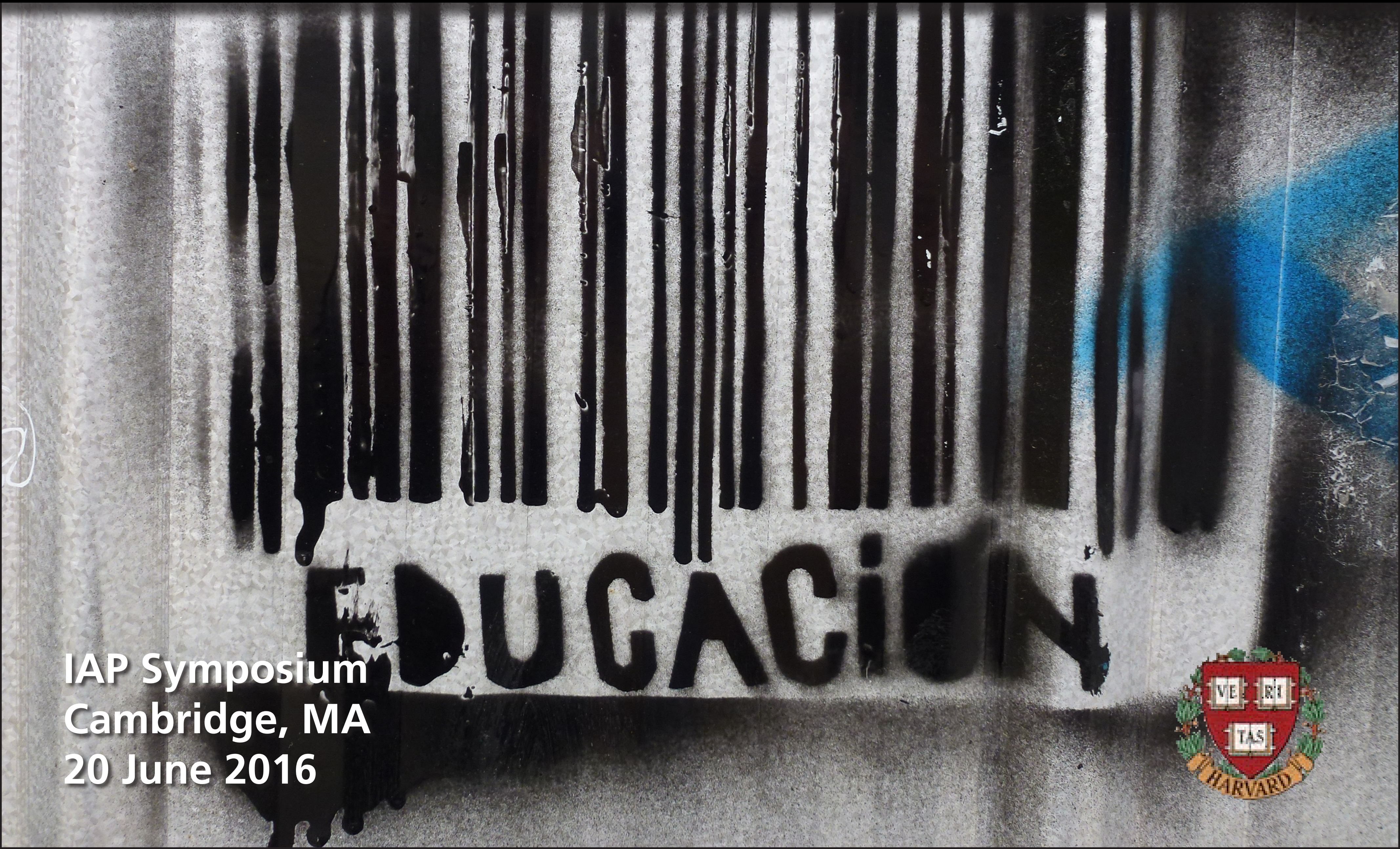
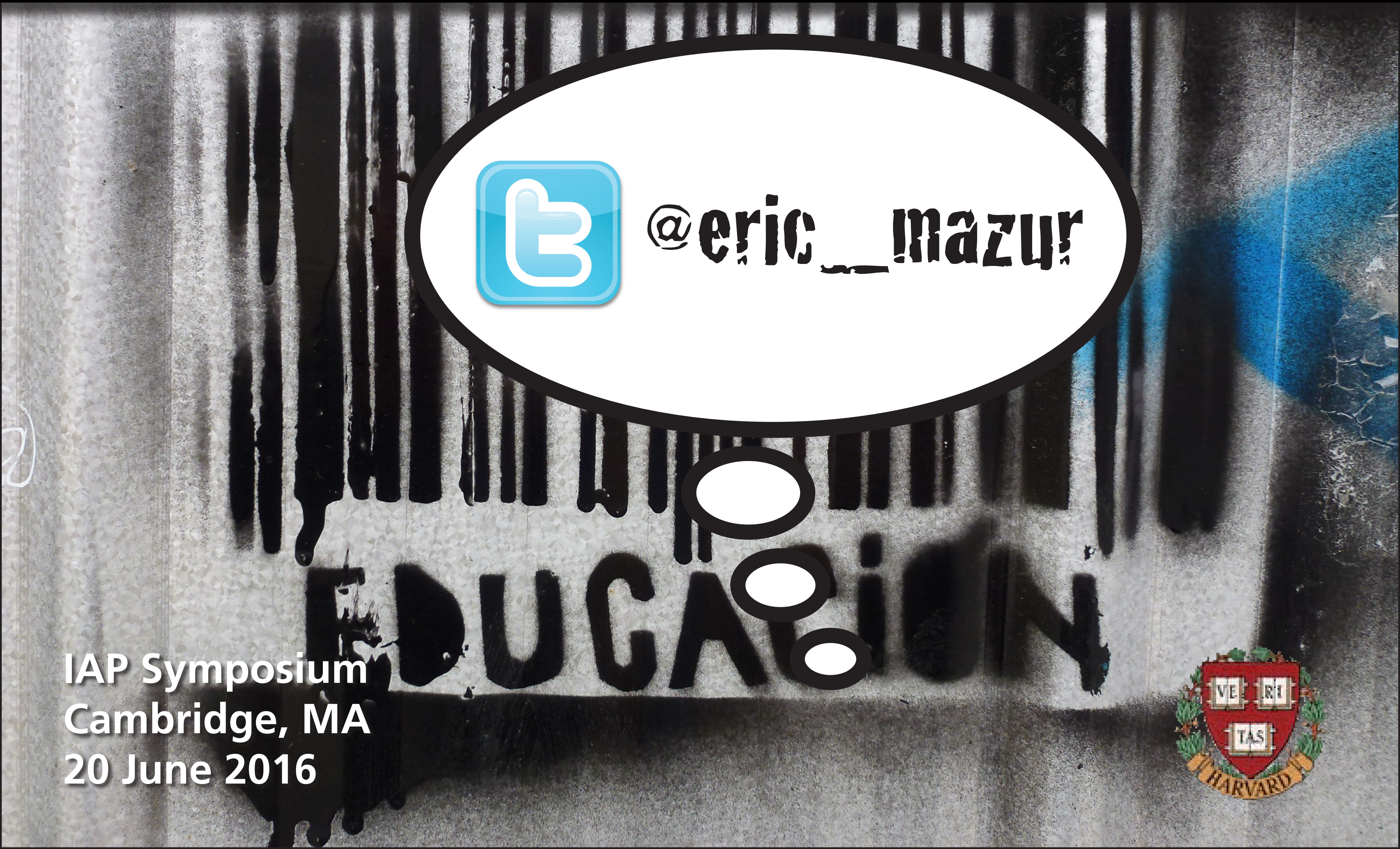
Interactive Learning: Technology in the Classroom



IAP Symposium
Cambridge, MA
20 June 2016

Interactive Learning:
Technology in the Classroom



@eric_mazur

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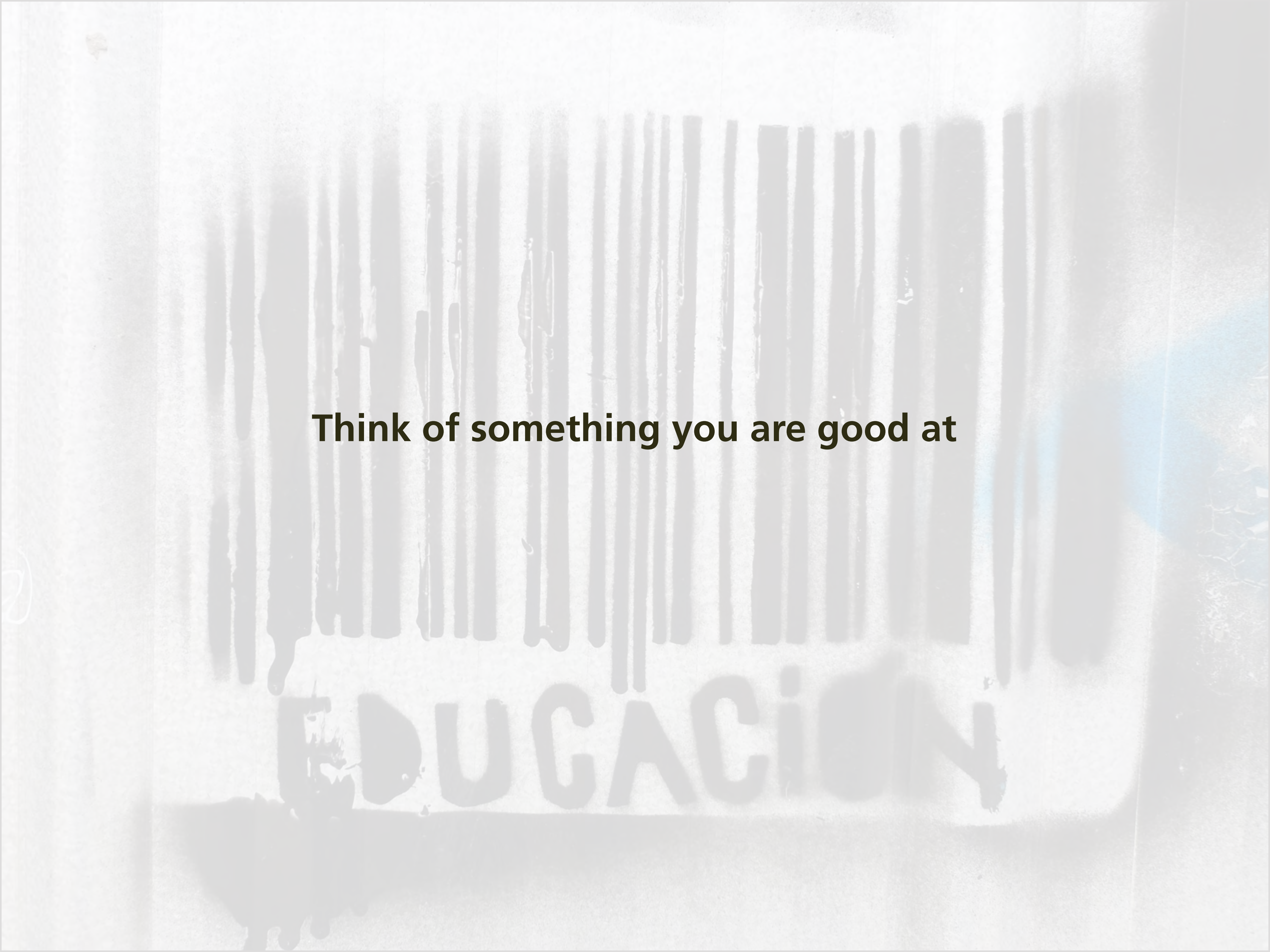
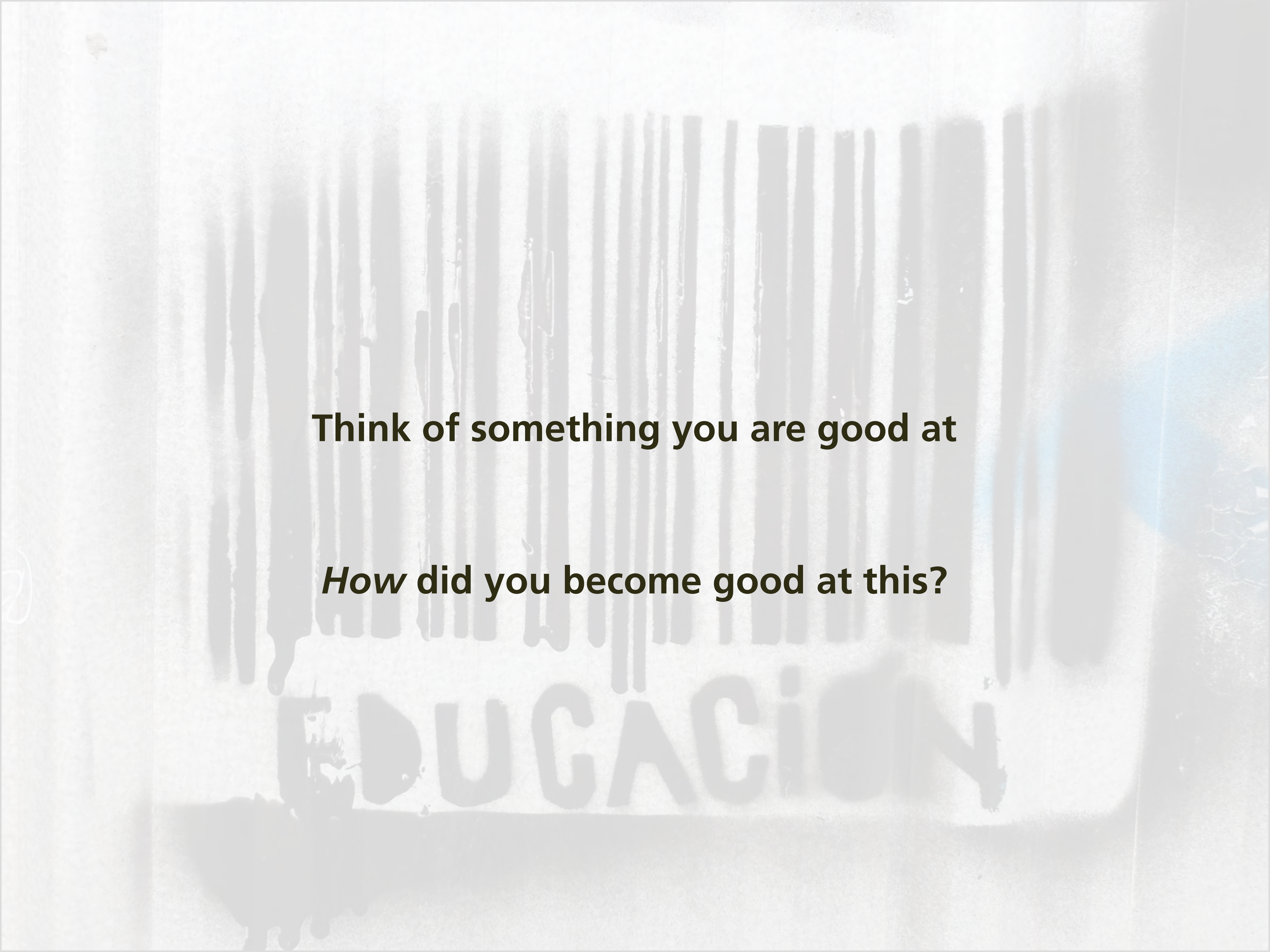


Think of something you are good at



Think of something you are good at

How **did you become good at this?**

Became good at it by:

1. trial and error
2. lectures
3. practicing
4. apprenticeship
5. other

1 education

① **education** ② **PI**

① education

② PI

③ test

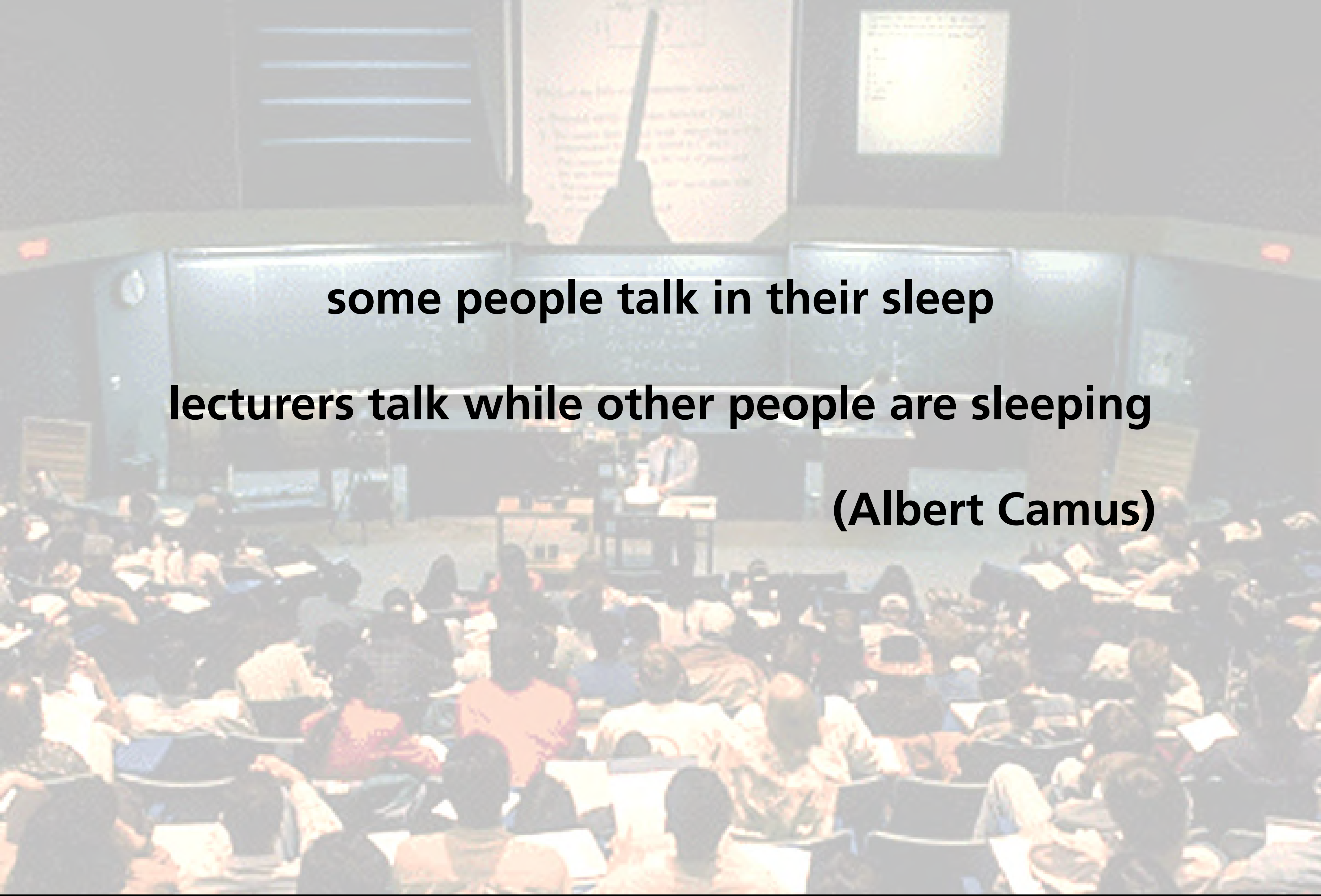
① education ② PI ③ test

What happens in a lecture?

1 education

some people talk in their sleep

1 education

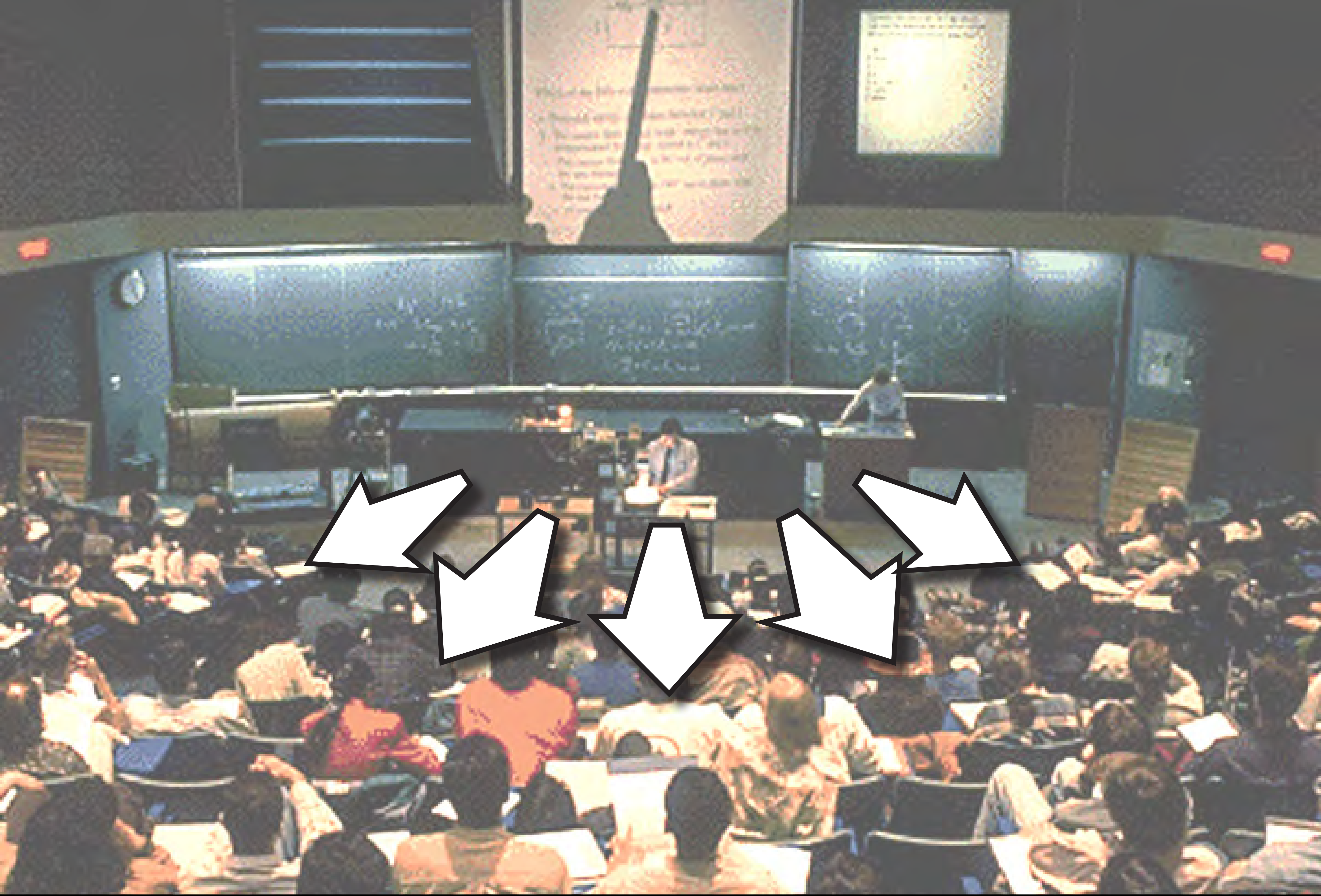


some people talk in their sleep

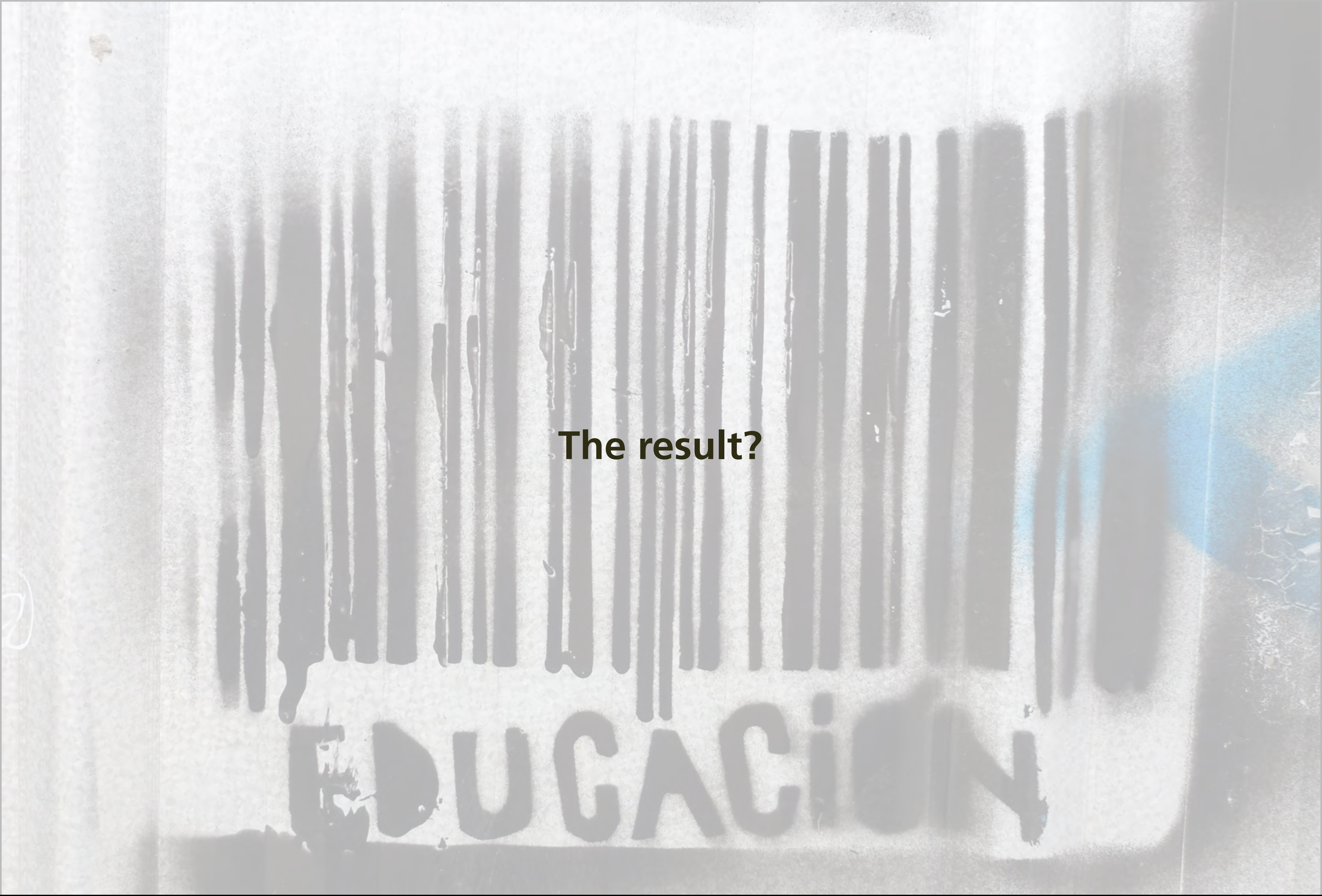
lecturers talk while other people are sleeping

(Albert Camus)

1 education



1 education



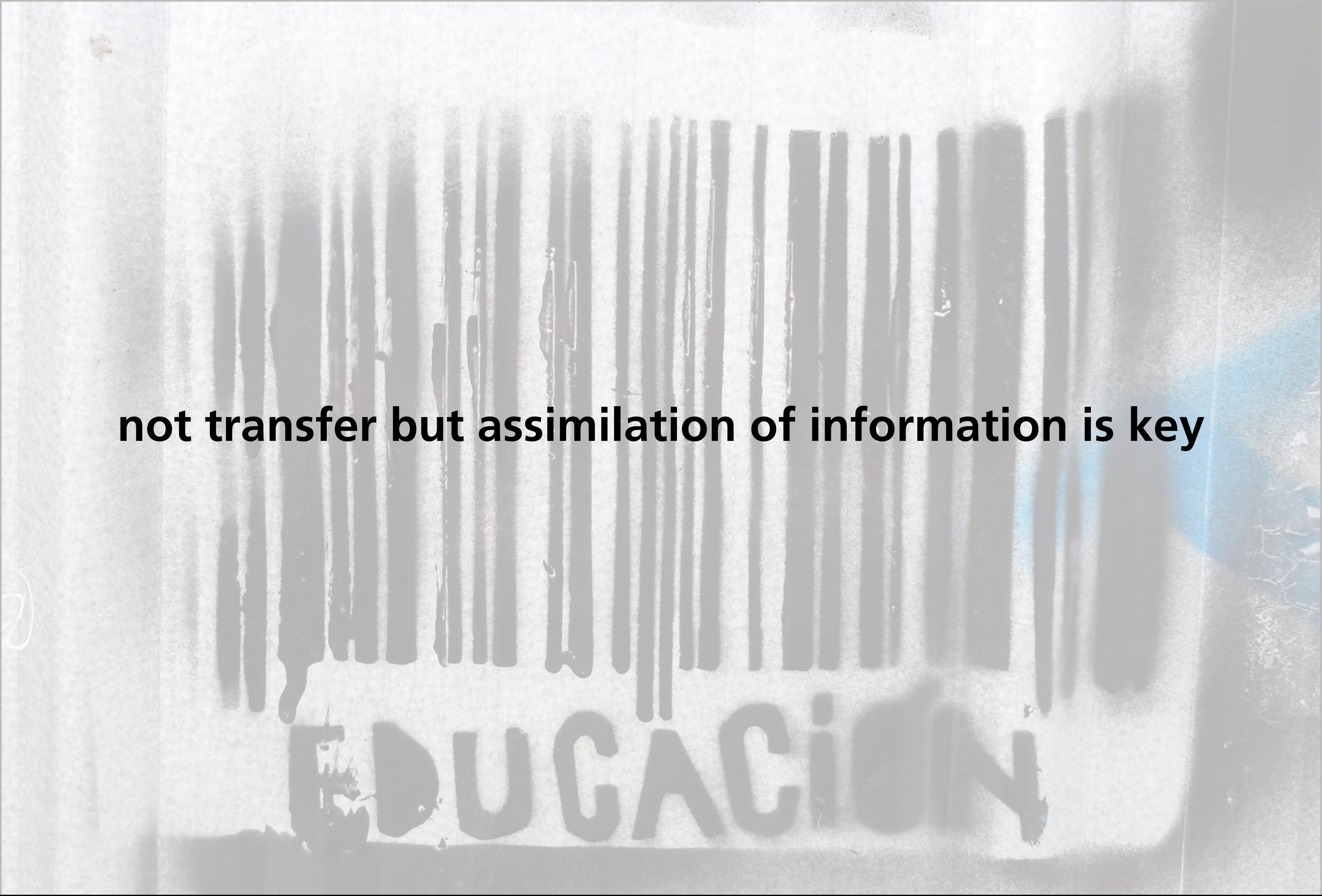
The result?

