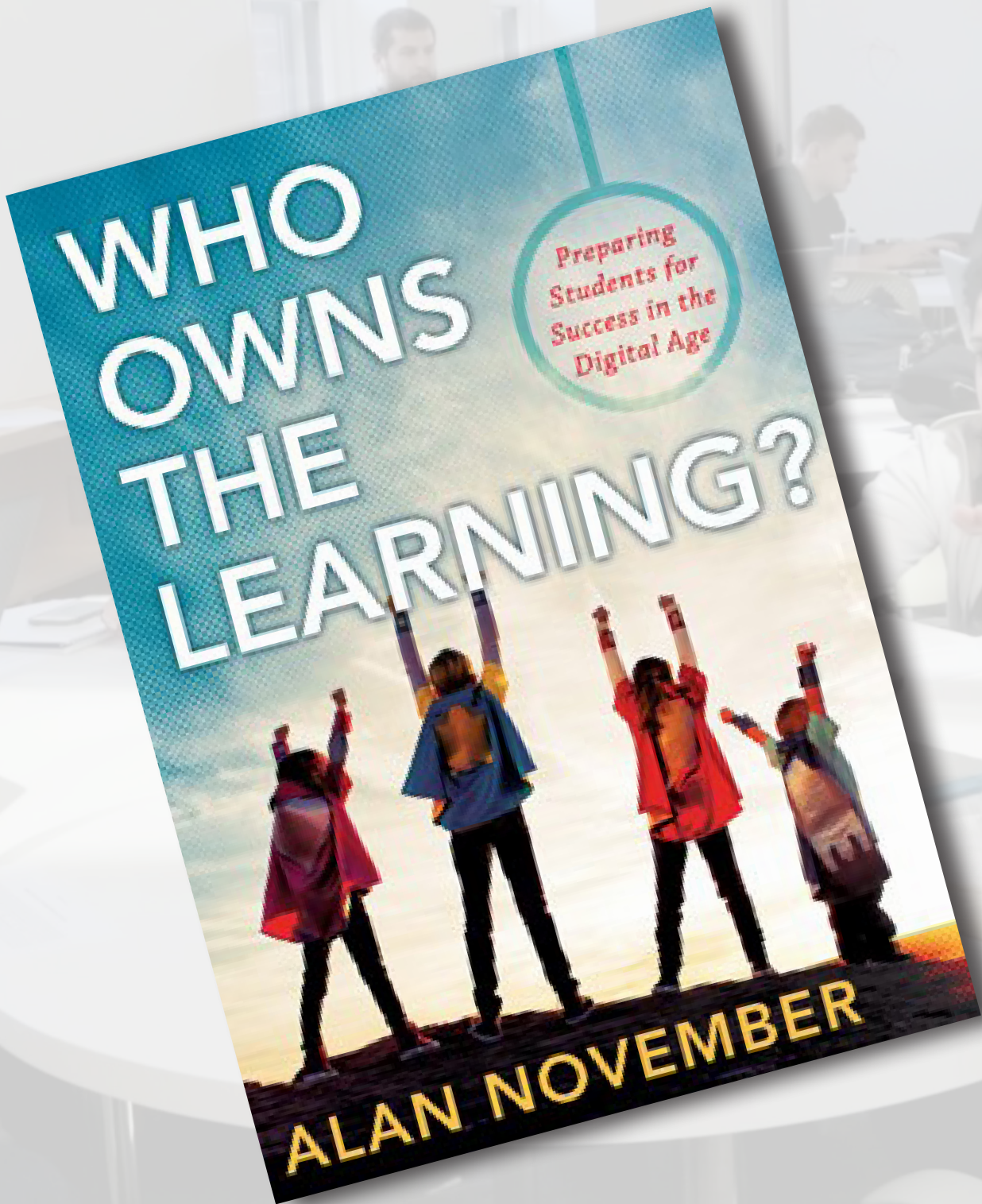
Flat space, deep learning



@eric_mazur

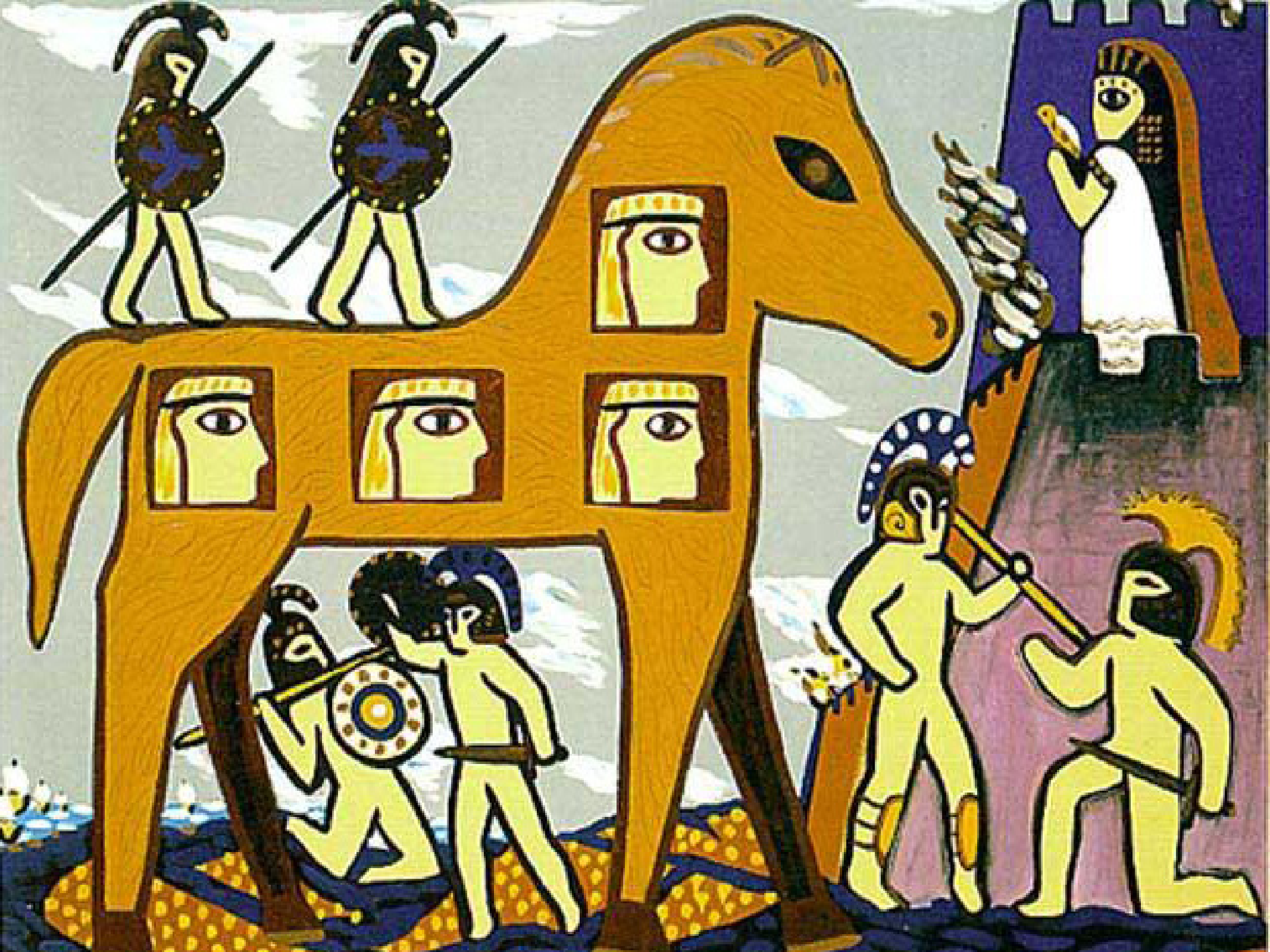
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Ownership of learning *physics*?





