

# Confessions of a converted lecturer



Conference on Educational Innovation  
Universiteit Leiden  
Leiden, Netherlands, 23 November 2015





# Confessions of a converted lecturer



**@eric\_mazur**

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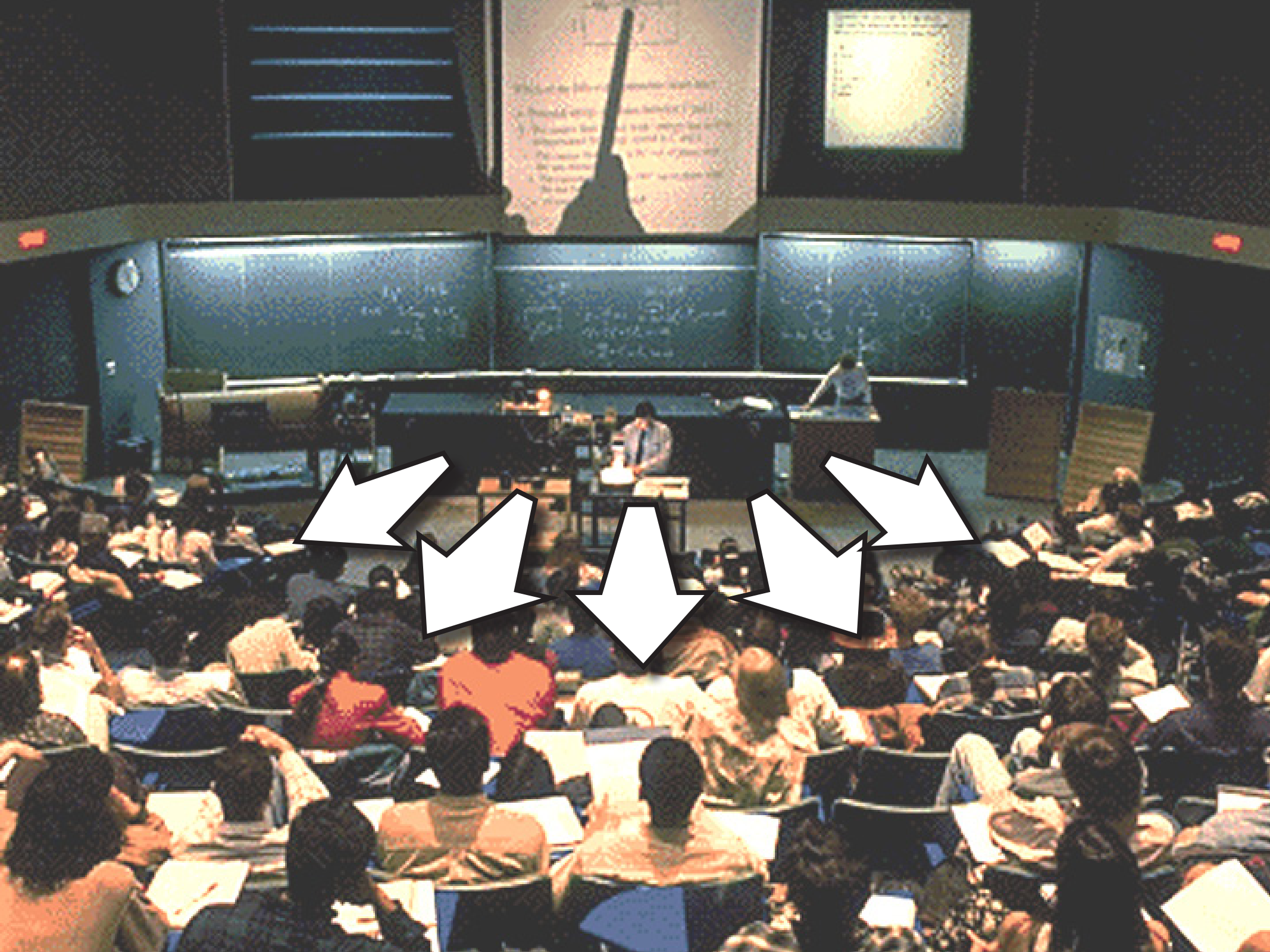




1. The first of the following statements is true  
2. The second statement is false  
3. The third statement is true  
4. The fourth statement is false  
5. The fifth statement is true  
6. The sixth statement is false  
7. The seventh statement is true  
8. The eighth statement is false  
9. The ninth statement is true  
10. The tenth statement is false

1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10













**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)**



The word "Peer" is written in a large, white, sans-serif font with a light blue outline. A dashed yellow line with an arrow at the end forms a circle around the two 'e's. A dotted blue line with an arrow at the end starts from the right side of the 'e's and points towards the word "INSTRUCTION" at the bottom right.

# Peer

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

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

The word "INSTRUCTION" is written in a white, sans-serif font, tilted upwards from left to right. A dotted blue line with an arrow at the end starts from the bottom left and points towards the word.

