

# Peer Instruction



**@eric\_mazur**

Physics and Astronomy New Faculty Workshop  
College Park, MD, 20 June 2016





What are the following...  
1. Personal...  
2. The...  
3. The...  
4. The...  
5. The...

- 1. ...
- 2. ...
- 3. ...
- 4. ...
- 5. ...

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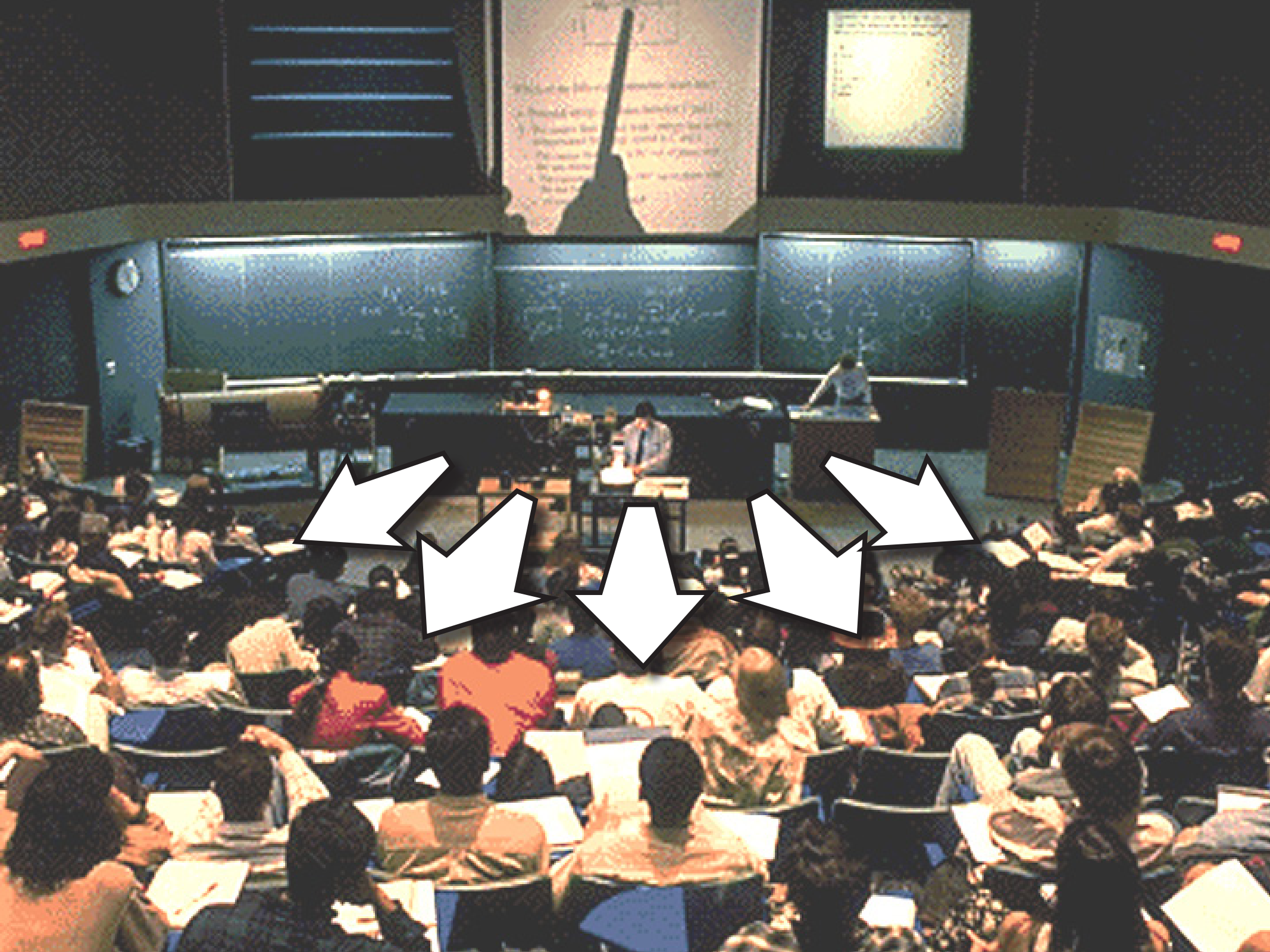
...  
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...  
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...









What are the following...  
A...  
The...  
The...  
The...  
The...

- 1.
- 2.
- 3.
- 4.
- 5.





The image features a painting of a face, possibly by Francis Bacon, with the eyes looking through horizontal slats. The painting is rendered in a style with visible brushstrokes and a somewhat distorted perspective. The background of the painting is a mix of light and dark tones. Overlaid on the center of the painting is the text "an illusion..." in a bold, red, serif font. The text is slightly transparent, allowing the underlying painting to be seen through it. The overall composition is centered and balanced.

**an illusion...**







**1. transfer of information**



**1. transfer of information**

**2. assimilation of that information**




**1. transfer of information (in class)**

2. assimilation of that information



**1. transfer of information (in class)**

**2. assimilation of that information (out of class)**



**Should focus  
on THIS!**

1. transfer of information (in class)