team & project-based approach





information transfer


faculty-centered





interaction

student-centered



no lectures

no exams



CLASS

1st exposure



ROOM

deeper understanding



1st exposure



deeper understanding



1st exposure



deeper understanding



1st exposure



deeper understanding



1st exposure



deeper understanding



1st exposure



deeper understanding



1st exposure



deeper understanding

1 information transfer

2 projects



1st exposure



deeper understanding



1st exposure

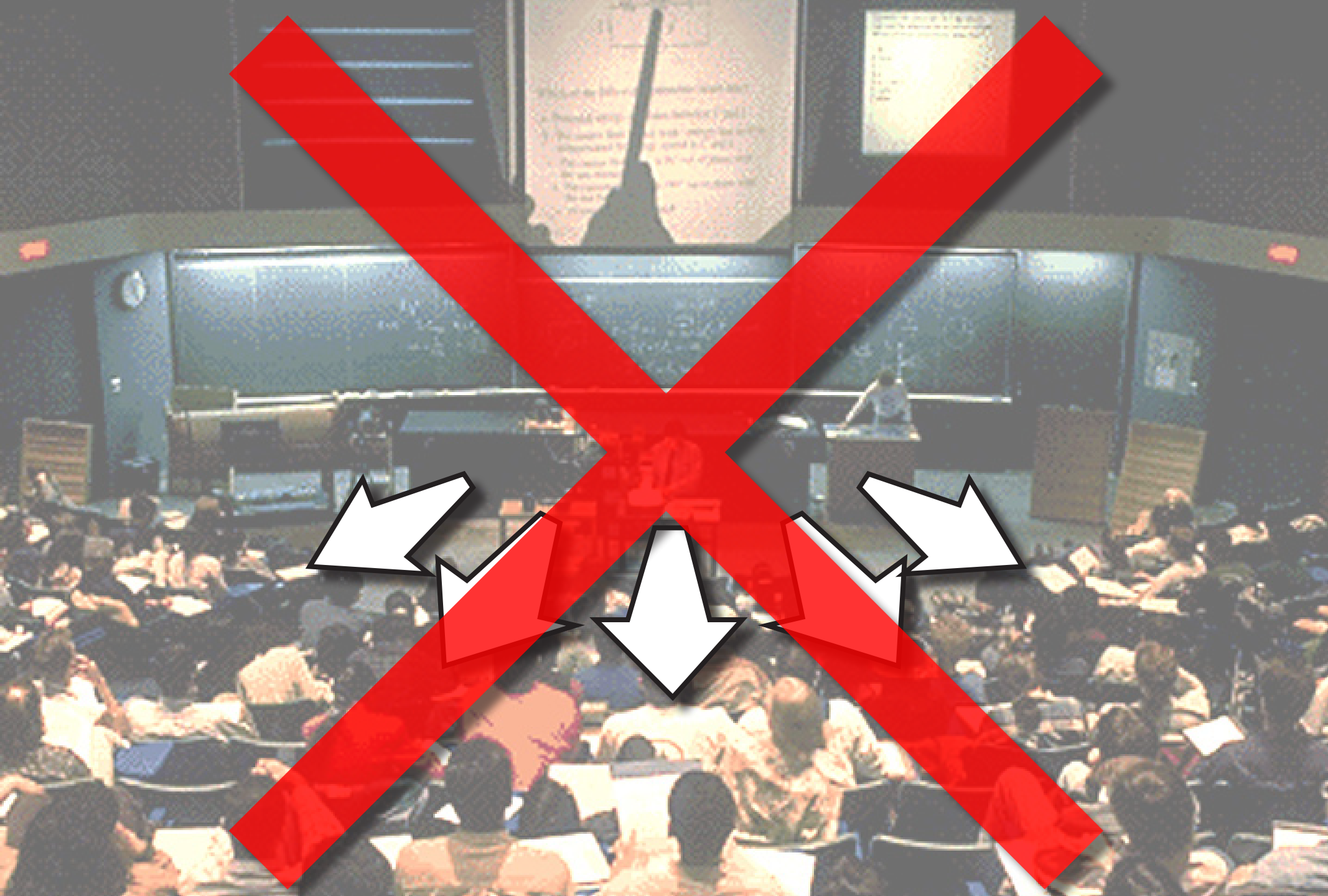


deeper understanding

1 information transfer

2 projects

3 in-class activities



1 information transfer



Solution

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

1 information transfer

Perusal

every student prepared for every class

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. A familiar example is your 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 surface, such as a smooth surface of ice. 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.

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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 shove, it will eventually stop. The smoothness of the block and the roughness 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 velocity decreases due to *friction*—the resistance to motion that an object encounters when it slides on 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 decreases over ice is hardly observable. The velocity decreases 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.



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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 never stop. 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 commonly encountered in your lab or class. Although there is still some friction both for the track and for 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.

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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 is more or less true. If the surfaces are 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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see who is online

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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 force that opposes the motion of an object encountered during the interaction. In the velocity-versus-time graph, the velocity decreases as the block slides over ice. This 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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highlighting text...

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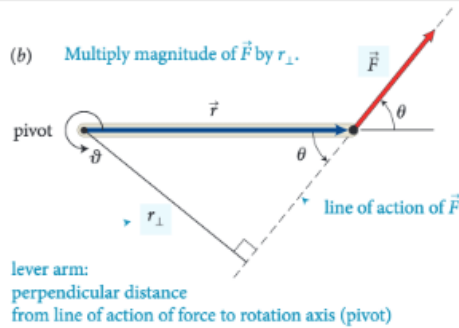
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opens chat window

? 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



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 ϑ . 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 ϑ 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.

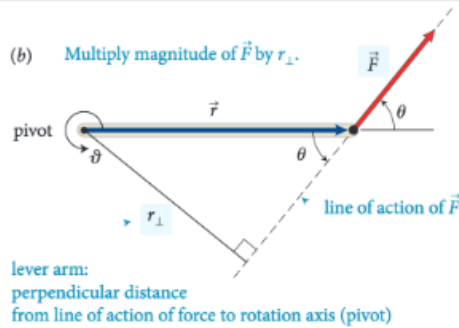
For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of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

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

Example 12.2 Torques on lever

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

CONCEPTS



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reference point
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? 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 we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

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? 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. Oct 22 8:48 pm

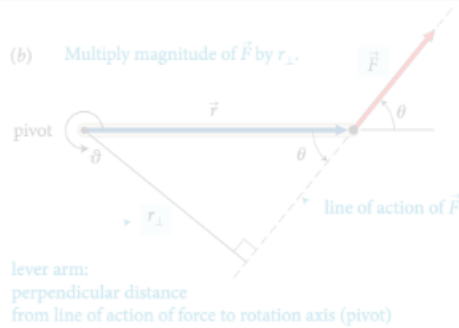
Perusall AP50 Fall 2015 » Chapter 12 Group 1's comments Page 284 Eric Mazur

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1 information transfer



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

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- On the very left, we see th...
- It's interesting that the white ...
- Is the reference frame i... 2
- How does force affect ... 2
- I was curious about this, t... 3
- I understand partially w... 3
- In this class, we always emp...
- The part before this wa... 2
- The extended free-body d... 4
- This just means the net... 3
- I don't understand why ... 3
- It is important to note that... 2
- This reminds me of when we ...
- Torque is the ability of a forc...
- it sounds like it is sayin... 3
- So then do we have a p... 5
- Since torque is the cross pro...
- The right-hand rule can al... 3
- I don't understand how ... 3
- Orientation-based descriptio...
- I don't really understand... 2
- How small is small? As ... 3
- I think it would be slightly ...
- While I believe I underst... 3
- (a) The change in rotationa...
- As we saw earlier in the chap...

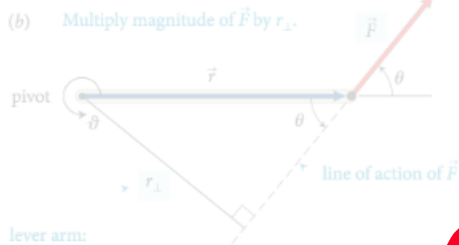
use combination of

intrinsic and extrinsic motivation drivers

1 design

2 approach

rubric-based assessment



- quality (thoughtful reading & interpretation)

over 20,000 annotations!

1 design

2 approach

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



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

reference point

\vec{F}_1

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

virtually all students complete all readings!

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 we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

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. Oct 20 12:38 am

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. Oct 22 8:48 pm

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.