# INSTRUCTION



**question**



**question**



**think**



**question**



**think**



**poll**



**question**



**think**



**poll**



**discuss**



**question**



**think**



**poll**



**discuss**



**repoll**



**question**



**think**



**poll**



**discuss**



**repoll**



**explain**









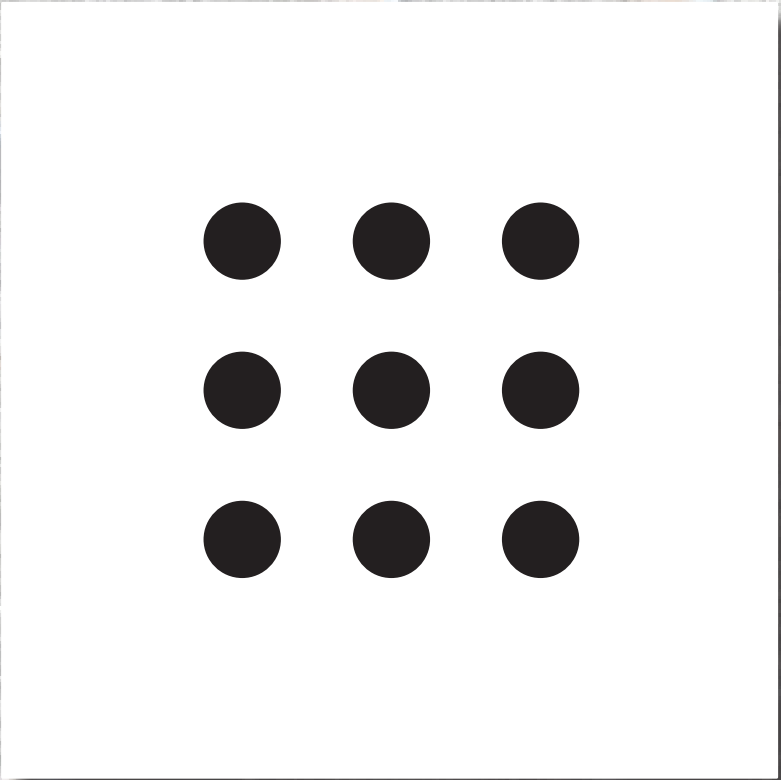
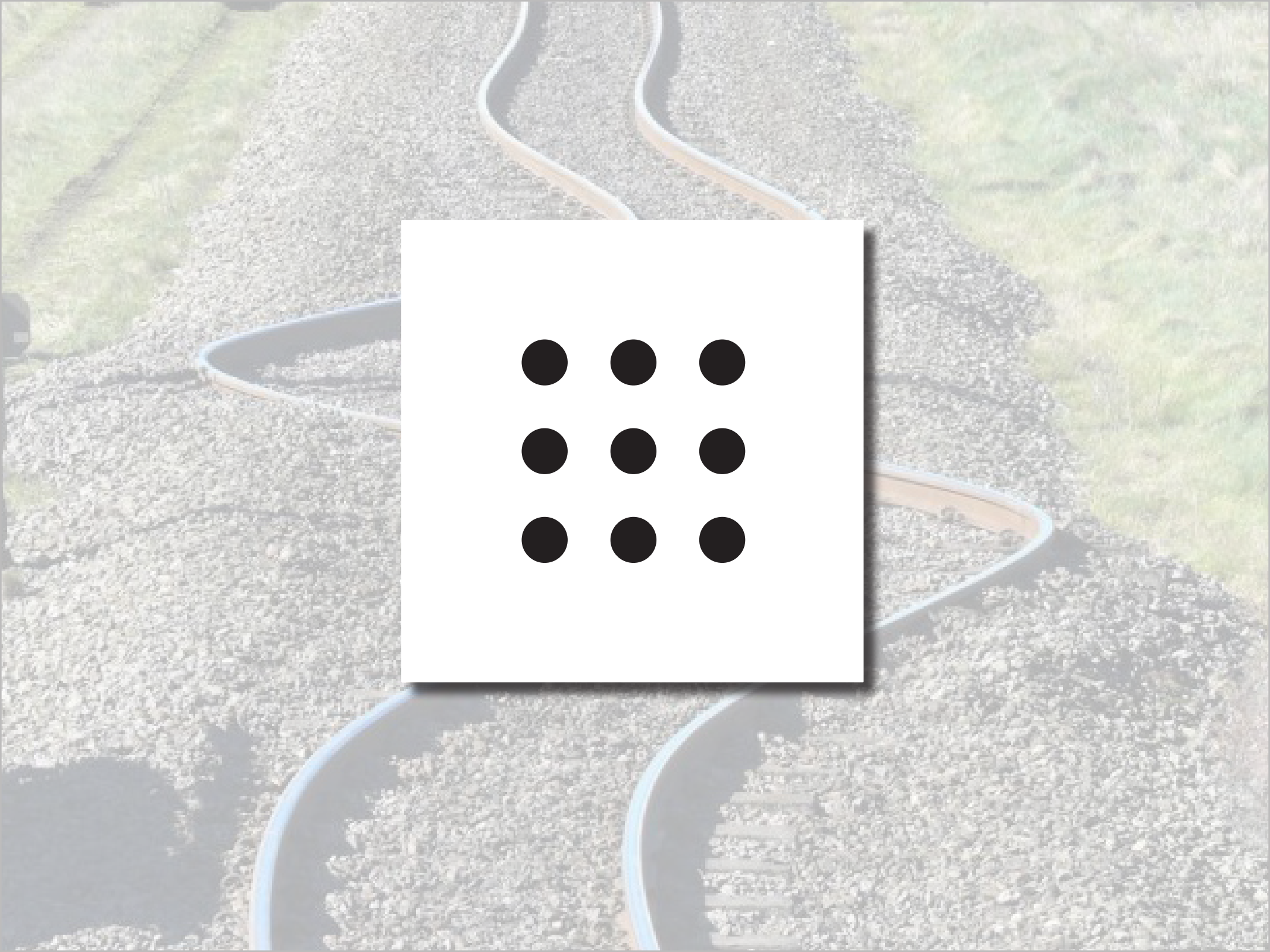




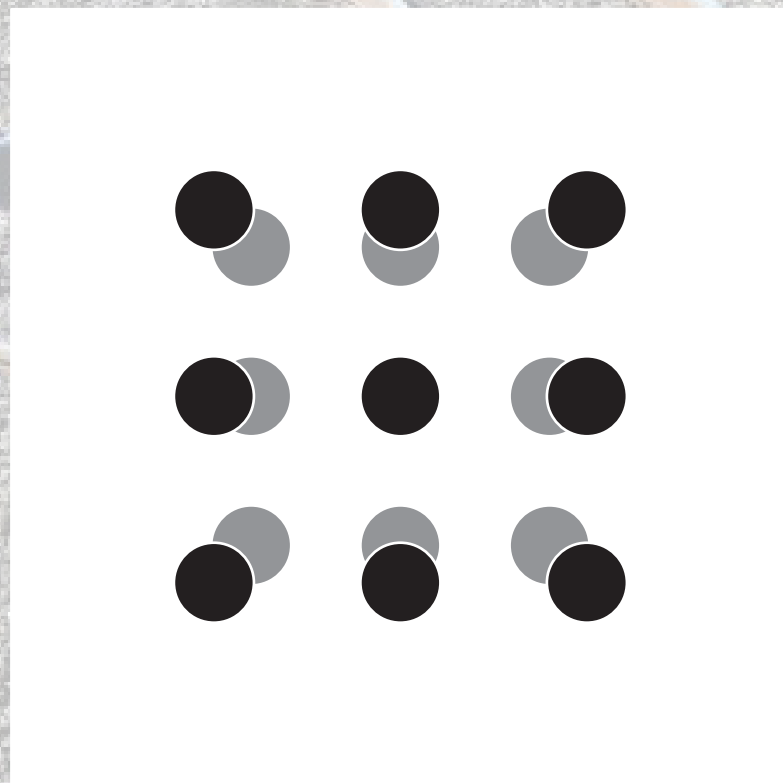


A photograph of a railway track with a wavy, undulating path, illustrating the concept of thermal expansion. The track is composed of gravel and wooden sleepers, and the rails are curved in a series of gentle S-shapes. The surrounding area is grassy.

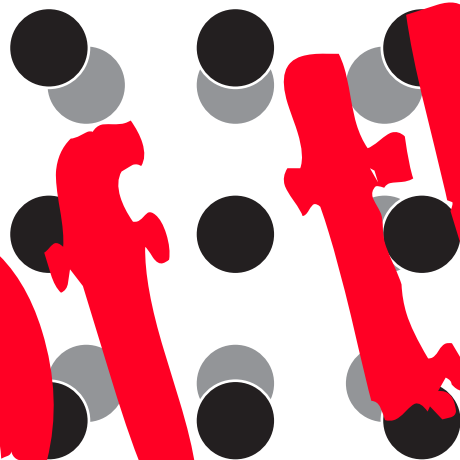
**thermal expansion**







**all of them**





**Consider a rectangular metal plate  
with a circular hole in it.**



**Consider a rectangular metal plate with a circular hole in it.**

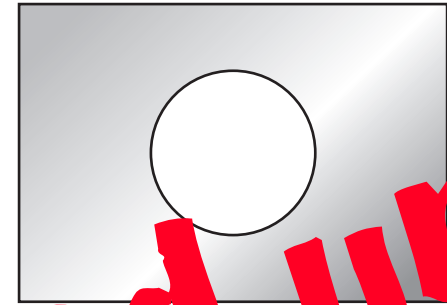


**When the plate is uniformly heated, the diameter of the hole**

- 1. increases.**
- 2. stays the same.**
- 3. decreases.**



Consider a rectangular metal plate with a circular hole in it.