**2. assimilation of that information (out of class)**



**1. transfer of information (in class)**

**2. assimilation of that information (out of class)**



**1. transfer of information (out of class)**

**2. assimilation of that information (in class)**



# Peer

**1. transfer of information (out of class)**

**2. assimilation of that information (in class)**

INSTRUCTION

question

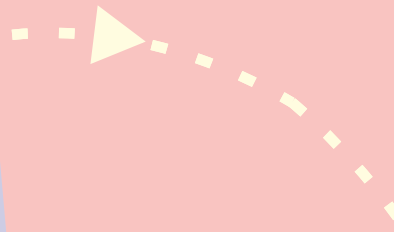
INSTRUCTION

**question**



**think**

**r**



**INSTRUCTION**

**question**



**think**



**poll**

INSTRUCTION

**question**



**think**



**poll**



**discuss**

INSTRUCTION

**question**



**think**



**poll**



**discuss**



**repoll**

**repoll**

**question**



**think**



**poll**



**discuss**

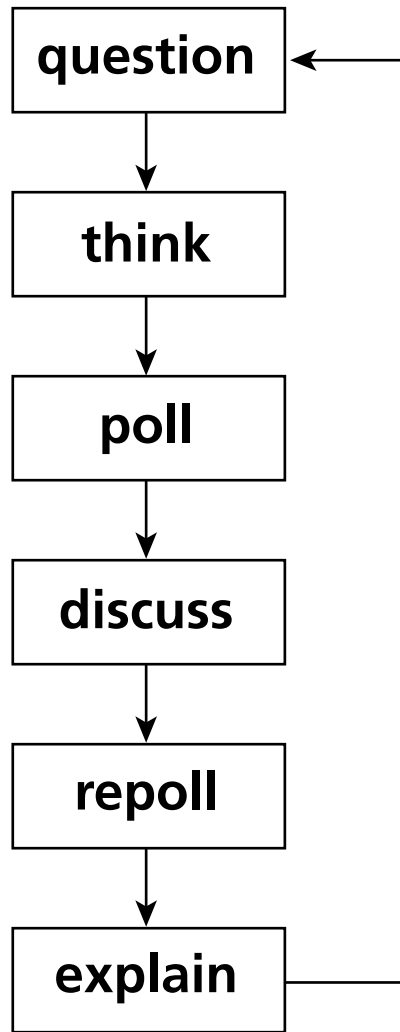


**repoll**

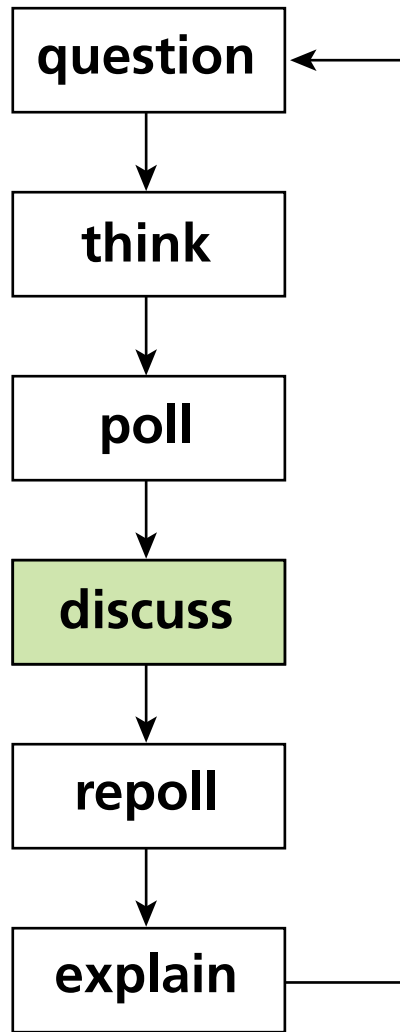


**explain**

INSTRUCTION





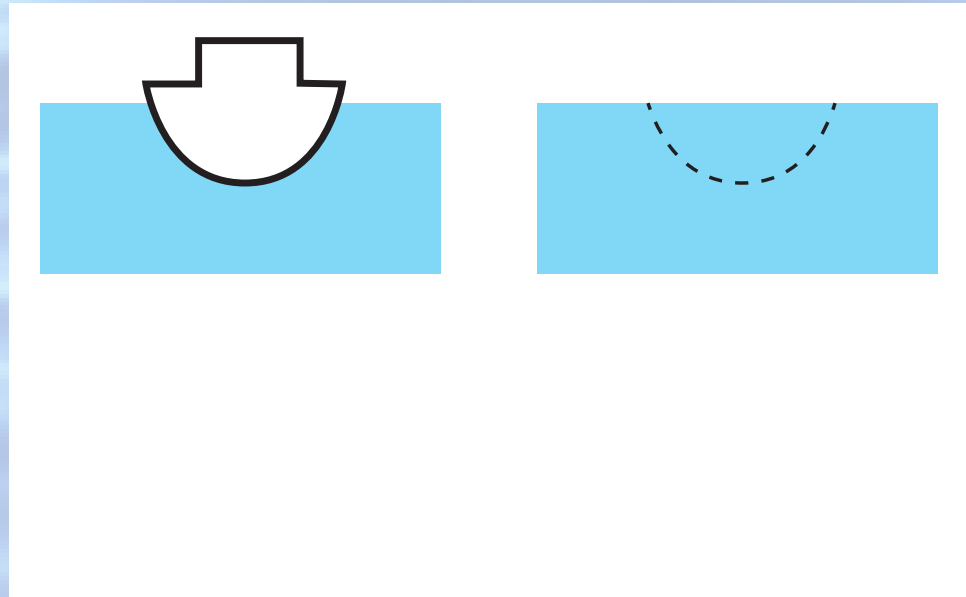




# **Archimedes Principle**

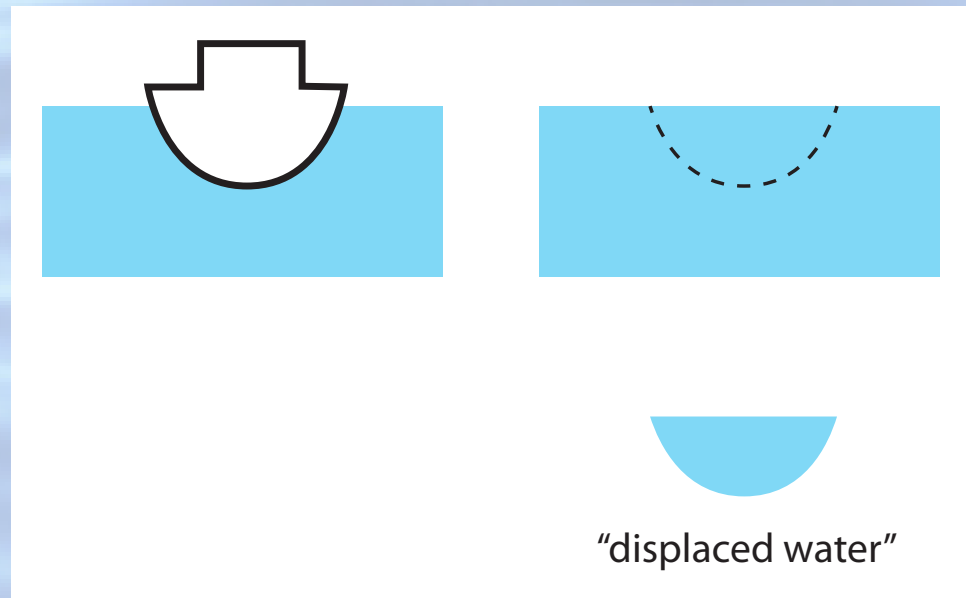
**An object submerged either fully or partially in a fluid experiences an upward buoyant force the magnitude of which is equal to the magnitude of the force of gravity exerted on the fluid displaced by the object.**

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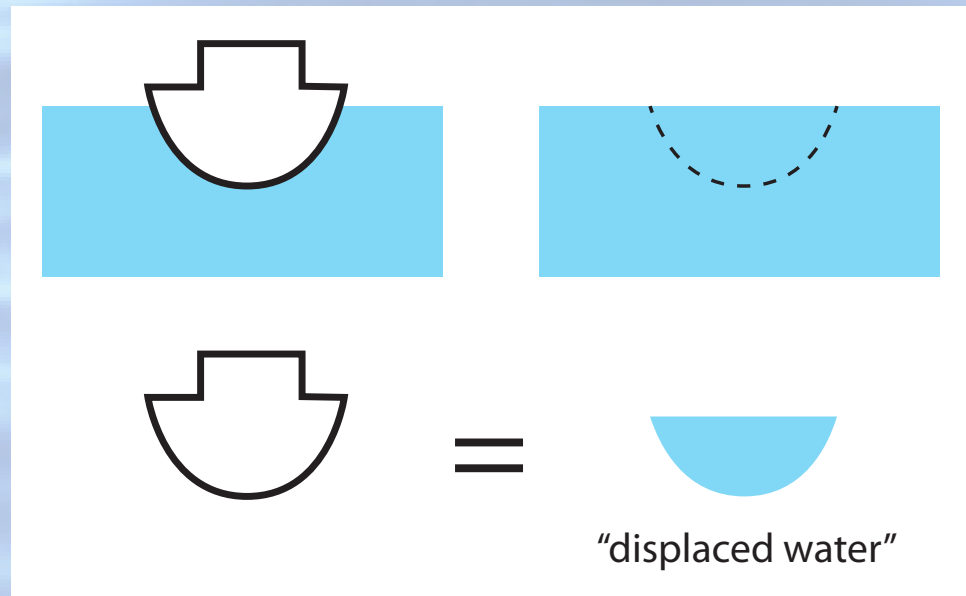
**The volume of displaced fluid is equal to the volume of the submerged portion of the object.**

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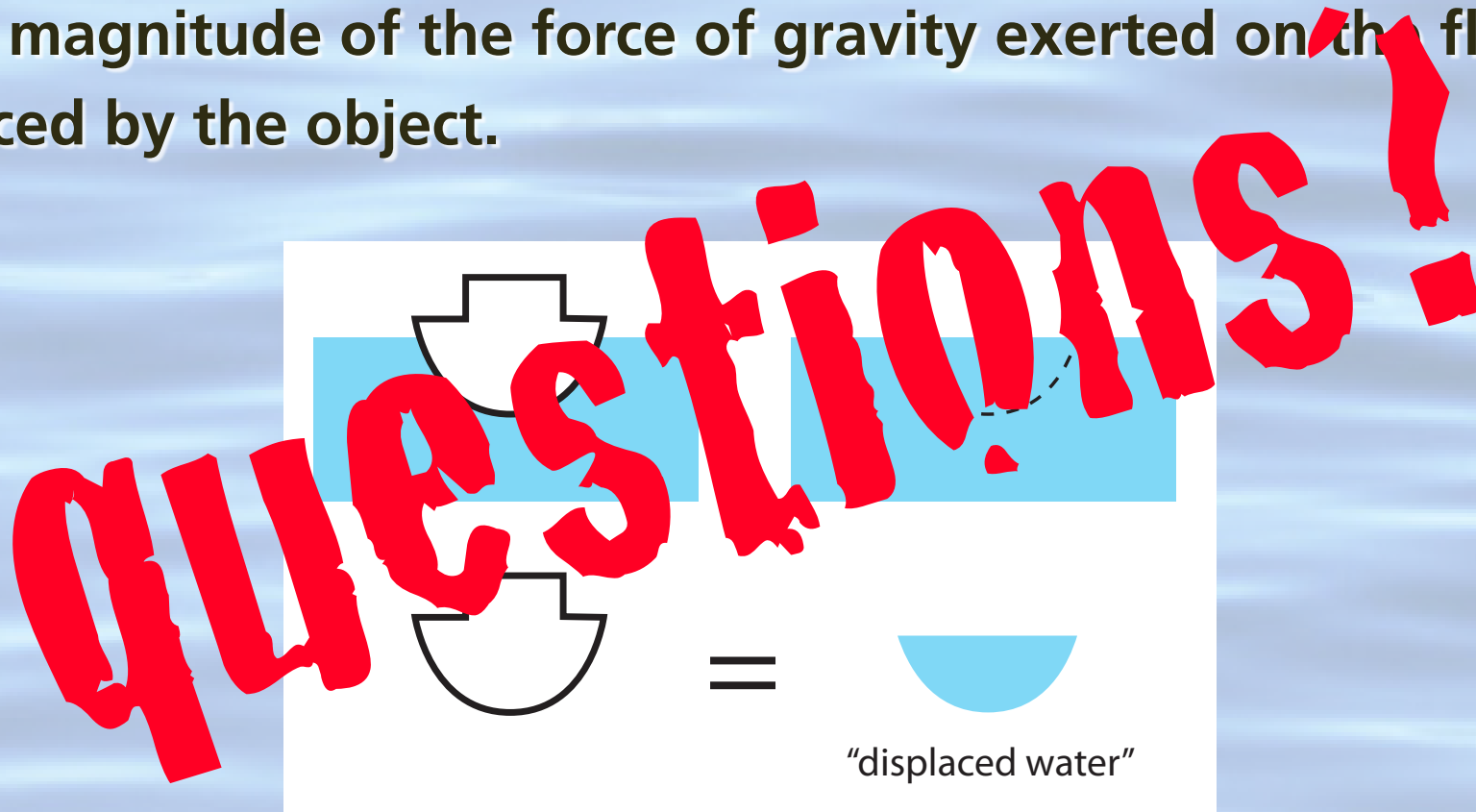
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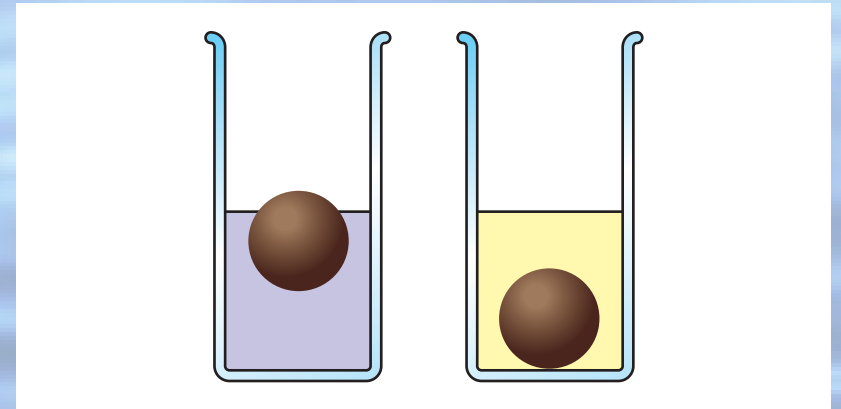
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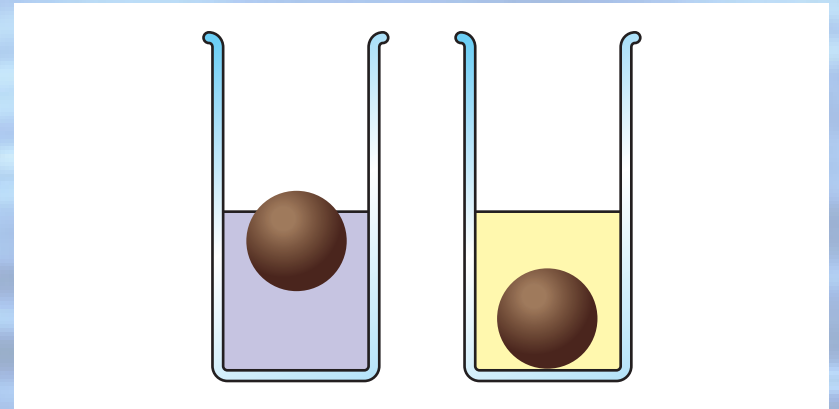
The volume of displaced fluid is equal to the volume of the submerged portion of the object.