Lack of learning

1 education

Lack of learning

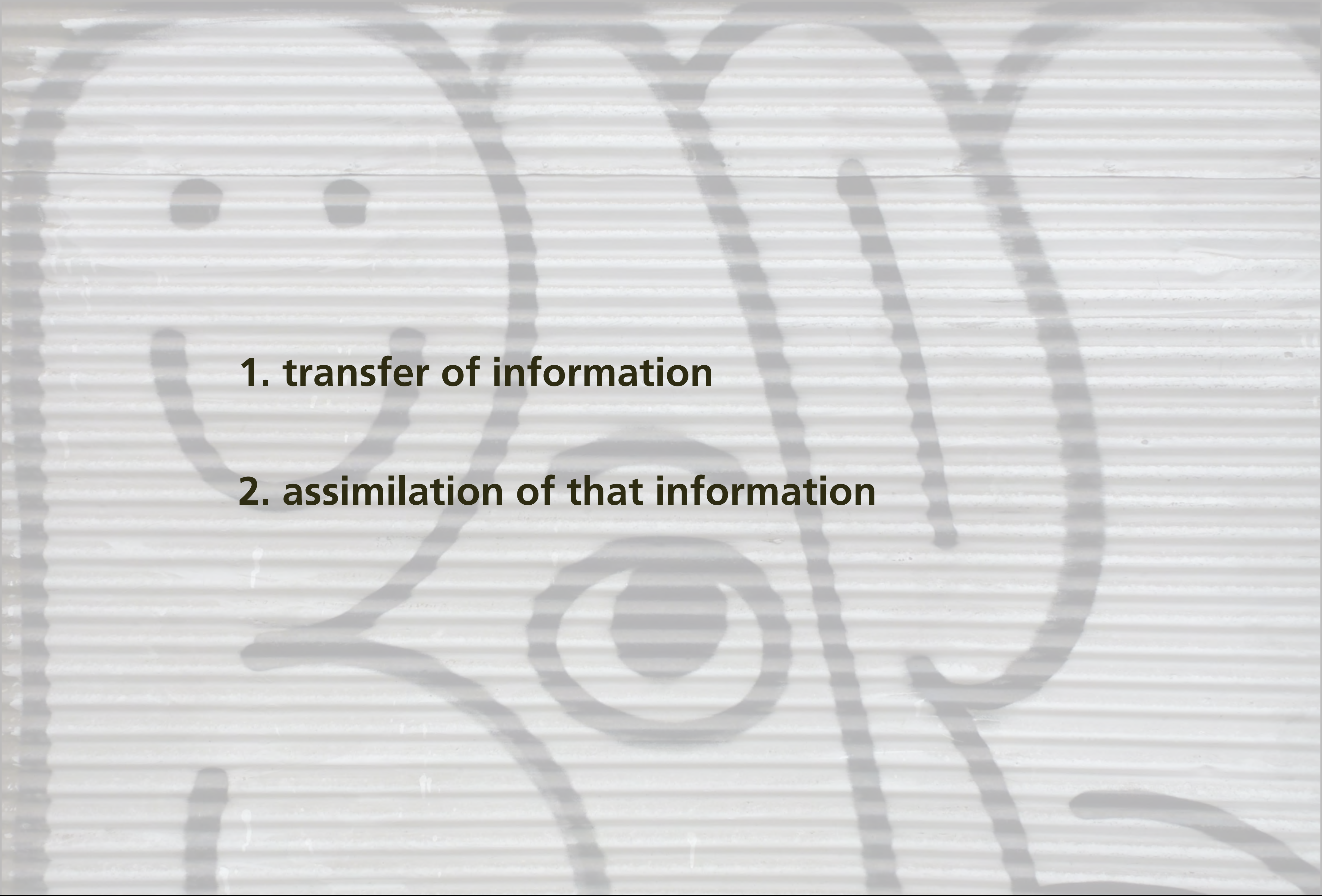
Lack of retention



not transfer but assimilation of information is key

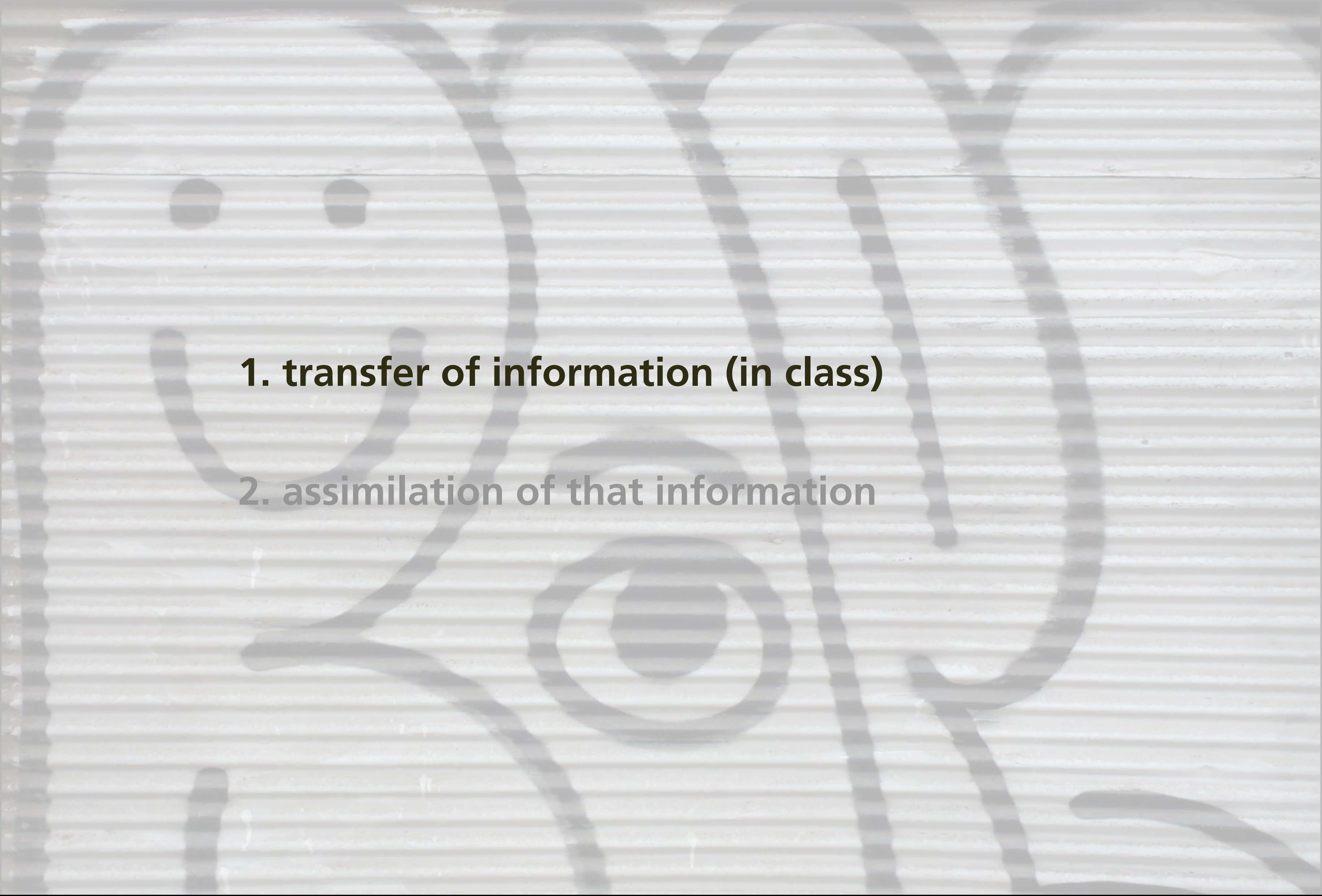
❶ education ❷ PI

1. transfer of information



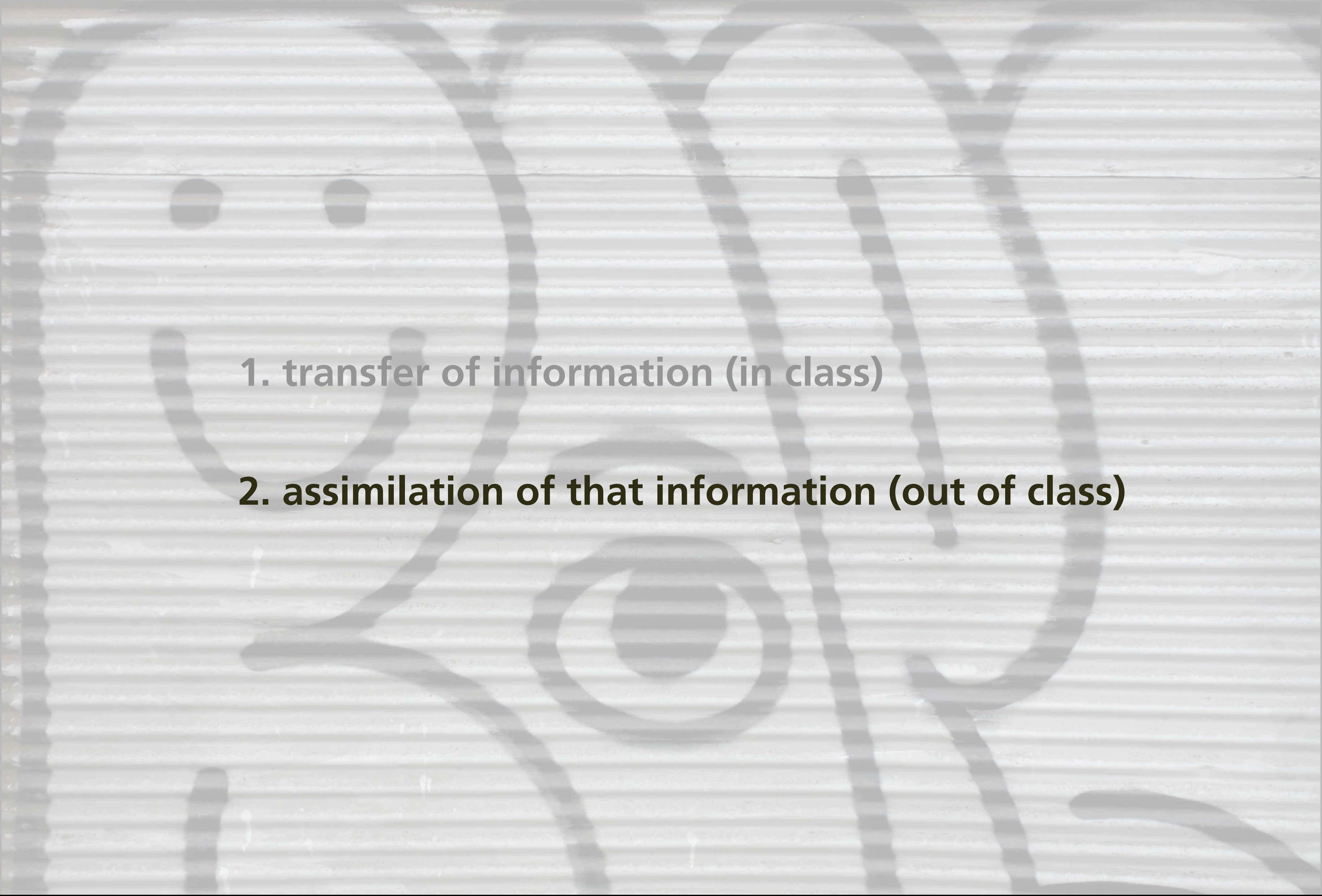
1. transfer of information

2. assimilation of that information



1. transfer of information (in class)

2. assimilation of that information



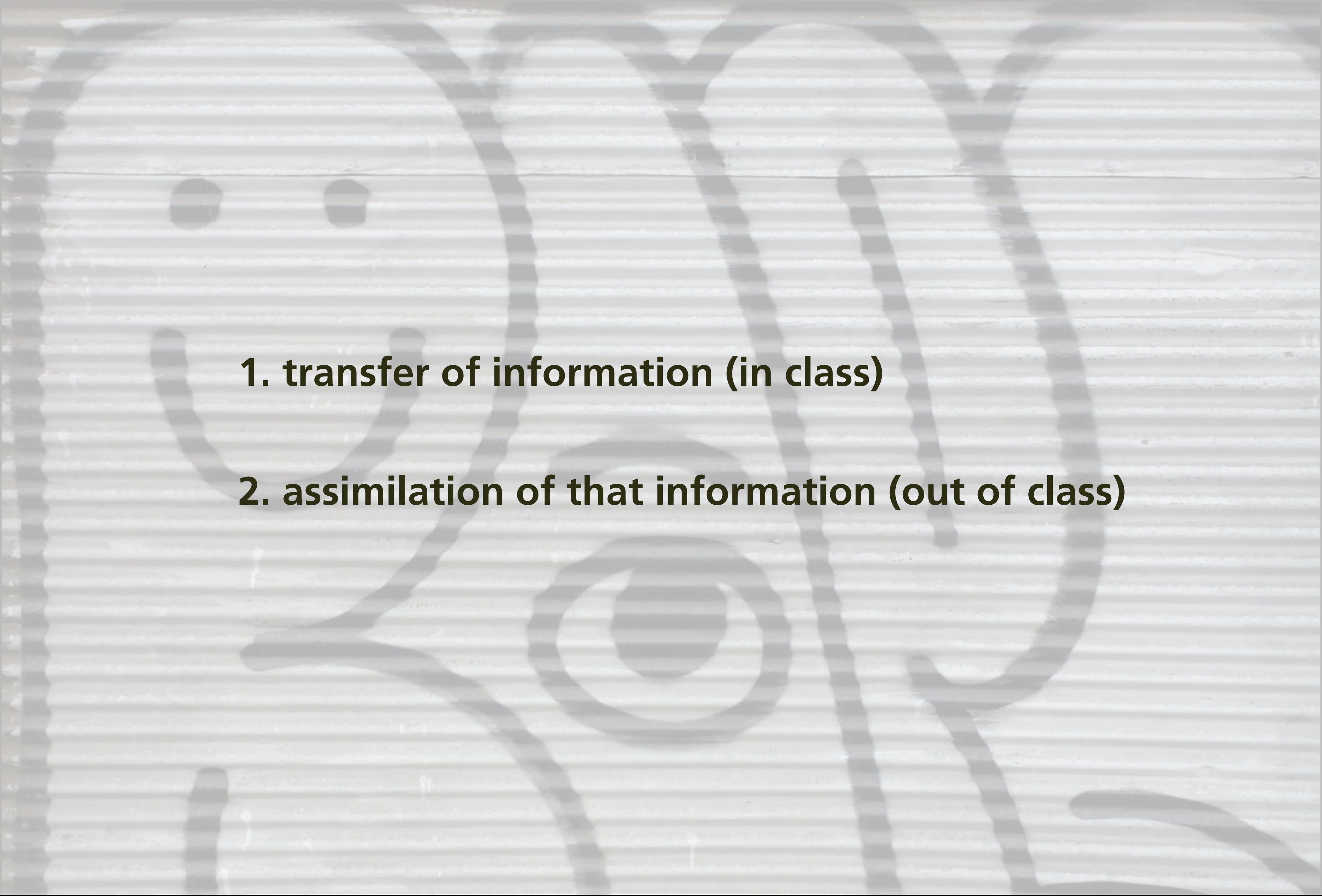
1. transfer of information (in class)

2. assimilation of that information (out of class)

Should focus on THIS!

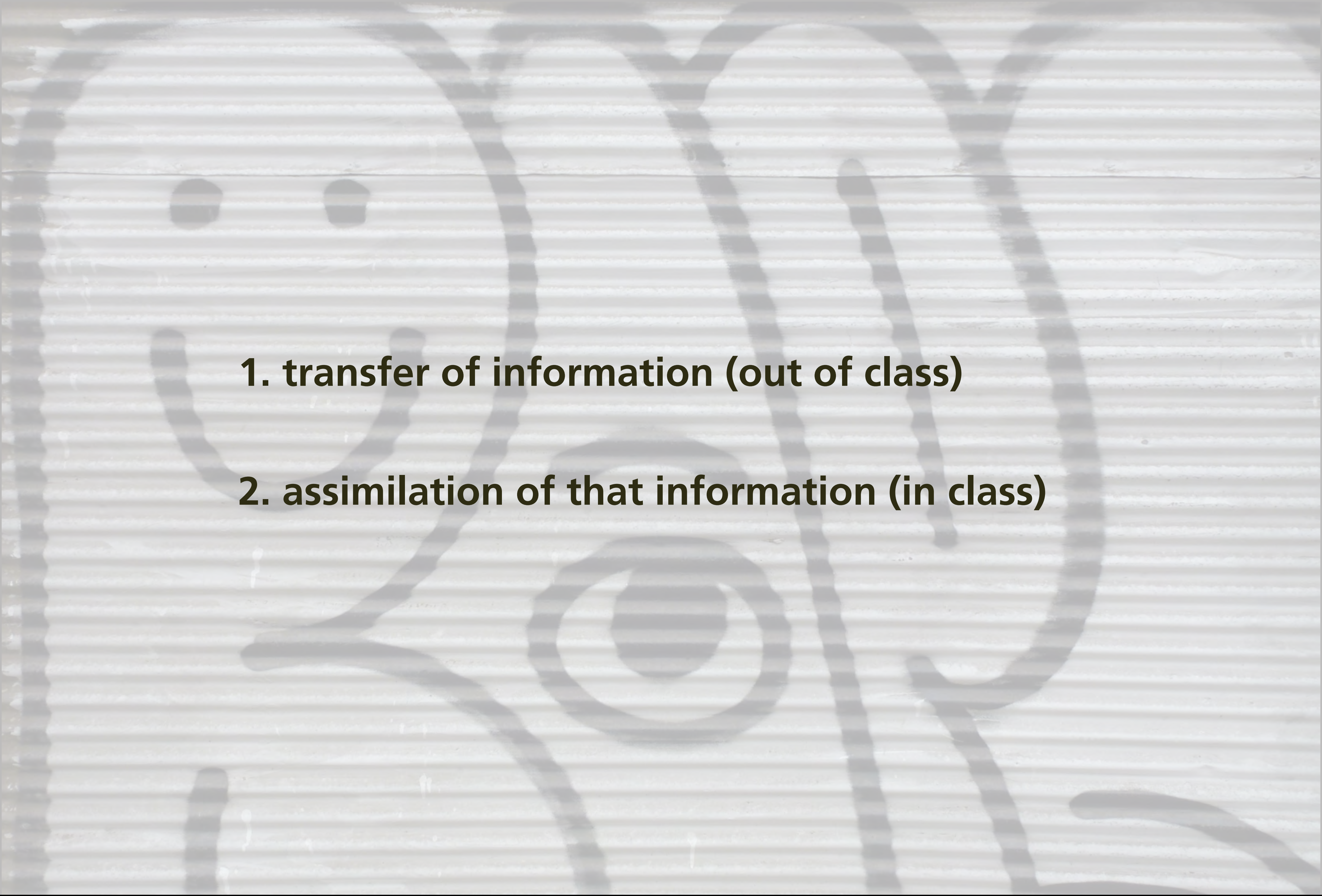
1. transfer of information (i

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 INSTRUCTION

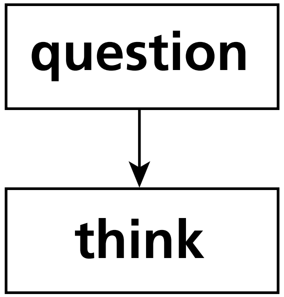
1. transfer of information (out of class)

2. assimilation of that information (in class)