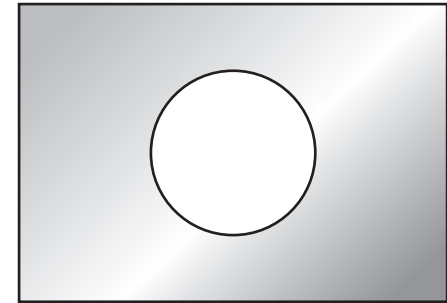
When the plate is uniformly heated, the diameter of the hole

1. increases.
2. stays the same.
3. decreases.

**you got all fired up!**

**Consider a rectangular metal plate with a circular hole in it.**

**When the plate is uniformly heated, the diameter of the hole**



- 1. increases.**
- 2. stays the same.**
- 3. decreases.**



**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.**

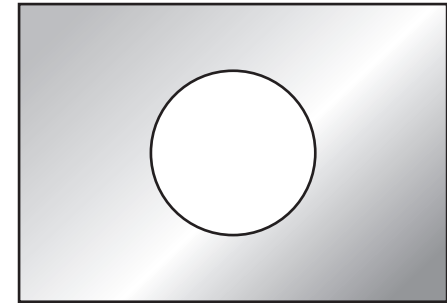
**You...**

- 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 a rectangular metal plate with a circular hole in it.**

**When the plate is uniformly heated, the diameter of the hole**



- 1. increases.**
- 2. stays the same.**
- 3. decreases.**

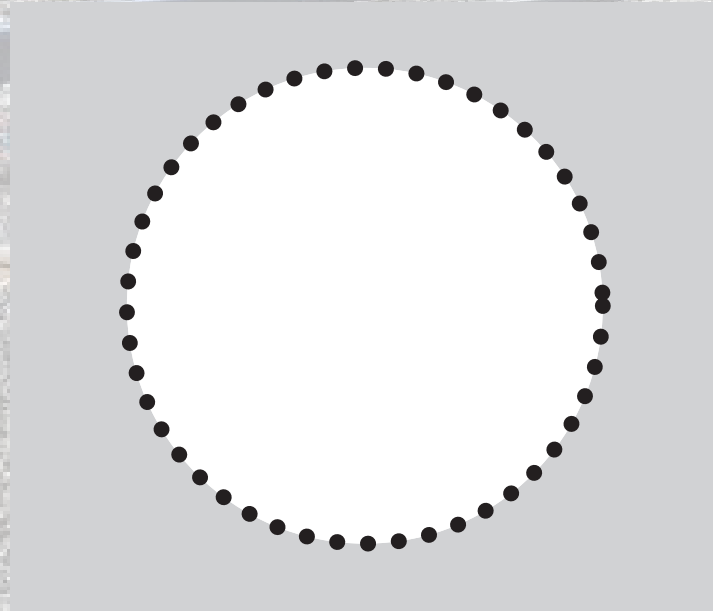
**Consider a rectangular metal plate with a circular hole in it.**



**When the plate is uniformly heated, the diameter of the hole**

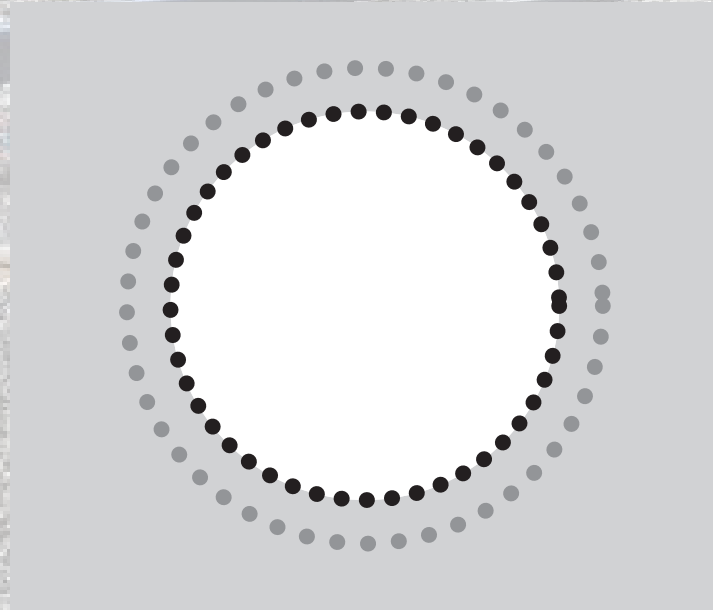
- 1. increases. ✓**
- 2. stays the same.
- 3. decreases.