**Consider an object that floats in water, but sinks in oil. When the object floats in water, most of it is submerged.**

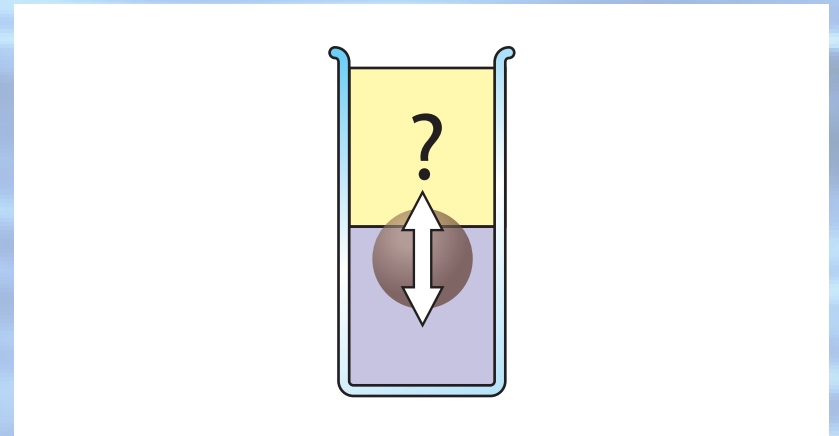


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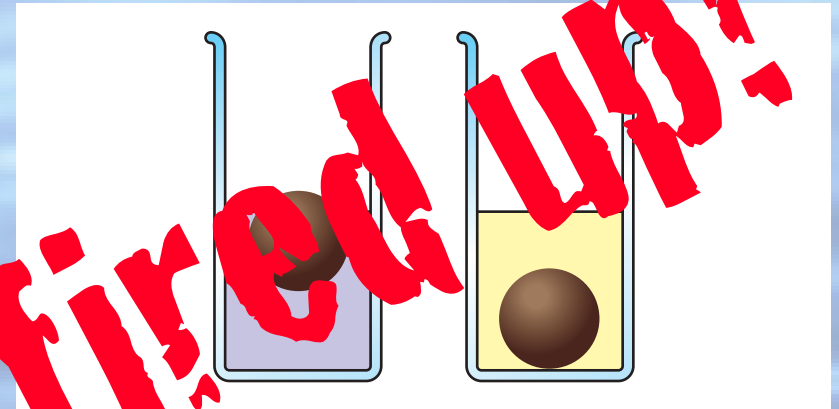


**If we slowly pour the oil on top of the water so it completely covers the object, the object**

- 1. moves up.**
- 2. stays in the same place.**
- 3. moves down.**

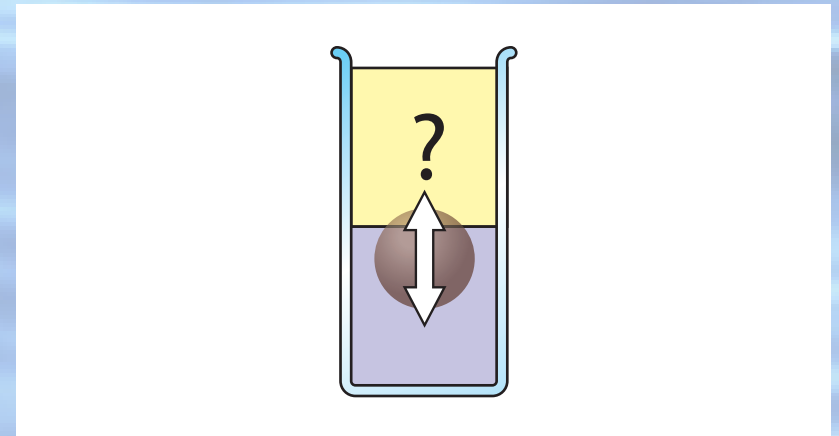


Consider an object that floats in water, but sinks in oil. When the object floats in water, most of it is submerged.



If we slowly pour the oil on top of the water so it completely covers the object, the object

1. moves up.
2. stays in the same place.
3. moves down.



**Before I tell you the answer, let's analyze what happened.**

**Before I tell you the answer, let's analyze what happened. You...**

**Before I tell you the answer, let's analyze what happened. You...**

**1. made a commitment**

**Before I tell you the answer, let's analyze what happened. You...**

- 1. made a commitment**
- 2. externalized your answer**

**Before I tell you the answer, let's analyze what happened. You...**

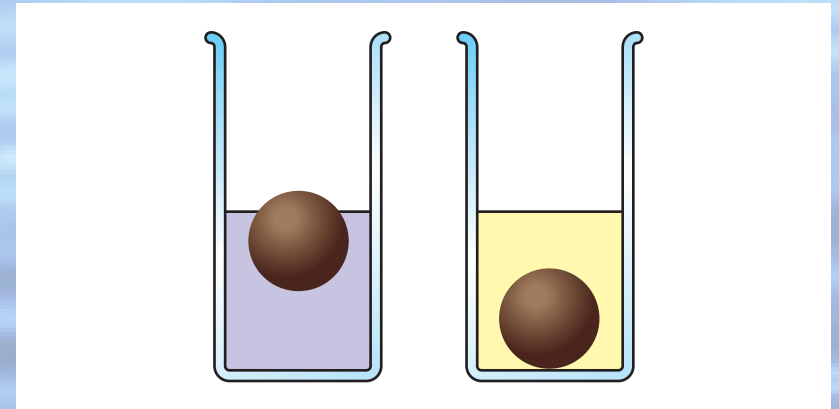
- 1. made a commitment**
- 2. externalized your answer**
- 3. moved from the answer/fact to reasoning**



**Before I tell you the answer, let's analyze what happened. You...**

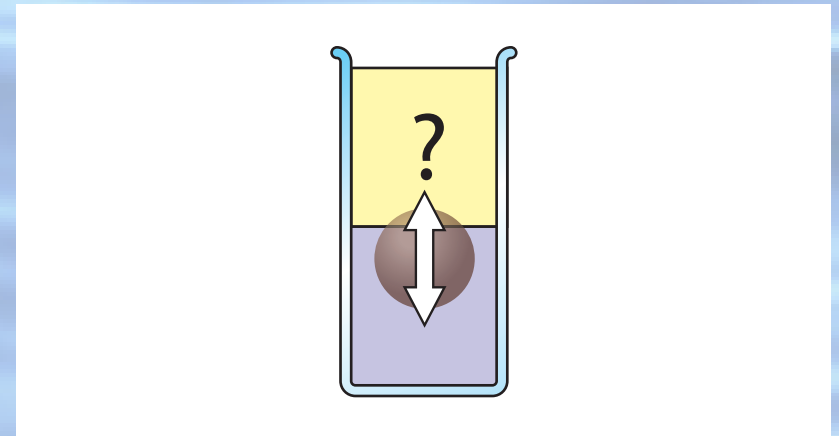
- 1. made a commitment**
- 2. externalized your answer**
- 3. moved from the answer/fact to reasoning**
- 4. became emotionally invested in the learning process**

**Consider an object that floats in water, but sinks in oil. When the object floats in water, most of it is submerged.**

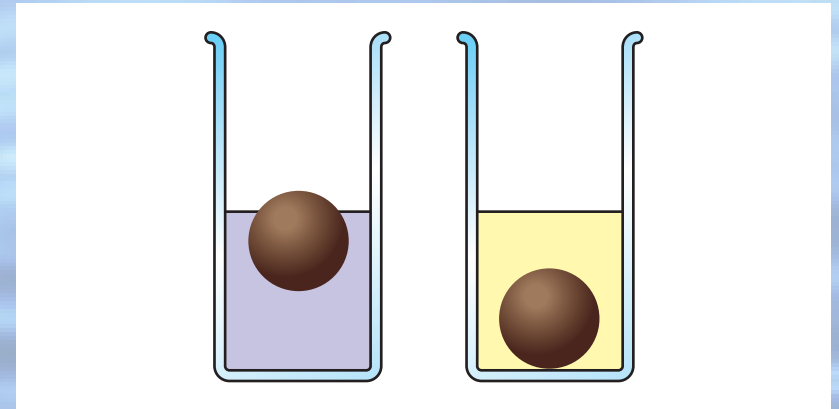


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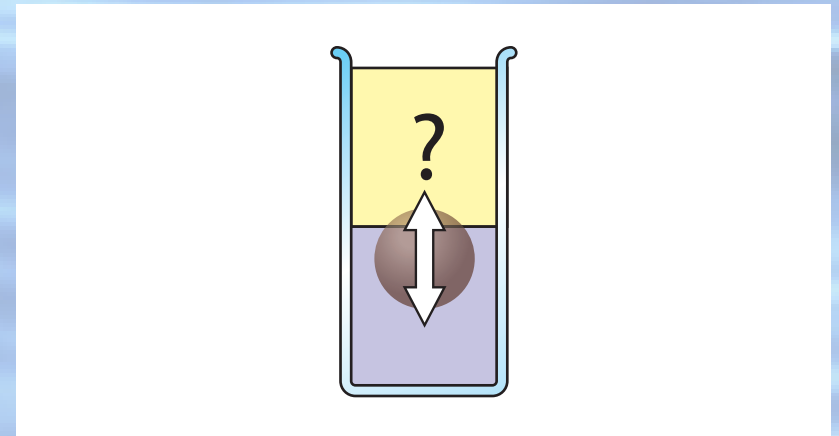