question

① education

② PI

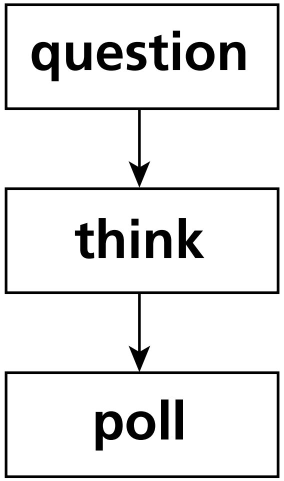


question

think

① education

② PI

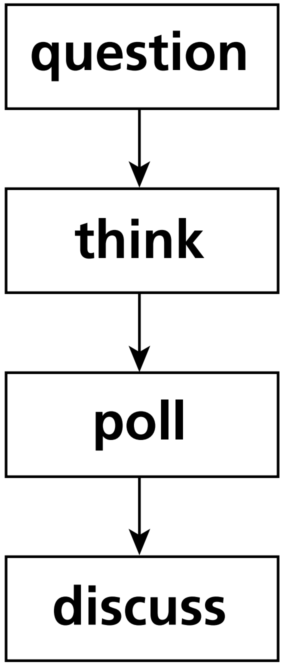


question

think

poll

① education ② PI

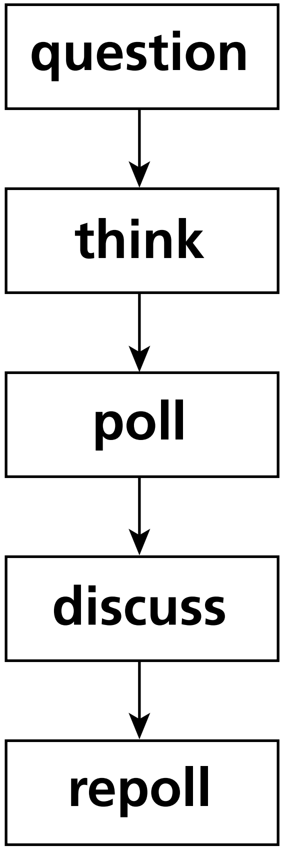


question

think

poll

discuss



question

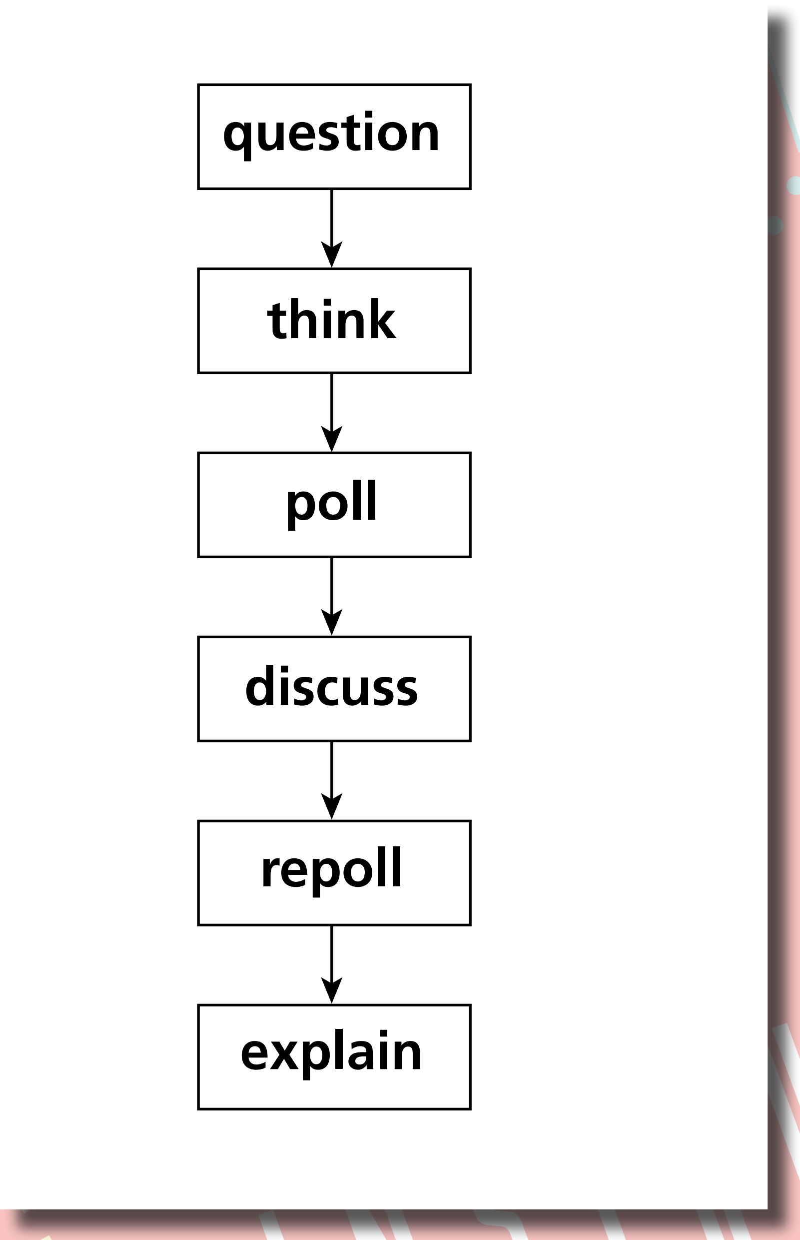
think

poll

discuss

repoll

① education ② PI



question

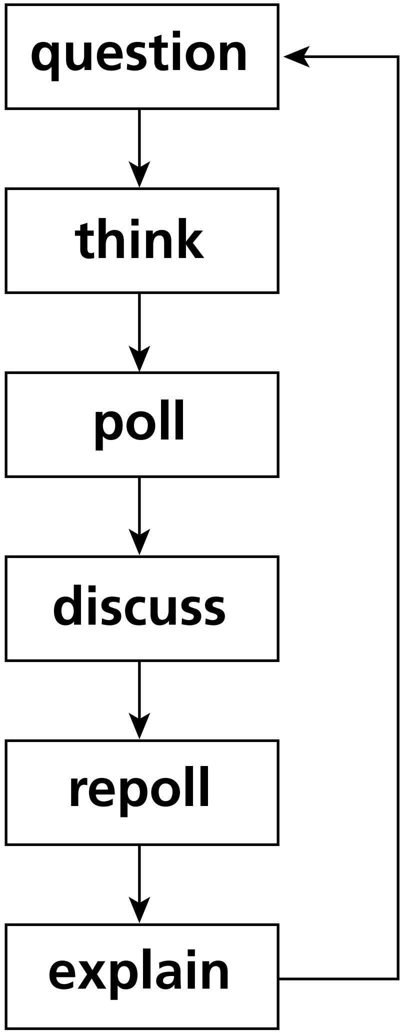
think

poll

discuss

repoll

explain



question

think

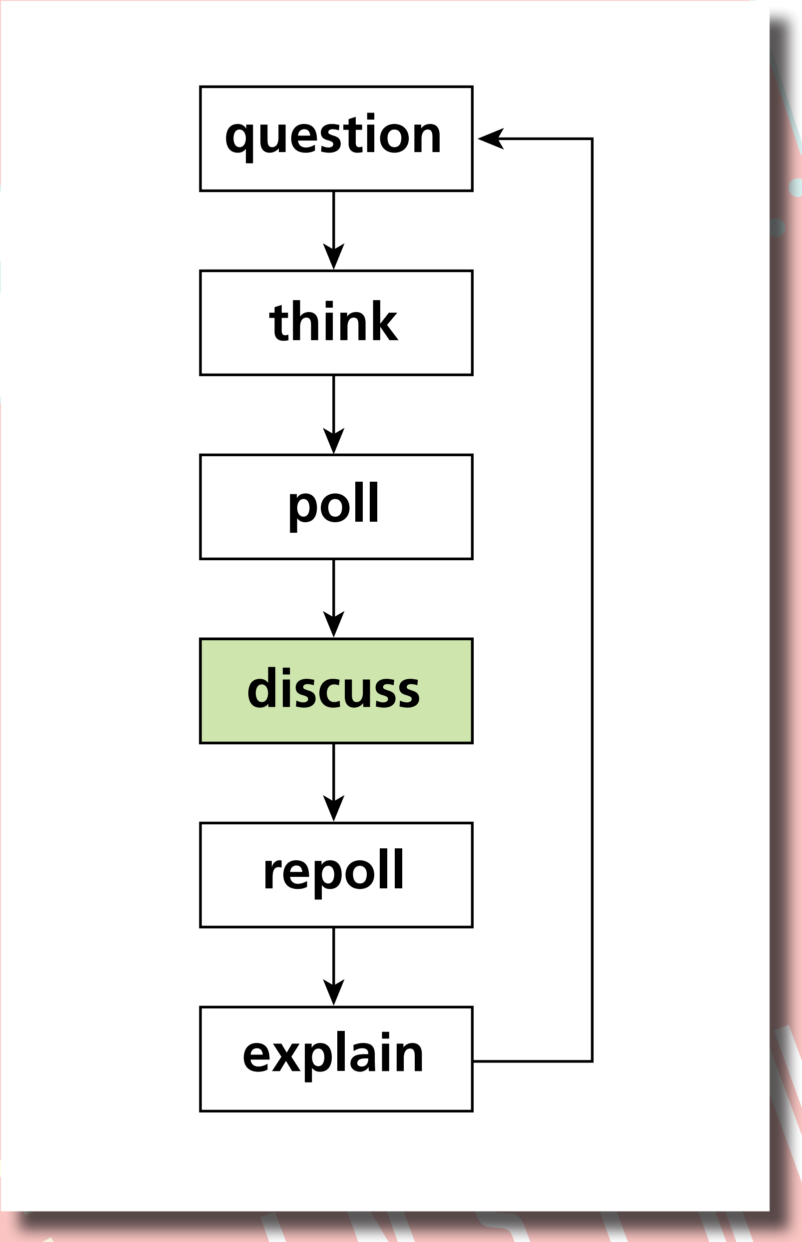
poll

discuss

repoll

explain

① education ② PI


question

think

poll

discuss

repoll

explain

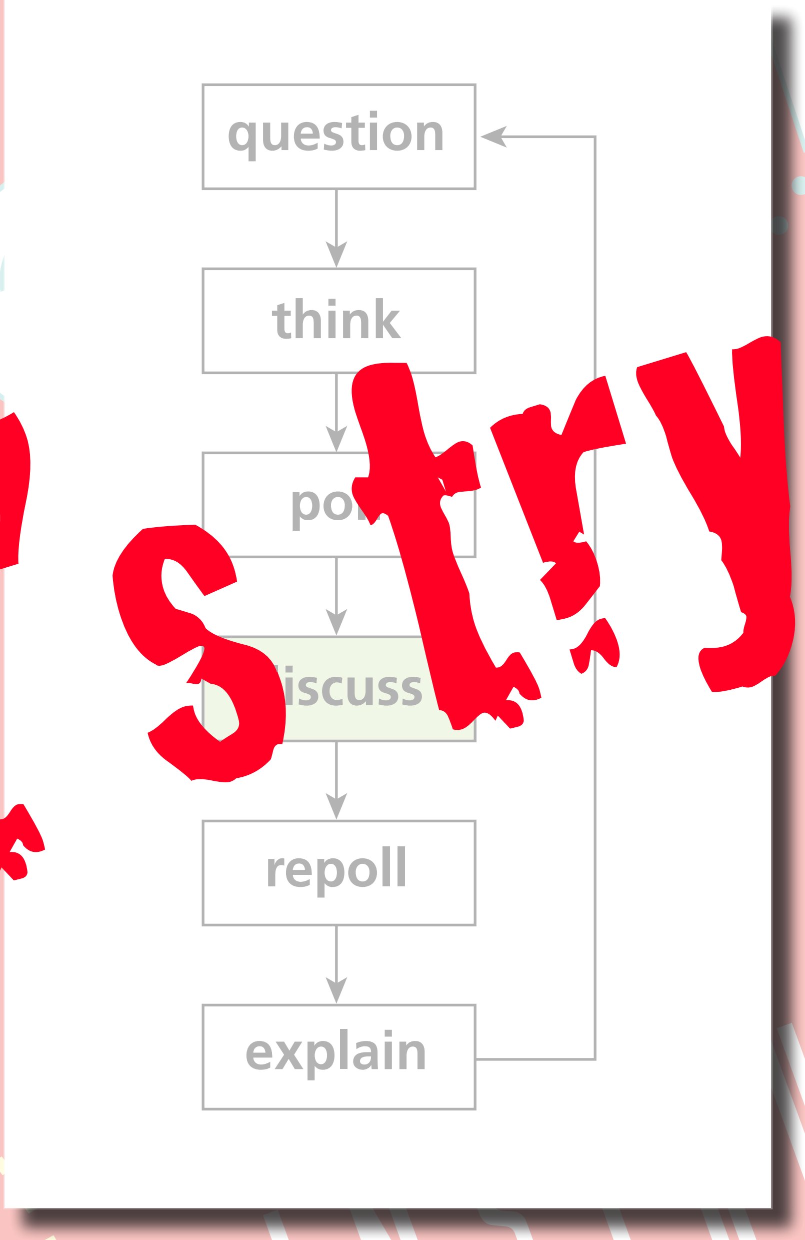
① education

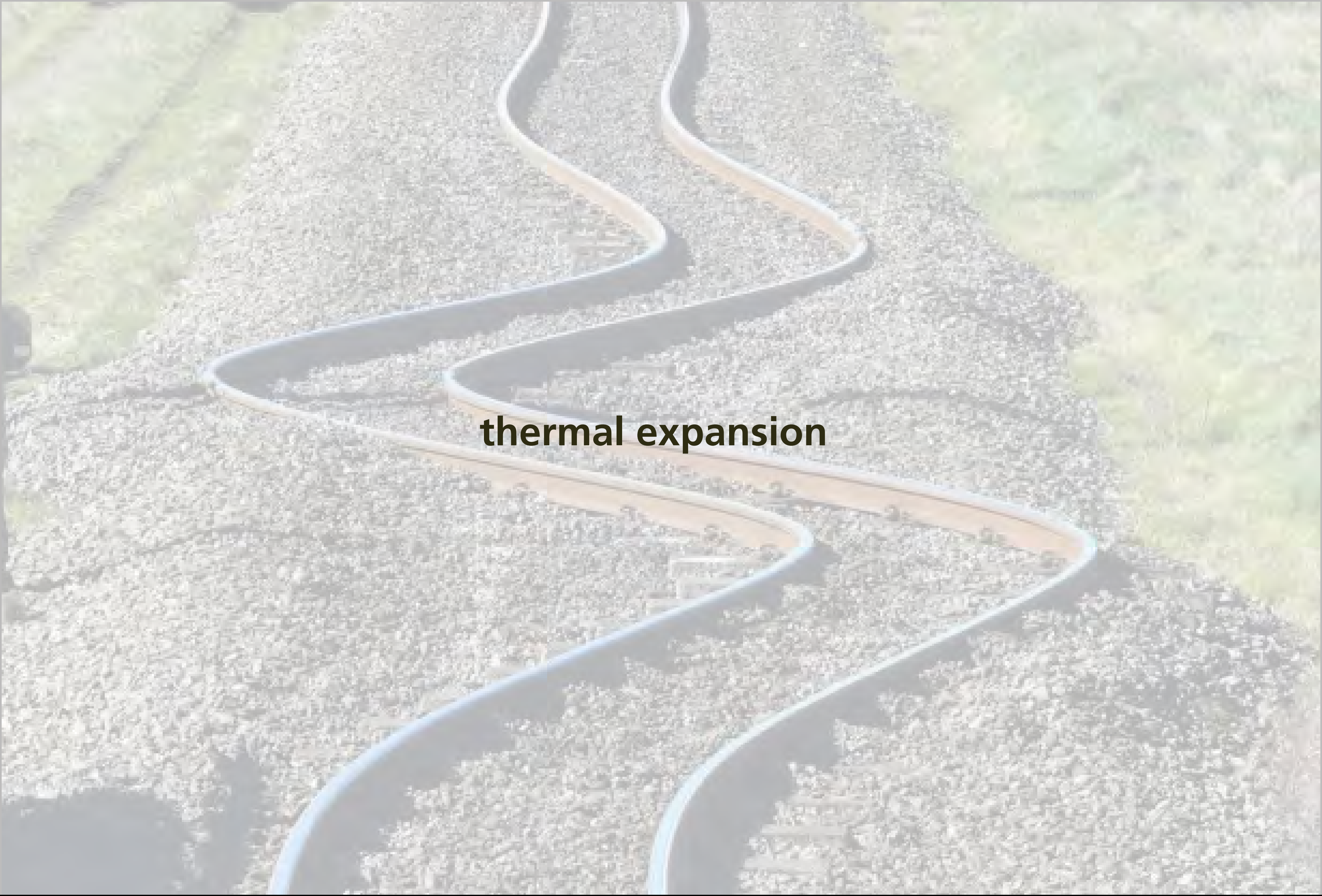
② PI

① education

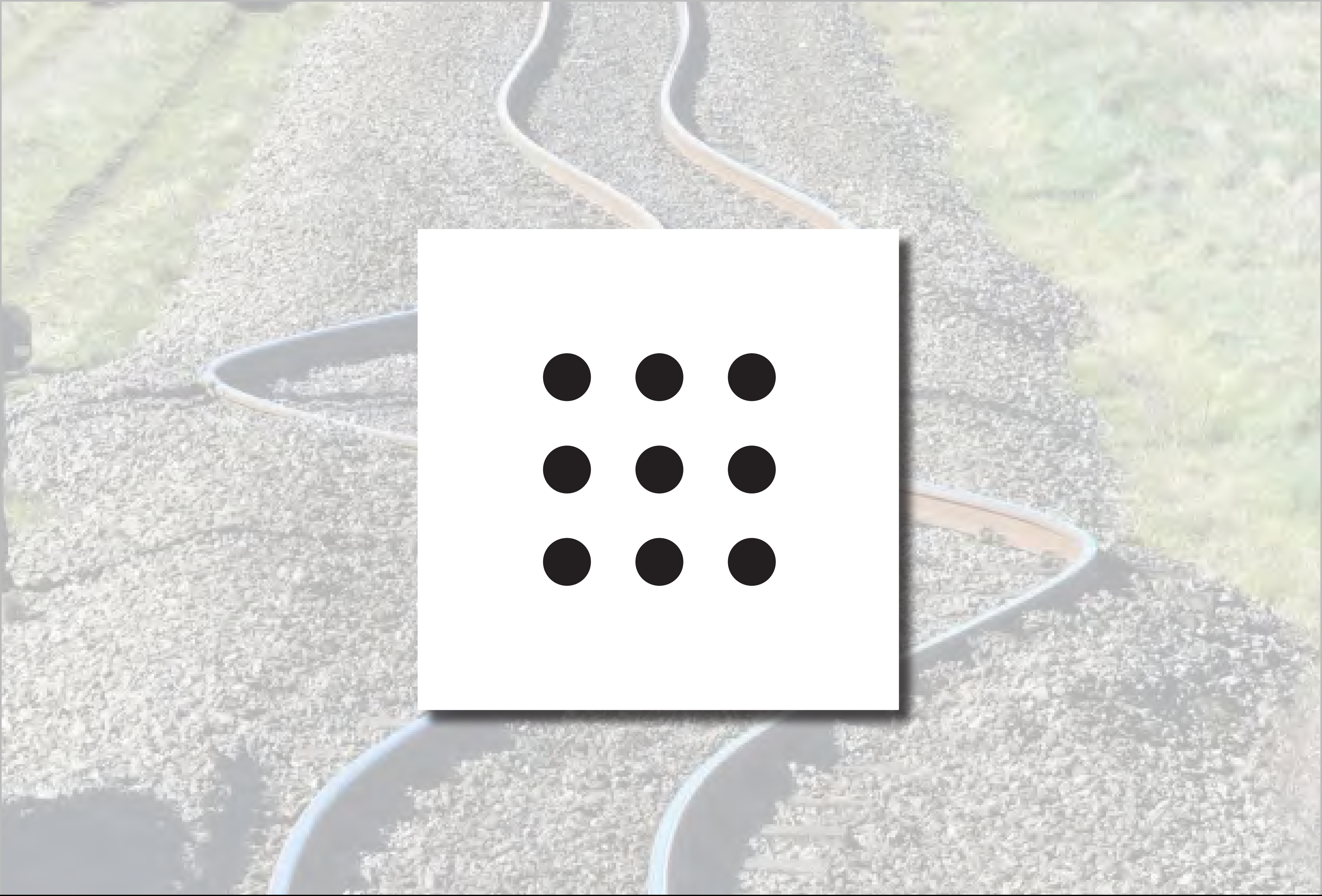
② PI

Let's try it!

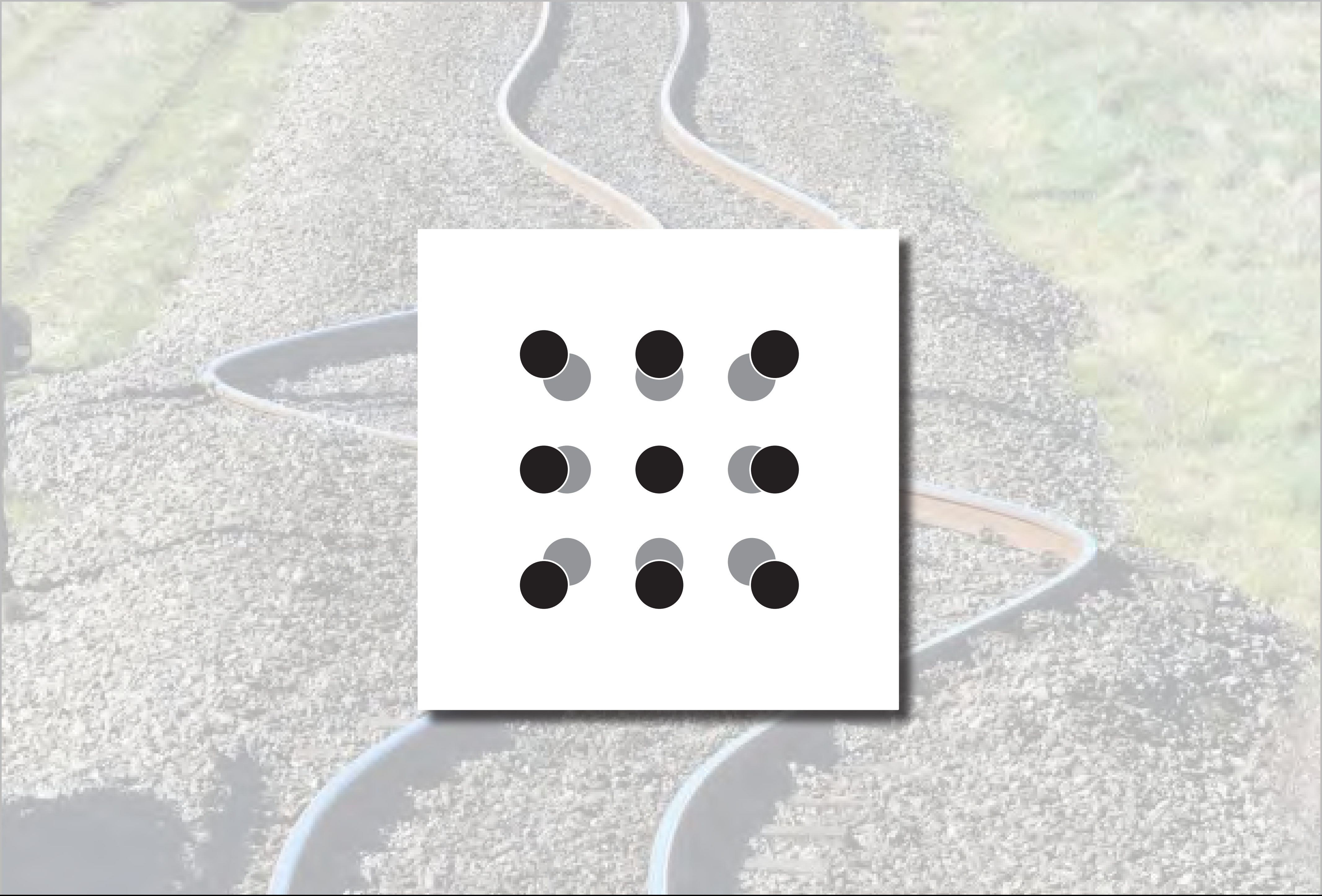




thermal expansion



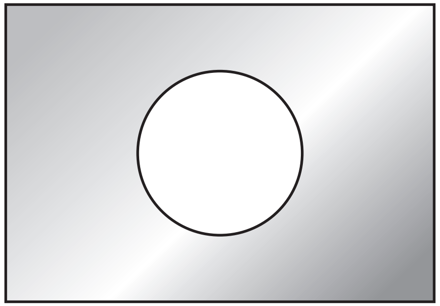
① education ② PI



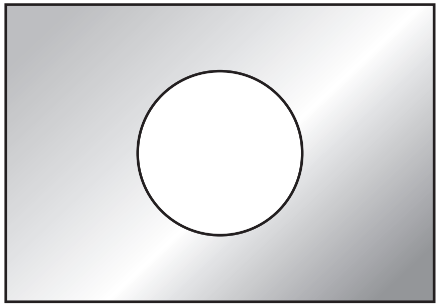
① education ② PI

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.

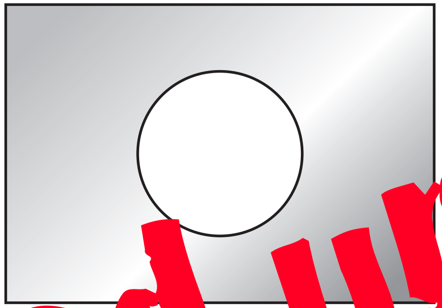


When the plate is uniformly heated, the diameter of the hole

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

① education ② PI ③ test

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



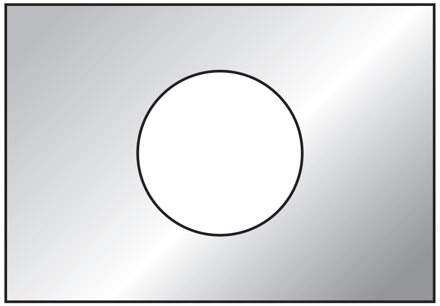
When the plate is uniformly heated, the diameter of the hole

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

you got all fired up!

① education ② PI ③ test

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…

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…

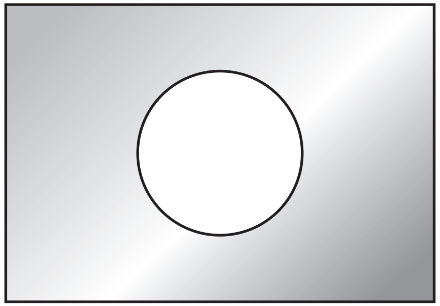
1. made a commitment
2. externalized your answer
3. moved from the answer/fact to reasoning

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

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① education ② PI ③ test

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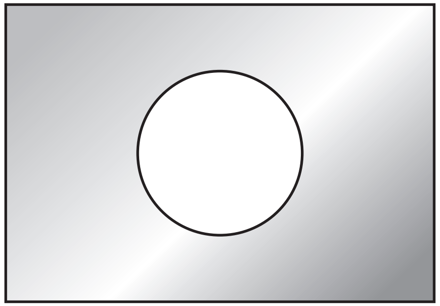
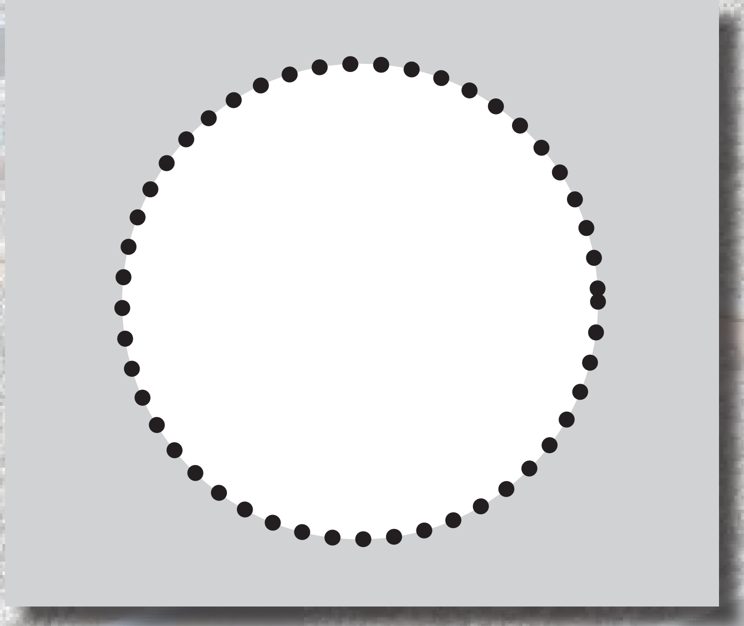


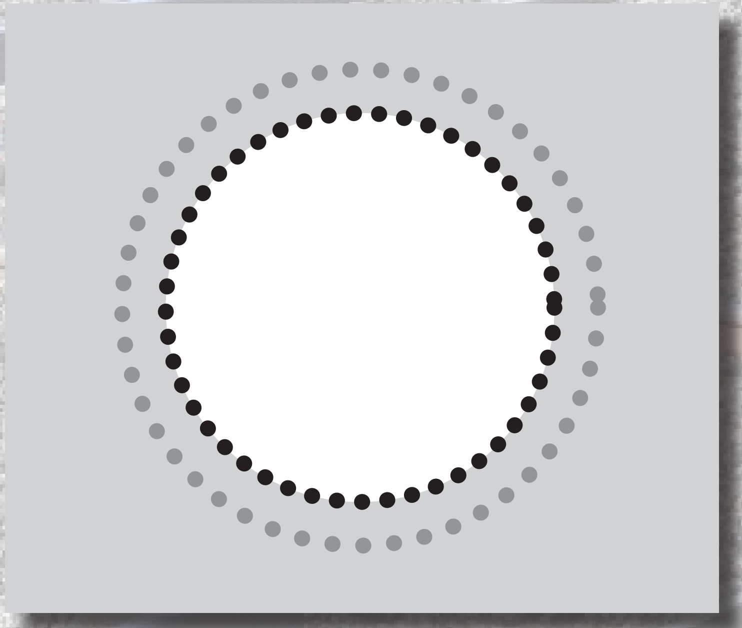
When the plate is uniformly heated, the diameter of the hole

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

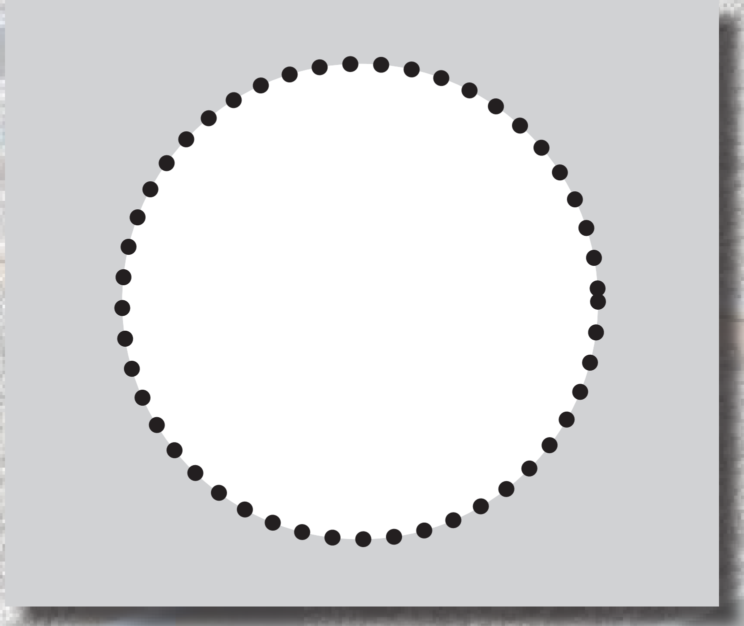
consider atoms at rim of hole



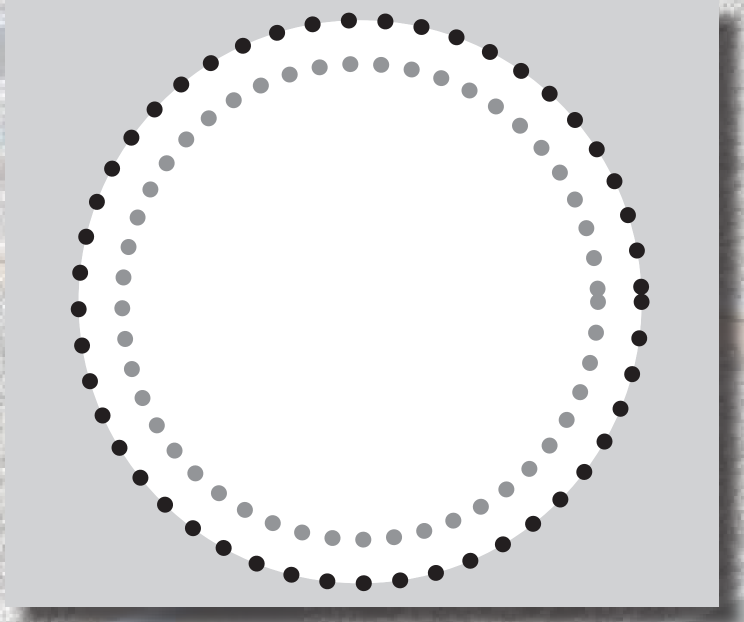
consider atoms at rim of hole



consider atoms at rim of hole



consider atoms at rim of hole



consider atoms at rim of hole

you won't forget this

① education ② PI ③ test

Peer

back to PI

INSTRUCTION

1 education
2 PI
3 test

Greater learning gains

Greater learning gains

Better retention

① education ② PI ③ test

in a lecture, students…

in a lecture, students…

1. don’t pay utmost attention

in a lecture, students…

1. don’t pay utmost attention
2. think they know it

in a lecture, students…

1. don’t pay utmost attention

2. think they know it

3. are not confronted with misconceptions

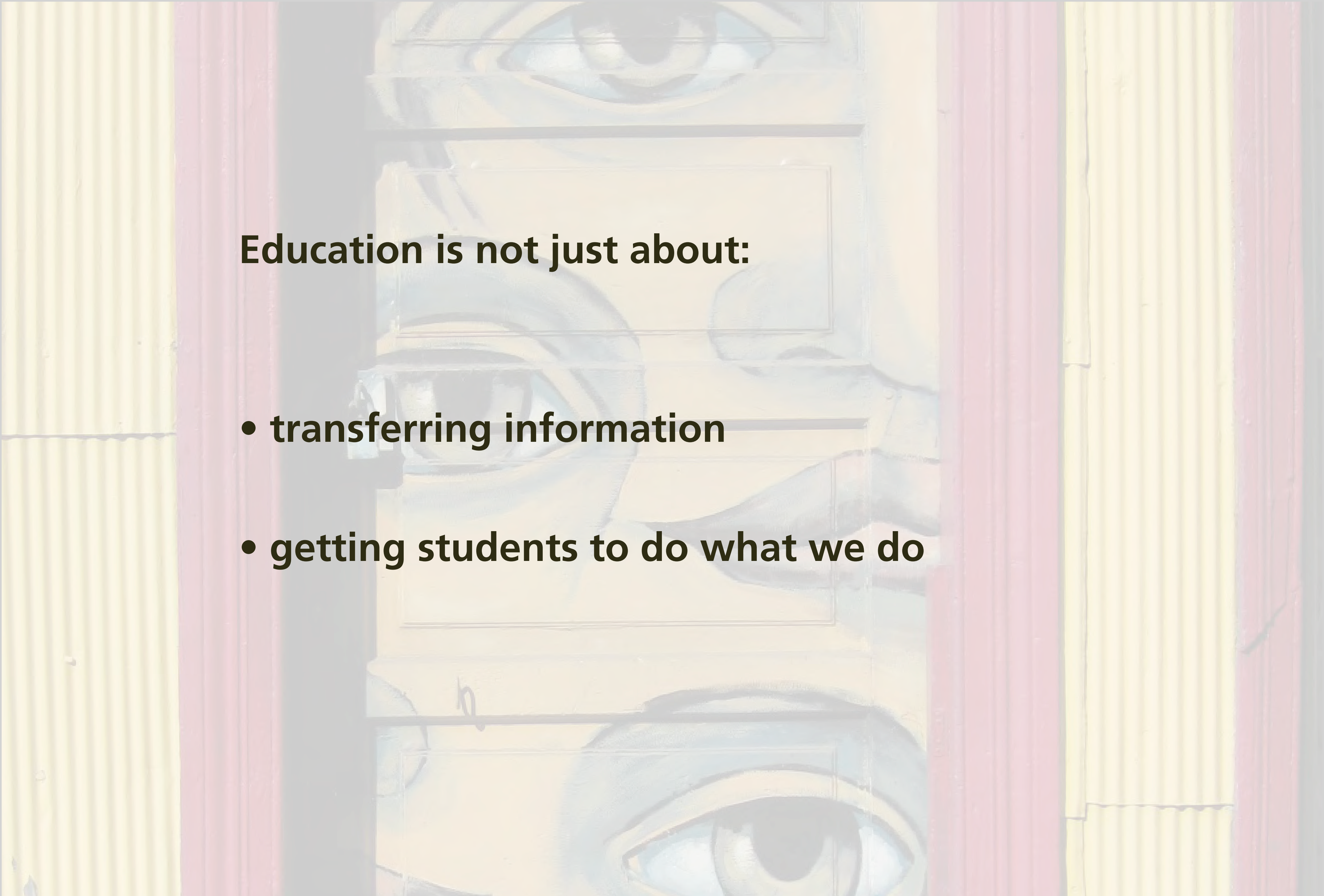
in a lecture, students…

1. don’t pay utmost attention
2. think they know it
3. are not confronted with misconceptions

false sense of security

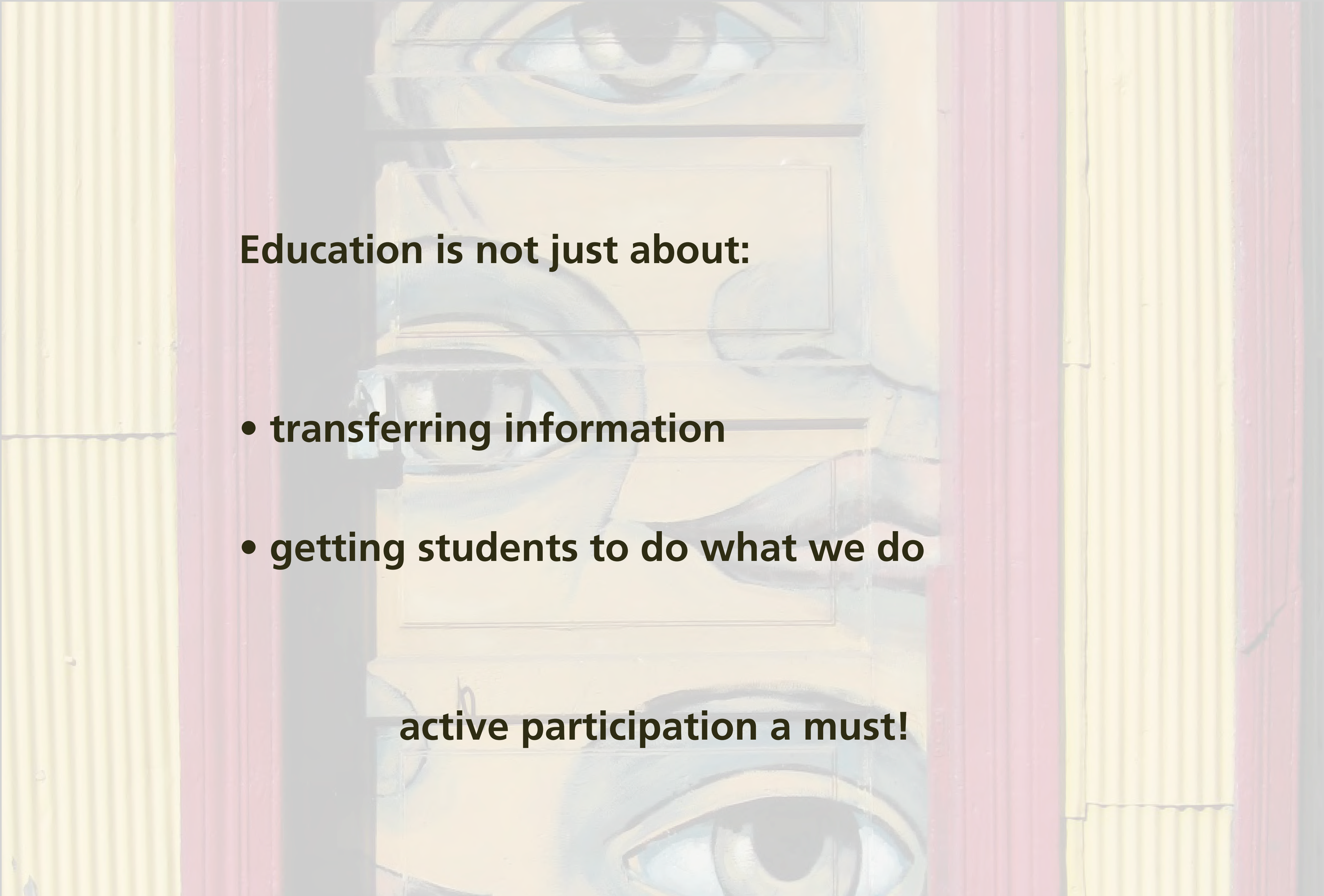
① education ② PI ③ test

an illusion. . .