**consider atoms at rim of hole**

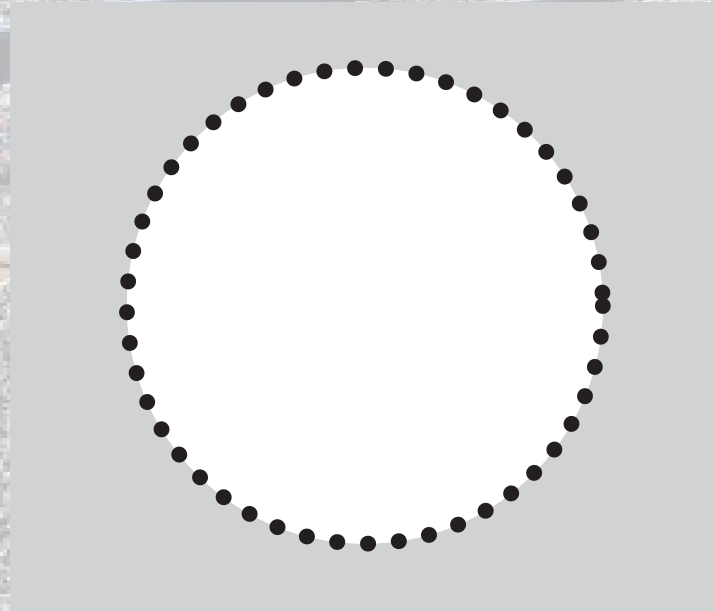




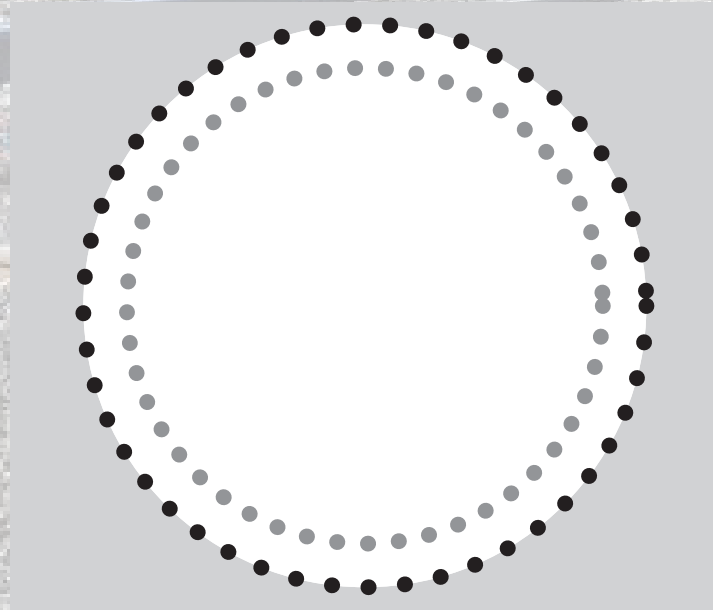
**consider atoms at rim of hole**



**consider atoms at rim of hole**



**consider atoms at rim of hole**





consider atoms at rim of hole

**you won't forget this**



Peer

back to pl

INSTRUCTION

**Higher learning gains**

INSTRUCTION

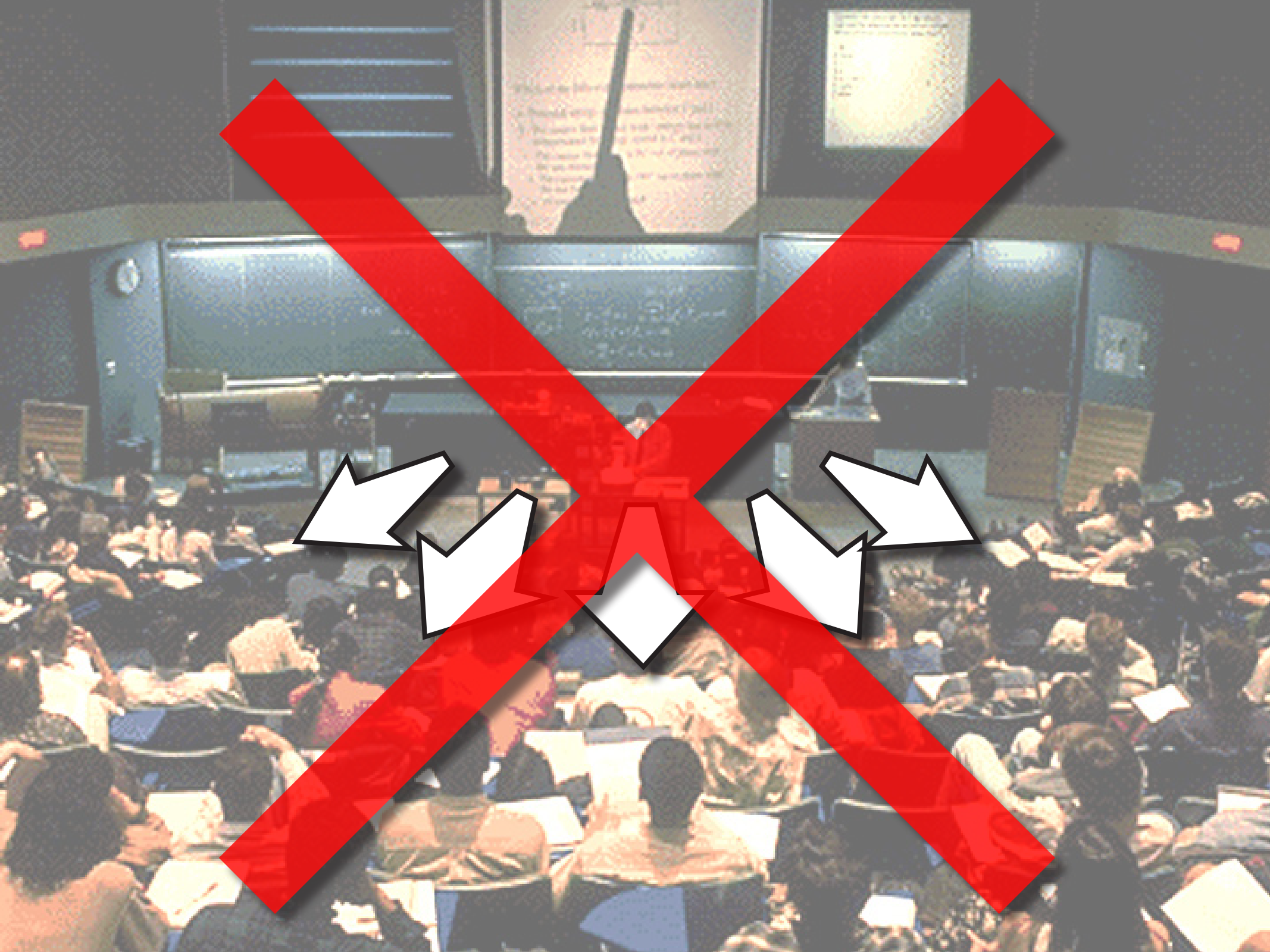




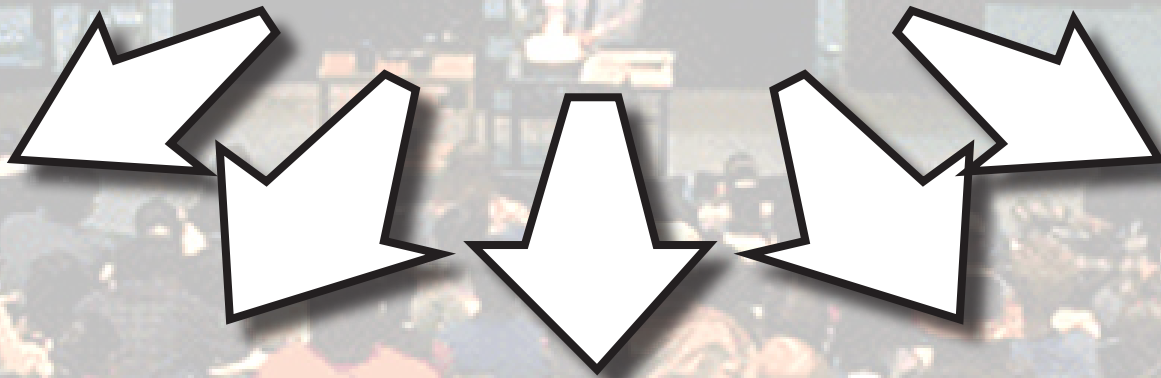
**Higher learning gains**

**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



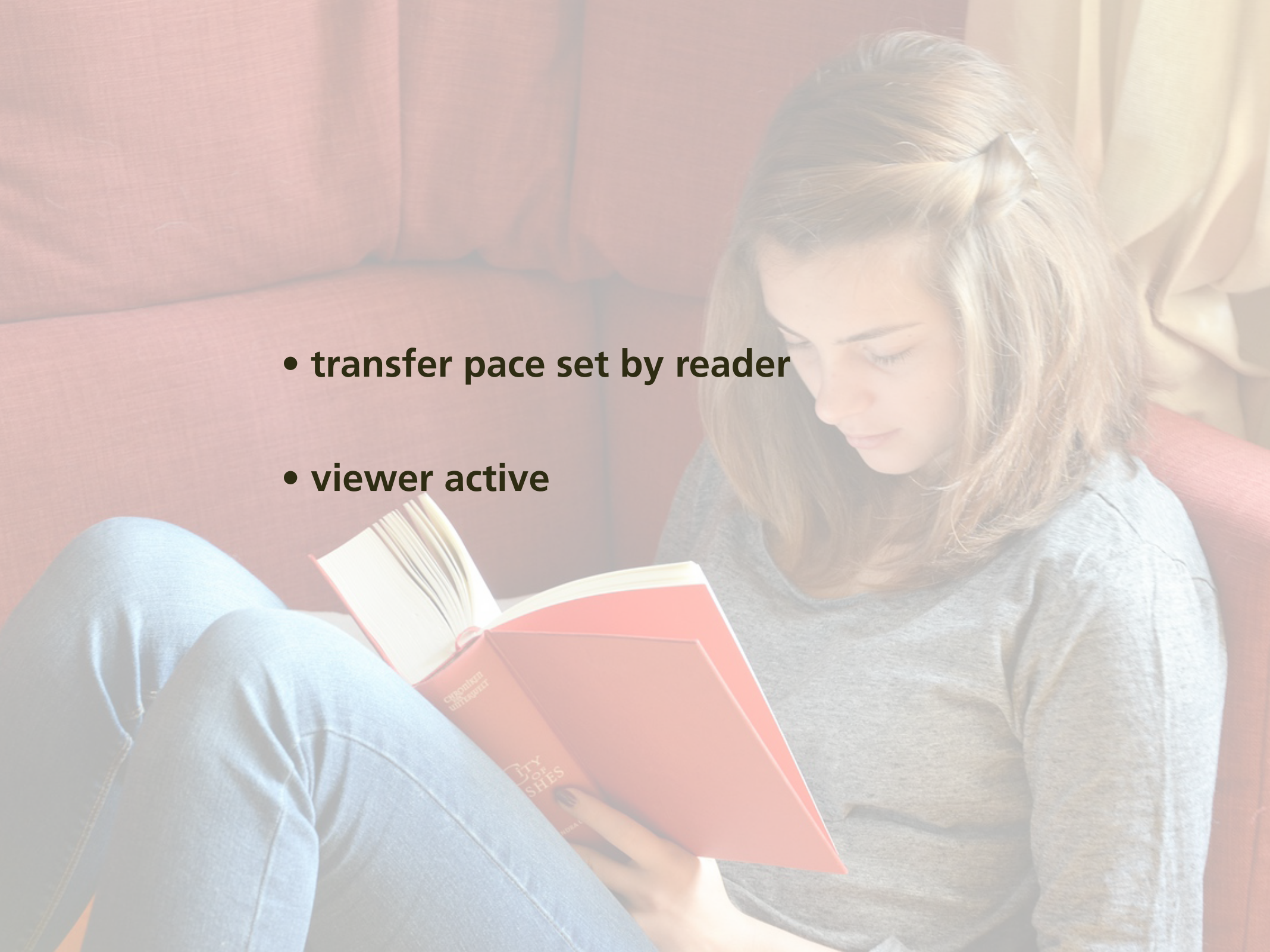




**we're simply moving this outside classroom!**






- 
- **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)**

A stylized illustration of a classroom with several students sitting at desks. The students are represented by simplified, colorful shapes in shades of yellow, green, blue, purple, and pink. They are all facing forward, and some are holding pens or pencils. The desks are light brown, and the background is a solid light gray.

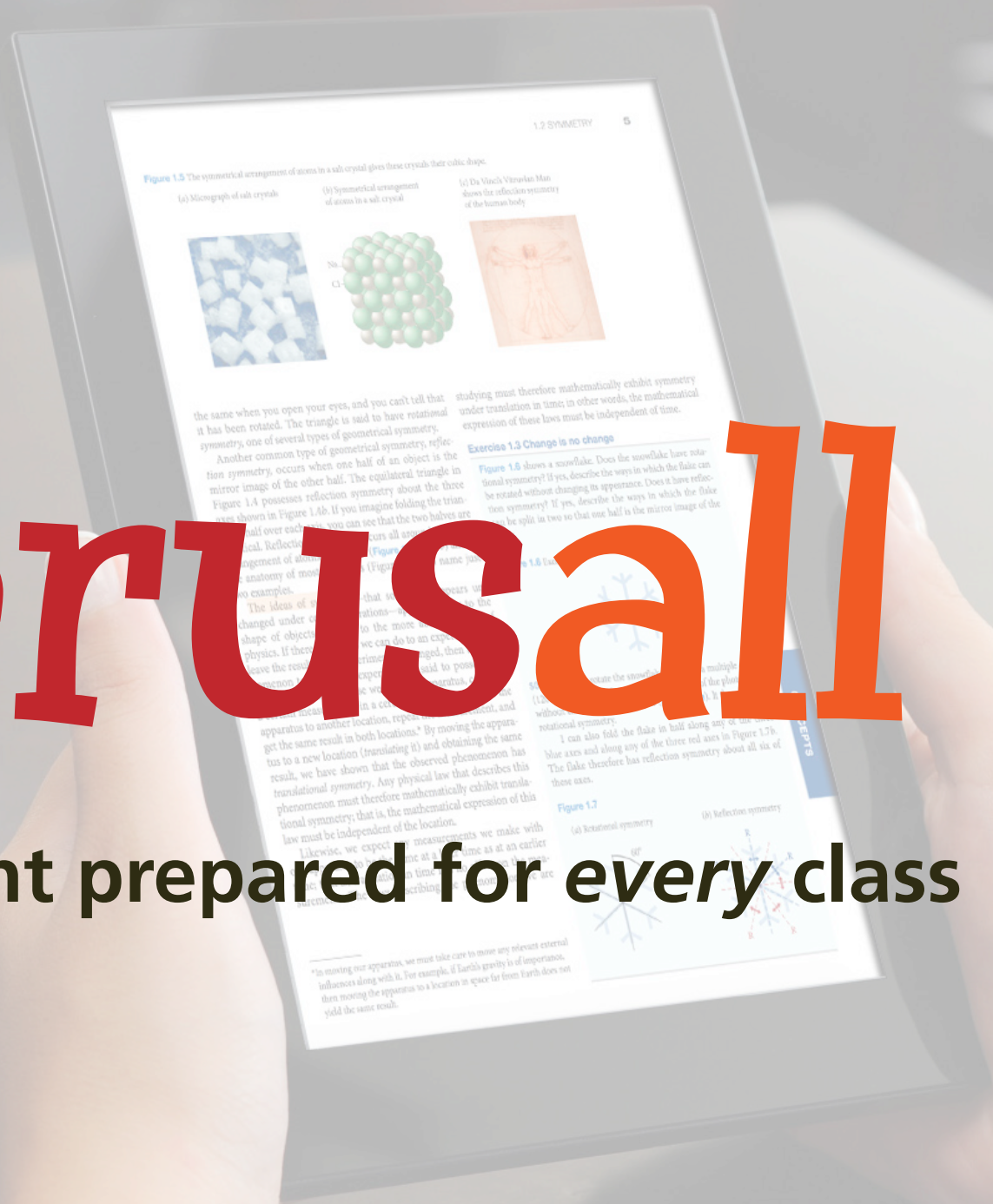
**Solution**

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



# Perusall

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. Notice that you have had a very ordinary day experience: A hockey puck slides easily on ice but not on a rough road.

Figure 4.1 shows how the velocity of a wooden block decreases on three different surfaces. The slowing down is due to *friction*—the resistance to motion that one surface or object encounters when moving over another. Notice that, during the interval 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 very 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.

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



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



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

**In the absence of friction, objects moving along a horizontal track keep moving without slowing down.**

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



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

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

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 track, in which a thin layer of air is blown through a series of small holes in the track, creating a cushion of air 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 wheeled carts, as shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For the carts shown in Figure 4.2 is horizontal, carts move without slowing down appreciably. In the absence of friction, the carts would continue moving along a horizontal track without slowing down.

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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.