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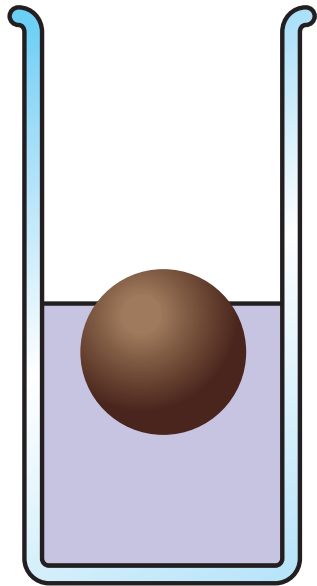


If we slowly pour the oil on top of the water so it completely covers the object, the object

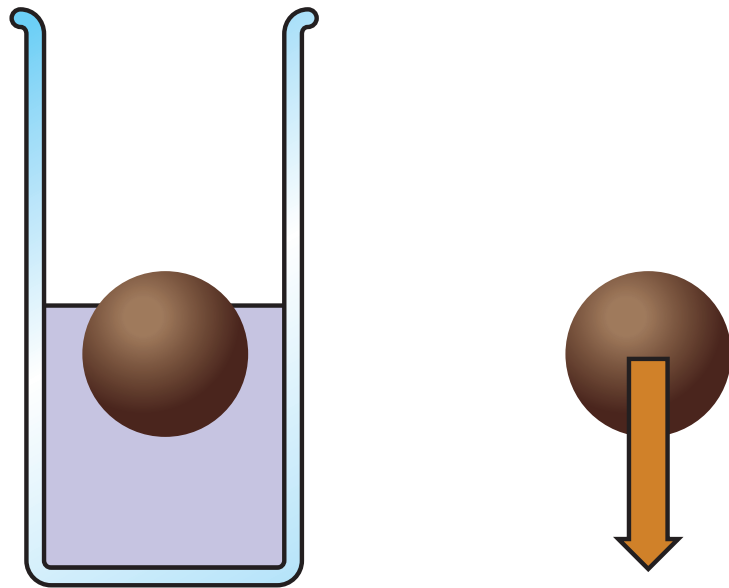
1. moves up. ✓
2. stays in the same place.
3. moves down.