Education is not just about:

- transferring information
- getting students to do what we do



Education is not just about:

- transferring information
- getting students to do what we do

active participation a must!

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Technology in the Classroom

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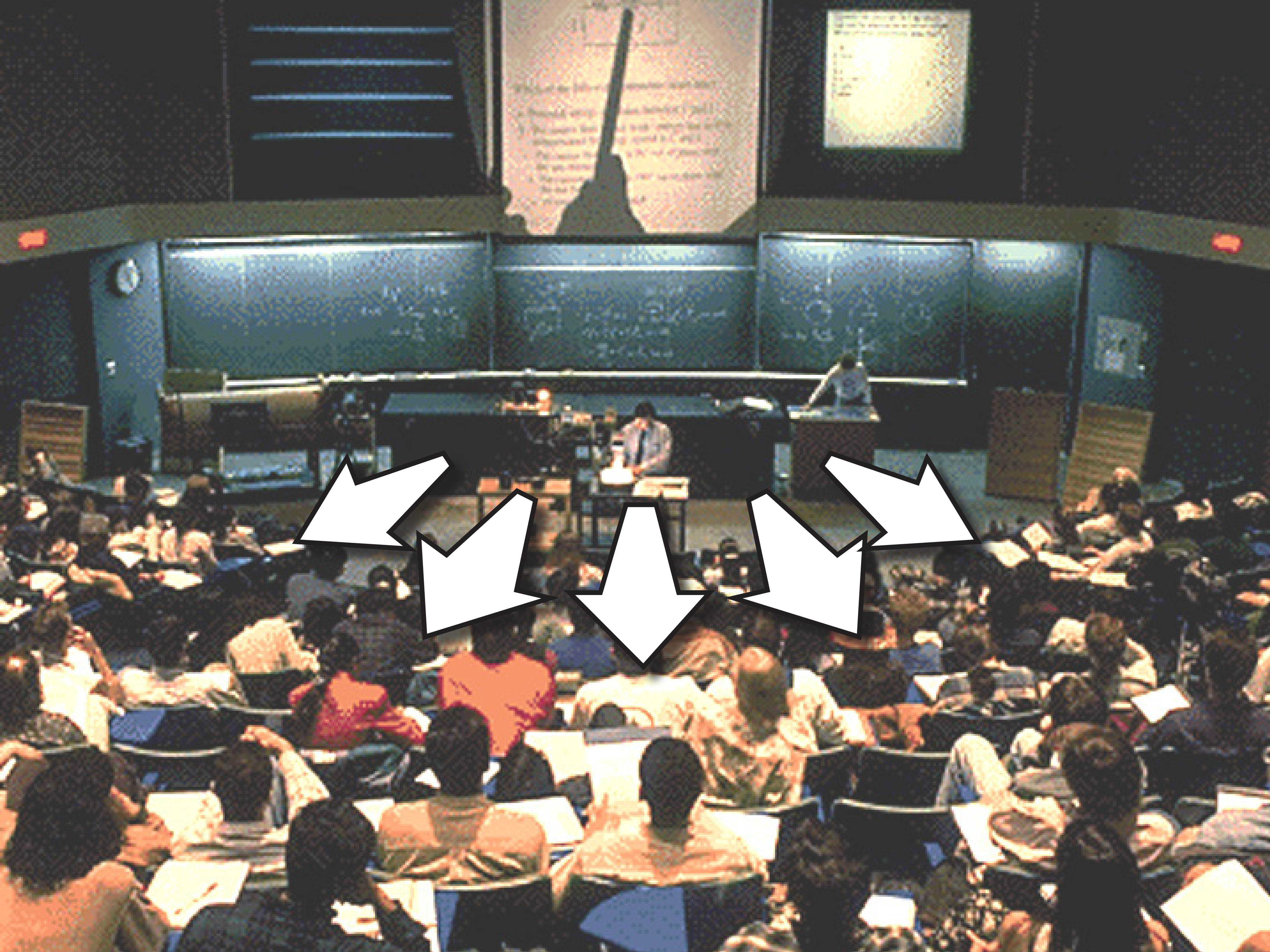


CLASS

ROOM

1st exposure

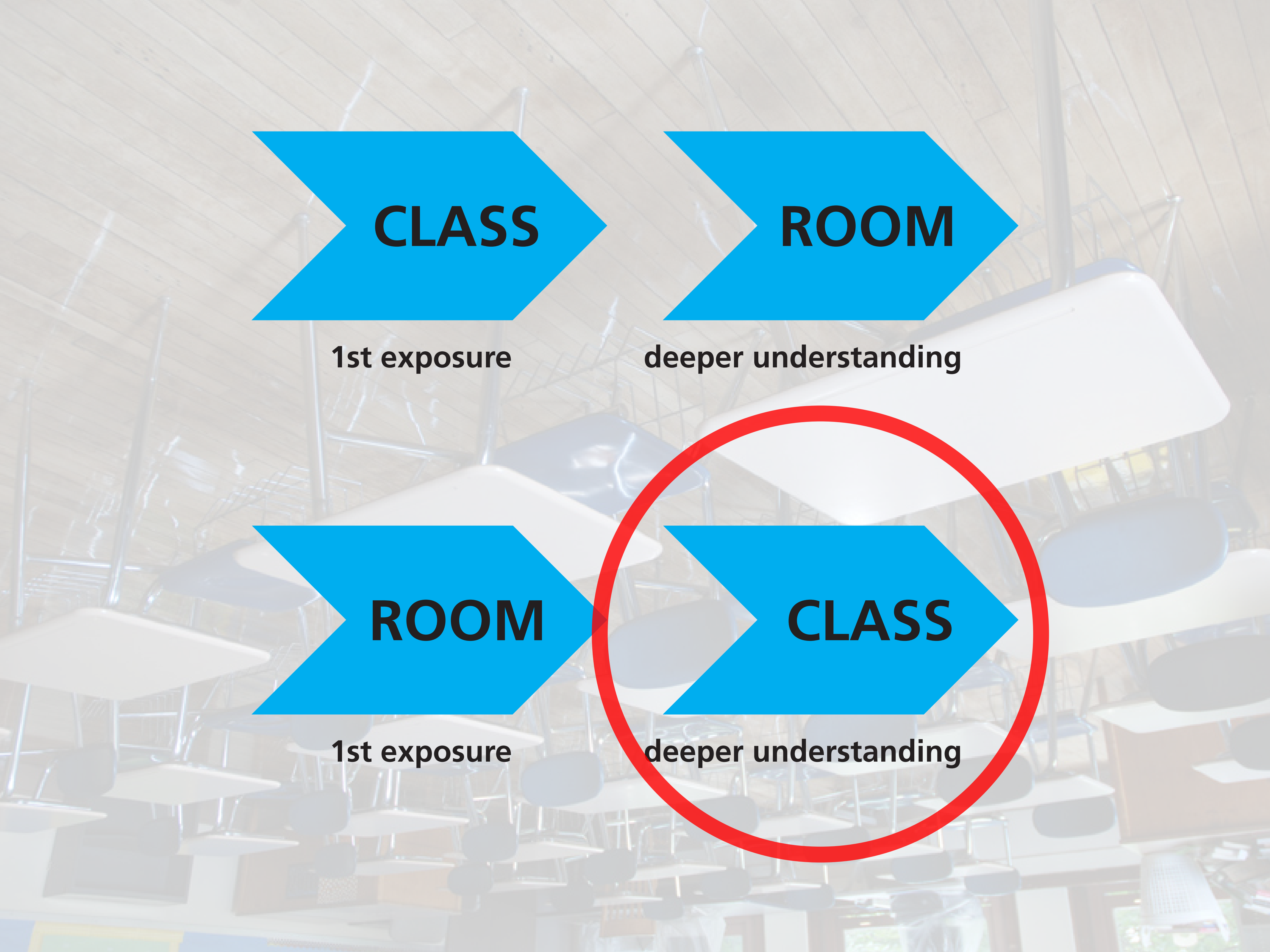
deeper understanding

CLASS **ROOM**

1st exposure deeper understanding

ROOM **CLASS**

1st exposure deeper understanding

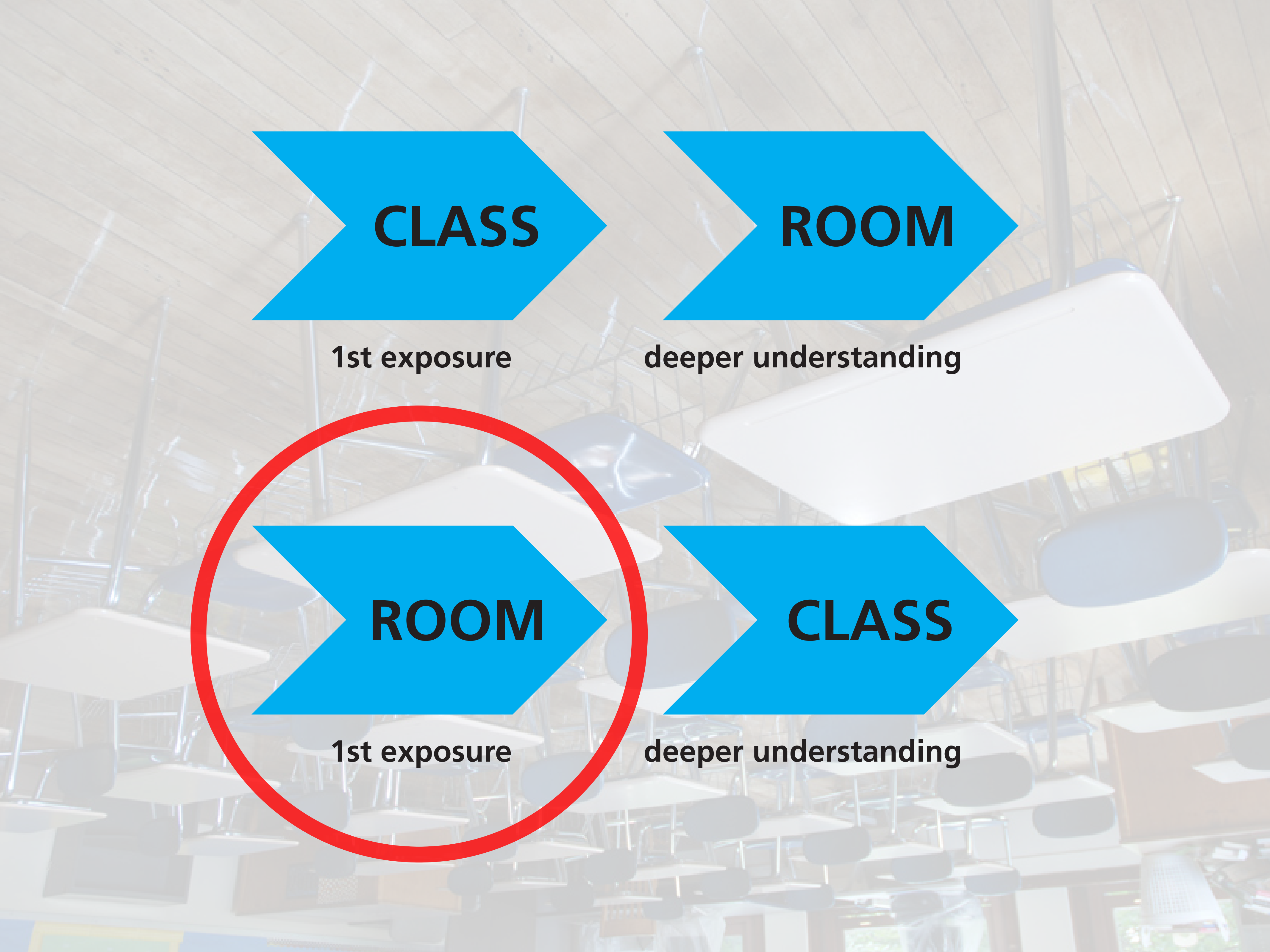


CLASS **ROOM**

1st exposure deeper understanding

ROOM **CLASS**

1st exposure deeper understanding

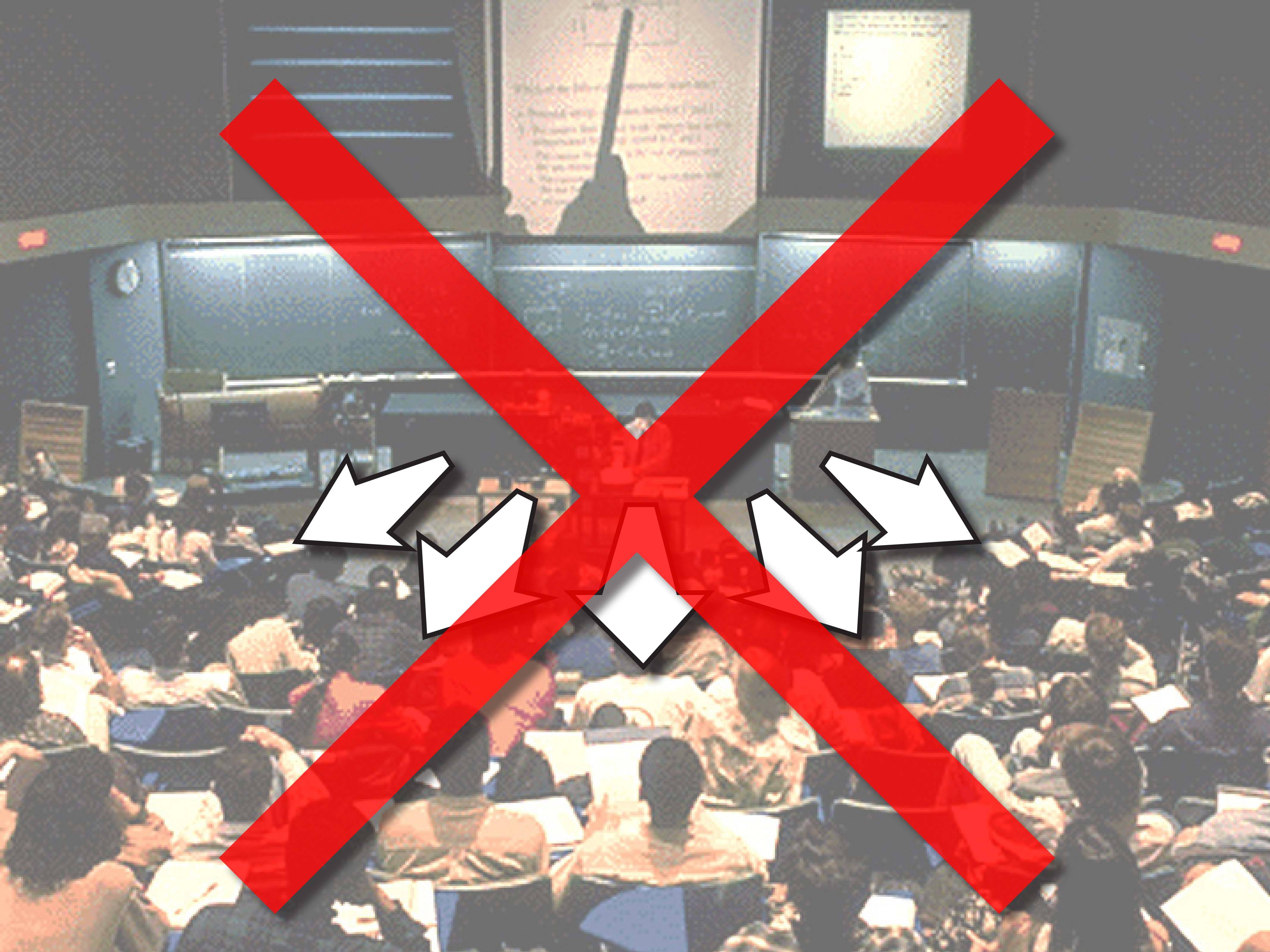


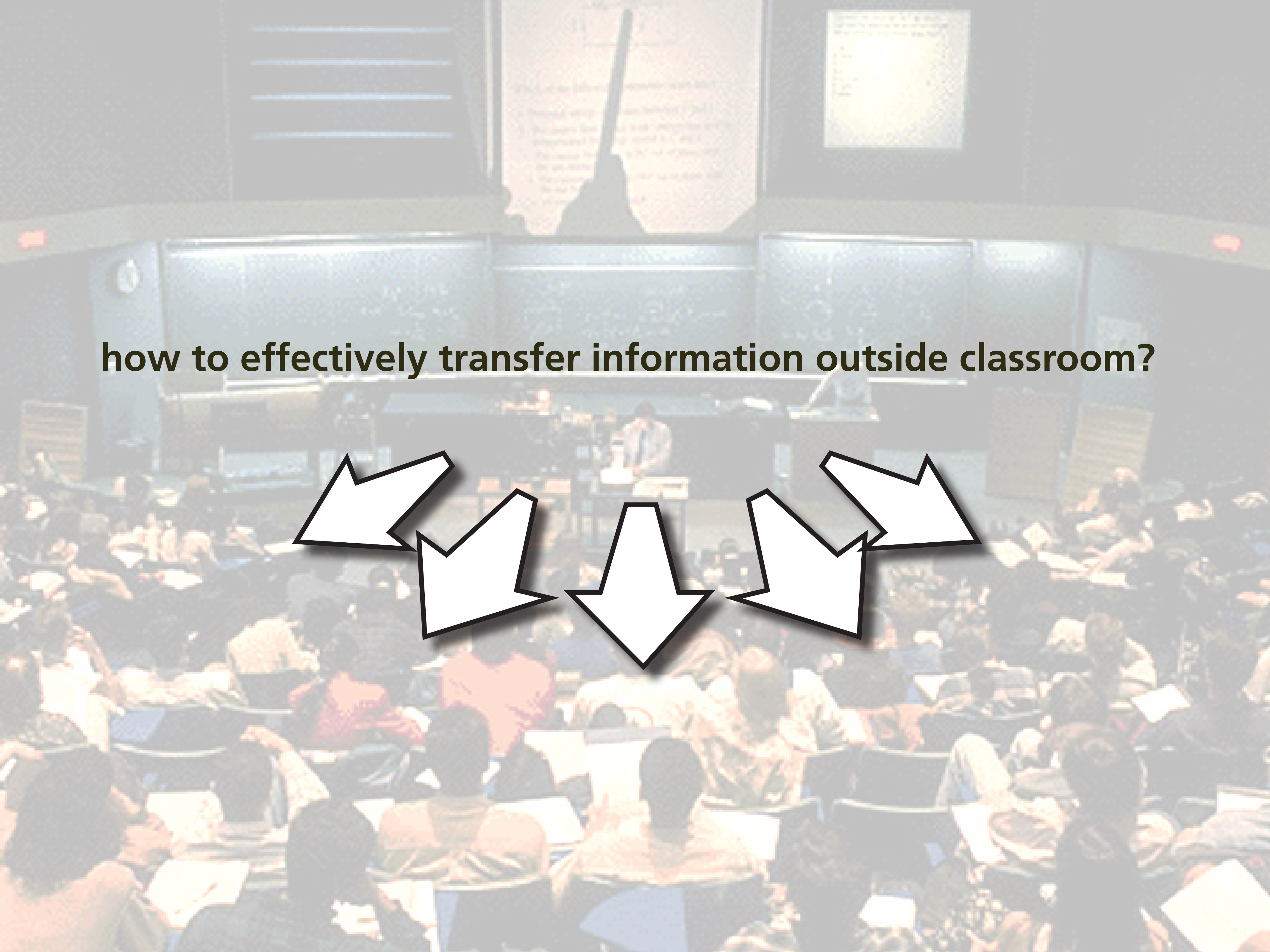
CLASS **ROOM**

1st exposure deeper understanding

ROOM **CLASS**

1st exposure deeper understanding

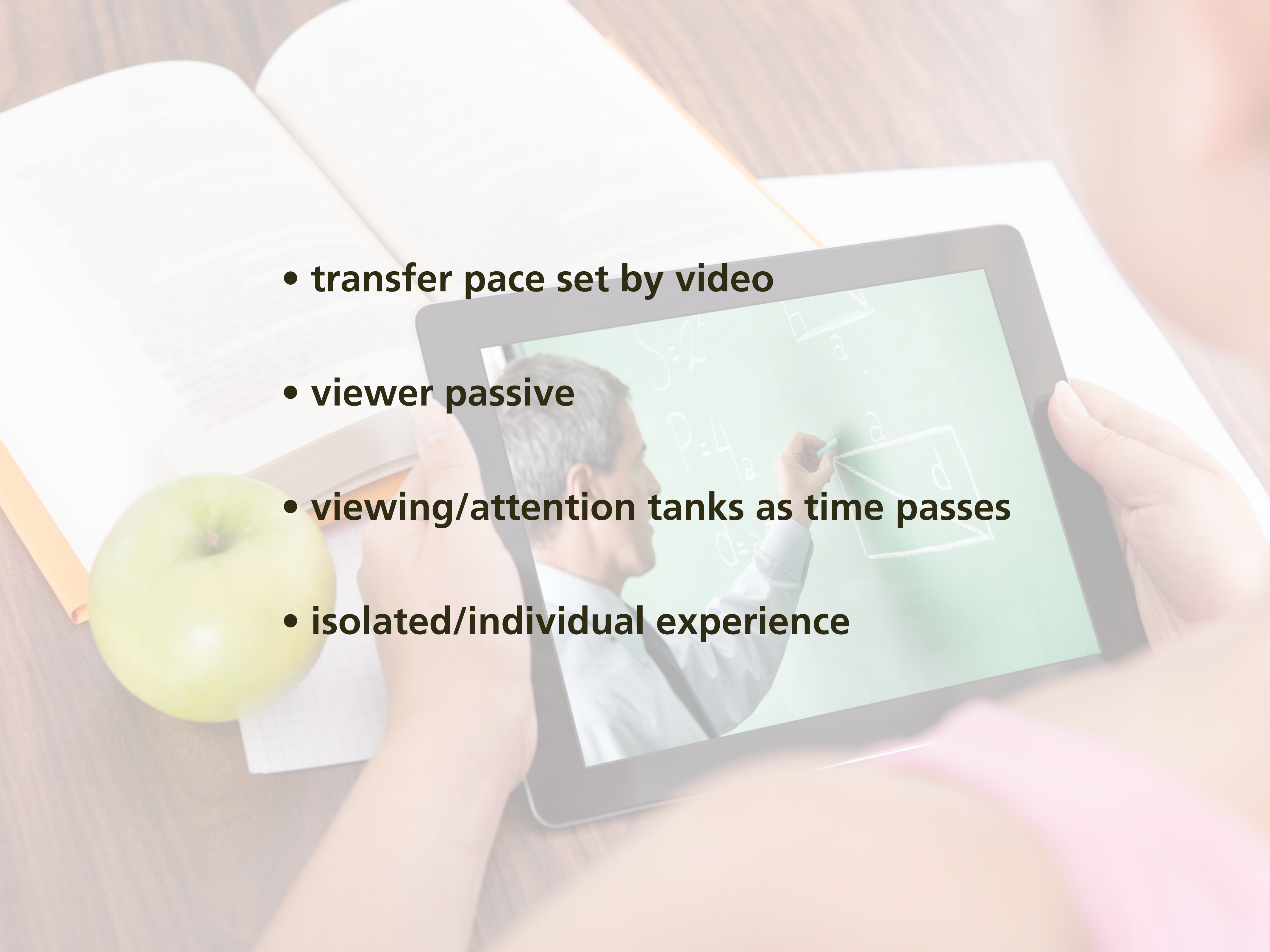




how to effectively transfer information outside classroom?


P=4a
a
a
d

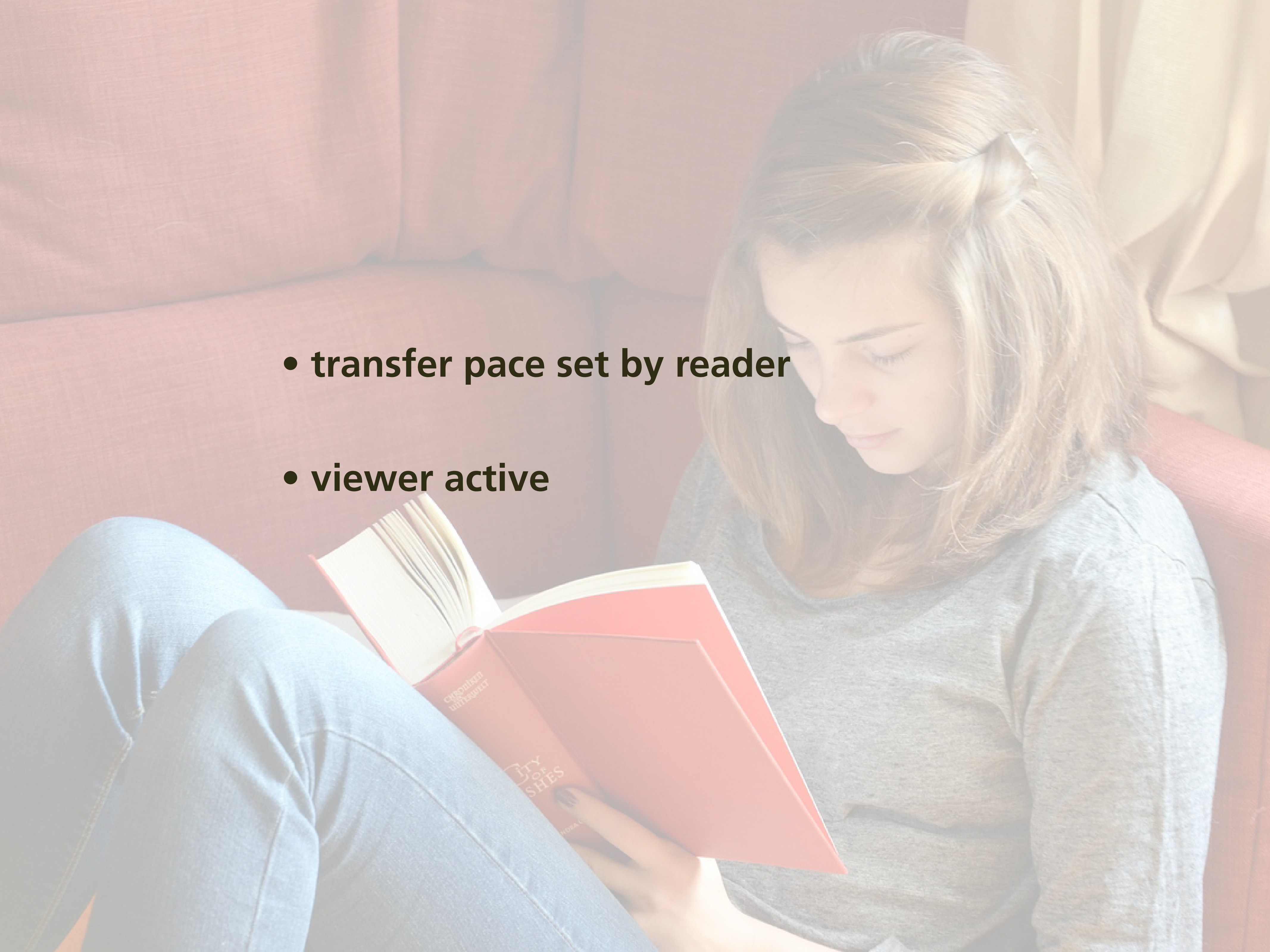
but…



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

we’re simply moving this outside classroom!