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

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



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



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

**In the absence of friction, objects moving along a horizontal track keep moving without slowing down.**

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



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



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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 wooden surface, this may take a long time. If the surface is 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 on the rough surface. The block slides easily over ice because there is very little friction between the two surfaces. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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



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



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

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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 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.



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...opens chat window



Enter your comment or question and press Enter



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Enter your comment or question and press Enter

## 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.

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



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



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

**In the absence of friction, objects moving along a horizontal track keep moving without slowing down.**

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



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

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

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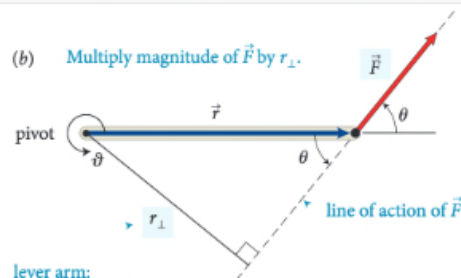
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(b) Multiply magnitude of  $\vec{F}$  by  $r_{\perp}$ .

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).

reference point



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

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

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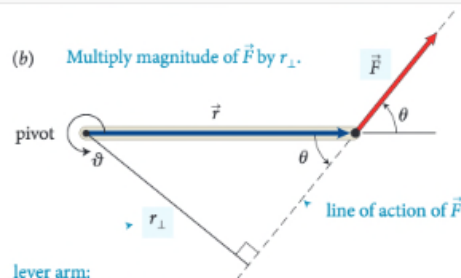
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**12.2** In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can 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  $\vec{F}_3$  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?

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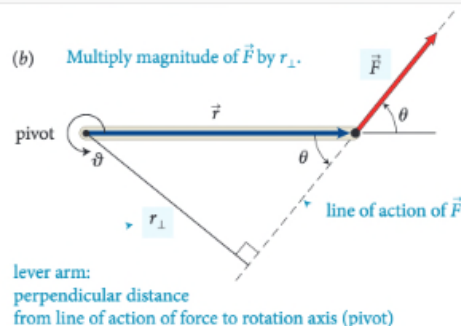
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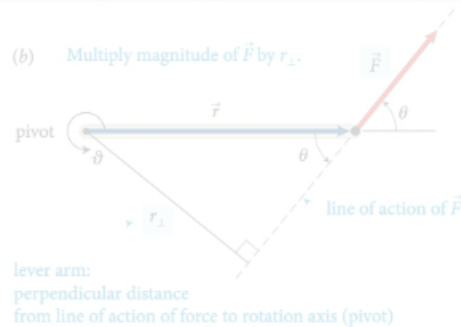
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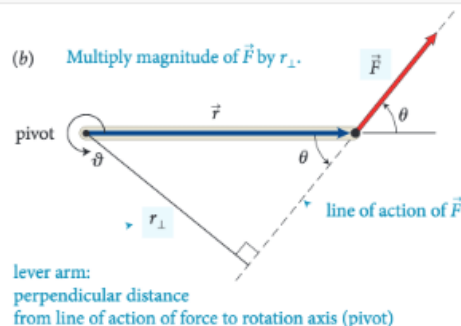
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Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

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.

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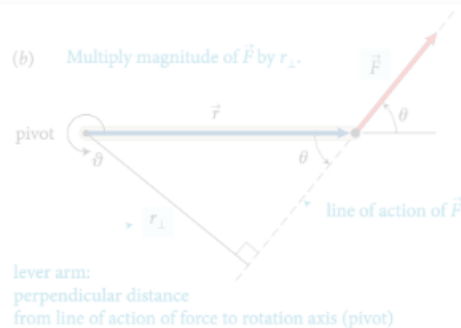
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## option 3: mark as answered



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# how to get students to participate?

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Oct 20 12:09 am

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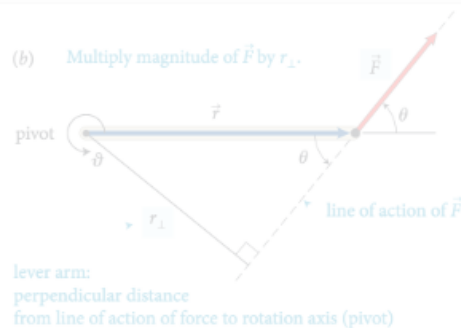
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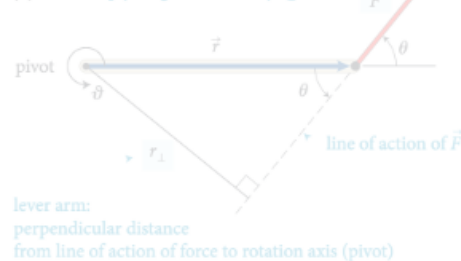
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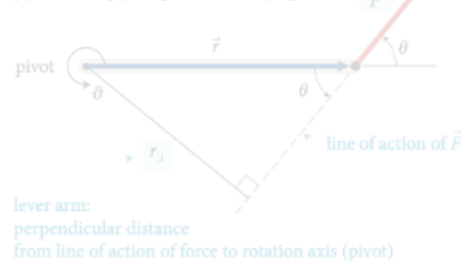
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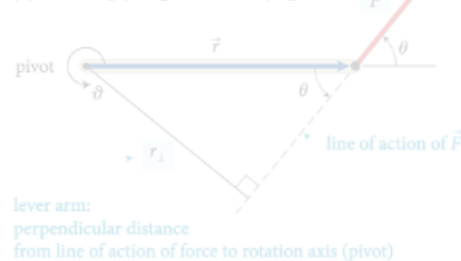
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The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force  $\vec{F}_1$  to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise 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 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. ✓

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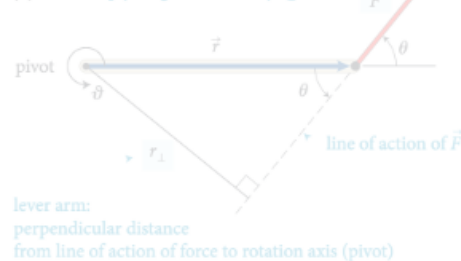
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# rubric-based assessment

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- quality (thoughtful reading & interpretation)

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- quantity (minimum 10)

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## rubric-based assessment

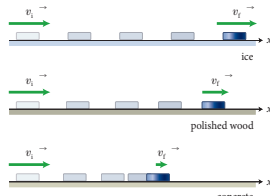
In the preceding two chapters, we developed a mathematical framework for describing motion along a straight line. In this chapter, we continue our study of motion by investigating inertia, a property of objects that affects their motion. The experiments we carry out in studying inertia lead us to discover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

#### 4.1 Friction

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

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

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



CONCEPTS

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



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows low-friction carts you may have encountered in your lab or class. Although there is still some friction both for low-friction tracks and for the track shown in Figure 4.2, this friction is so small that it can be ignored during an experiment. For example, if the track in Figure 4.2 is horizontal, carts move along its length without slowing down appreciably. In other words:

In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

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

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

#### 4.2 Inertia

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

#### ANNOTATION

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

#### EVALUATION

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

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

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

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

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

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

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

Responds to the question by thoughtfully interpreting the text

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

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

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

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

No substance. Does not demonstrate any thoughtful reading.

No substance. Does not demonstrate any thoughtful reading.