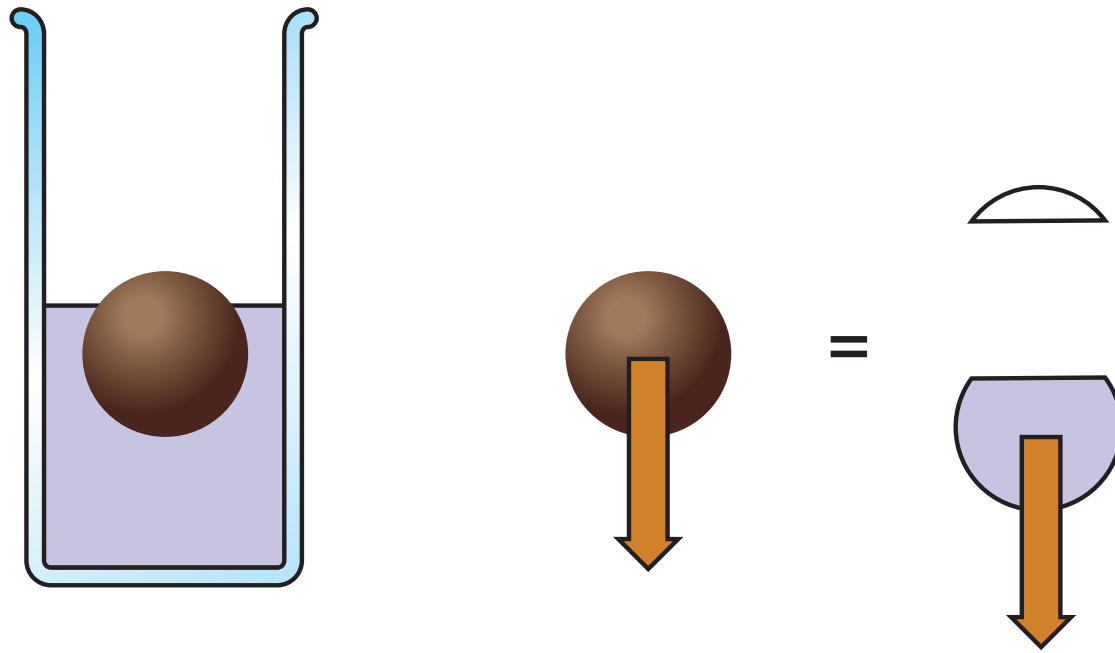
**remember: amount of displaced fluid**



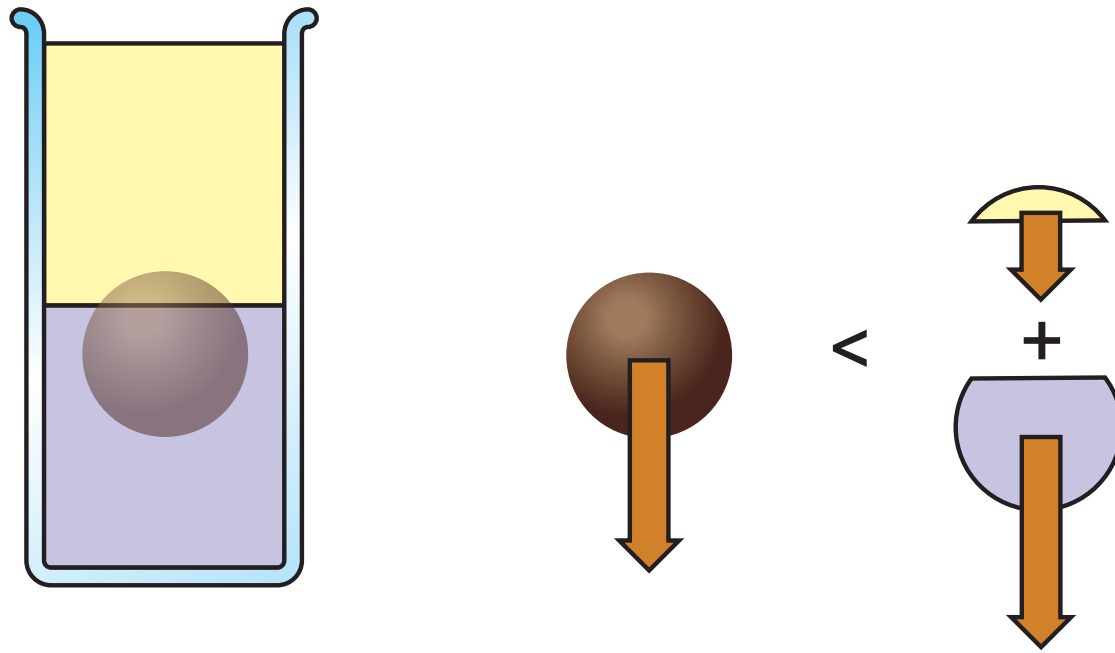
**remember: amount of displaced fluid**



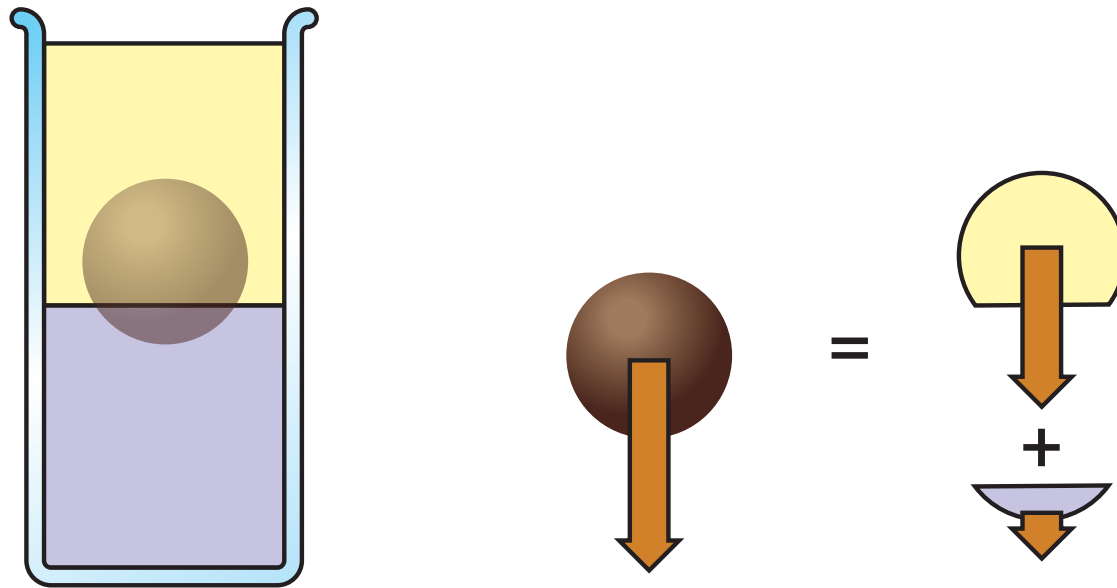
**remember: amount of displaced fluid**



**remember: amount of displaced fluid**



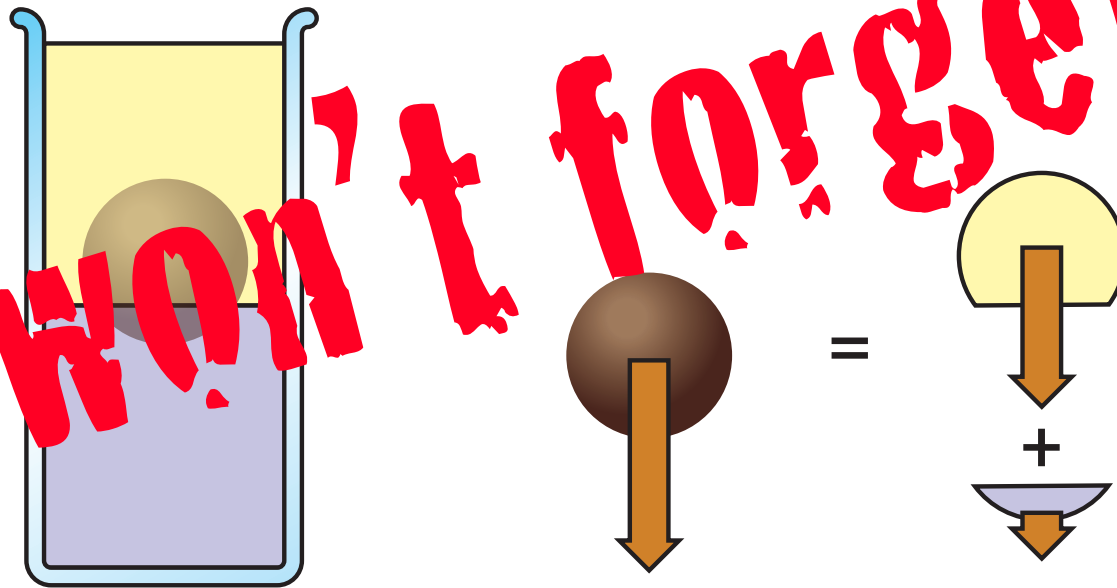
**remember: amount of displaced fluid**





remember: amount of displaced fluid

**you won't forget this**



Peer

back to pi

INSTRUCTION

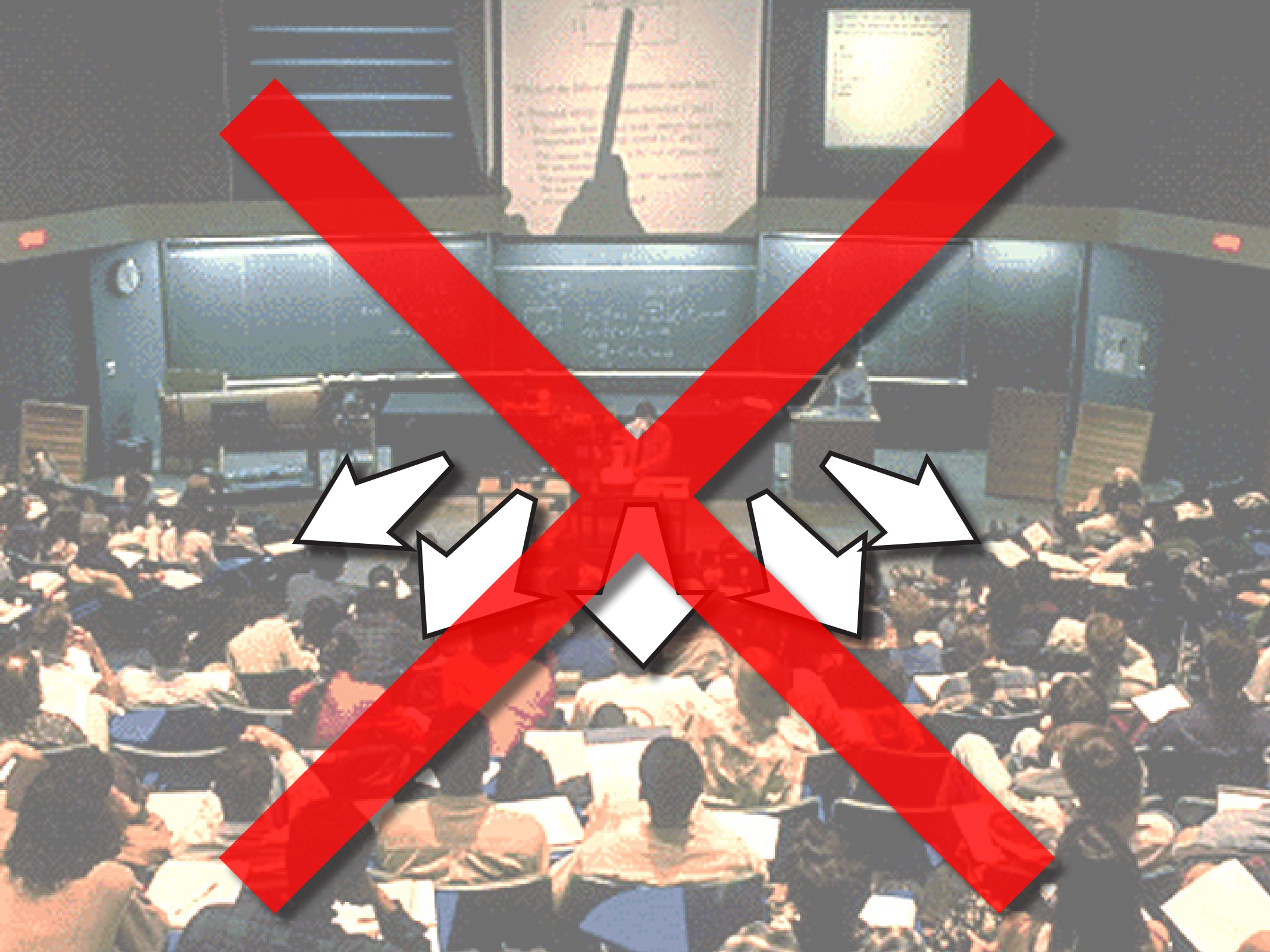
**Higher learning & gains**

INSTRUCTION

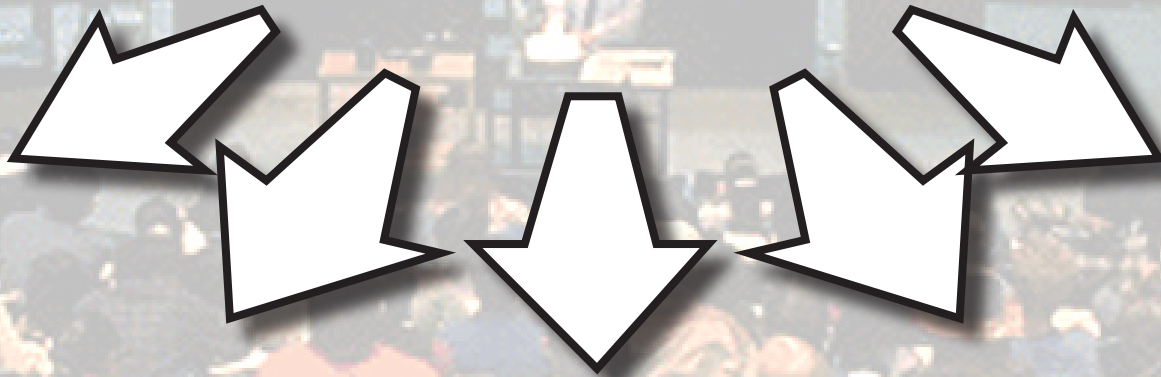
**Higher learning gains**

**Better retention**

**INSTRUCTION**



**how to effectively transfer information outside classroom?**





**but...**





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

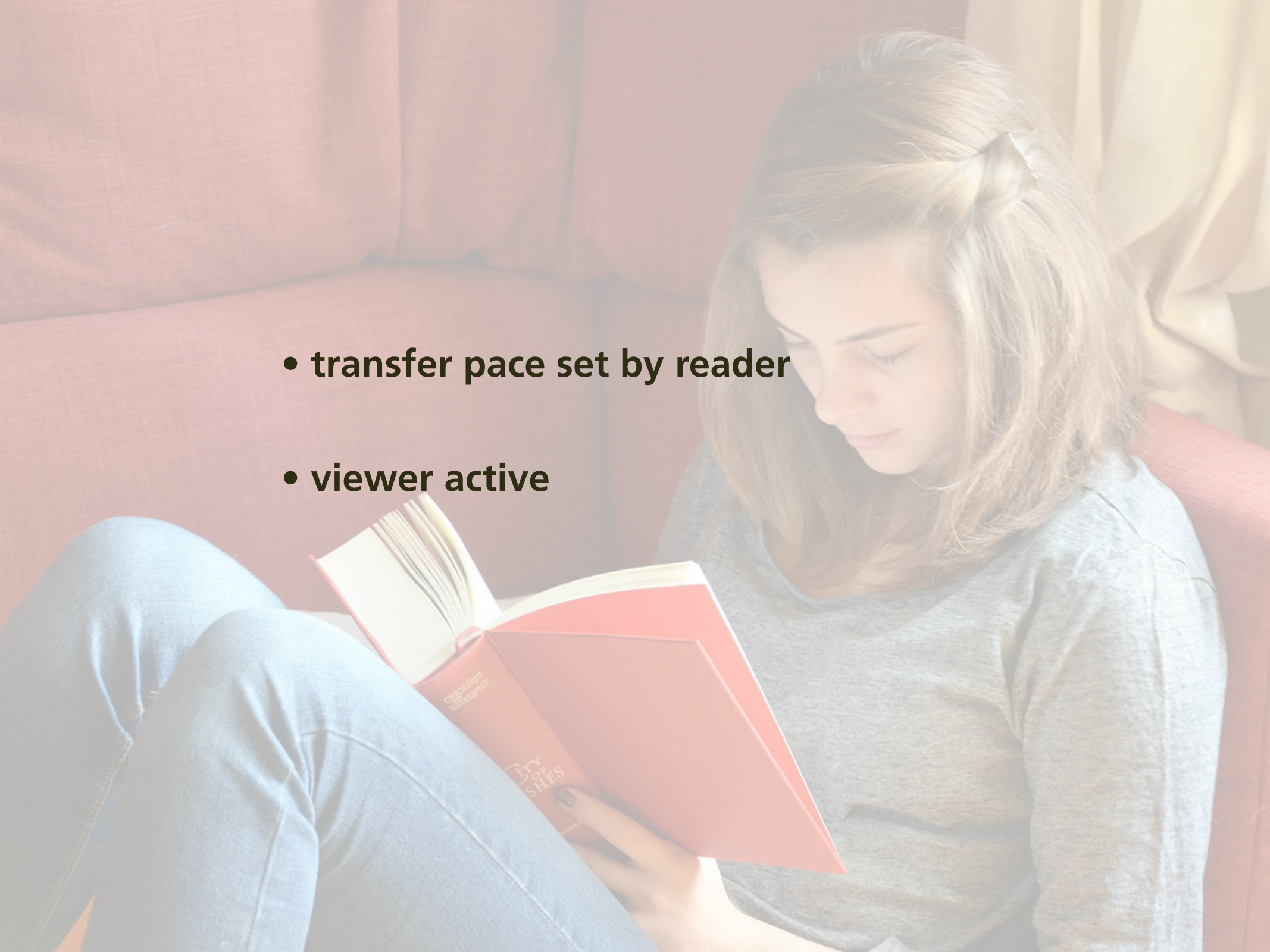




**we're simply moving this outside classroom!**




- **transfer pace set by reader**
- **viewer active**



**but...**





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



**want:**

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



**want:**

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

**(without additional instructor effort)**





**Solution**

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

# 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. Think of the difference in 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 decreases as the block slides over ice; it hardly decreases on the smooth wooden surface; and it decreases rapidly on the rough wooden 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.

**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 is blown through a series of holes in the table, creating a thin layer of air that 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?

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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 of motion, the velocity-versus-time graph, the velocity decreases over time. On ice, the velocity decreases very little because there is very little friction between the block and the surface. The effect of friction is to slow the block down with respect to each other—in this case, the block and the surface it is sliding on. The longer it takes for the block to come to rest, the smaller the friction is.

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.



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



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highlighting text...

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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 minimized. The wheels on the labeled carts in Figure 4.2 also minimize friction. 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:

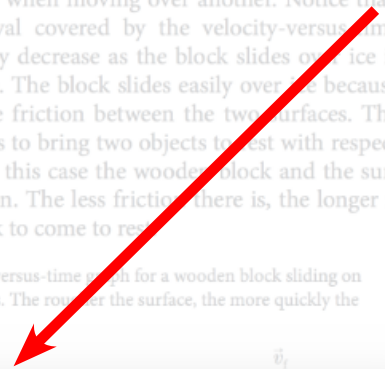
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Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.



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?

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## 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 decreases as the block slides over ice; it 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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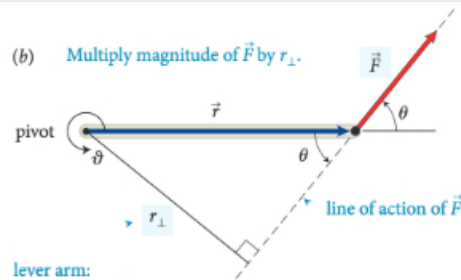
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(b) Multiply magnitude of  $\vec{F}$  by  $r_{\perp}$ .



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

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 forces exerted on it, showing their points of application on the rod (Figure 12.6).

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.

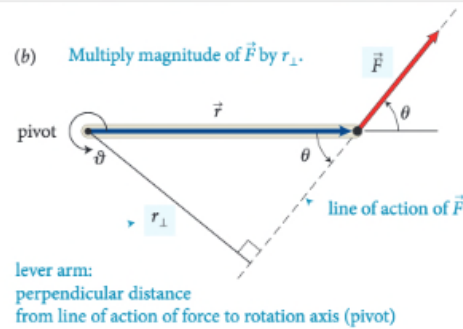


**12.2** In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

### 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 makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

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



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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  $\vec{F}_{pr}^c$  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. ✓

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**question flag**





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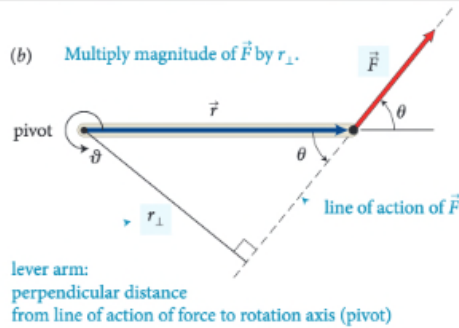


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## email notifications

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](#)

I don't understand how the lever arm distance is determined. I know some sort of

I think you mean the direction separation distance, you can use the parameters of the system to explain how to choose

This is a great question. You can think of this in terms of torque is  $\tau = r \times F$ , where  $F$  is the force. We know that in regards to "r" it means is that this is the distance to the point where the force is applied in the general convention of the direction which has the axis and to the force

Enter your comment

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$\vec{r}_{\perp}$

reference point

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On the very left, we see th...

It's interesting that the white ...

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# 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.

## option 1: reply

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

Profile picture of a user

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Profile picture of a user