CHRONIKEN
UNTERWELT
CITY OF
SHES

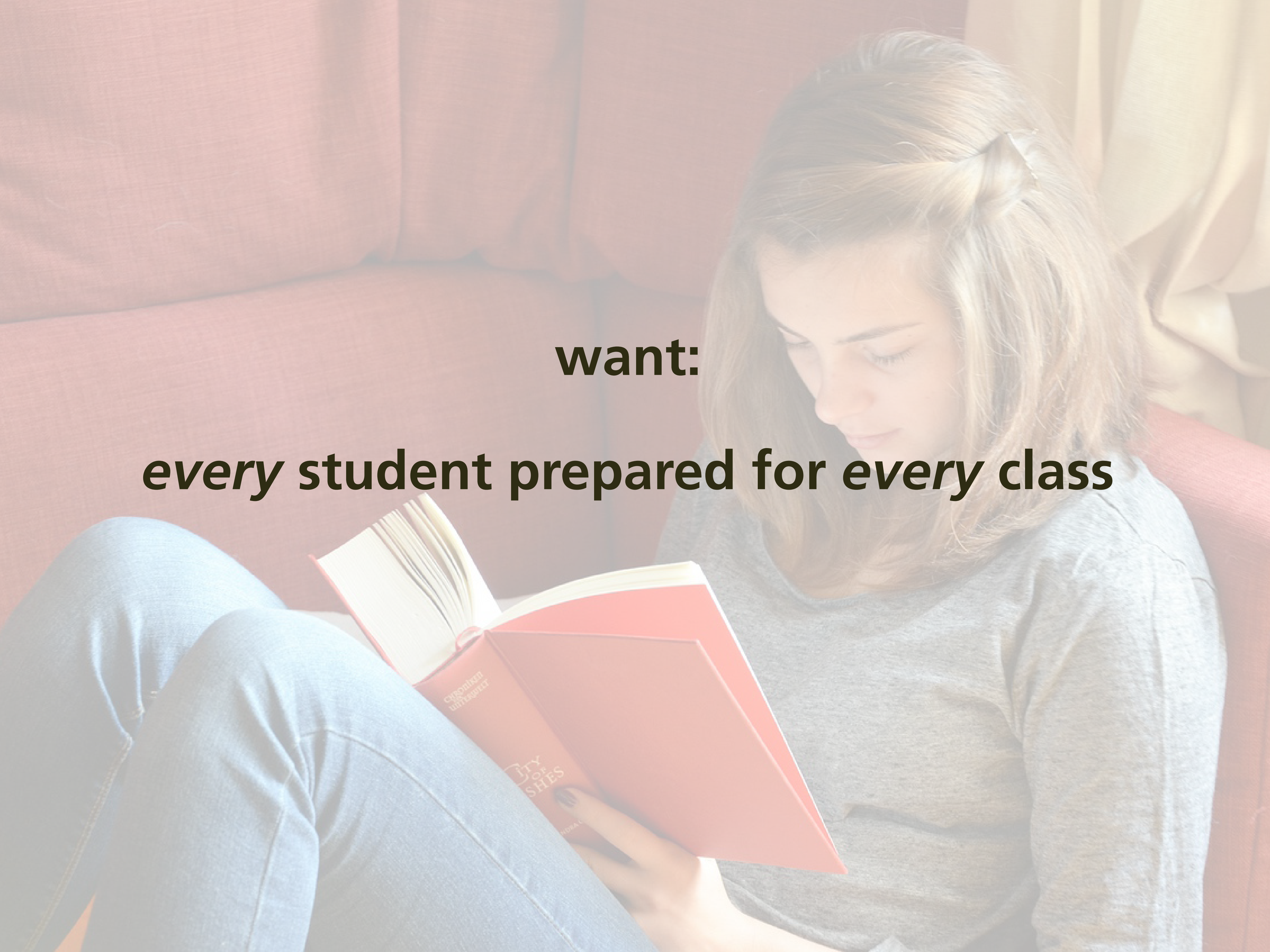


- **transfer pace set by reader**
- **viewer active**

but…

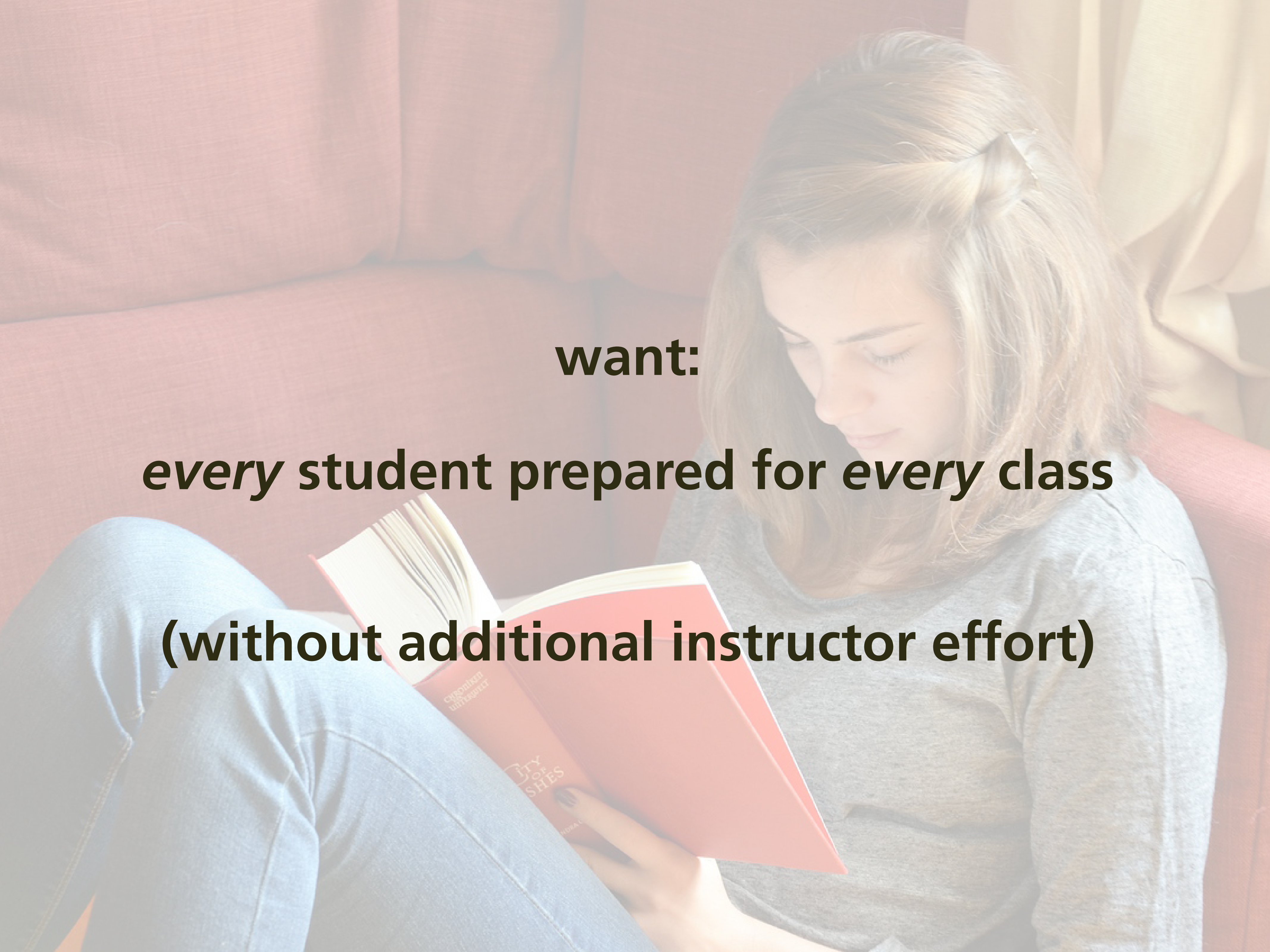
isolated/individual experience &

no real accountability



want:

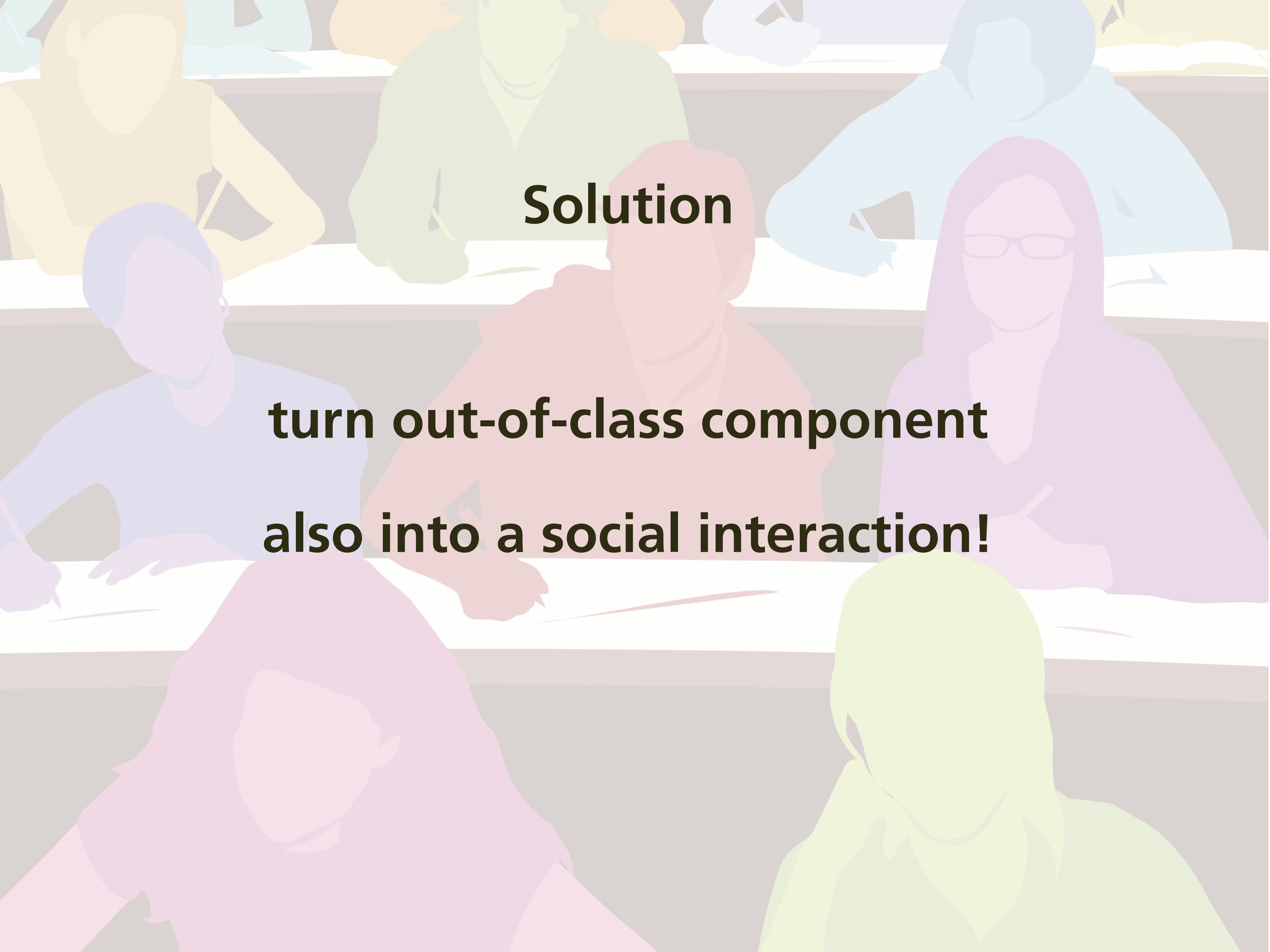
every student prepared for *every* class



want:

every student prepared for *every* class

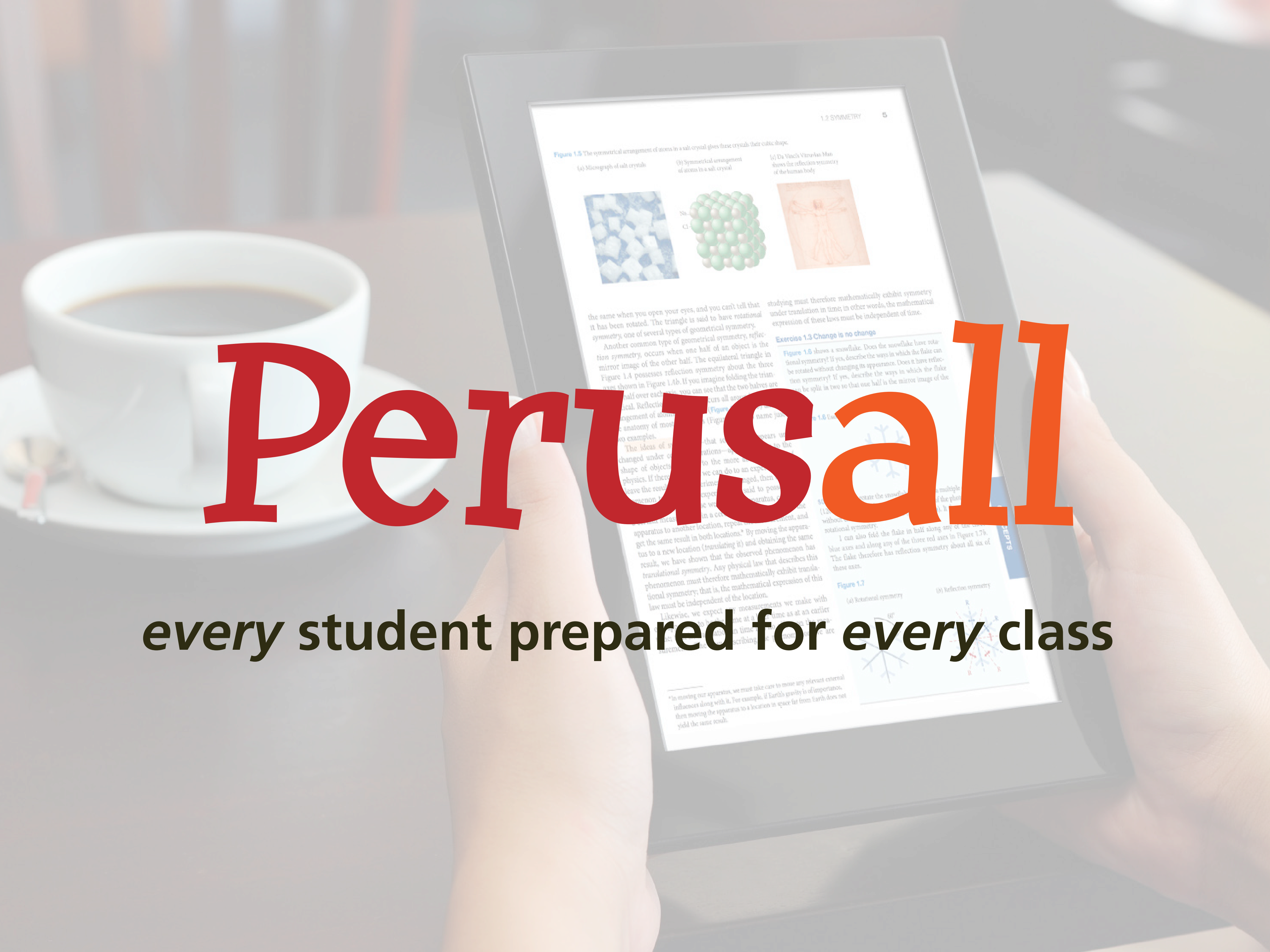
(without additional instructor effort)



Solution

turn out-of-class component

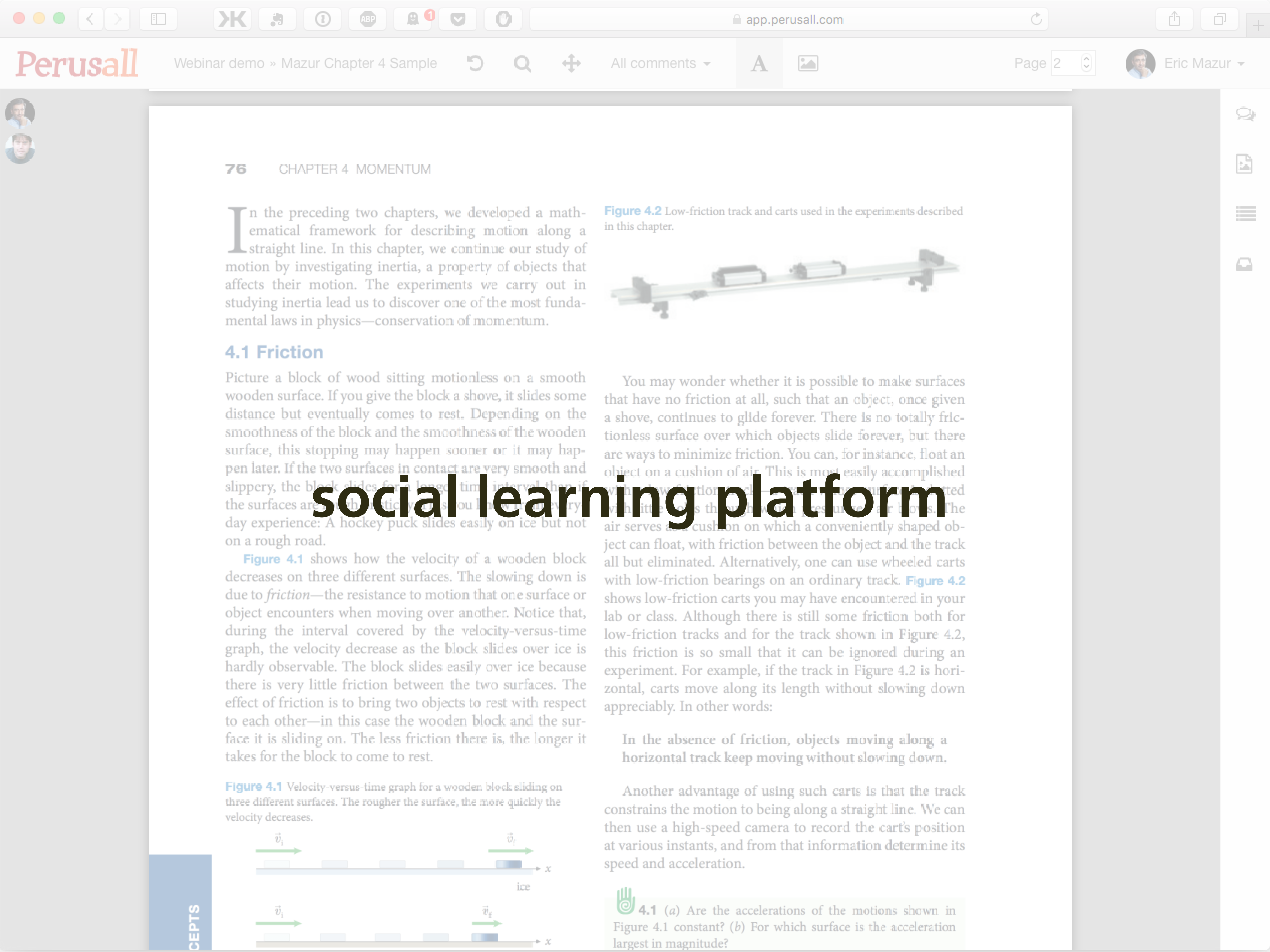
also into a social interaction!



Perusall

every student prepared for *every* class

social learning platform



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, as you know from everyday experience: A hockey puck slides easily on ice but not on a rough road.

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

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

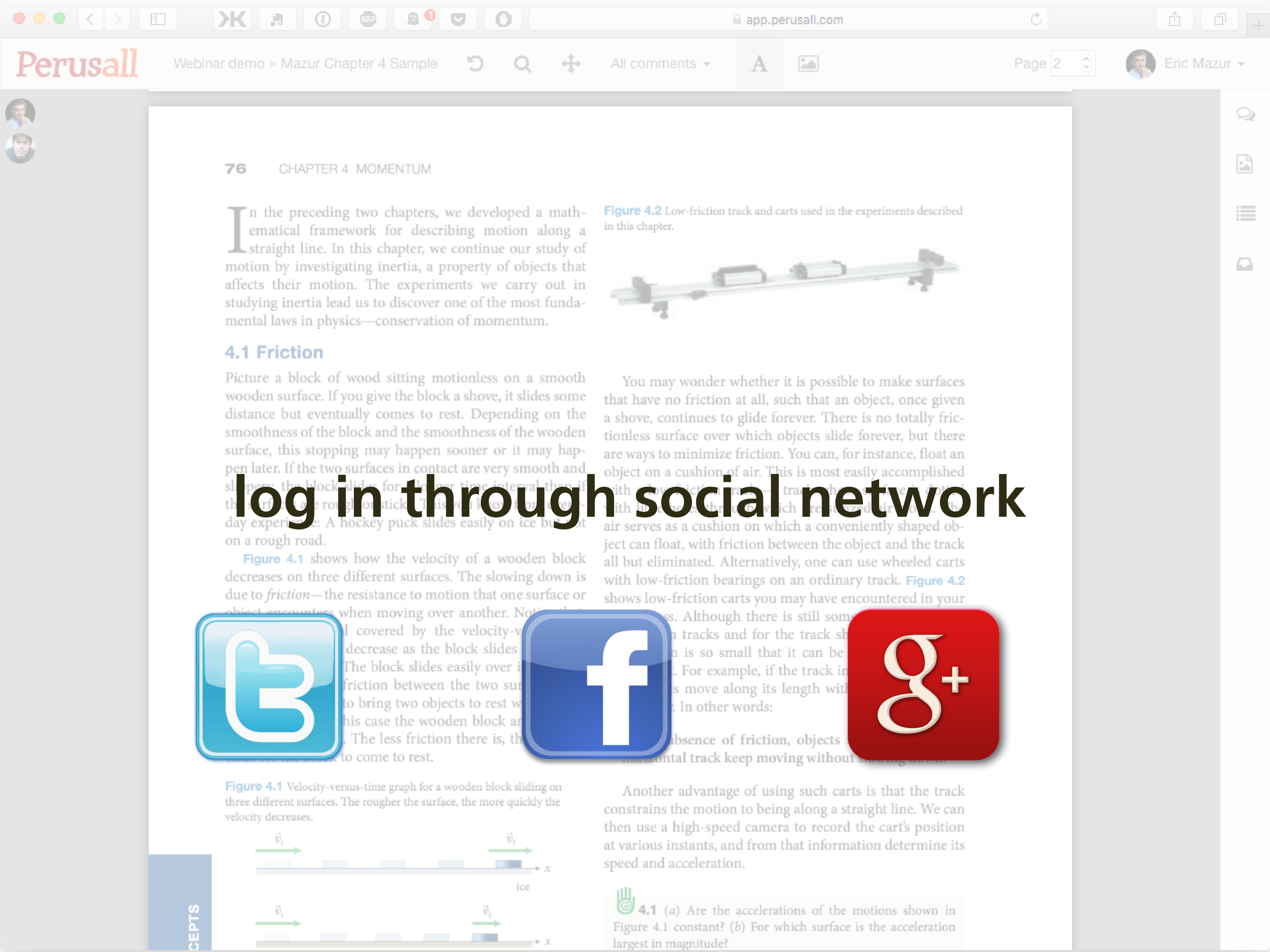
Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.

You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air flows. 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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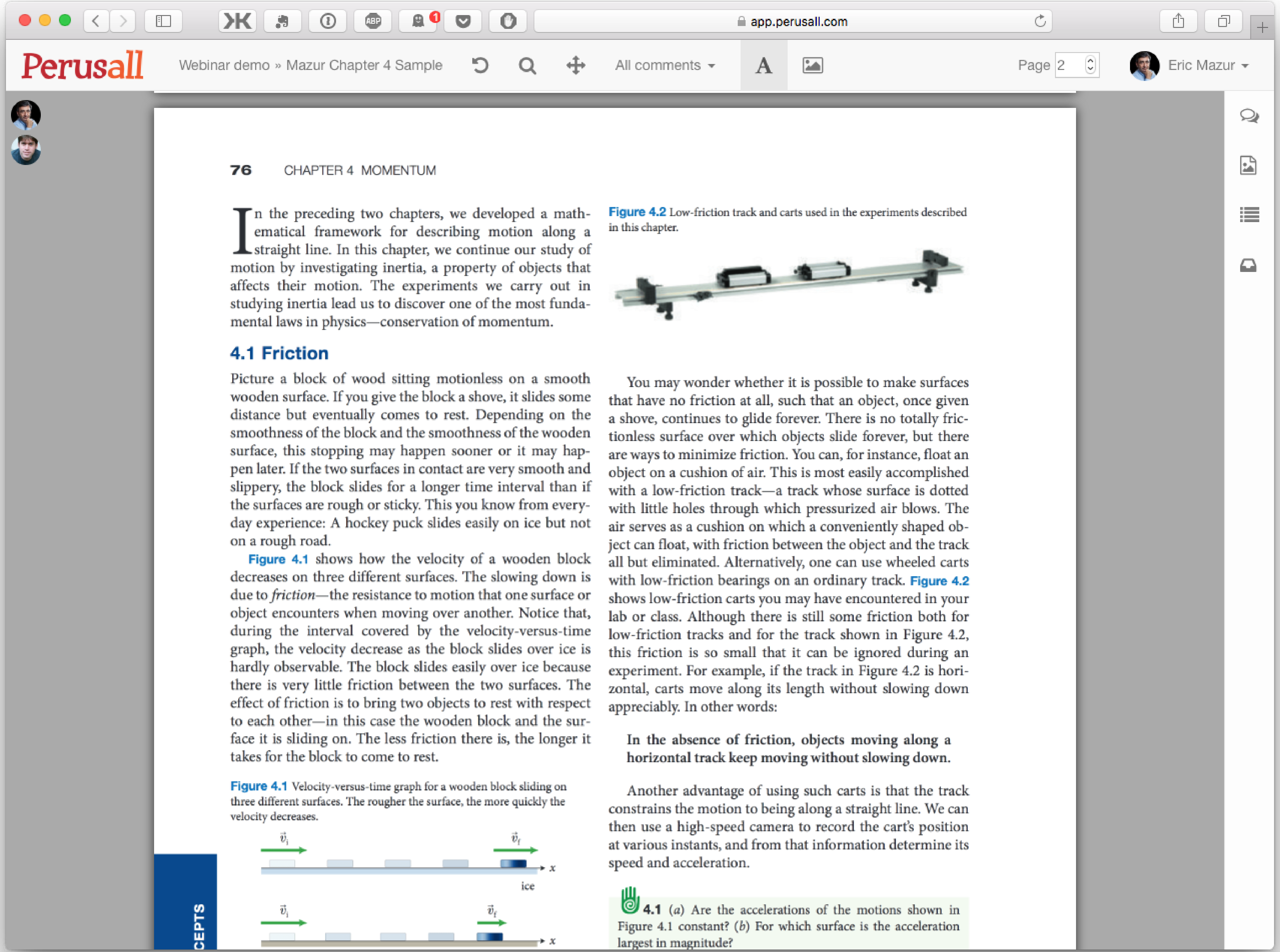

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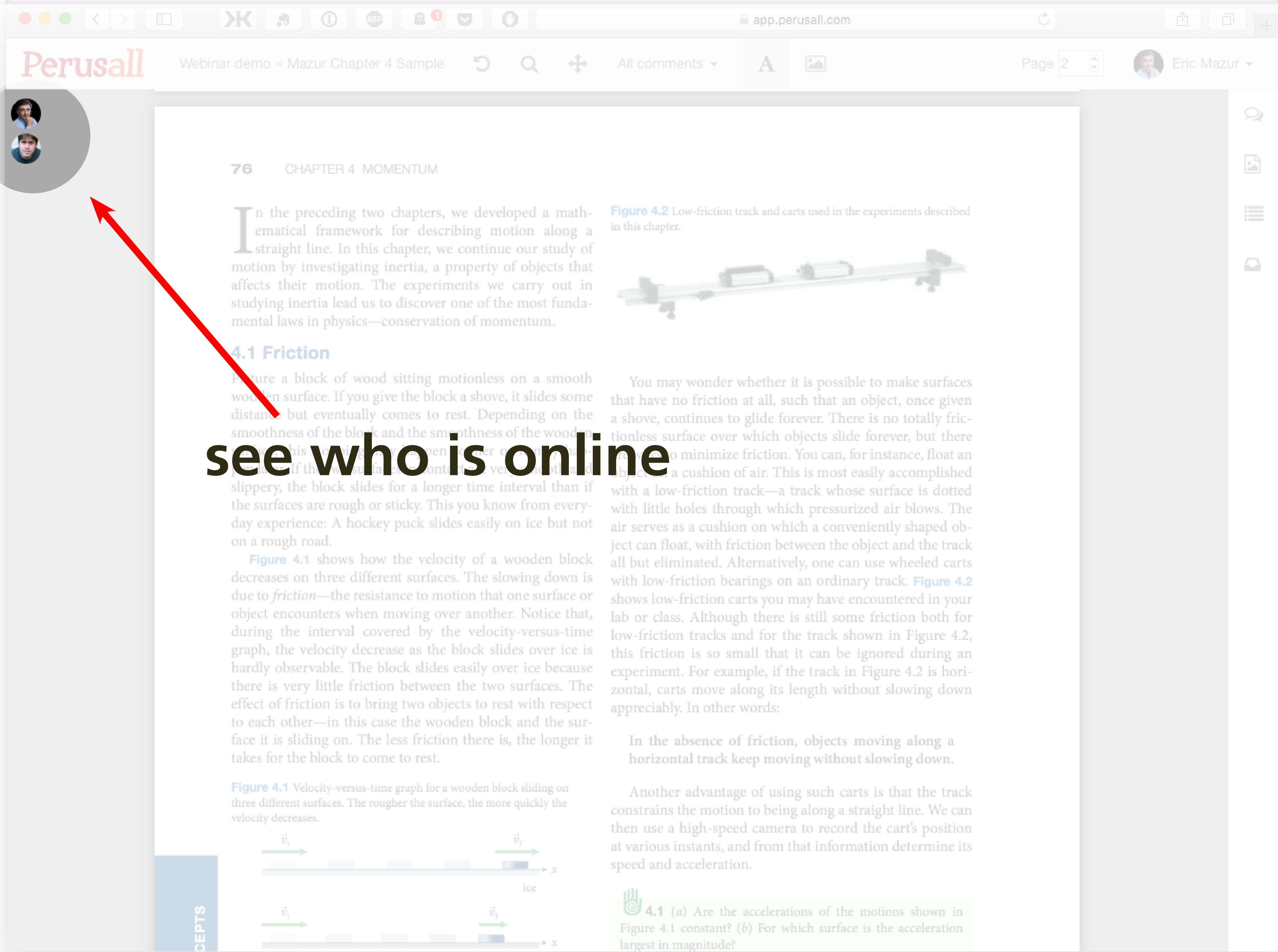

76 CHAPTER 4 MOMENTUM

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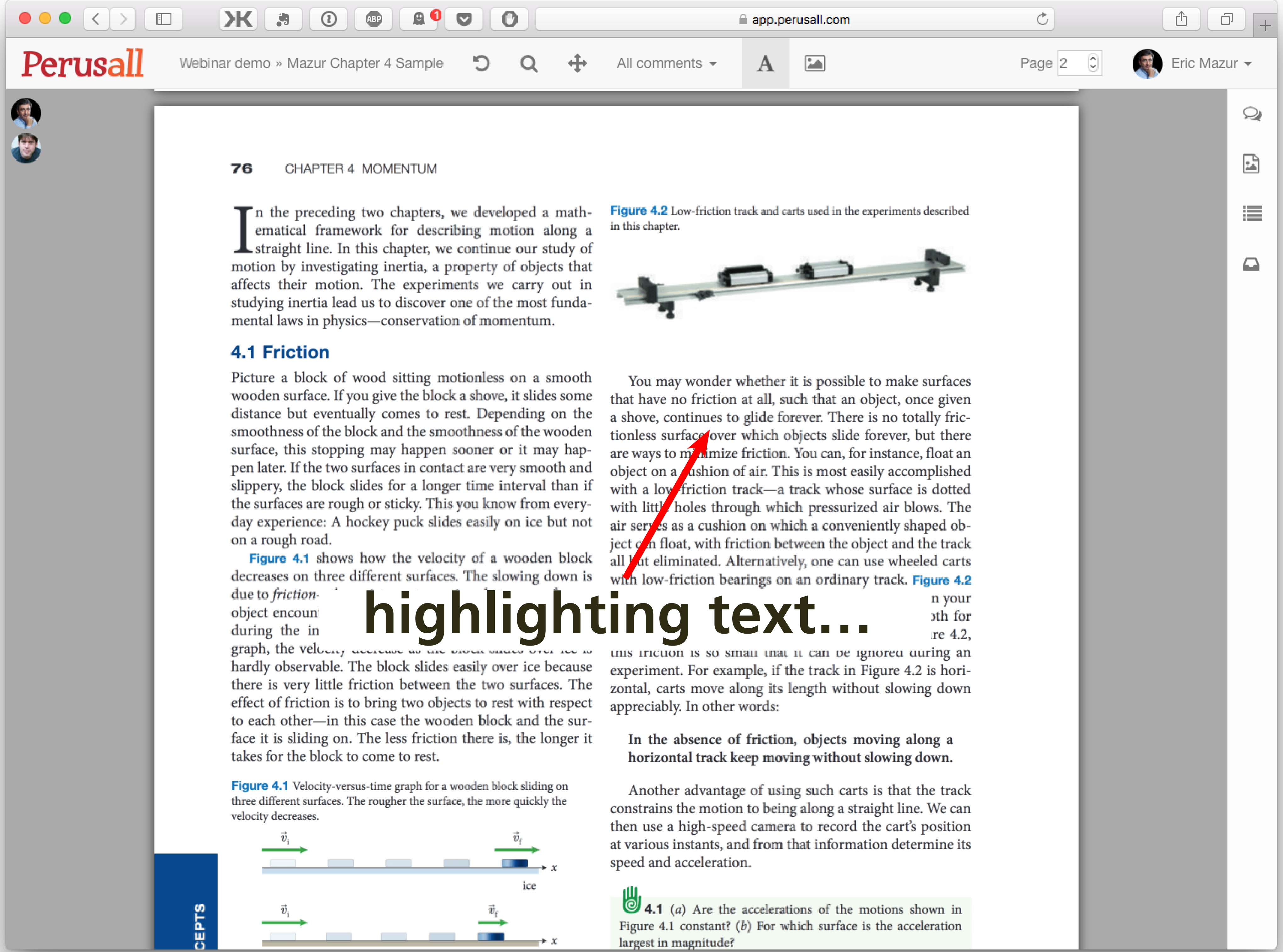