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



## ANNOTATION

## EVALUATION

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

2



**Example 10.10** A wheel of mass  $10\text{ kg}$  and radius  $0.3\text{ m}$  is free to rotate about a frictionless axis through the center and perpendicular to the page. A force of magnitude  $10\text{ N}$  is exerted tangentially to the rim of the wheel, as shown in Figure 10.19. Find the magnitude of the net torque on the wheel about the axis.

# ANALYSIS

- **timeliness** (before class)

# • distribution (not cost)

# Equilibrium & Torque

For the rod to be in static equilibrium, 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 that if an object is in static equilibrium, the sum of the torques is zero.

# 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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The extended free-body diagram is shown in Figure 10.11. The forces acting on the object are: weight ( $W$ ), normal force ( $N$ ), friction force ( $f$ ), and applied force ( $F$ ). The weight force acts vertically downward, the normal force acts vertically upward, the friction force acts horizontally to the left, and the applied force acts horizontally to the right. The object is at rest, so the net force is zero. The forces are balanced, and the object remains stationary.

👉 This just means the net.

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# Introduction

**11**

# Introduction

... ..

# rubric-based assessment

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



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

- quality (thoughtful reading & interpretation)

action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be

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# how do you process all of that??

- 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 after multiplying the 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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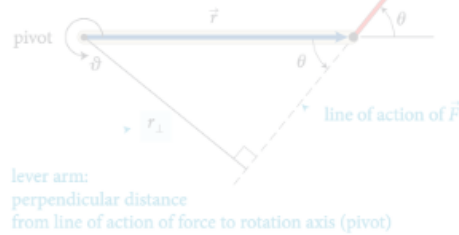
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## rubric-based assessment

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- quality (though future research interpretation)

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For a static equilibrium problem, you must choose a reference point to calculate the 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 point where a force is exerted, we can eliminate that force from the calculation.



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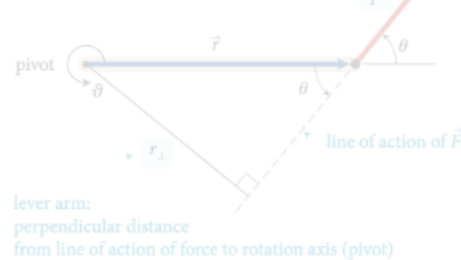
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# fully automated assessment

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



- 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 have 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. The question is, how do you explain how to choose the sign?

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

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 one 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. We like to choose the pivot as a reference point, but that is not the only choice. 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?

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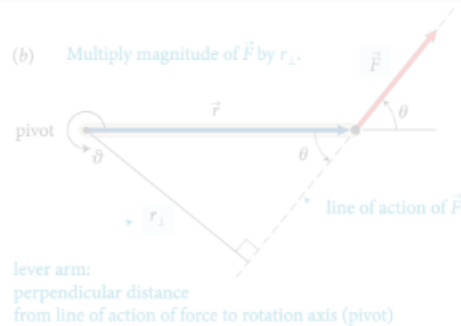
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		Total number of annotations			16
		Total number of annotations submitted on time			11
		Average quality of top 10 annotations submitted on time			1.80
		2 = demonstrates thorough and thoughtful reading and insightful interpretation of the reading, 1 = demonstrates reading, but no (or only superficial) interpretation of the reading, 0 = does not demonstrate any thoughtful reading or interpretation			
		Distribution of annotations			3.8
		0 = clustered, 5 = evenly distributed throughout assignment			
		Assignment score			1
		scores range from 0 to 3			



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# connect pre-class and in-class activities

I don't think we can calculate torque without knowing the direction of the force. Even if we know the magnitude of the force, we need to know the direction of the force to calculate torque. 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.

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.

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# confusion report

## 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

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



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

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# motivating factors



Intrinsic:

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

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



lever arm:

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

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# motivating factors



Intrinsic:

- social interaction

- tie-in to in-class activity

Extrinsic:

- assessment (fully automated)

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# motivating factors

***"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"***

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The screenshot displays the Perusall app interface. At the top, the browser address bar shows 'app.perusall.com'. The app header includes the 'Perusall' logo, the course 'AP50 Fall 2015 » Chapter 12', and the user 'Eric Mazur'. The main content area shows a physics textbook page titled 'torque' with a diagram of a lever and text explaining torque. Overlaid on the right side is a list of student annotations, each with a question mark icon and a count of responses. The annotations include questions about torque, reference frames, and the right-hand rule. At the bottom, there is a text input field for comments.

Perusall AP50 Fall 2015 » Chapter 12

Page 284 Eric Mazur

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

The diagram shows a horizontal rod with a pivot at the left end. A force  $\vec{F}$  is applied at the right end, making an angle  $\theta$  with the horizontal. The lever arm distance  $r_{\perp}$  is the perpendicular distance from the pivot to the line of action of  $\vec{F}$ .

**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 forces.

**Exercise 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...  
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(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

# motivating factors

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

*All the other students on my floor are disappointed their Prof isn't using Perusall because they don't read the book."*

Ohio State student

Perusall AP50 Fall 2015 » Chapter 12 Page 284 Eric Mazur

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

pivot  $\vec{r}$   $\theta$   $\vec{F}$   $\theta$  line of action of  $\vec{F}$   $r_{\perp}$

lever arm:  $r_{\perp}$  is the perpendicular distance from the pivot to the line of action of the force.

The lever arm distances must now be determined relative to the left end of the rod. The lever arm distance of force  $\vec{F}_1$  to this point is zero, and so the torque caused by that force about the left end of the rod is zero. If I choose counterclockwise as the positive direction of rotation,  $\vec{F}_2$  causes a negative torque about the left end of the rod; the force  $\vec{F}_{\text{pt}}$  exerted by the pivot causes a positive torque about the left end of the rod. The lever arm distance of  $\vec{F}_{\text{pt}}$  about the left end of the rod is  $r_1 + r_2$  that of  $\vec{F}_2$  is  $r_2$ . 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 when we chose the right end of the rod as the reference point.

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 right end. This is a general result: for a stationary object, the sum of the torques is zero. The reason is that the rod is not rotating about any point, and so the sum of the torques must be zero about any point.

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

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?