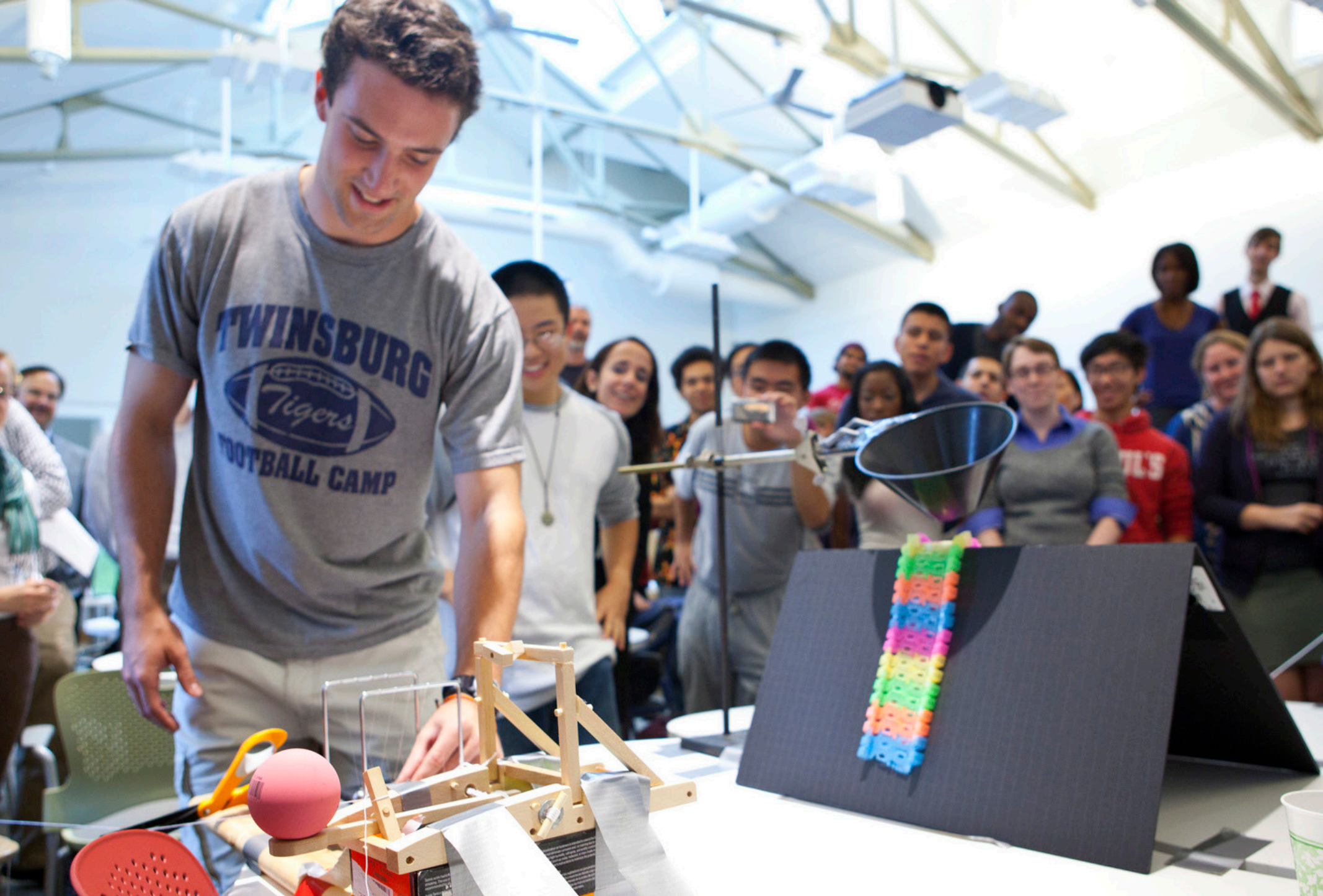
For a stationary object we can choose any reference point we like to calculate torques. It pays to choose a reference point that simplifies the calculation. As you have seen, we do not need to consider any force that is exerted at the reference point. So, by putting the reference point at the point of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

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

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}_2 is half as great as that of \vec{F}_1 . Horizontal force \vec{F}_3 is exerted on the lever

<http://perusall.com>



1 information transfer

2 projects

- 
- A young man in a grey t-shirt with 'TWINSBURG FOOTBALL CAMP' printed on it is focused on a wooden mechanical project on a table. He is surrounded by other students in a bright, modern classroom setting. In the background, a group of students is gathered around a table with a laptop and colorful stacking toys. The overall atmosphere is one of active learning and collaboration.
- **1 project/month (6 over 2 semesters)**
 - **new team formation for each project**

1 information transfer

2 projects

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 information transfer

2 projects

AP50 FALL 2014

Project Brief

Drag

Rube G

Sympho

Symphosium

1 information transf



1 design

2 approach

Projects



1 information transfer

2 projects

Projects

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

Projects

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

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

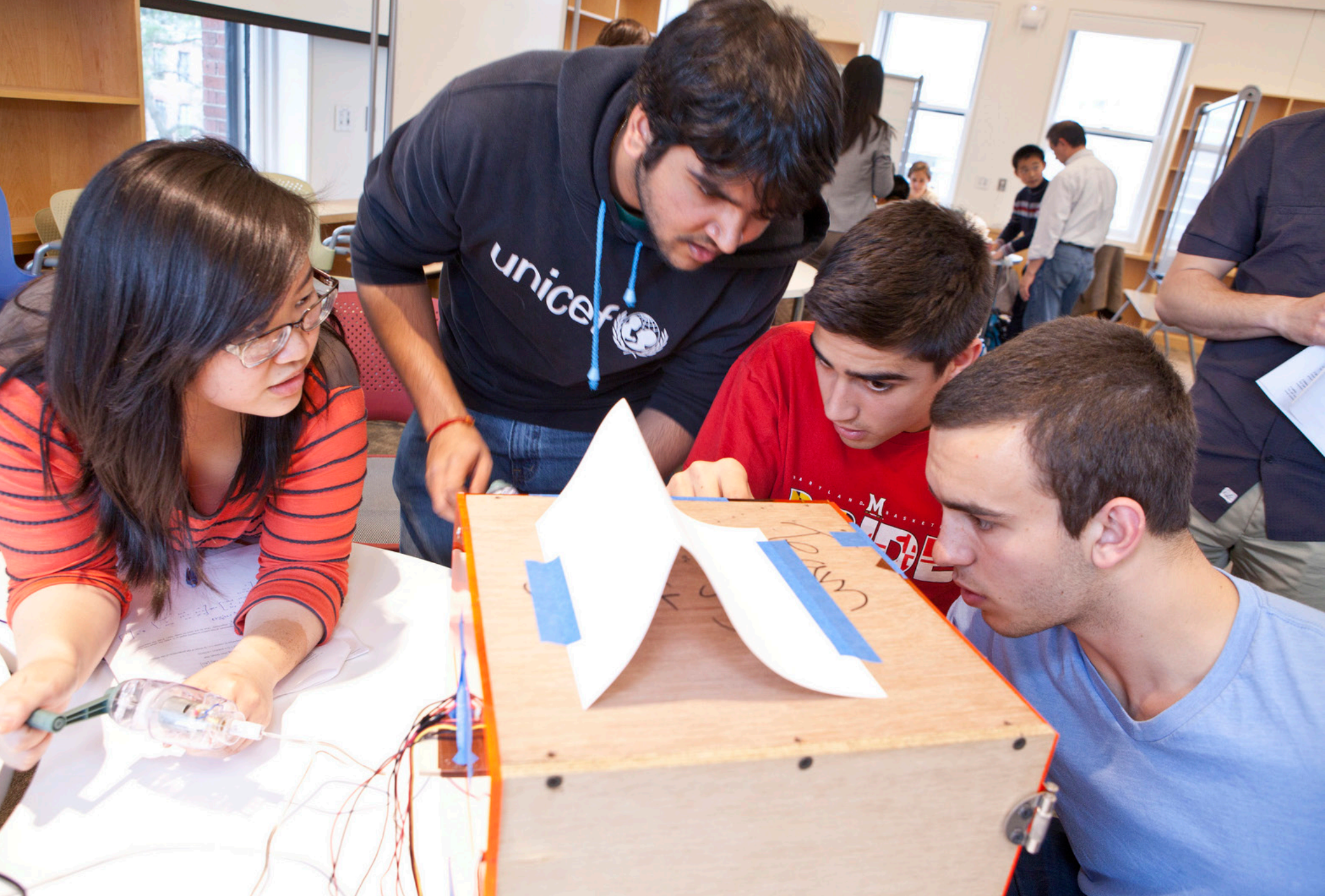
Milestones:

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



1 design

2 approach



1 information transfer

2 projects

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

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

1 information transfer

2 projects



1 information transfer

2 projects



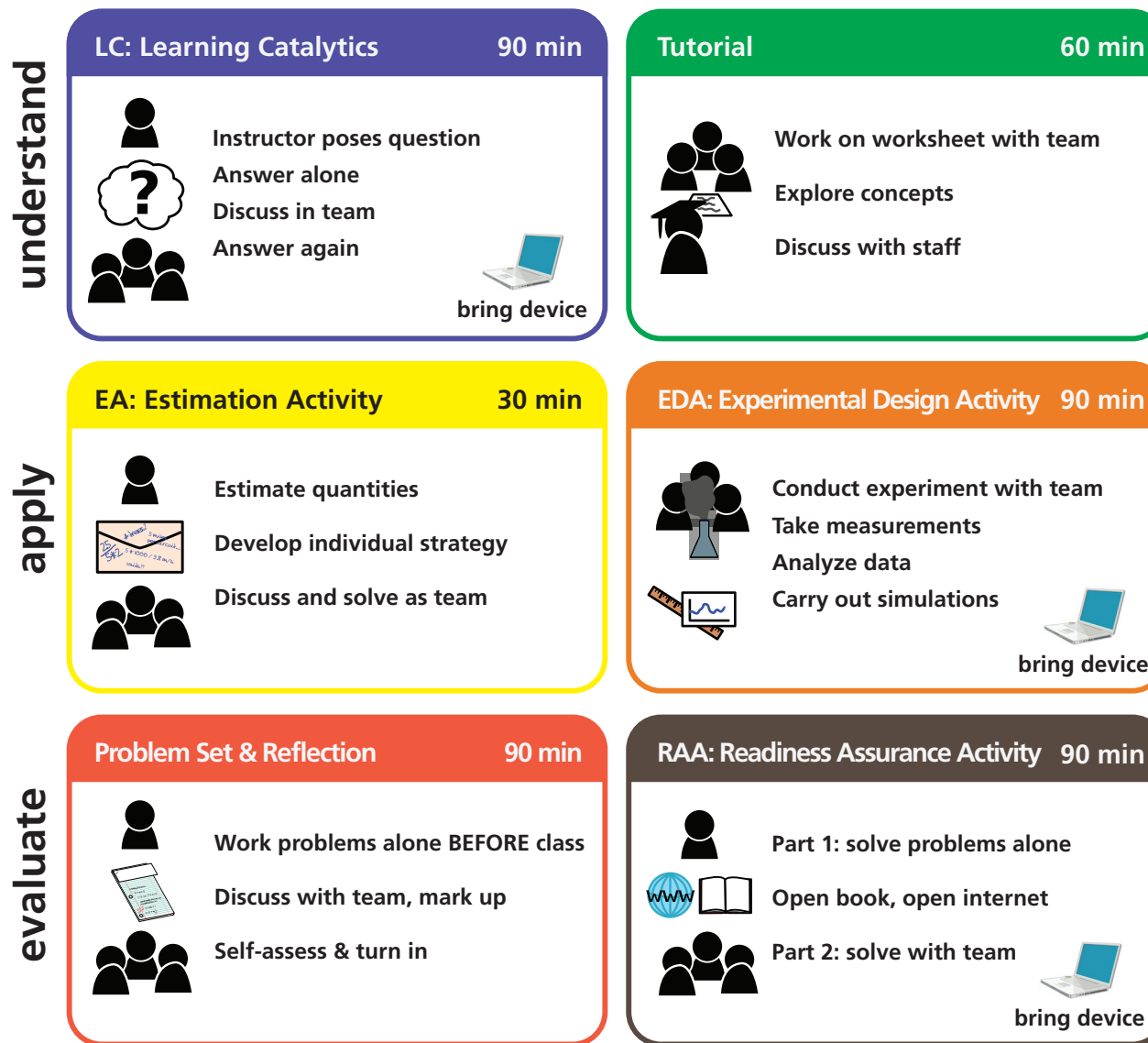
2 weekly 3-hour class periods

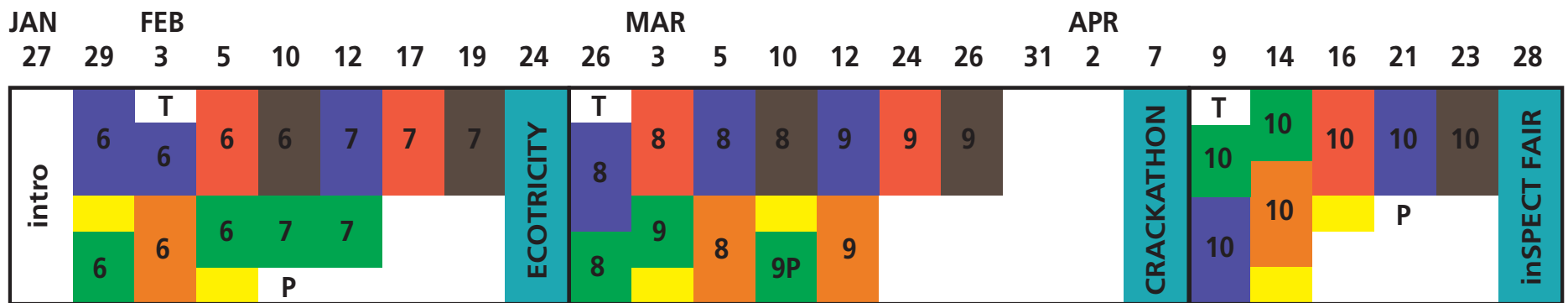
1 information transfer

2 projects

3 in-class activities

blend of 6 scaffolded "best practices"