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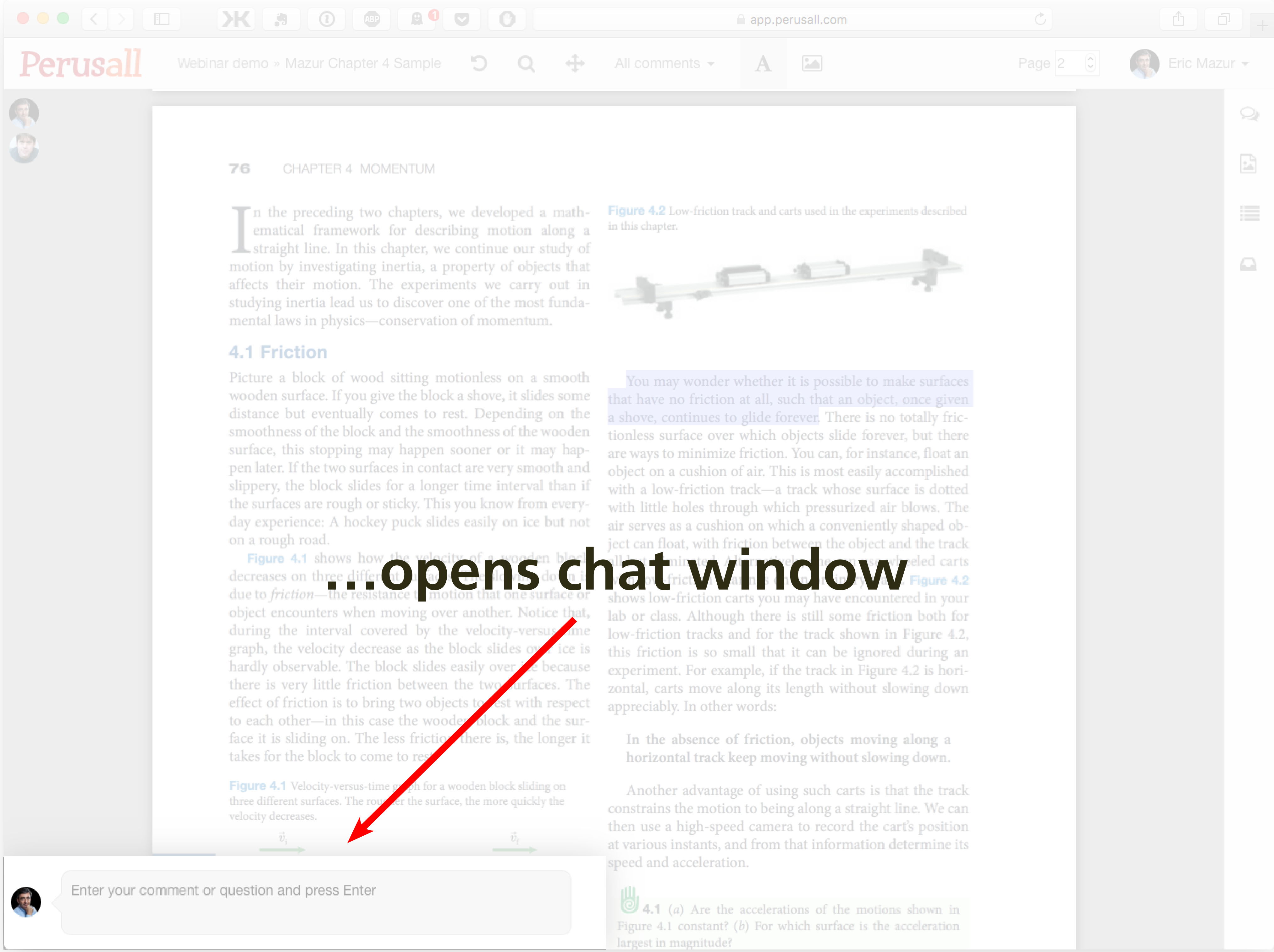

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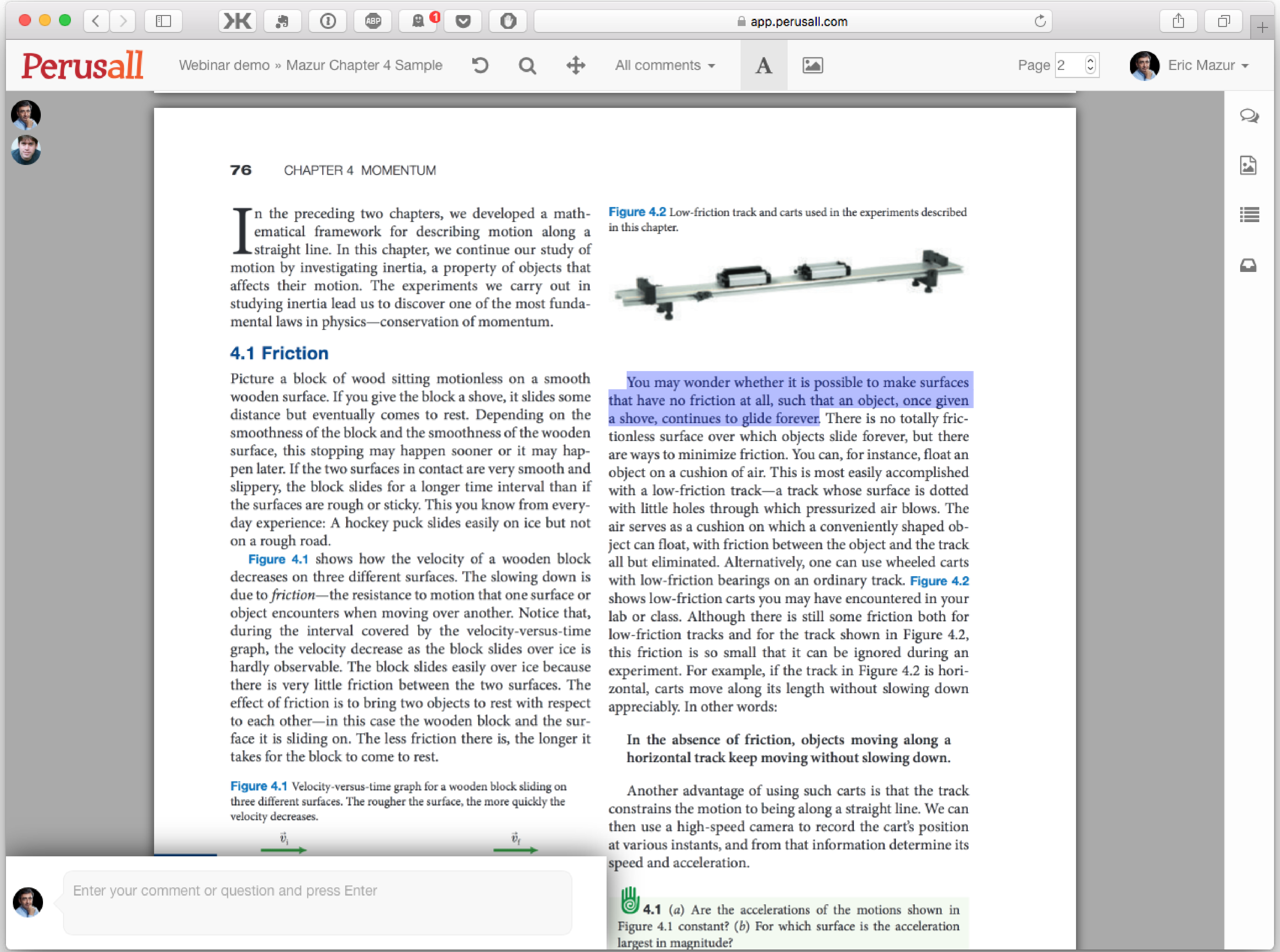

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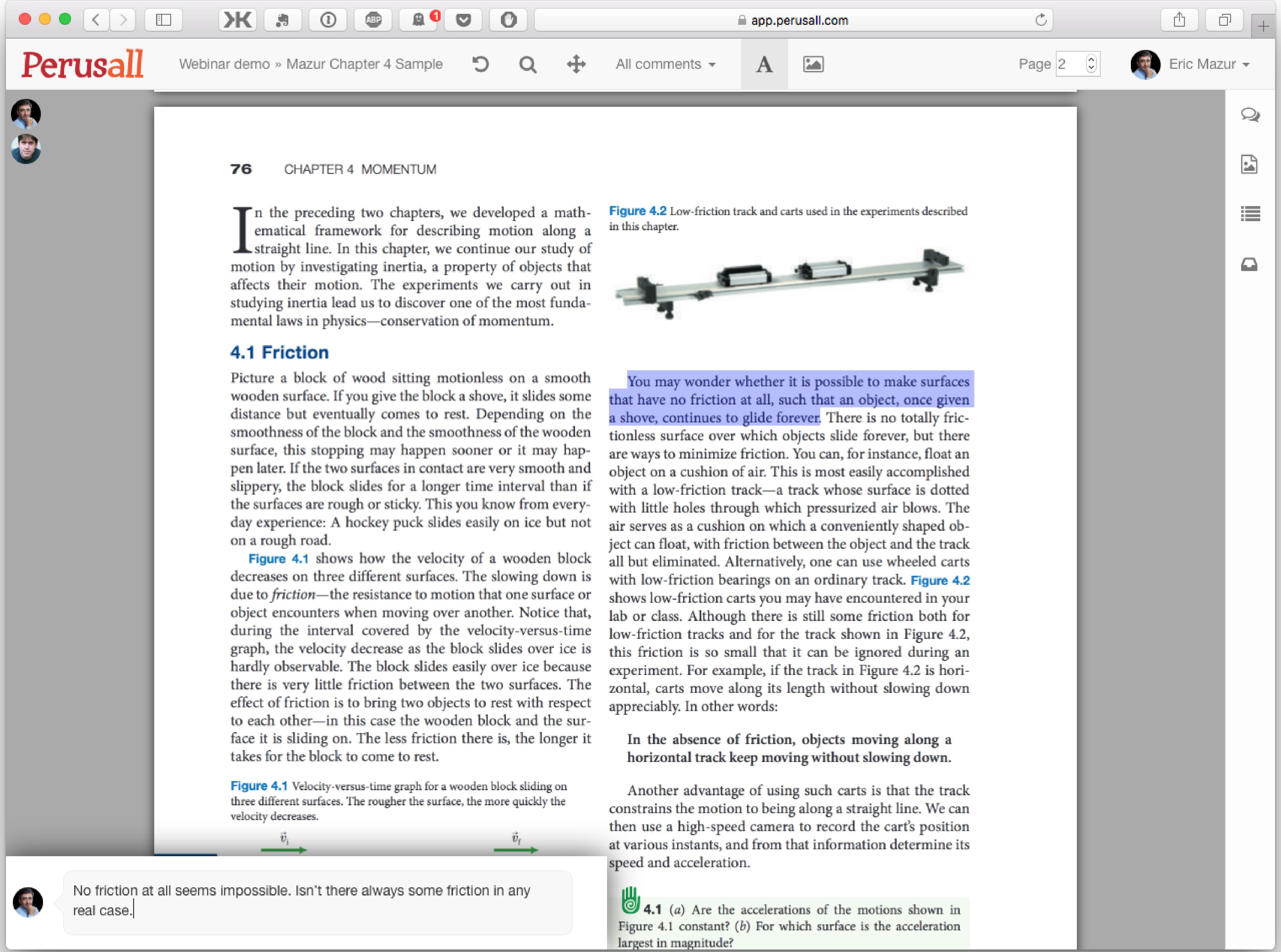

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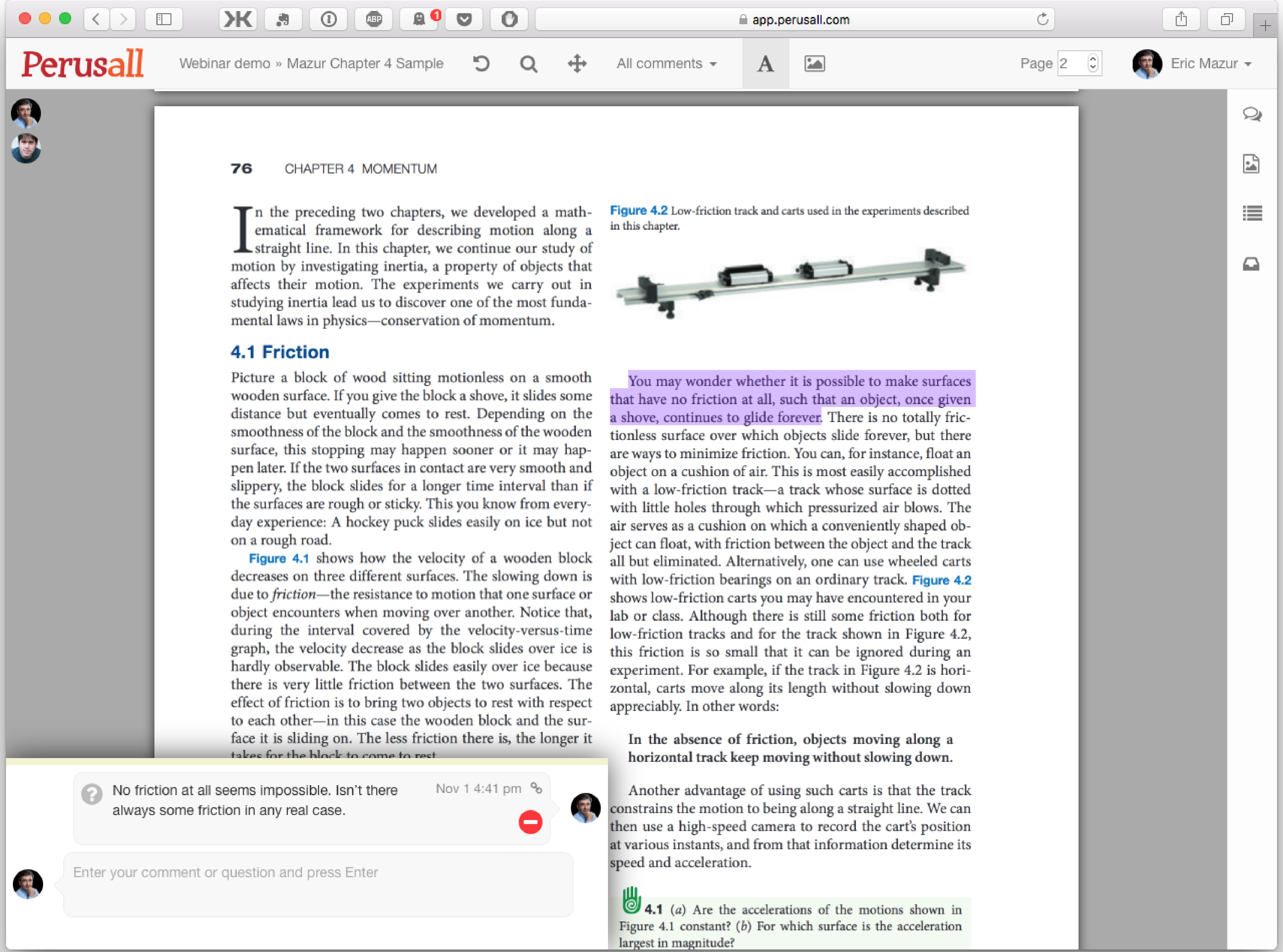

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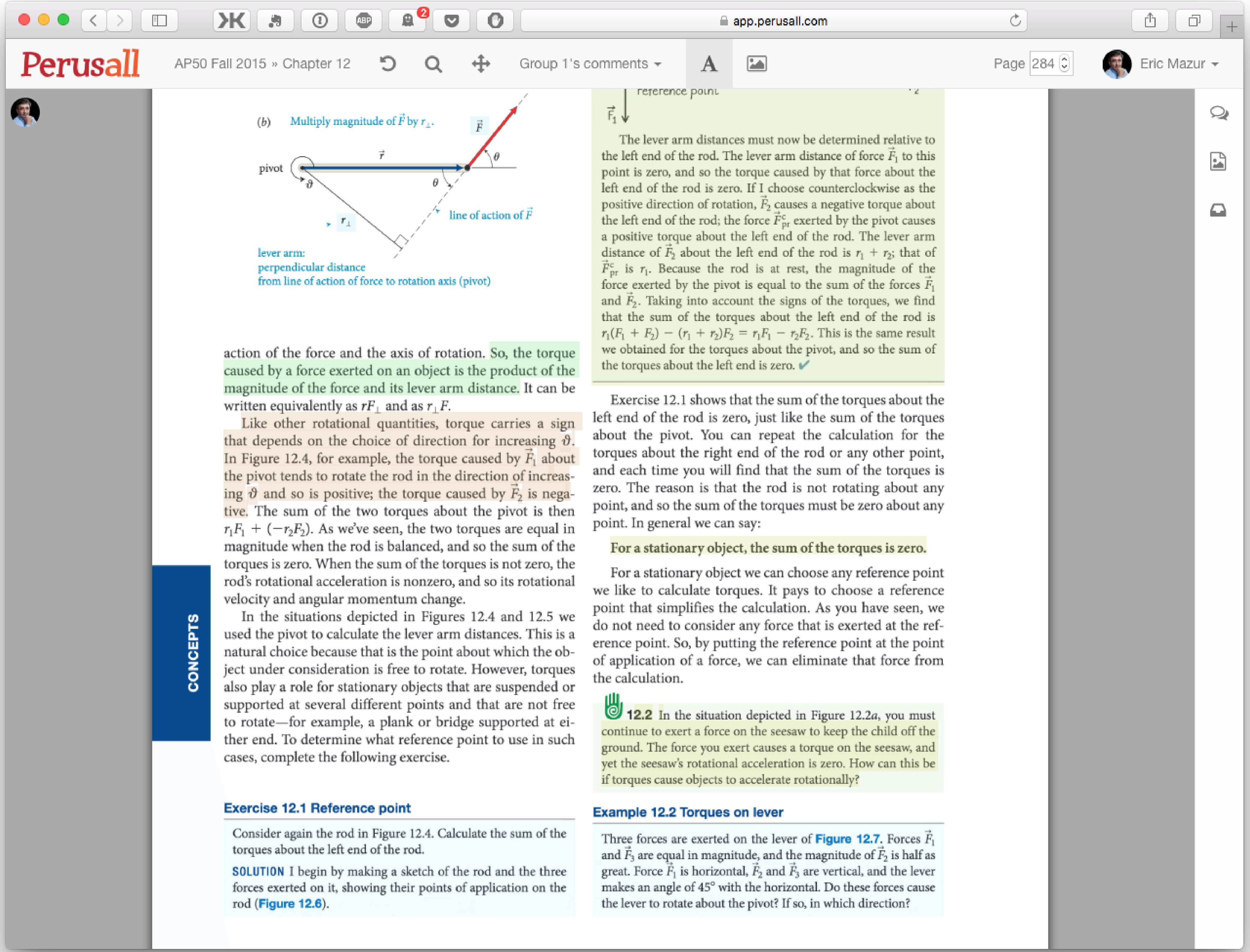


action of the force and the axis of rotation. So, the torque caused by a force exerted on an object is the product of the magnitude of the force and its lever arm distance. It can be written equivalently as $rF_\perp$ and as $r_\perp F$.

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

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

Exercise 12.1 Reference point

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

SOLUTION I begin by making a sketch of the rod and the three 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 $\vec{F}^c_{pr}$ 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 $\vec{F}^c_{pr}$ 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:

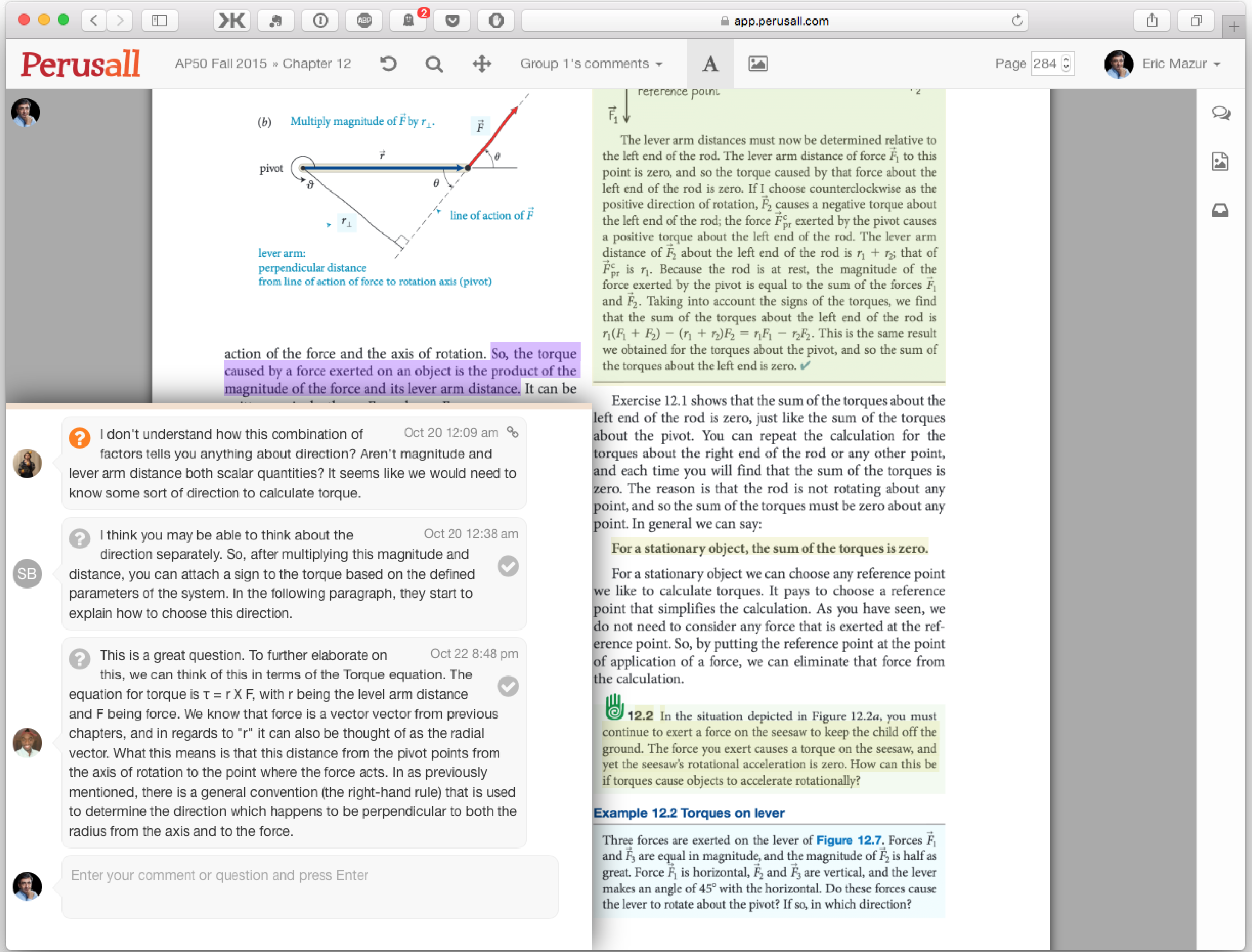
For a stationary object, the sum of the torques is zero.

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 12.2*a*, 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° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?



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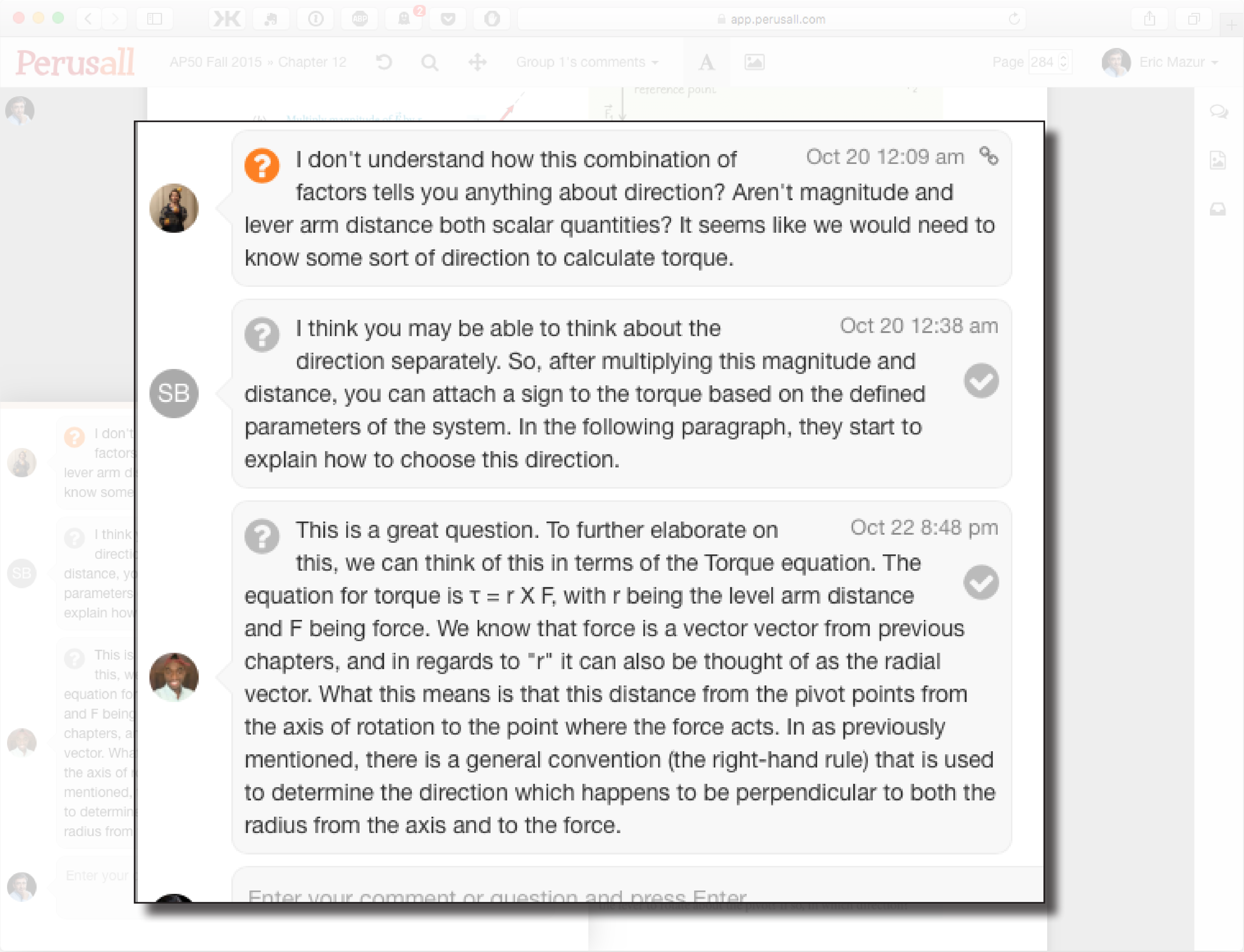

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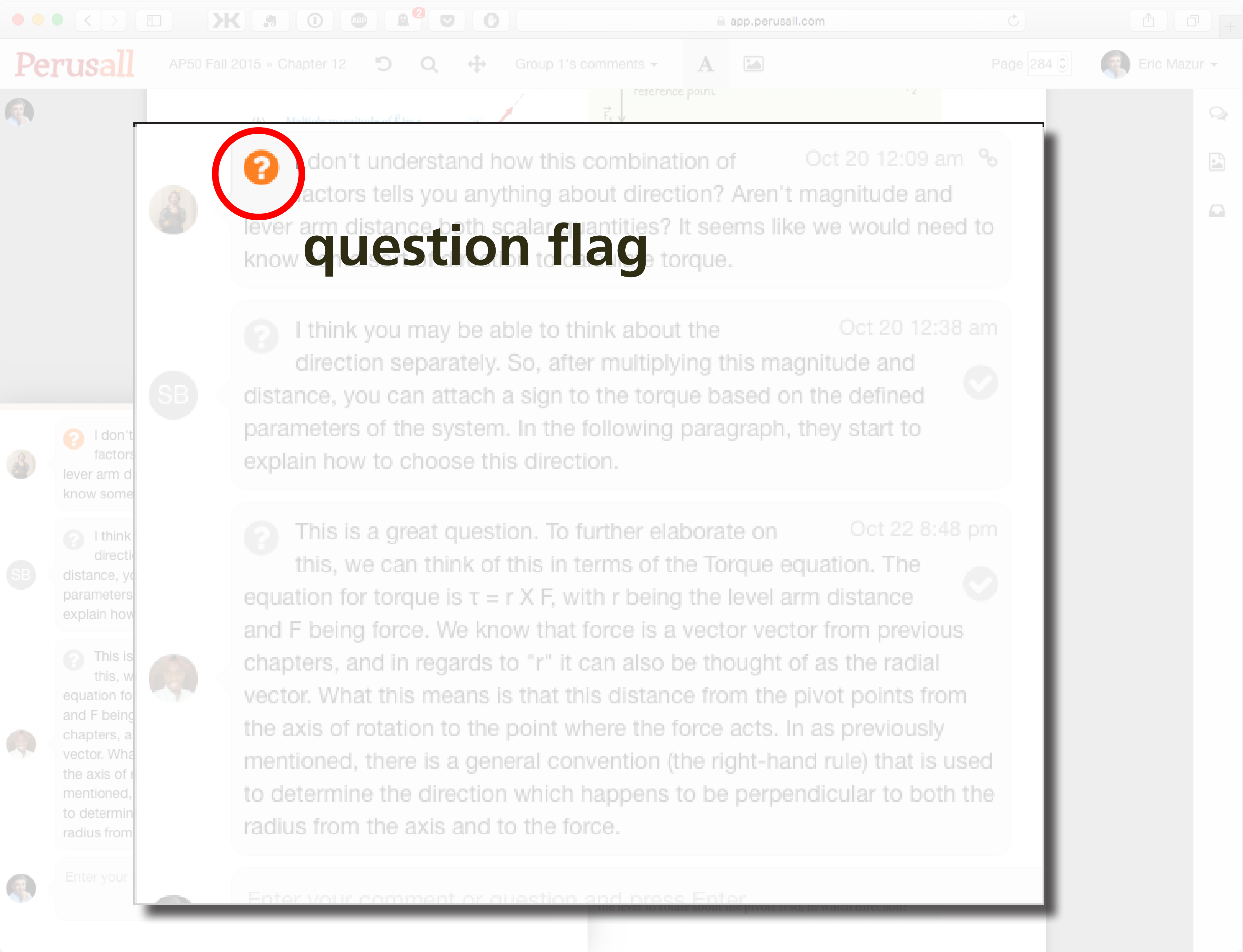