I think you mean the perpendicular distance, you can use the parameters of the problem to explain how to choose...

Profile picture of a user

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Enter your comment

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option 2: view chat

View conversation

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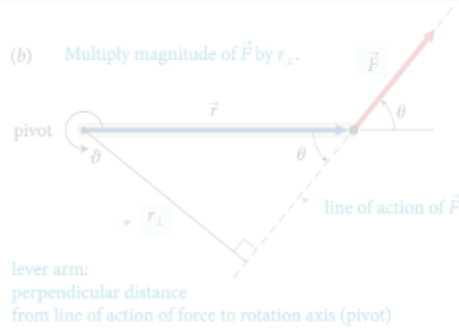
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View conversation

This comment helps my understanding

option 3: mark as answered



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 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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**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. Force  $\vec{F}_1$  is horizontal,  $\vec{F}_2$  and  $\vec{F}_3$  are vertical, and the lever makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

# how to get students to participate?

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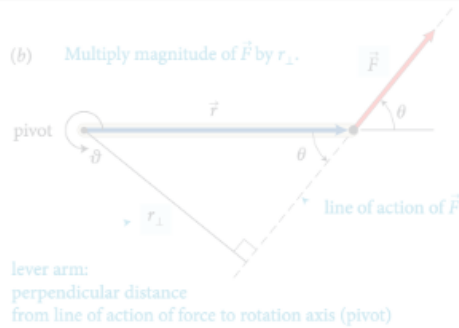
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reference point

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# use combination of

# intrinsic and extrinsic motivation drivers

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Enter your comment or question and press Enter

# 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)

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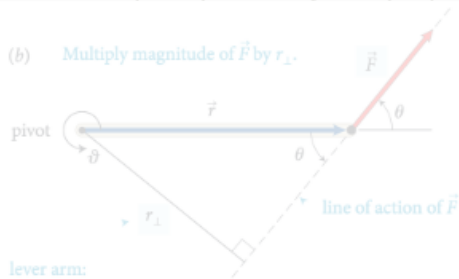
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# rubric-based assessment

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

- quality (thoughtful reading & interpretation)

- quantity (minimum 10)

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# rubric-based assessment

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

- quality (thoughtful reading & interpretation)

- quantity (minimum 10)

- timeliness (before class)

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- In this class, we always emp...
- 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...
- The type of diagram to use d...
- 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...
- Objects executing motion ar...
- Generally, for rotating bod... 2
- Does torque have the s... 3

# 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)

- quantity (minimum 10)

- timeliness (before class)

- distribution (not clustered)

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 elaborate 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.

Enter your comment or question and press Enter

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 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 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. Force  $\vec{F}_1$  is horizontal,  $\vec{F}_2$  and  $\vec{F}_3$  are vertical, and the lever makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

- On the very left, we see th...
- It's interesting that the white ...
- Is the refernece frame i... 2
- How does force affect ... 2
- I was curious about this, t... 3
- I understand partially w... 3
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- Objects executing motion ar...
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# 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 (thoughtfulness & in-depth)

action of the force and the rotation. So, the torque caused by a force  $\vec{F}$  is the product of the force's magnitude and the lever arm distance. It can

- quantity (minimum 10)

- timeliness (before class)

- direction (right or left)

**over 20,000 annotations!**

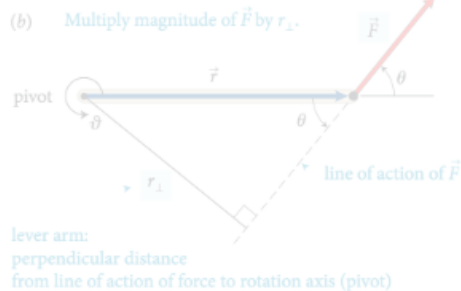
The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force  $\vec{F}_1$  about the left end of the rod is zero. If I choose the pivot at the left end of the rod, the force  $\vec{F}_2$  causes a positive direction of rotation,  $\vec{F}_3$  causes a negative direction of rotation about the left end of the rod; the force  $\vec{F}_3$  causes a positive direction of rotation about the left end of the rod. The lever arm distance of  $\vec{F}_2$  about the left end of the rod is  $r_2$ . The lever arm distance of  $\vec{F}_3$  about the left end of the rod is  $r_3$ . The sum of the torques about the left end of the rod is at rest, so the sum of the torques about the left end of the rod is equal to zero. The sum of the torques about the left end of the rod is  $\tau_2 + \tau_3 = r_2 F_2 - r_3 F_3$ . The result we obtain is the same as if we choose the pivot at the right end of the rod. The sum of the torques about the right end of the rod is  $\tau_1 + \tau_2 - \tau_3 = r_1 F_1 + r_2 F_2 - r_3 F_3$ . The sum of the torques about the right end of the rod is zero, just like the sum of the torques about the left end of the rod. You can repeat the calculation for the torques about the right end of the rod for any other pivot, 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 about any point is zero. In general we can choose any point as the pivot. For a rotating object we choose the pivot at the center of mass. We like to calculate torque about the center of mass because it is the point that is easiest to calculate. As you have seen, we do not need to know anything about the force at the reference point. The only thing that is needed is the reference point. The sum of the torques about the reference point is zero. We can calculate that force from the calculation.