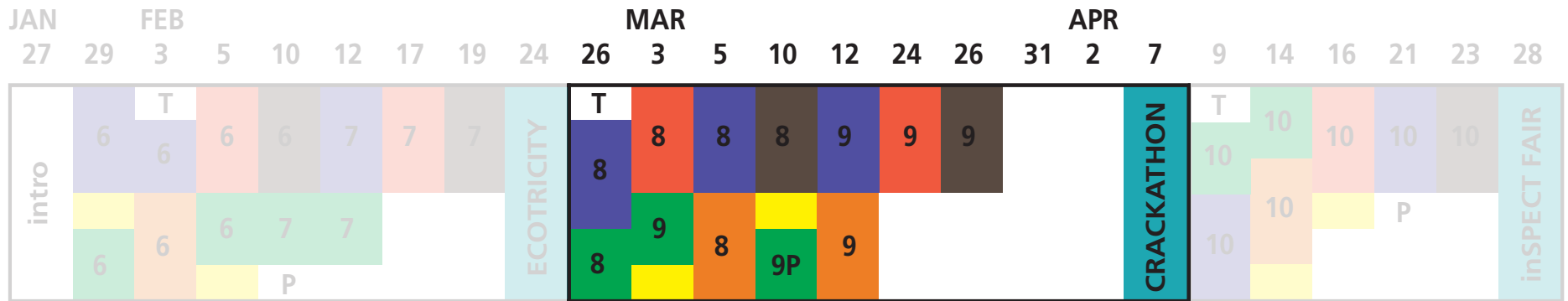


1 information transfer

2 projects

3 in-class activities

one project

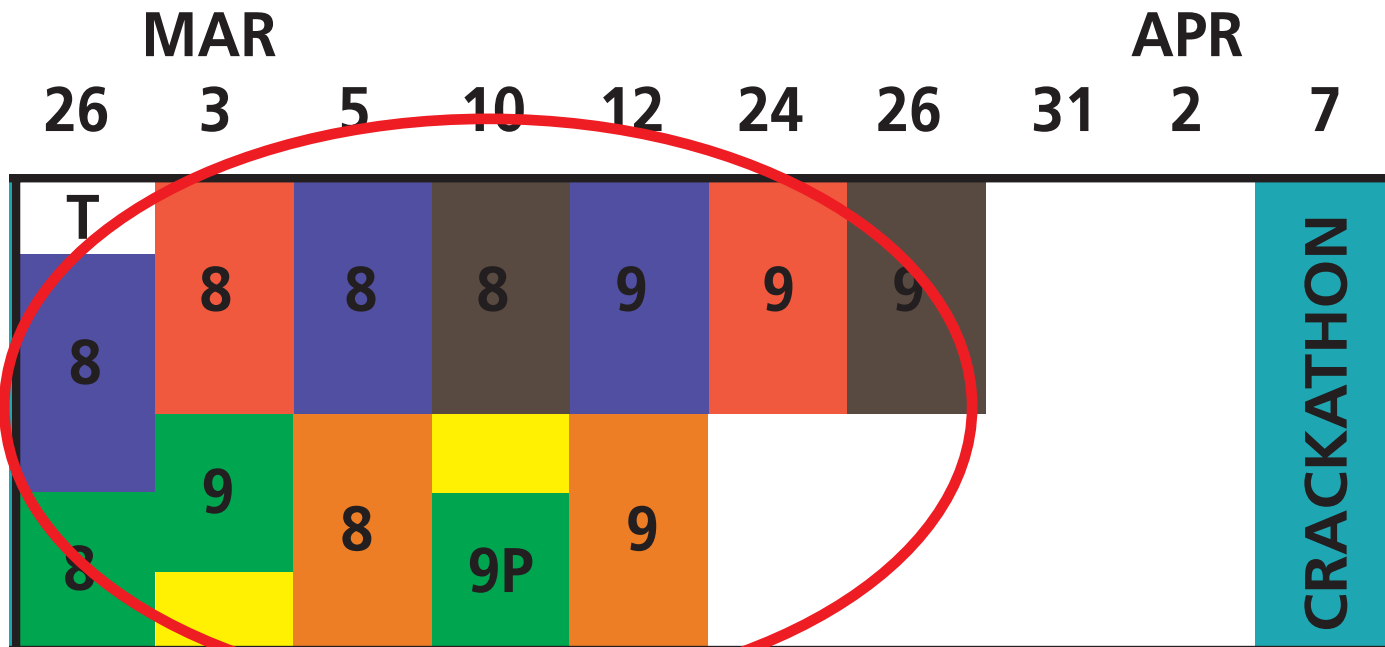


1 information transfer

2 projects

3 in-class activities

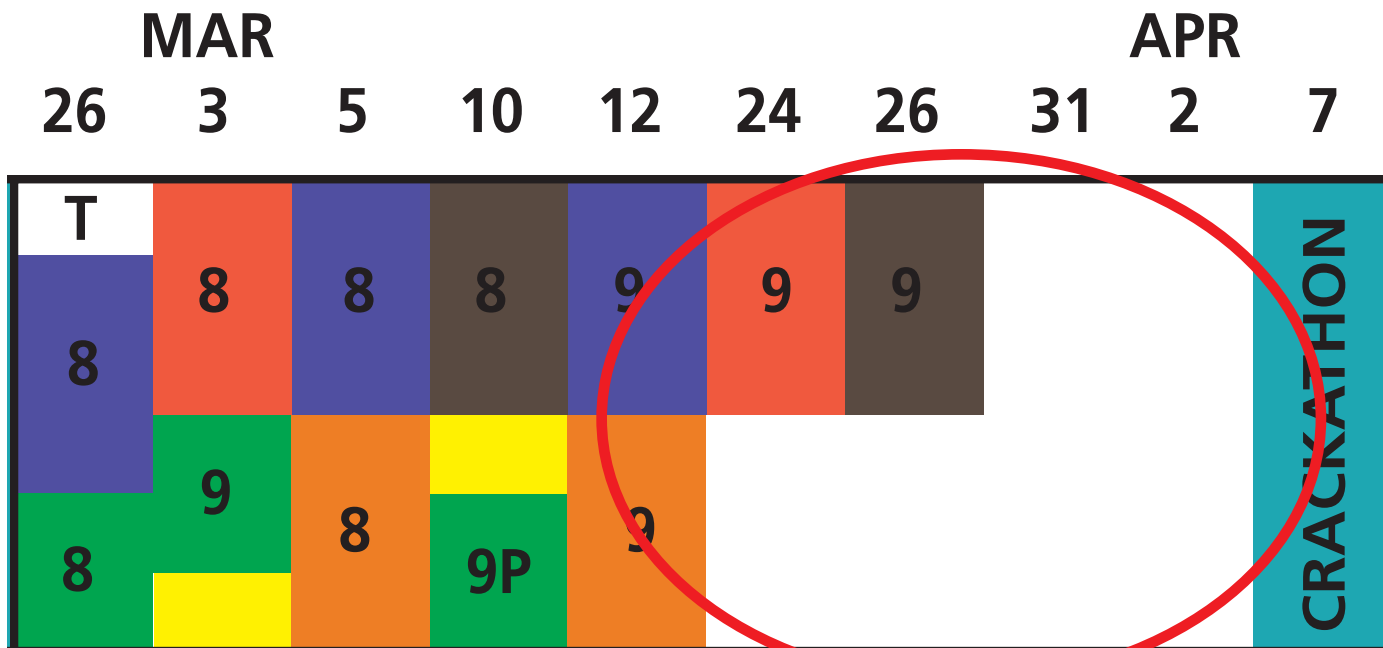
2/3 scaffolded, guided



1 information transfer

2 projects

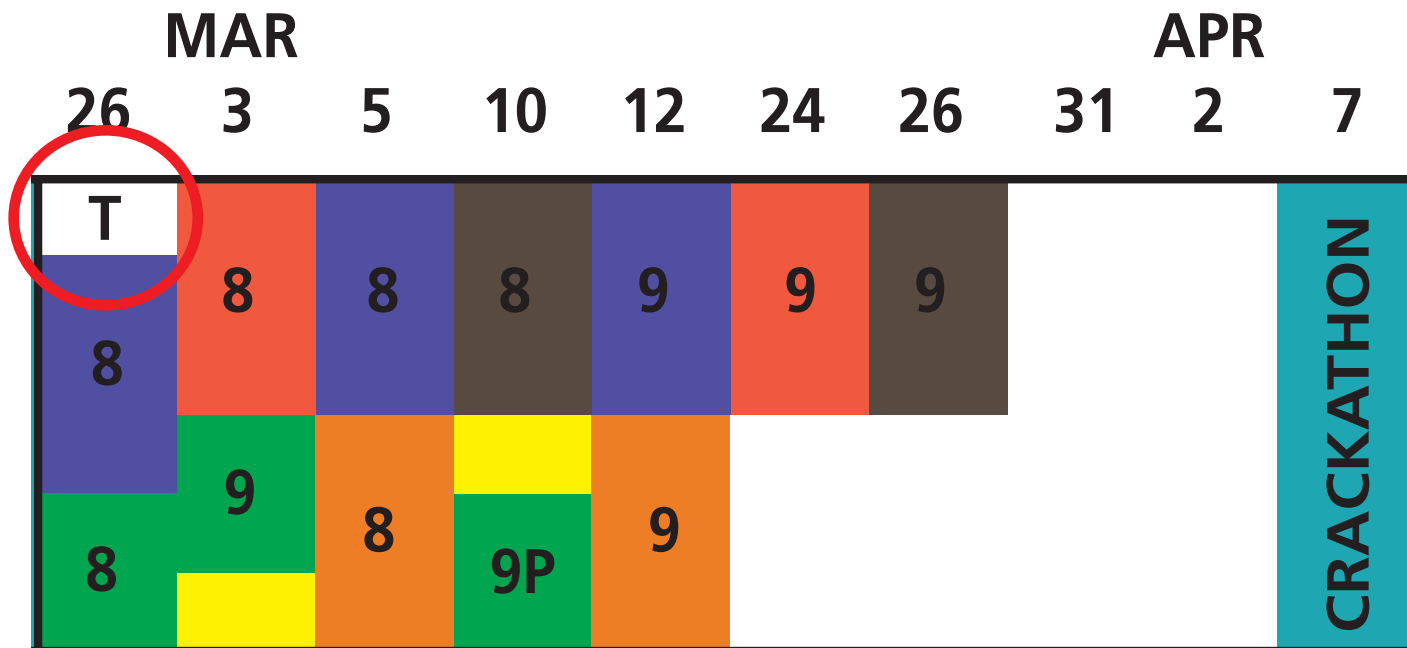
3 in-class activities



1/3 unguided

- 1** information transfer
- 2** projects
- 3** in-class activities

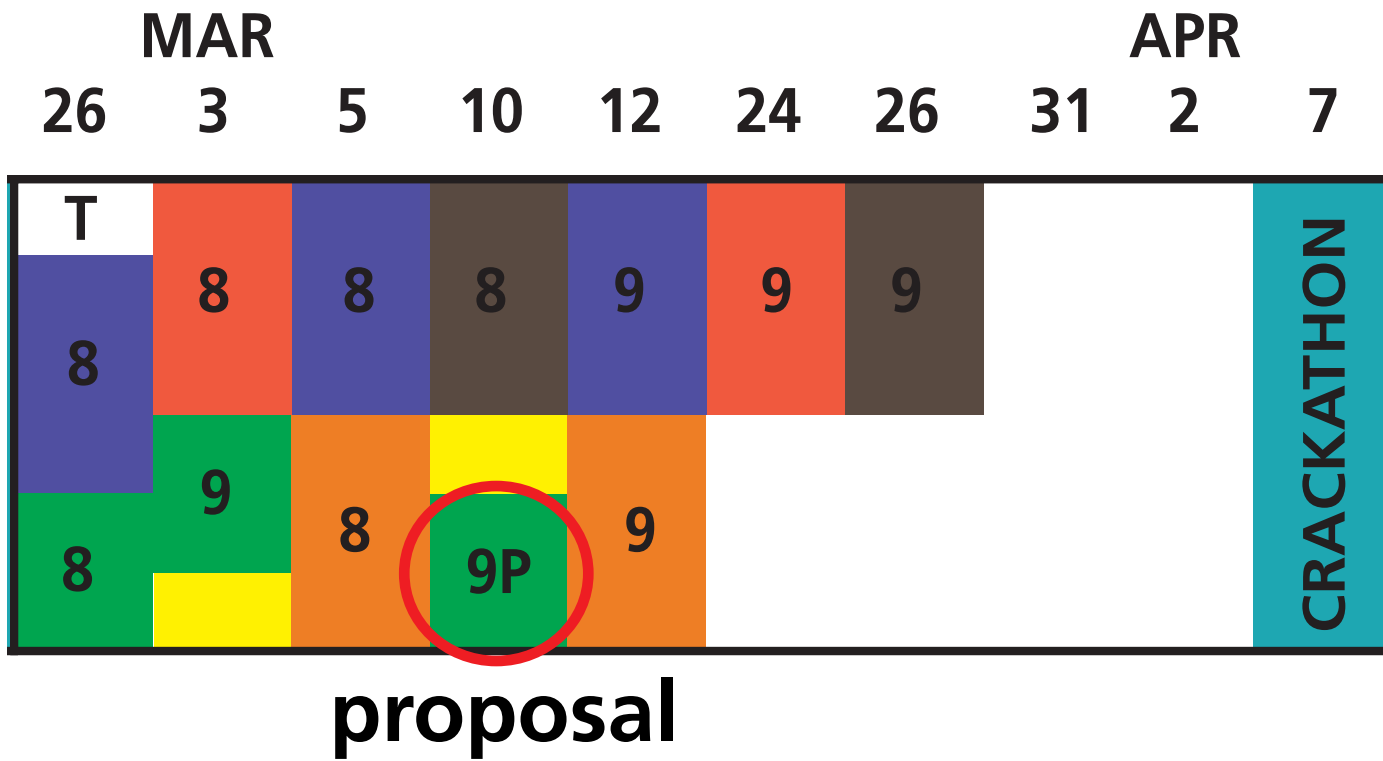
team intro



1 information transfer

2 projects

3 in-class activities



1 information transfer

2 projects

3 in-class activities



project fair

- 1** information transfer
- 2** projects
- 3** in-class activities

Assessment



- **self-directed learning**