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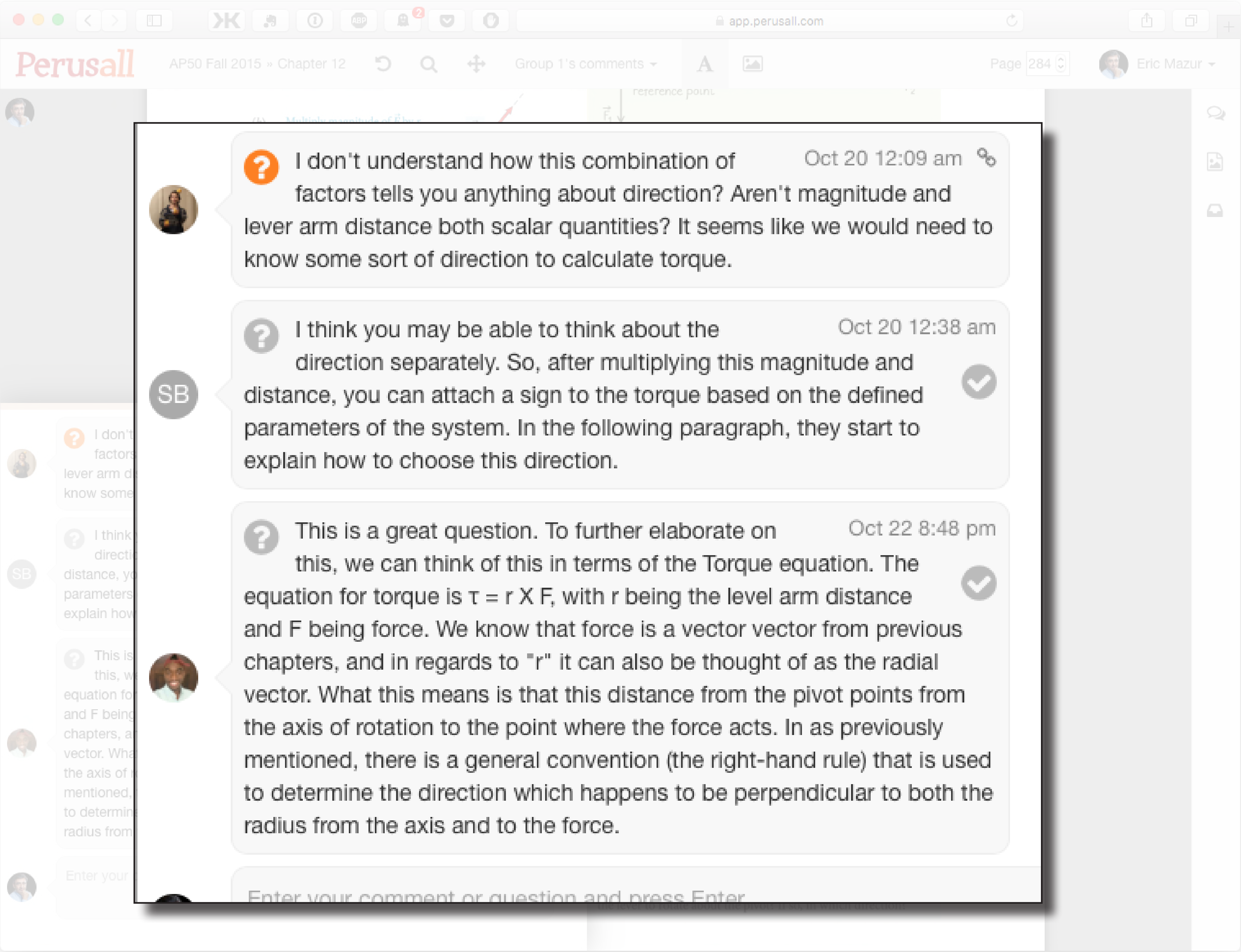

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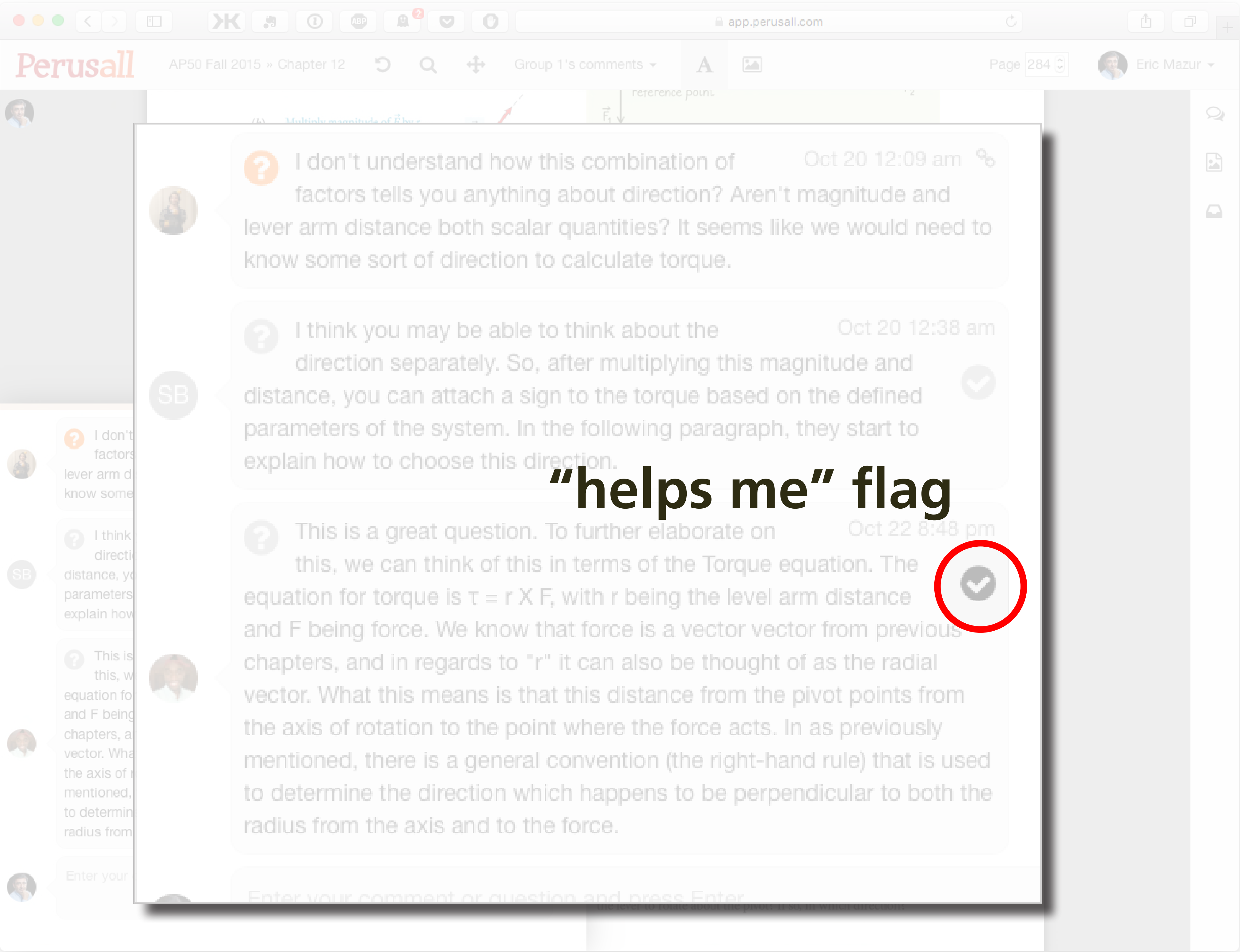

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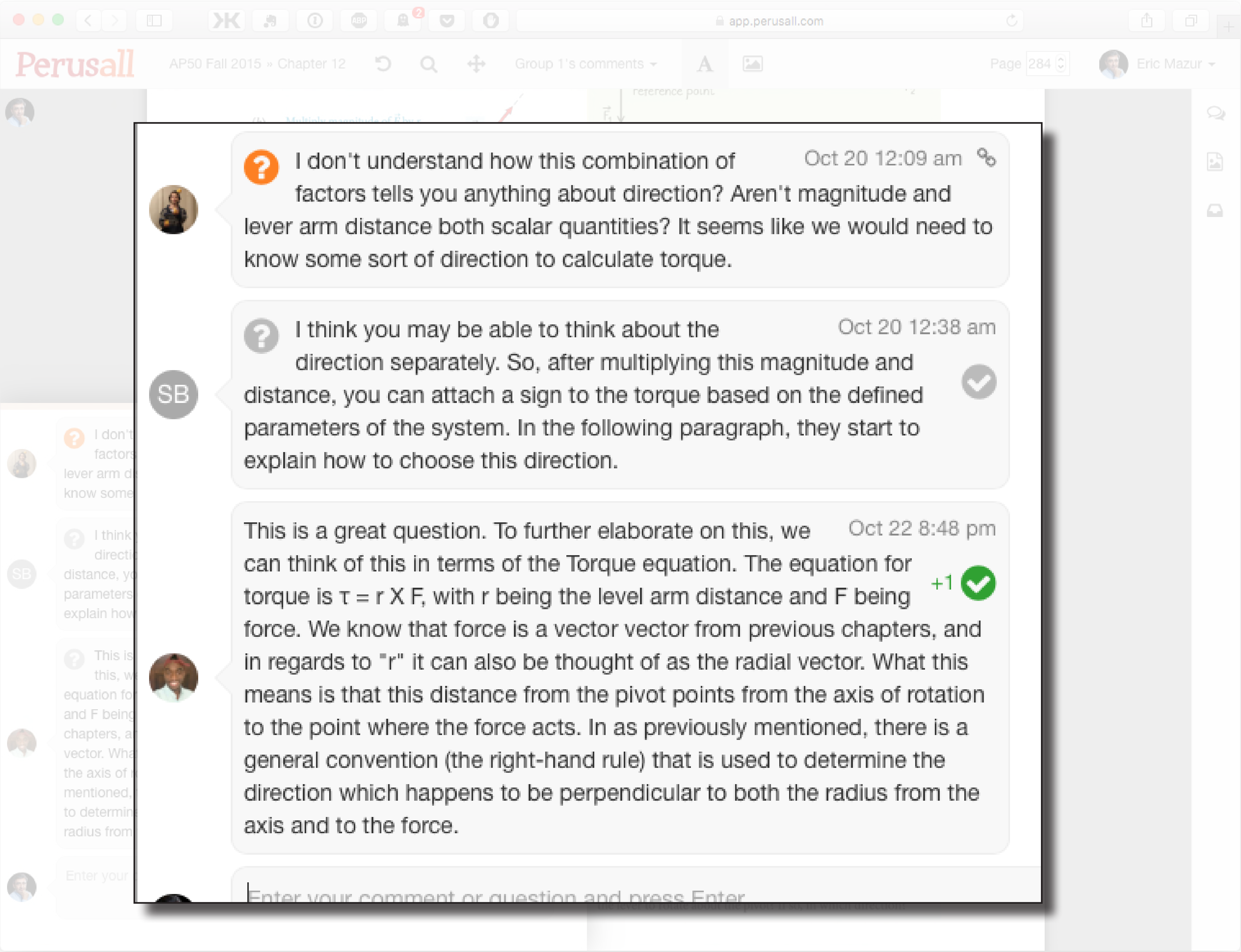
“helps me” flag



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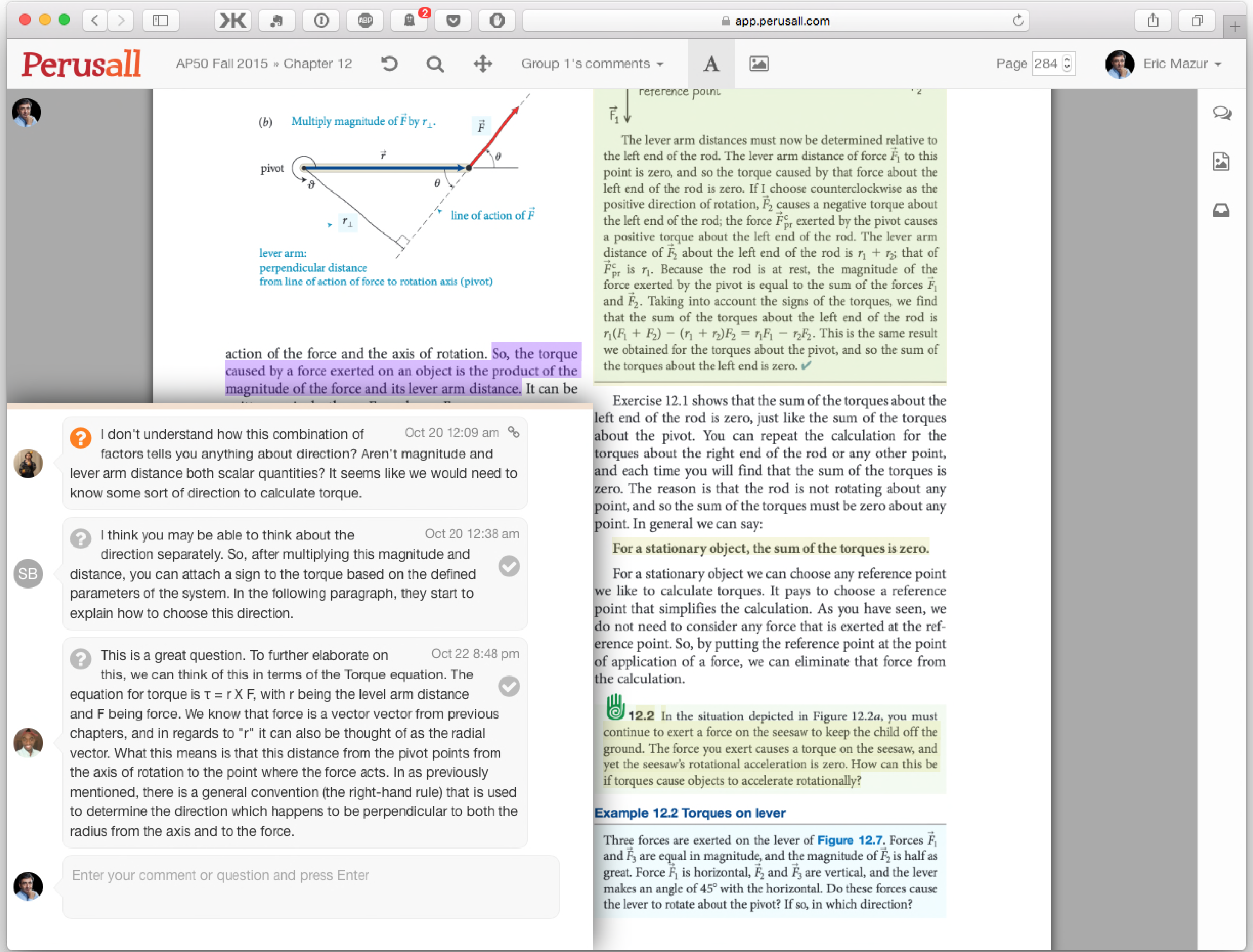

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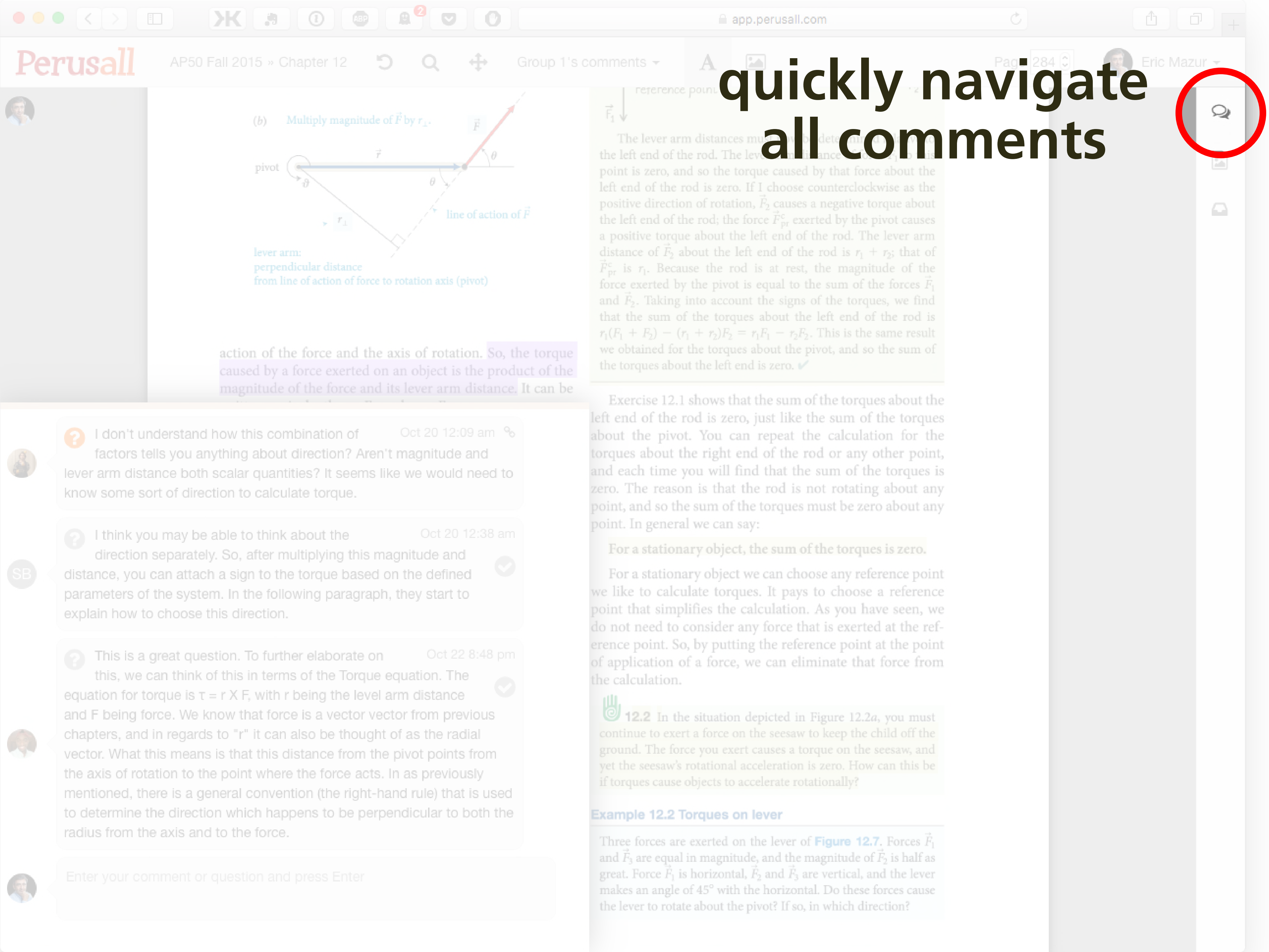

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reference point

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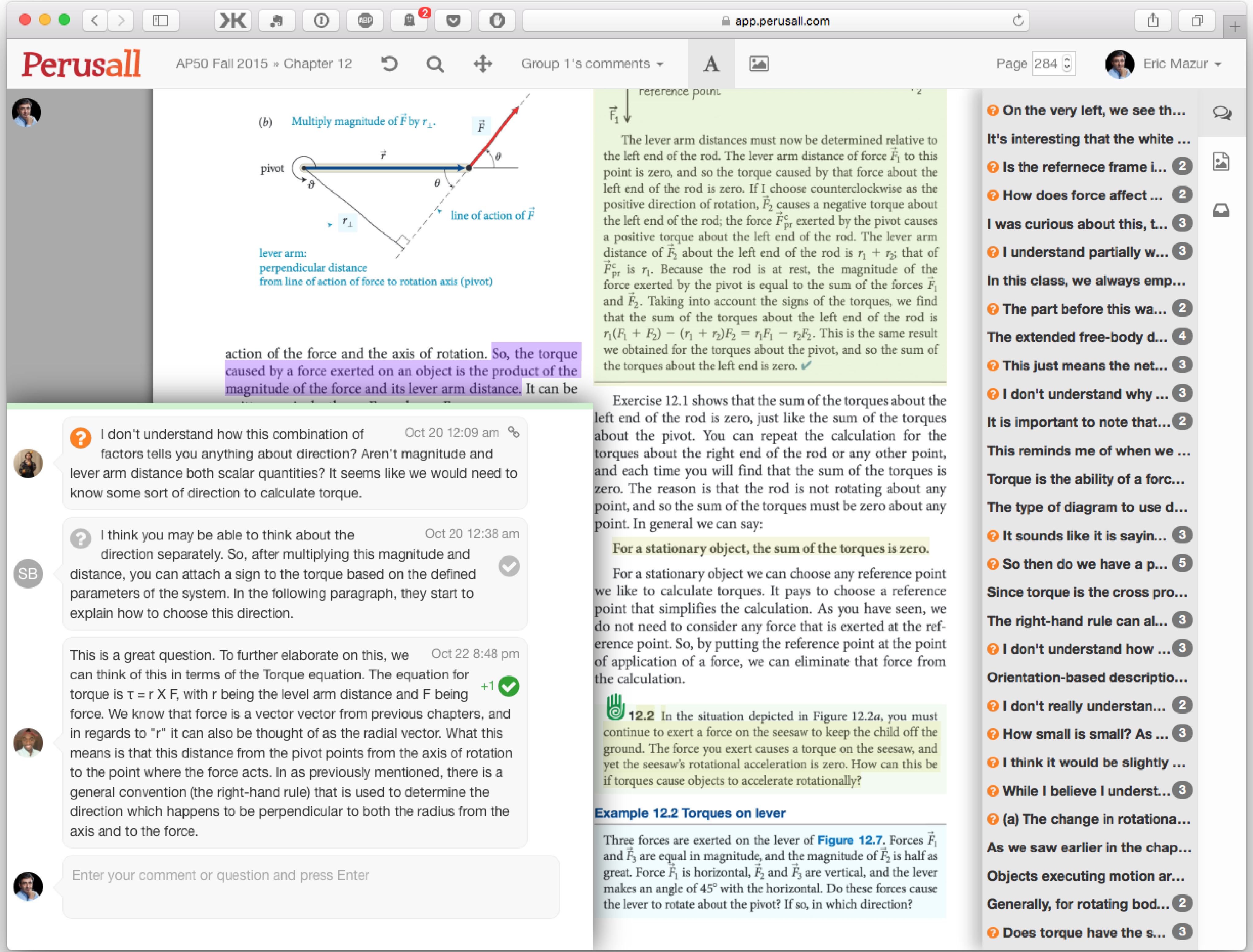

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- ? On the very left, we see th...
- It's interesting that the white ...
- ? Is the refernece frame i... 2
- ? How does force affect ... 2
- I was curious about this, t... 3
- ? I understand partially w... 3
- In this class, we always emp...
- ? The part before this wa... 2
- The extended free-body d... 4
- ? This just means the net... 3
- ? I don't understand why ... 3
- It is important to note that... 2
- This reminds me of when we ...
- Torque is the ability of a forc...
- 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 understan... 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

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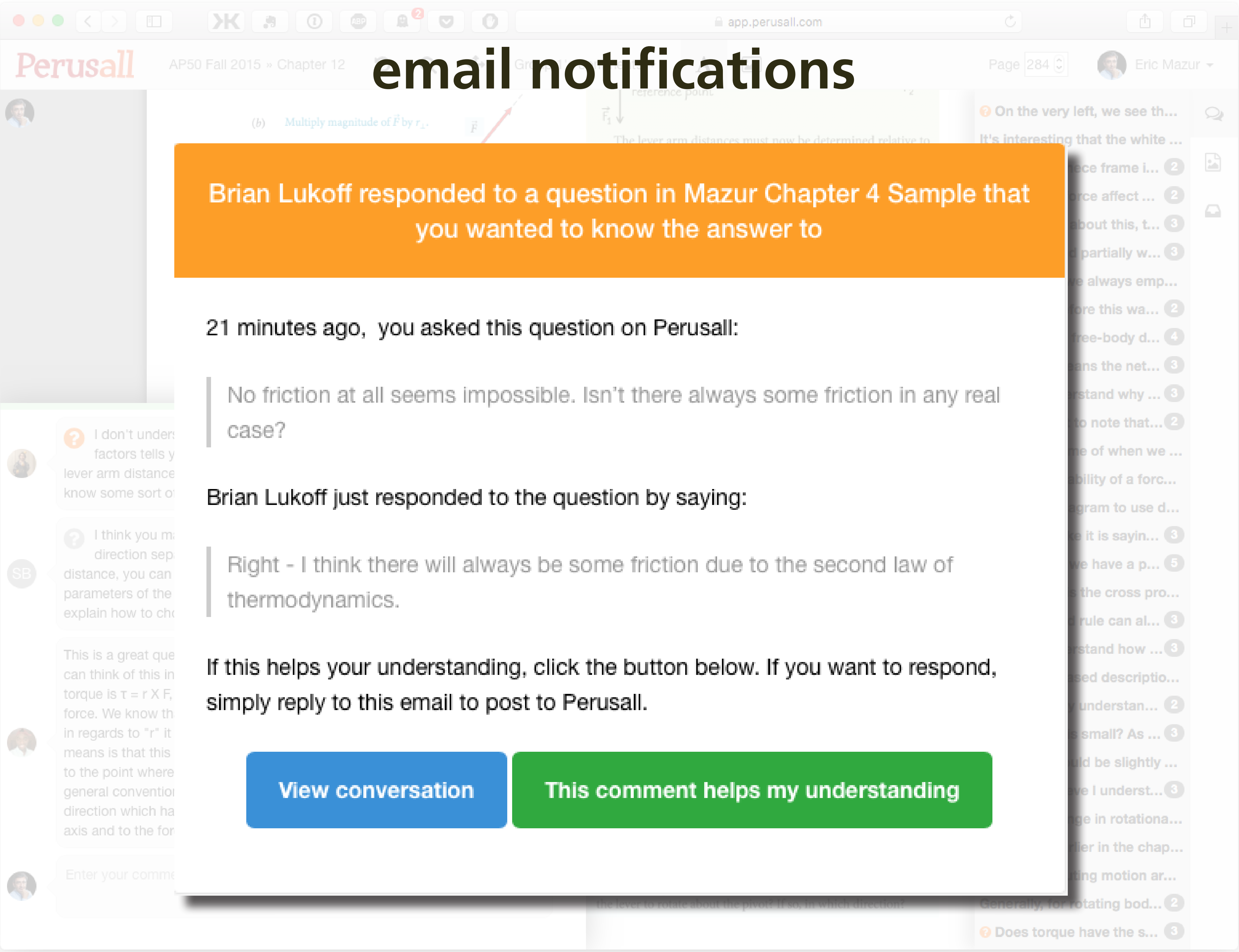

Brian Lukoff responded to a question in Mazur Chapter 4 Sample that you wanted to know the answer to

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?