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. Force  $\vec{F}_1$  is horizontal,  $\vec{F}_2$  and  $\vec{F}_3$  are vertical, and the lever makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

- Only left, we see th...
- It's just the white ...
- Is it for frame i...
- How does fo effect ...
- As u at this, t...
- Under p ally w...
- This class says emp...
- before this wa...
- The extended free-body
- This just means the net
- I don't understand why ...
- It is important that...
- sds when we ...
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- Objects executing motion ar...
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- Does torque have the s...

# rubric-based assessment



- quality (thoughtful reading & interpretation)

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. 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.

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. Force  $\vec{F}_1$  is horizontal,  $\vec{F}_2$  and  $\vec{F}_3$  are vertical, and the lever makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

- On the very left, we see th...
- It's interesting that the white ...
- Is the reference frame i...
- How does force affect ...
- I was curious about this, t...
- I understand partially w...
- In this class, we always emp...
- It's not before this wa...
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- This just means the net...
- I don't understand why ...
- is important to be in...
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- As we saw earlier in the chap...
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- Generally, for rotating bod...
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# how do you process all of that??

- quantity (minimum 10)
- timeliness (before class)
- distribution (not clustered)



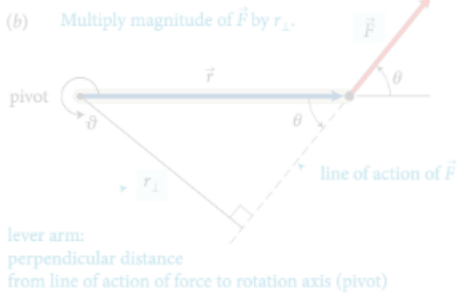
lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque.

I think you may be able to think about the direction separately. So, for finding the magnitude of the 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 elaborate on this, you 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 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.

Enter your comment or question and press Enter

# rubric-based assessment



The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force  $\vec{F}_1$  about the left end of the rod is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counter-clockwise as the positive direction of rotation,  $\vec{F}_2$  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 the perpendicular distance from the left end of the rod to the line of action of  $\vec{F}_2$ . This is the same result 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. For a static equilibrium problem, you can choose a reference point to calculate torques. 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 pivot, 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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- On the very left we see th...
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- As we saw earlier in the chap...
- Objects executing motion ar...
- Generally, for rotating bod...
- Does torque have the s...

**fully automated**

**you process all of that??**

**assessment**

- quality (though future research on interpretation)

- timeliness (before class)

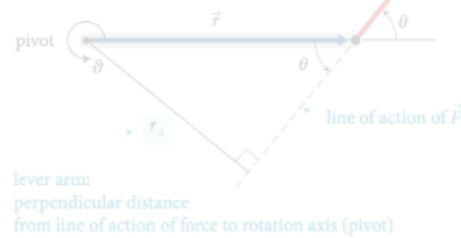
- distribution (not clustered)





# 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 the diagram above, you can explain how to choose the sign of the torque.

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.

Enter your comment or question and press Enter

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. The result is that the sum of the torques 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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On the very left, we see th...

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Is the reference frame i... 2

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I was curious about this, t... 3

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# gradebook

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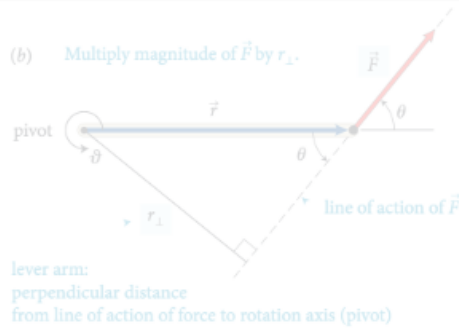
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Total number of annotations	<b>16</b>
Total number of annotations submitted on time	<b>11</b>
Average quality of top 10 annotations submitted on time	<b>1.80</b>
2 = demonstrates thorough and thoughtful reading and insightful interpretation of the 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	<b>3.8</b>
0 = clustered, 5 = evenly distributed throughout assignment	
Assignment score	<b>1</b>
scores range from 0 to 3	



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  $\vec{F}_{pr}^c$  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. This is true for any reference point. 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.

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# connect pre-class and in-class activities

I don't think you can think of torque as a scalar quantity. Torque is a vector. The magnitude of the torque is the product of the force and the 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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## 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?
- SB Using the right hand rule, I believe the answer is D. Is that correct? 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...

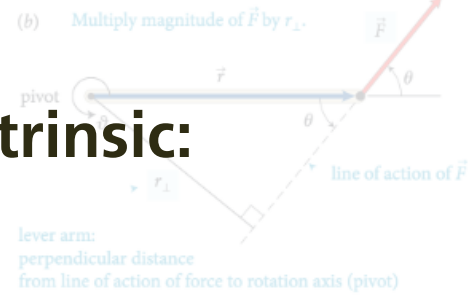
## earth magnetic field (6 questions)

- 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?
- AK Can someone explain why this type of bacteria knows what direction the earth's magnetic fields are facing?
- 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. Show more...

# motivating factors

## Intrinsic:

- social interaction



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 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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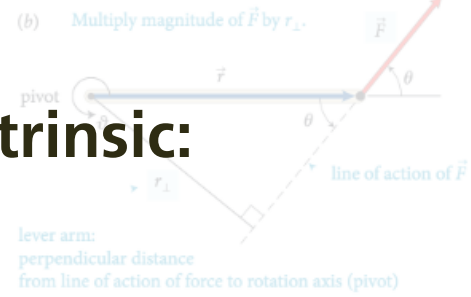
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Enter your comment or question and press Enter

# motivating factors

## Intrinsic:

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



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Enter your comment or question and press Enter

# motivating factors

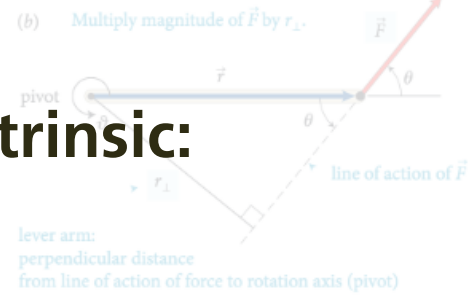
## Intrinsic:

- social interaction

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## Extrinsic:

- assessment (fully automated)



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Profile picture of a user.

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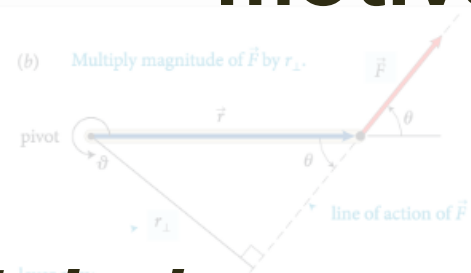
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Enter your comment or question and press Enter



# 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**



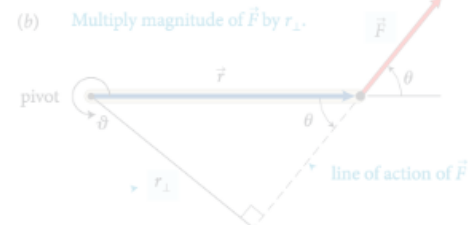
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Enter your comment or question and press Enter