- **content learning goals**
- **teamwork**
- **professionalism**



Ownership



Ownership

Course evaluation: 4.2/5



Ownership

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

Ownership

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

Ownership

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

Ownership

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

Ownership

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

3 hours and they don't *leave!*

Ownership

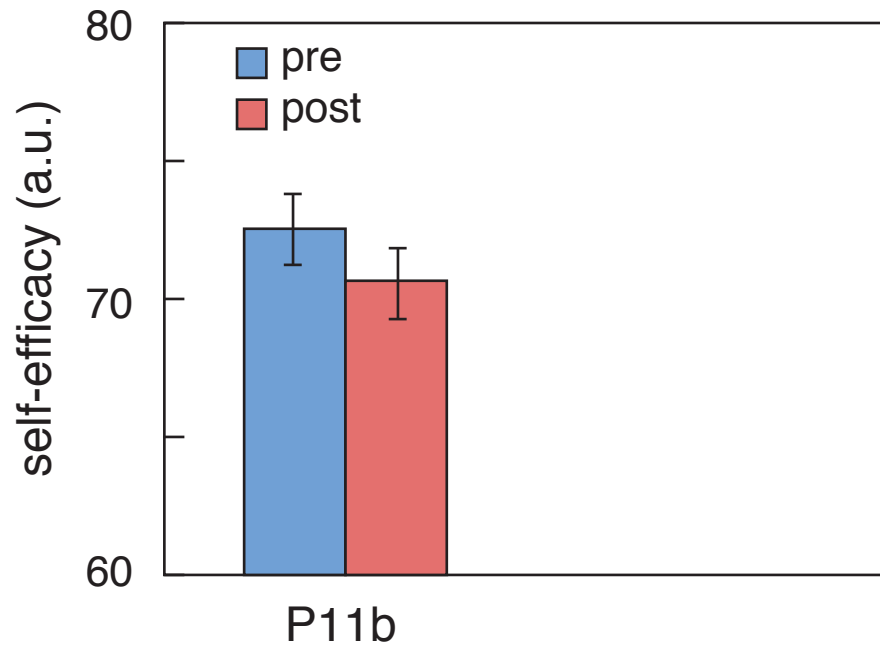
"I don't think I am well enough to make it through class. I feel terrible because I don't want to let my team down by not being there, but I don't think I'd be very helpful in my current state."

(via email)