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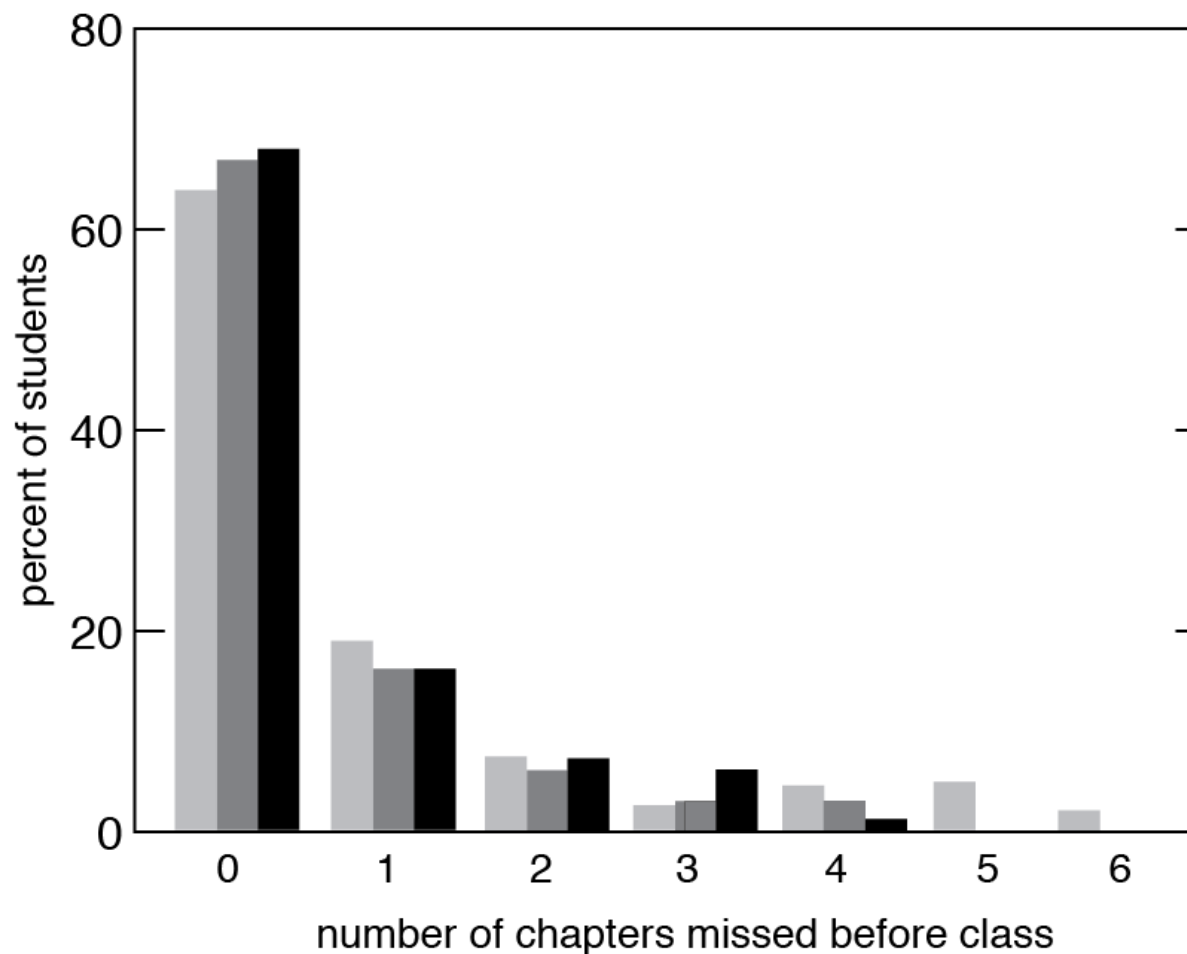
# class test results

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

$\vec{F}$

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



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Eric Mazur

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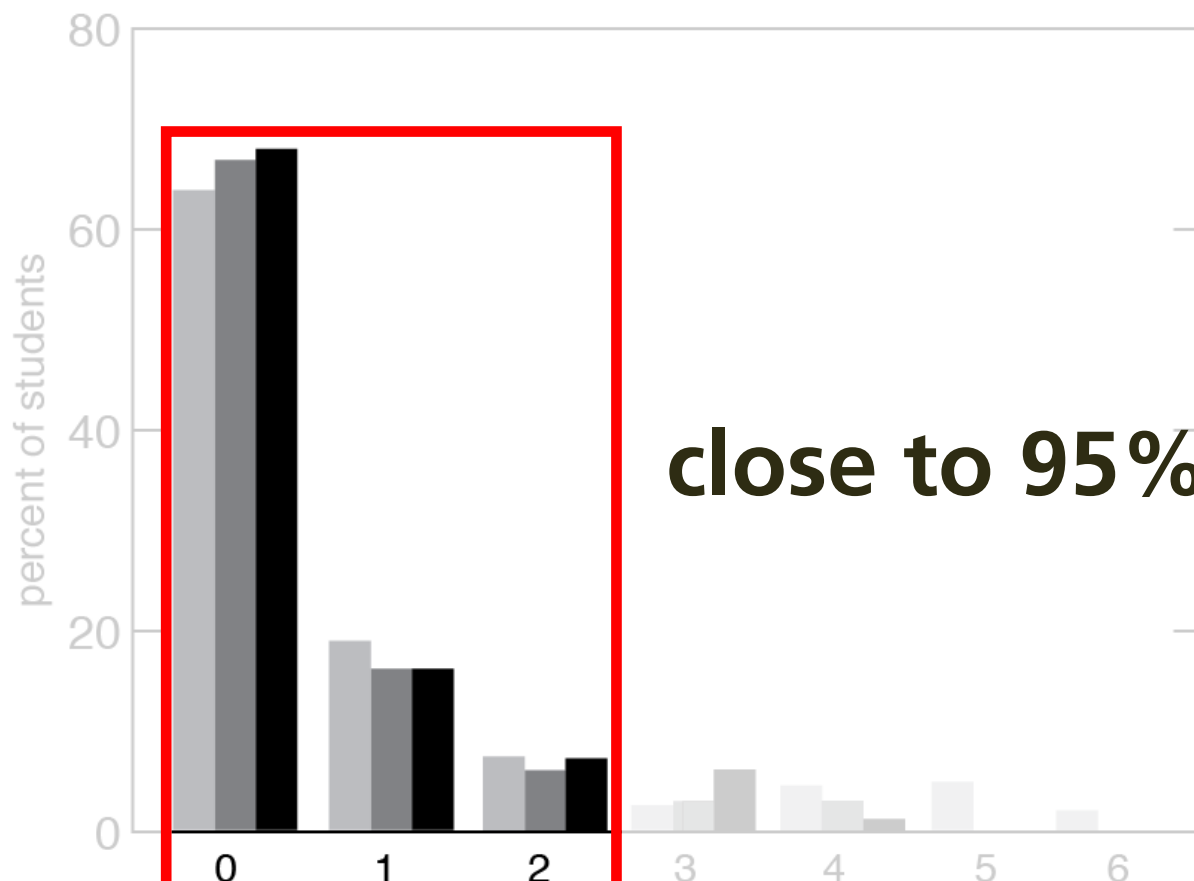
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close to 95%!

number of chapters missed before class

## 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?

Does torque have the s... 3

# class test results

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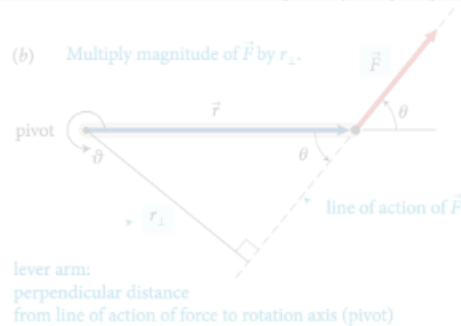
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Eric Mazur

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



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

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. ✓

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 right end of the rod and find that the sum of the torques is also 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  $\vec{F}_2$  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?

# every student prepared for every class

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I don't understand how this combination of... 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

Enter your comment or question and press Enter

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

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

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

## CONCEPTS

action of the force and the lever arm. So, the torque 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  $\theta$ . In Figure 12.4, for example, the torque caused by  $\vec{F}_1$  about the pivot is positive, while 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  $\vec{F}_{\text{pr}}$  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  $\vec{F}_{\text{pr}}$  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

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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?



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

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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 that are not free to rotate. For example, a person can stand on a seesaw 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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Consider a seesaw that is free to rotate about a pivot in 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?

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



**Education is not just about:**

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





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- **transferring information**
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**active engagement/social interaction a must!**



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