# 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

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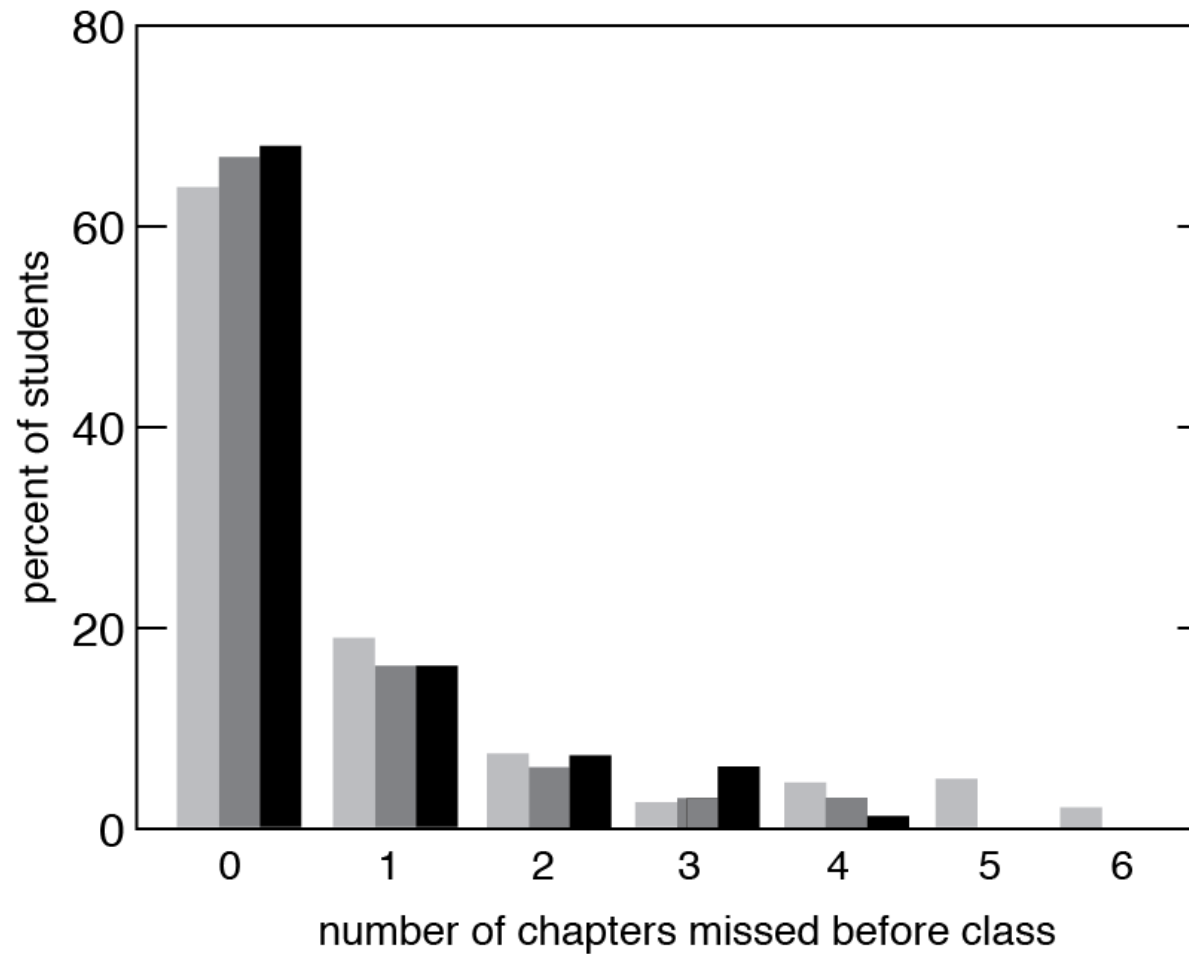
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## class test results

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

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## 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 makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

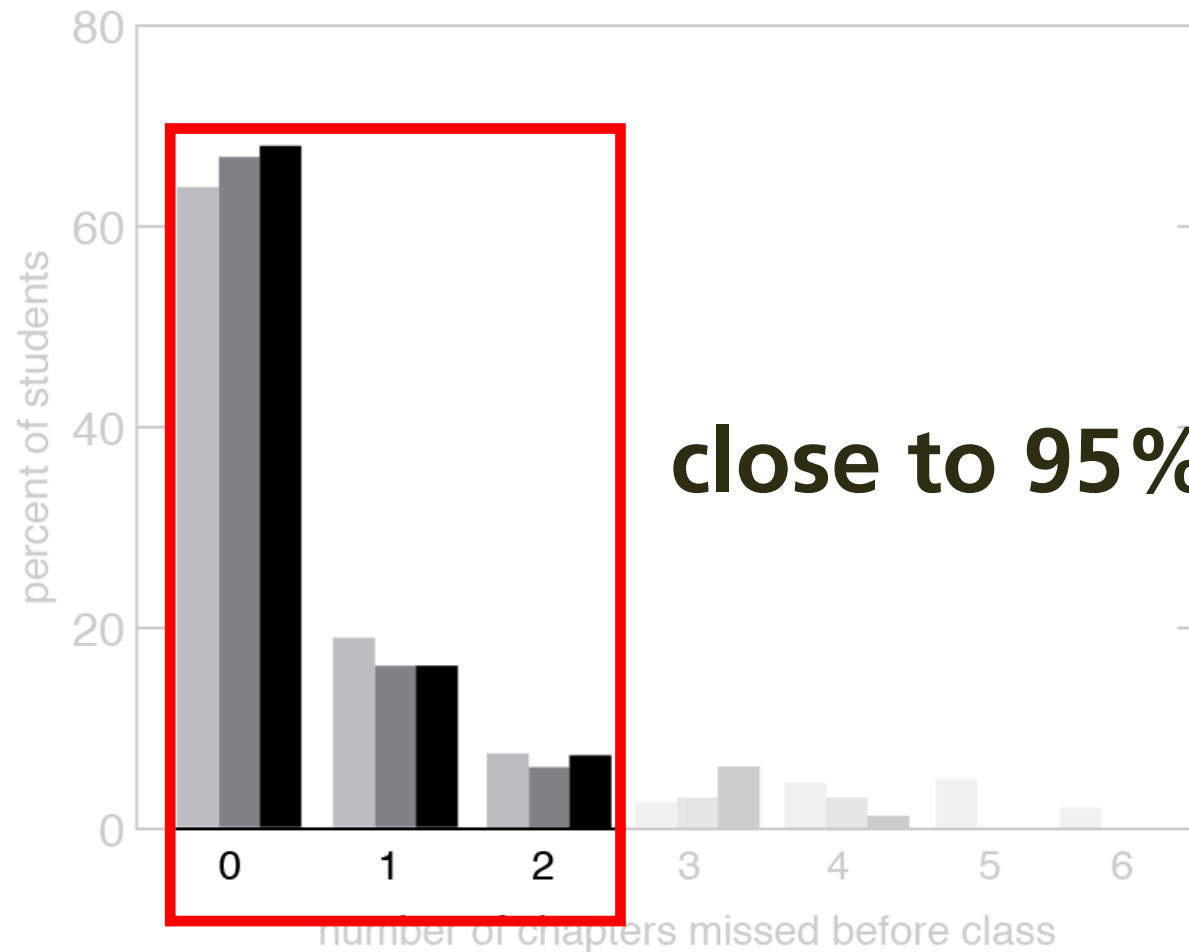
## class test results

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



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



close to 95%!

I don't understand how factors tells you any lever arm distance both s know some sort of direct

I think you may be a direction separately. distance, you can attach parameters of the system explain how to choose th

This is a great question. I can think of this in terms torque is  $\tau = r \times F$ , with  $r$  force. We know that force in regards to "r" it can also means is that this distance to the point where the force general convention (the r direction which happens to be perpendicular to both the radius from the axis and to the force.

Enter your comment or question and press Enter

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(a) The change in rotation...

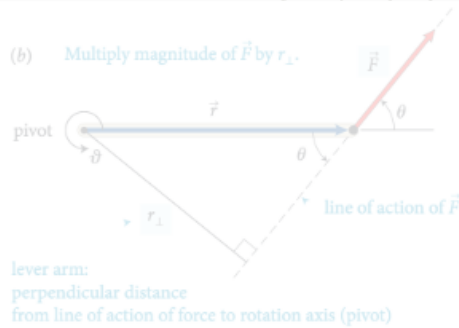
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# class test results



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**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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# every student prepared for every class

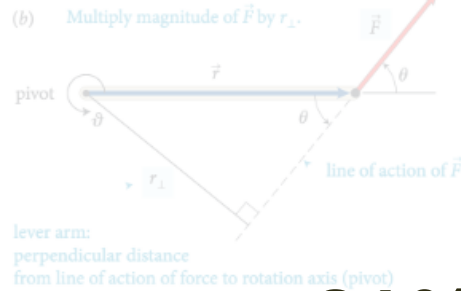
I don't understand how this combination of ... Oct 20 12:09 am

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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

Enter your comment or question and press Enter

# additional research data



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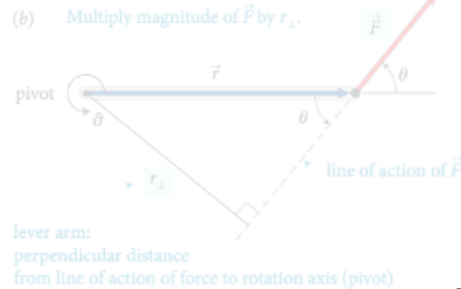
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• Engagement: 81% spend 2–6 hrs/wk reading

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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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# additional research data



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# additional research data

- **Engagement:** 81% spend 2–6 hrs/wk reading
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(b) Multiply magnitude of  $\vec{F}$  by  $r_{\perp}$ .



lever arm:  
perpendicular distance  
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**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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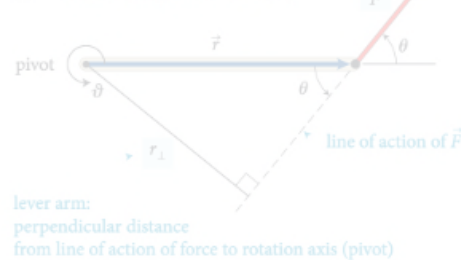
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(b) Multiply magnitude of  $\vec{F}$  by  $r_{\perp}$ .



- virtually 100% completion of assignments
- improved use of class time

## CONCEPTS

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 forces exerted on it, showing their points of application on the rod (Figure 12.6).

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perpendicular distance  
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Figure 12.7 shows a seesaw that is not rotating about 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 makes an angle of  $45^\circ$  with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

**all at no cost & without additional instructor effort!**

A painting of a face with large, expressive eyes looking through horizontal window blinds. The face is rendered in shades of blue and grey, with the eyes being a prominent feature. The blinds are light-colored, and the background is a mix of yellow and red tones.

**Education is not just about:**

- **transferring information**
- **getting students to do what we do**

The background of the slide features a close-up of a person's face, specifically their eyes and nose, looking through horizontal window blinds. The blinds are partially open, creating a grid-like pattern over the face. The lighting is soft, and the colors are muted, with a focus on the blue and grey tones of the person's skin and the yellow and red of the blinds.

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