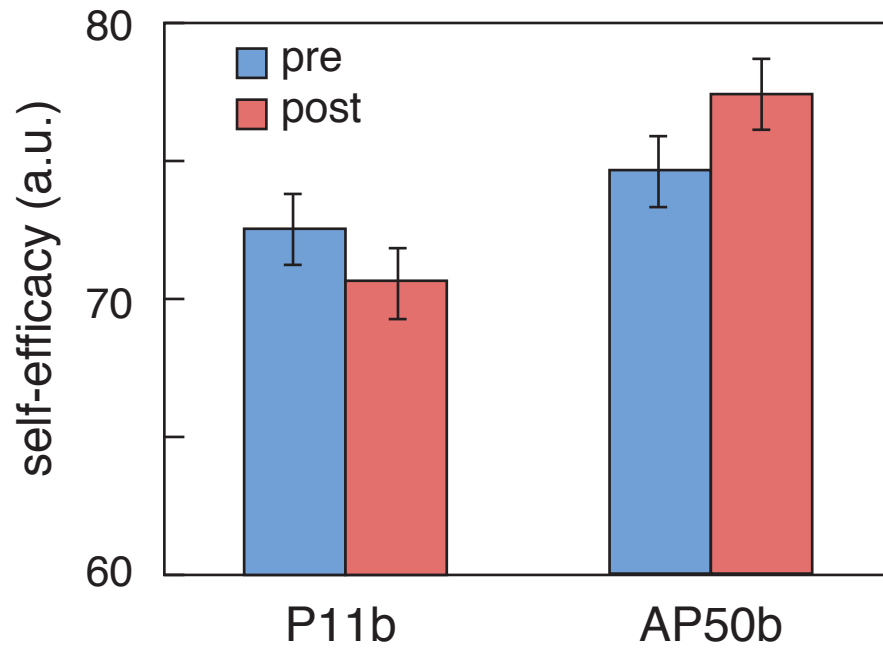
Self-efficacy



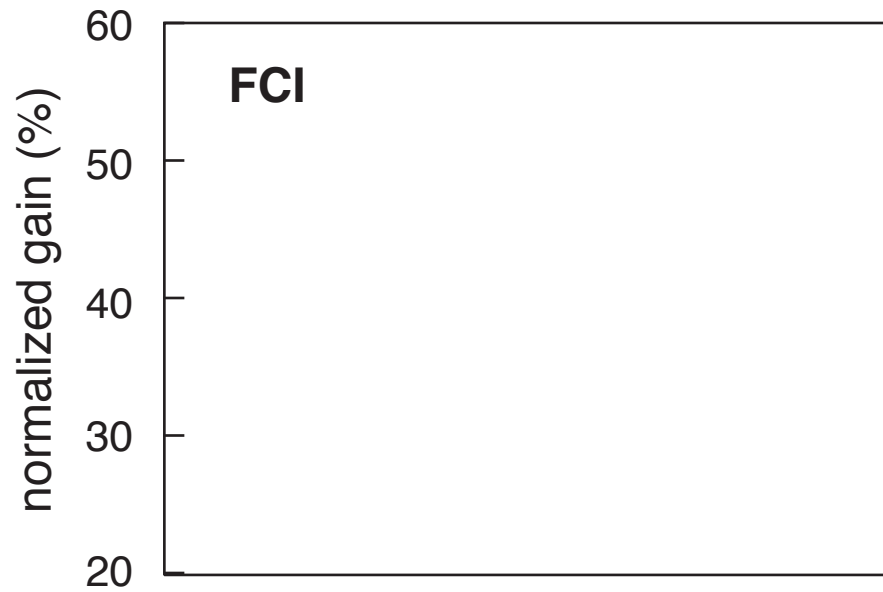
Self-efficacy



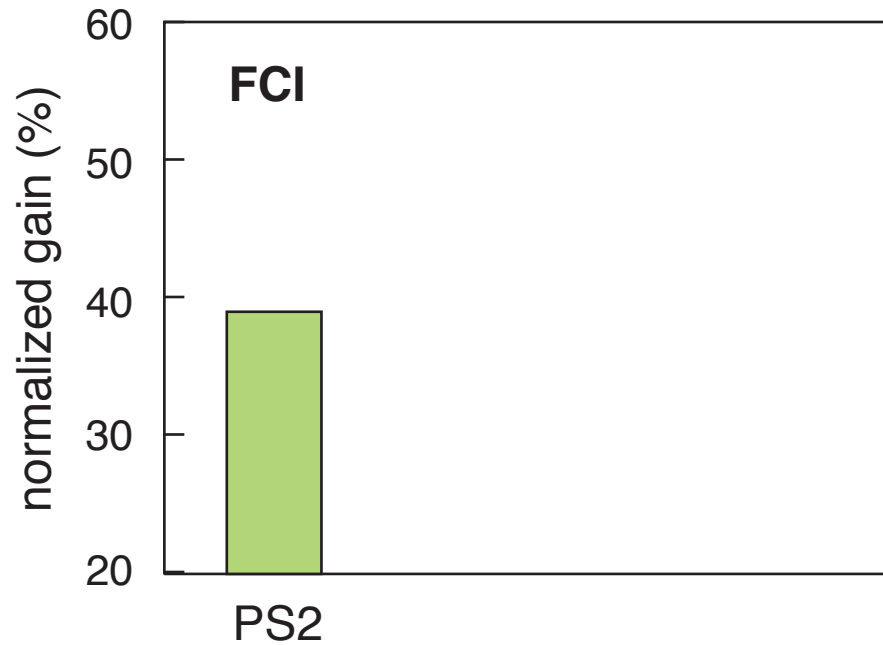
Self-efficacy



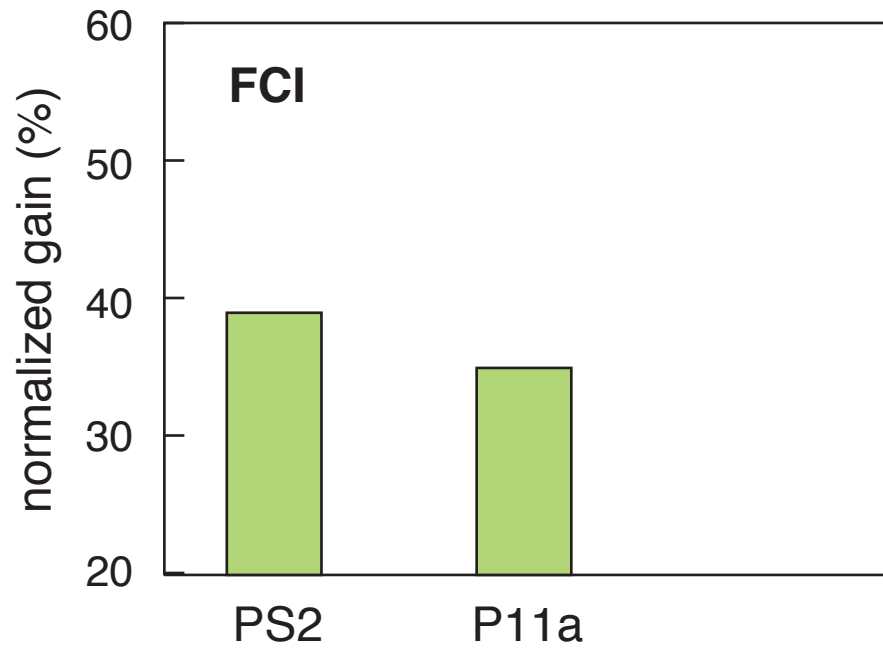
Conceptual Mastery



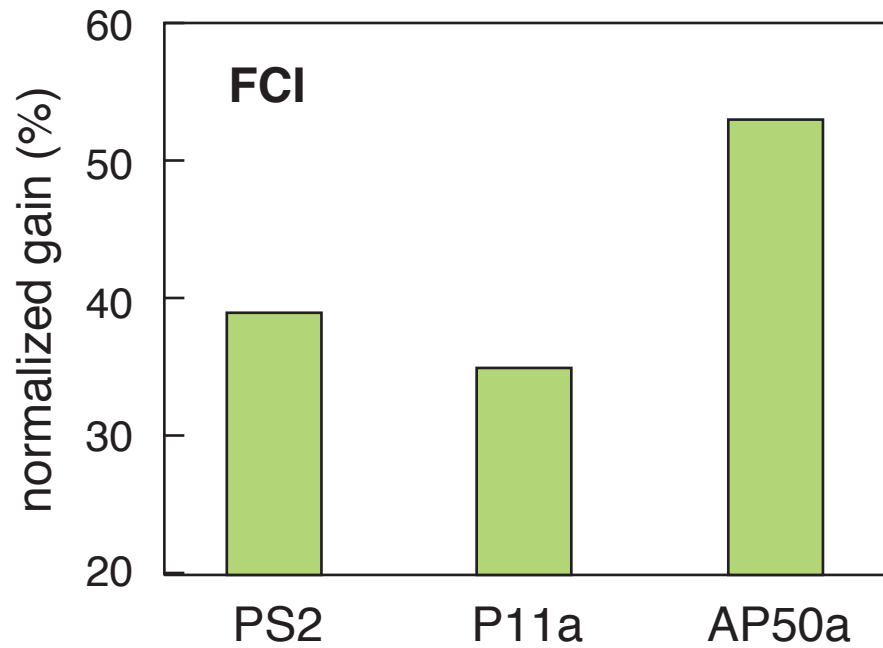
Conceptual Mastery



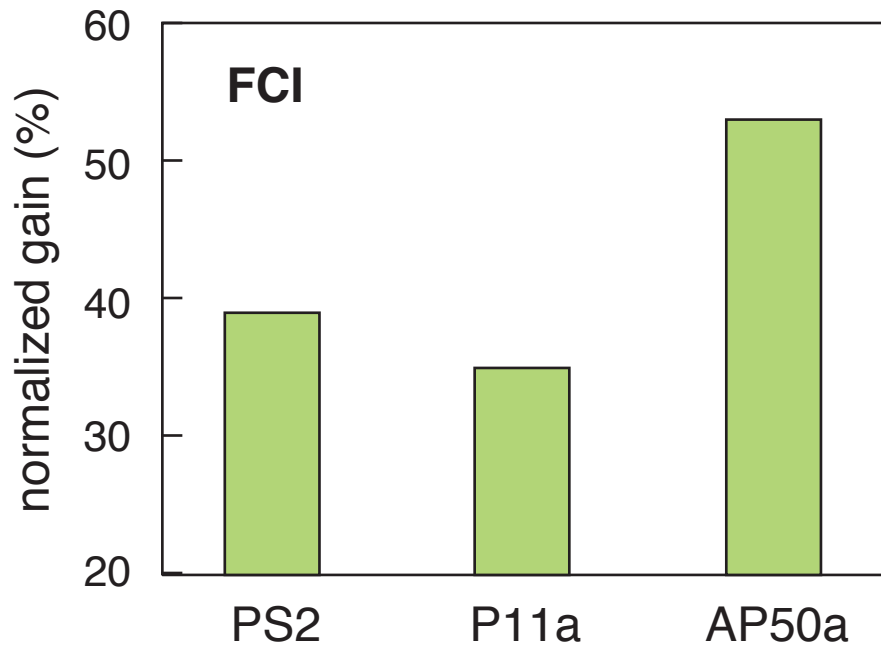
Conceptual Mastery



Conceptual Mastery

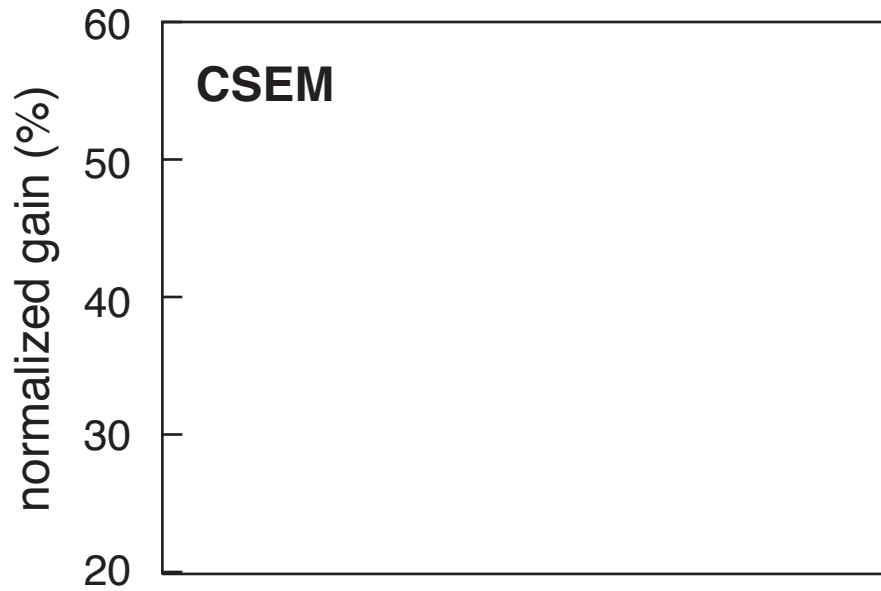


Conceptual Mastery

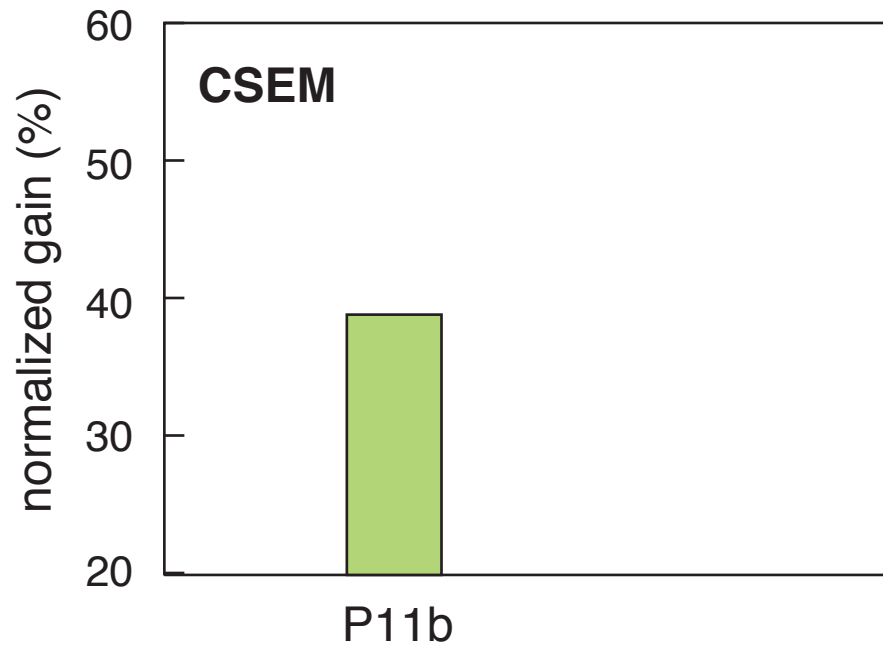


largest conceptual gain in *any* course past 6 yrs!

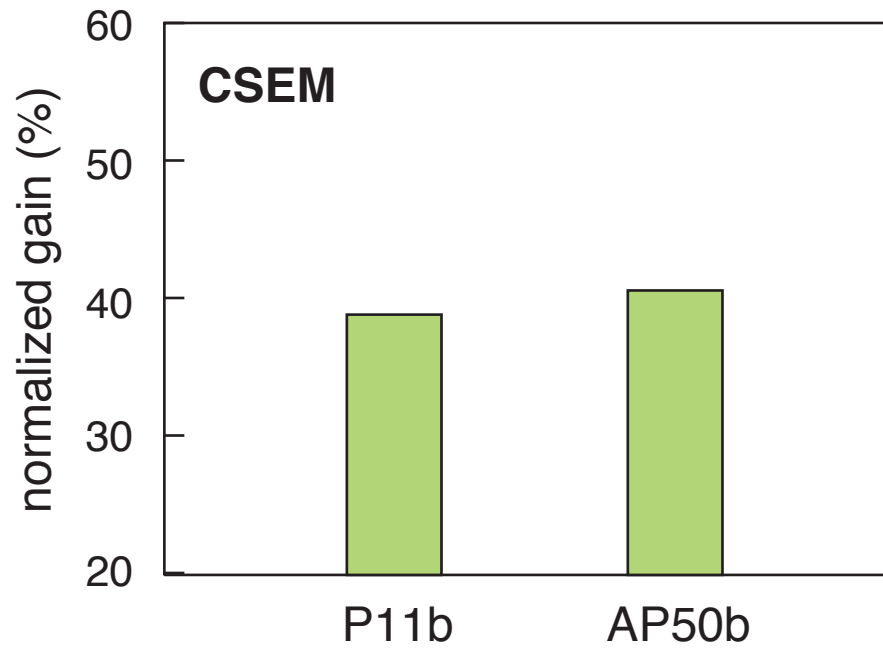
Conceptual Mastery



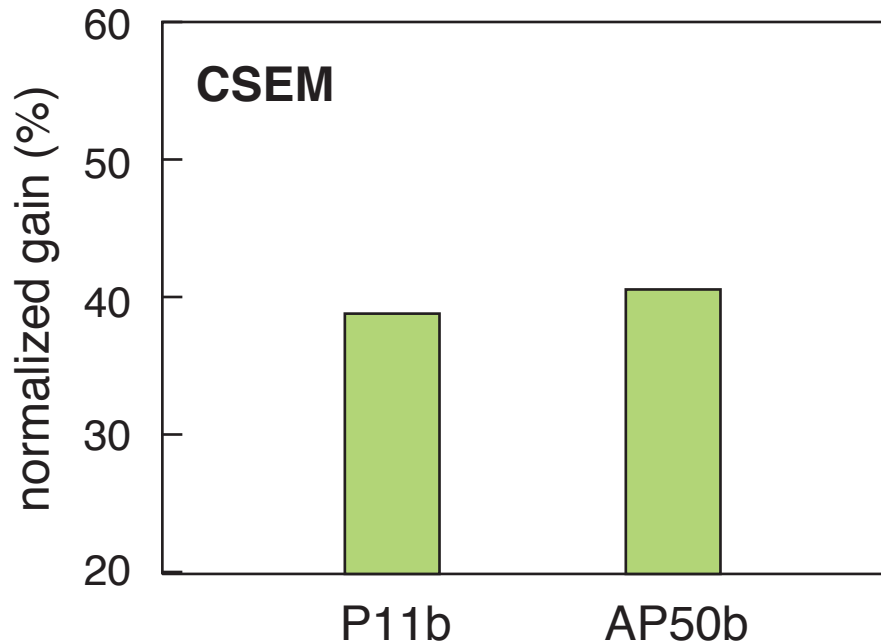
Conceptual Mastery



Conceptual Mastery



Conceptual Mastery



as good as when I do my best teaching!



A photograph of four students in a physics laboratory. A woman with glasses is leaning over a wooden box containing a pendulum experiment, holding a white cup. Two other women and a man are looking on with interest and smiles. The man is wearing a plaid shirt and yellow pants. The woman in the foreground is wearing a maroon hoodie. The background shows a typical lab setting with windows and equipment.

Can create ownership of learning physics!



Can create ownership of learning physics!



**“you come out with so much know-
ledge and experience and fun”**

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