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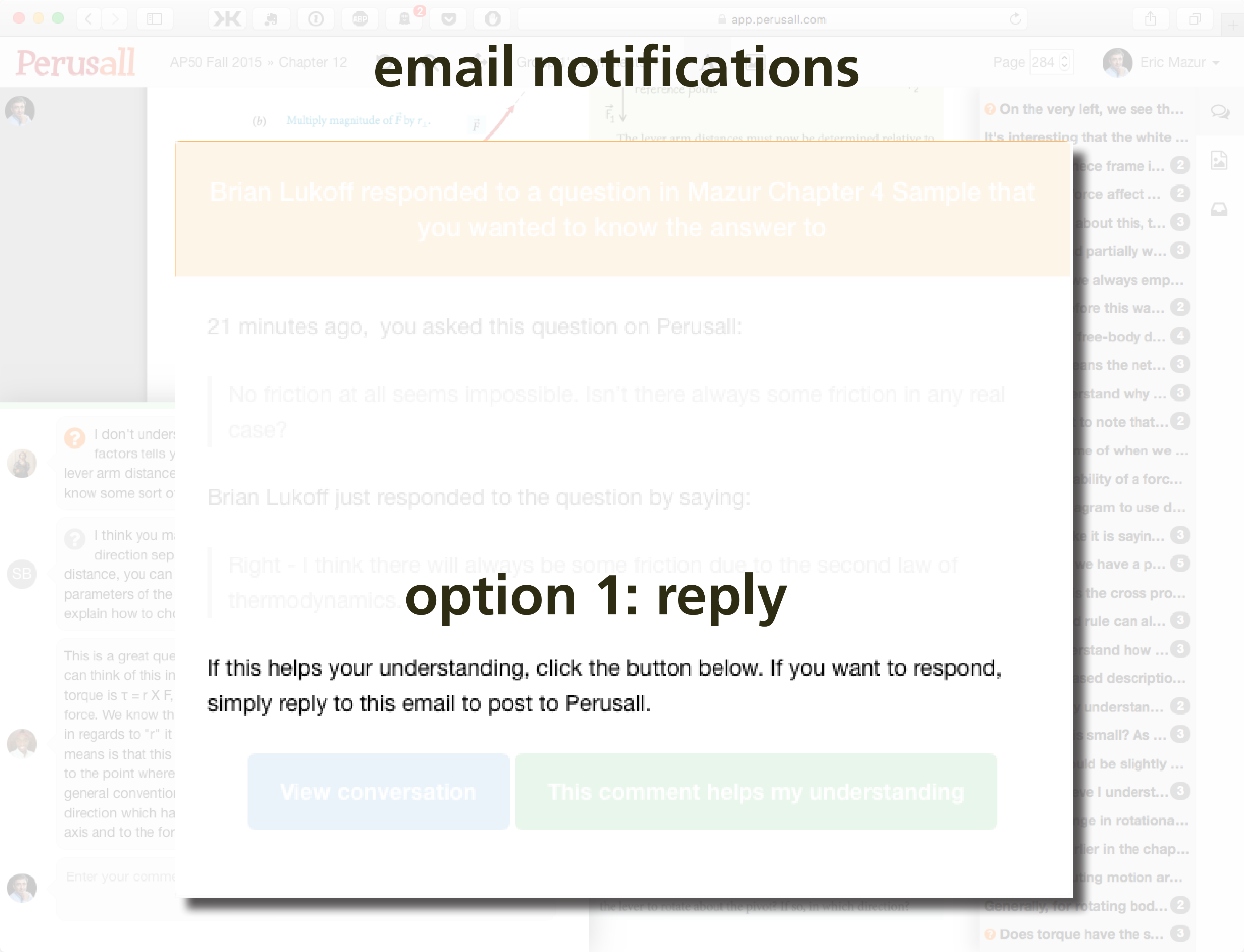

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option 1: reply

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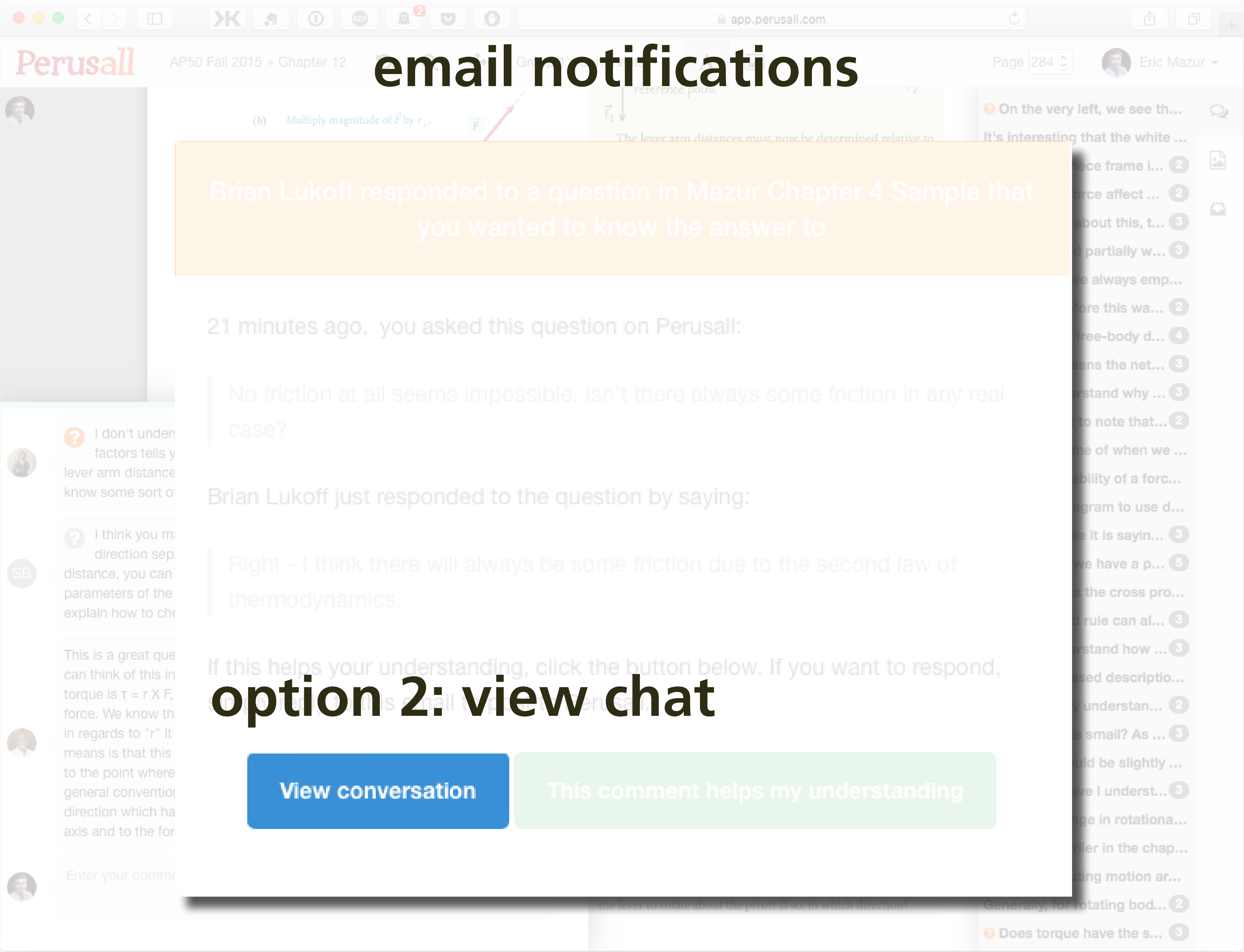

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option 2: view chat

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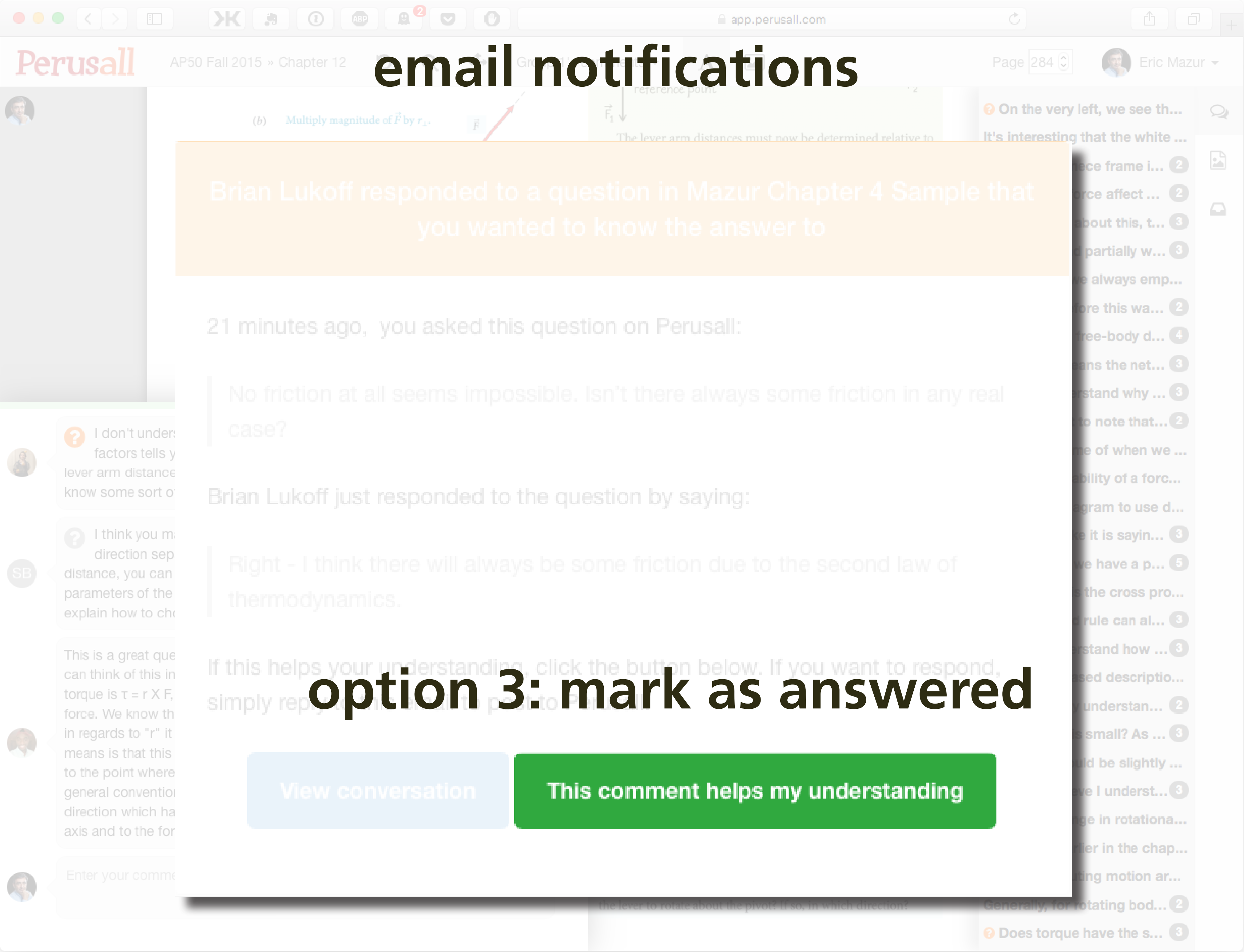

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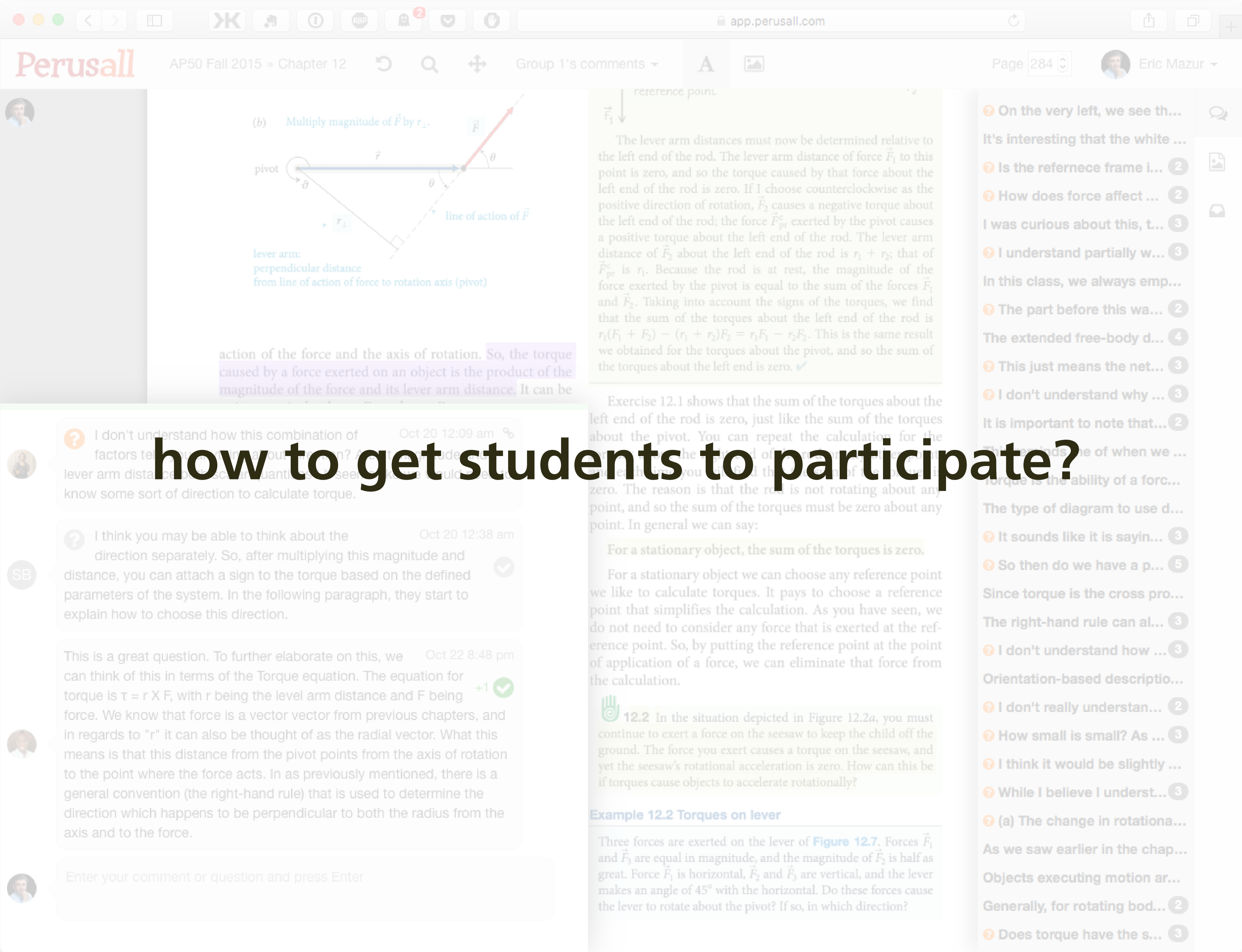
option 3: mark as answered

how to get students to participate?



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

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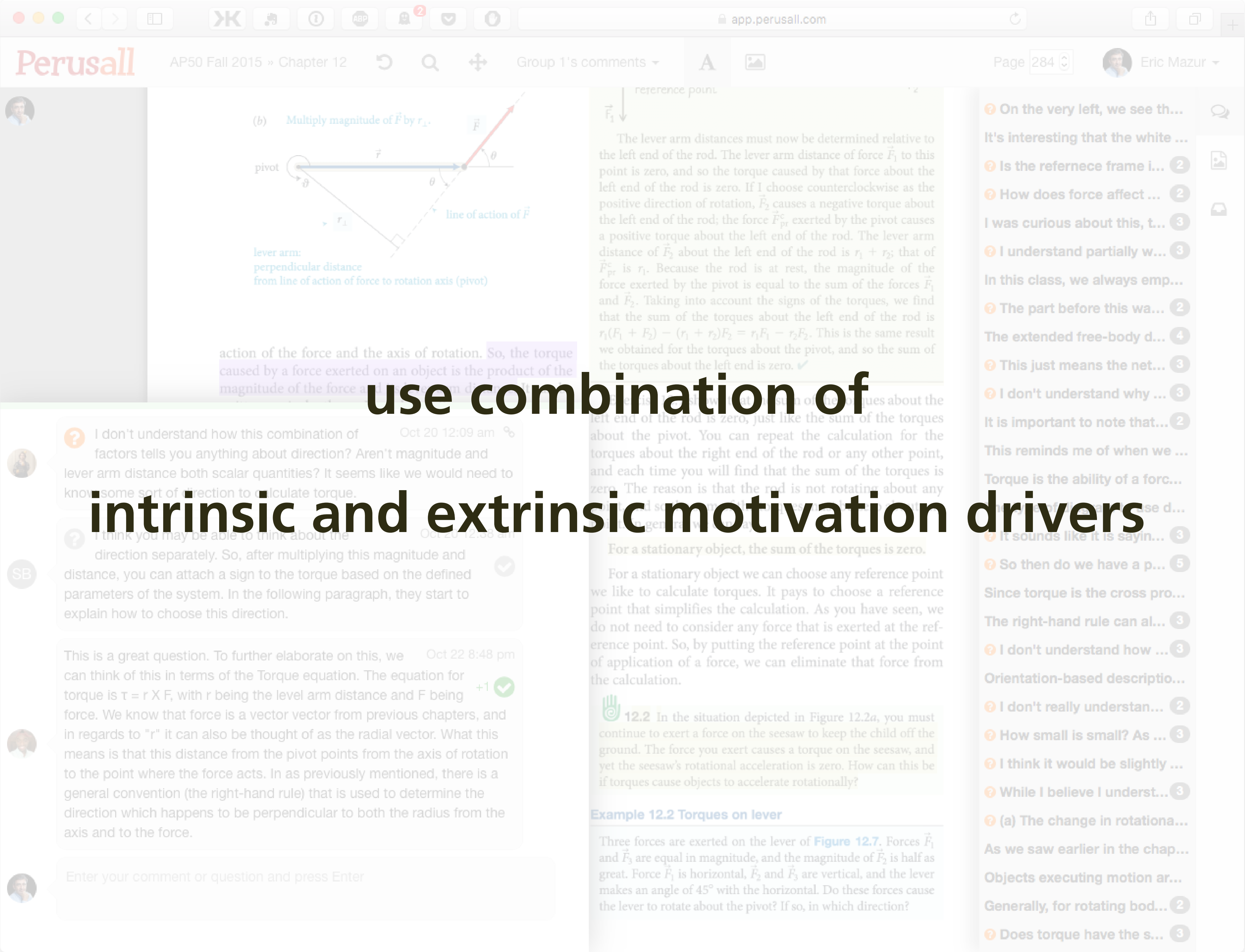

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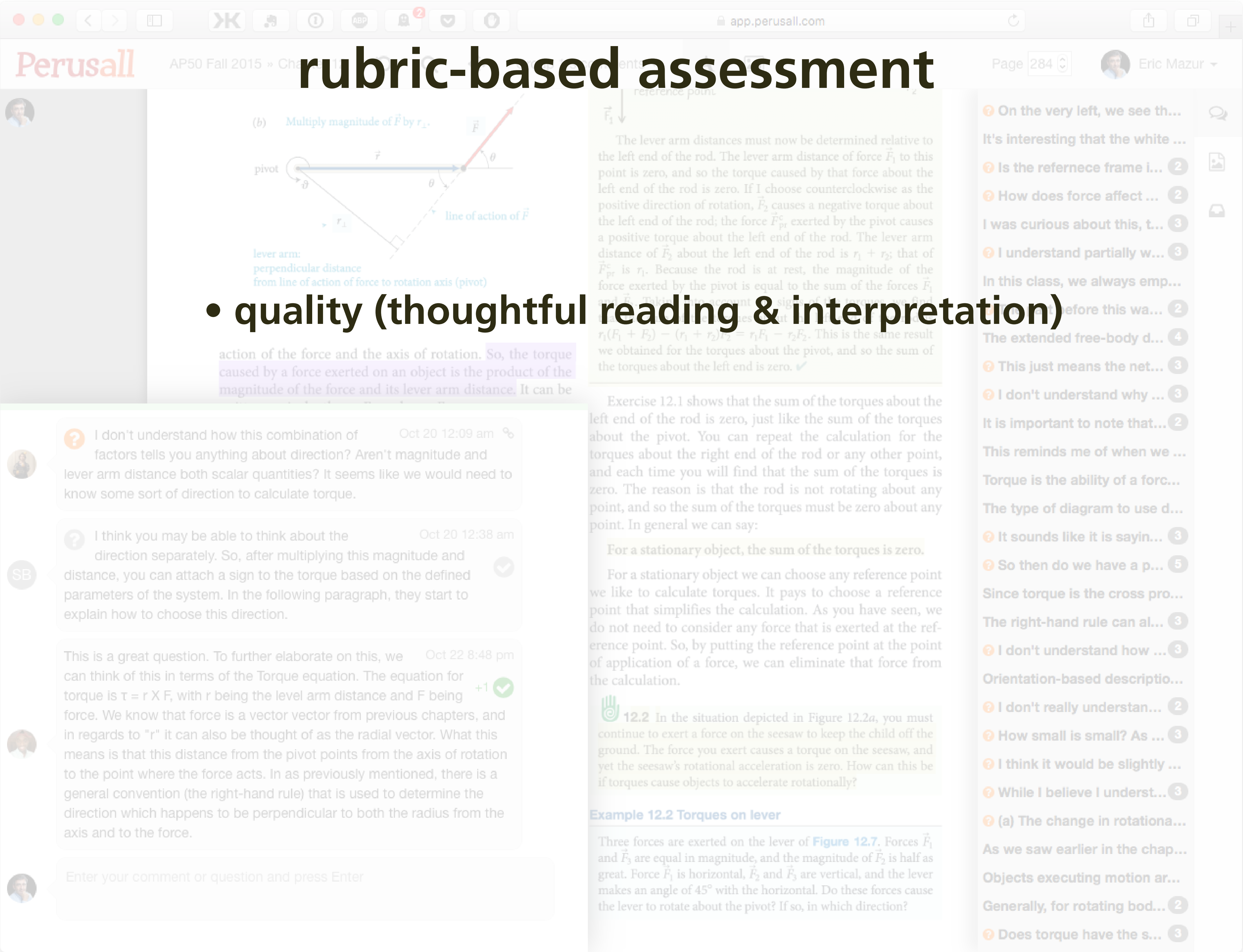
rubric-based assessment

- quality (thoughtful reading & interpretation)



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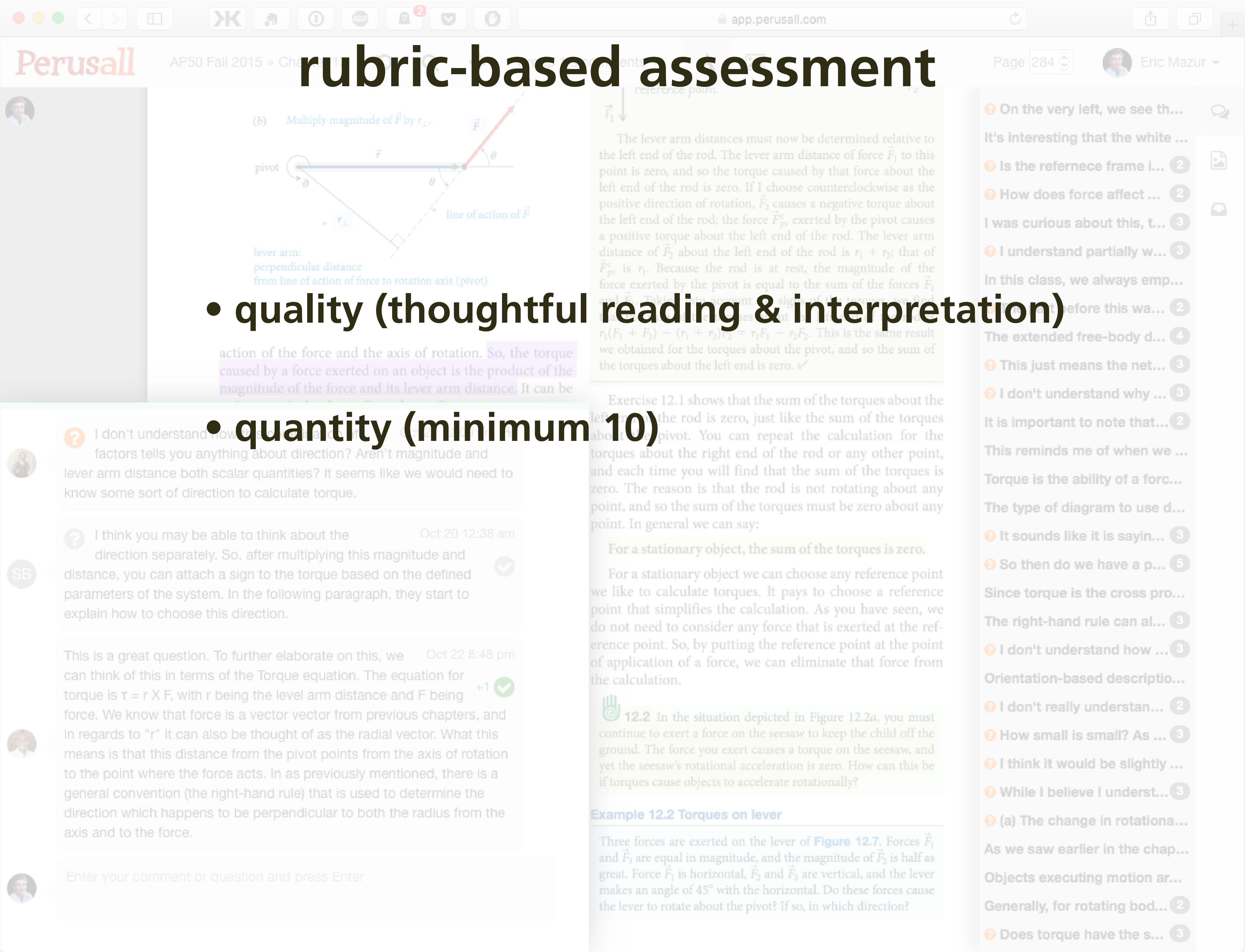

- quality (thoughtful reading & interpretation)
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rubric-based assessment

- quality (thoughtful reading & interpretation)
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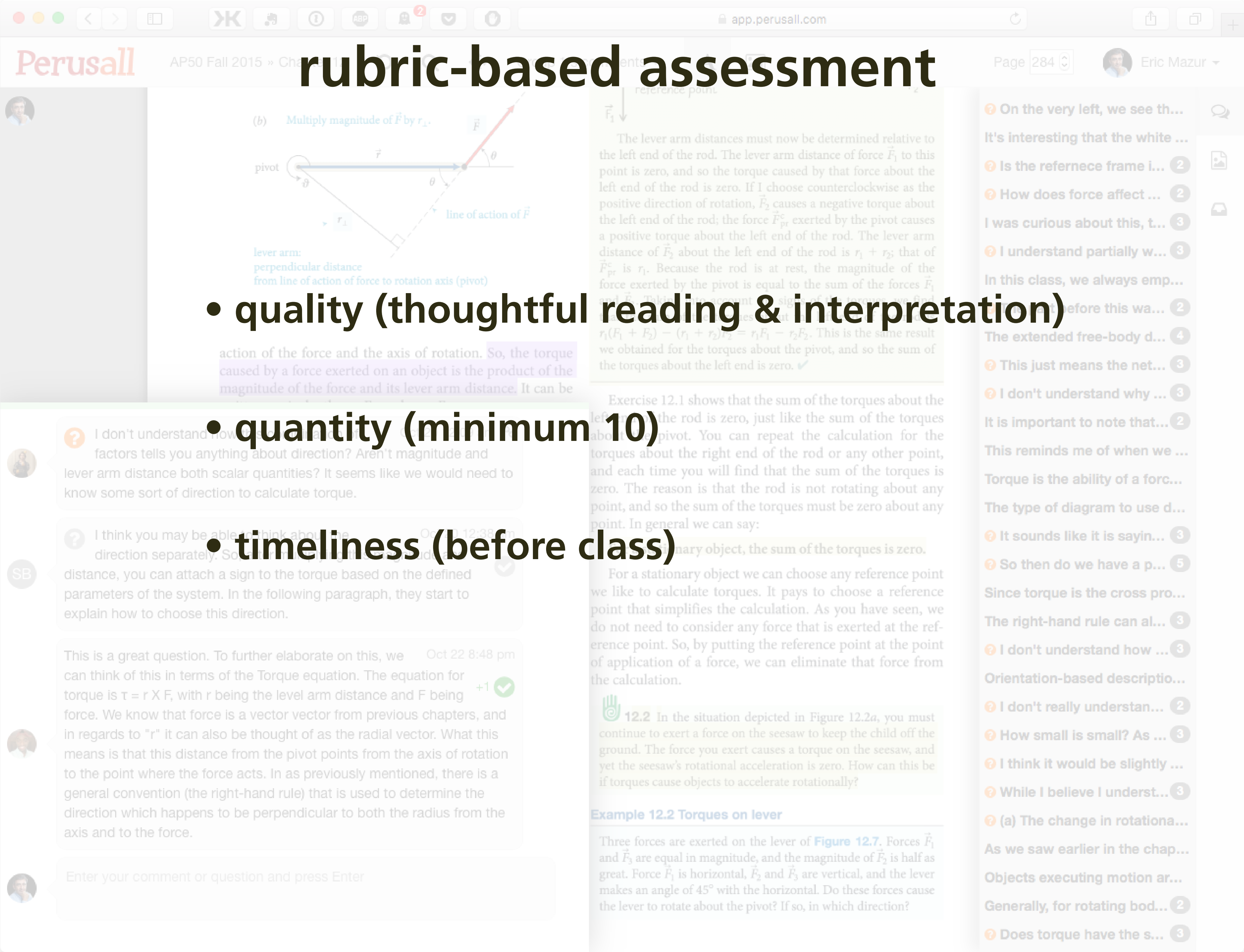

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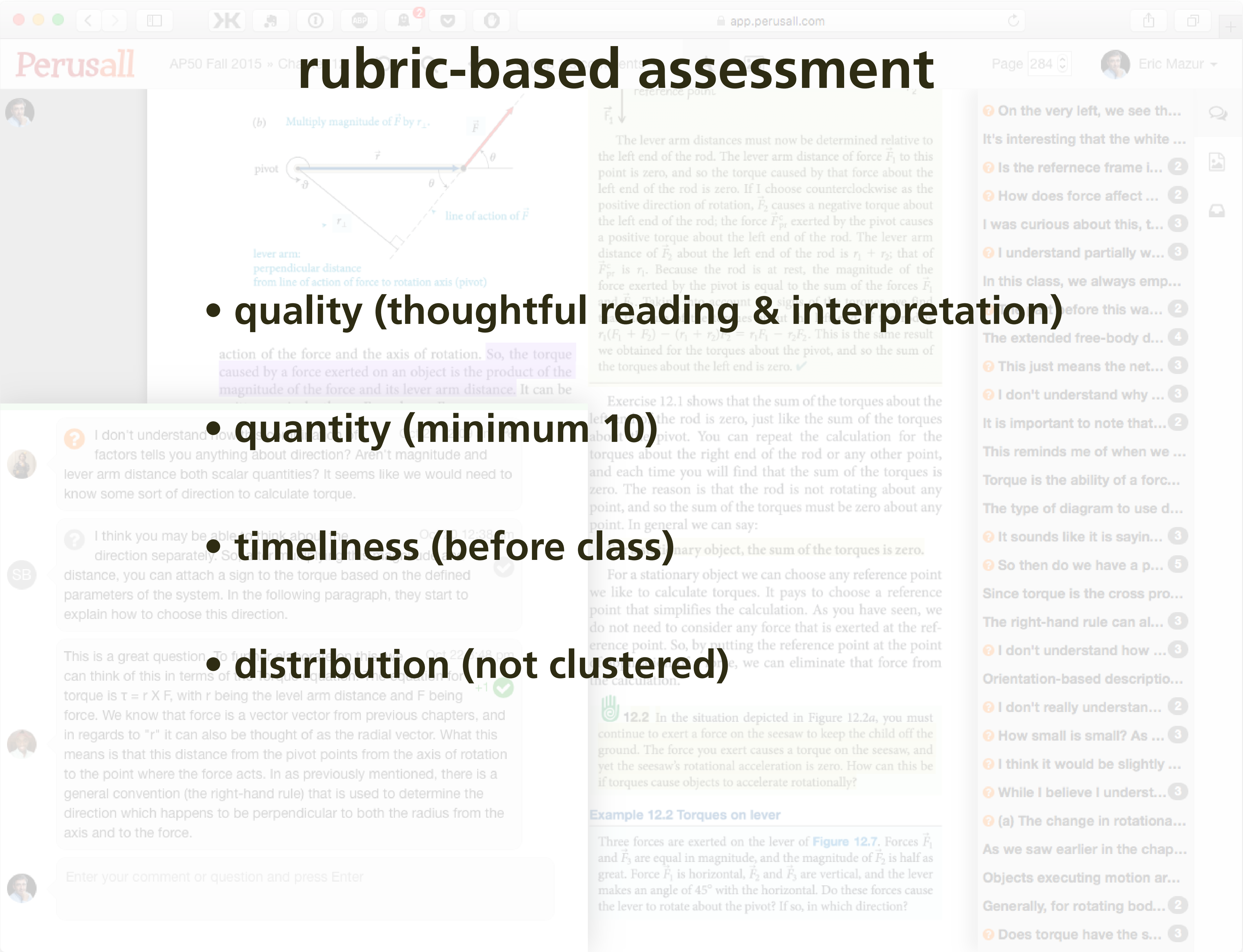
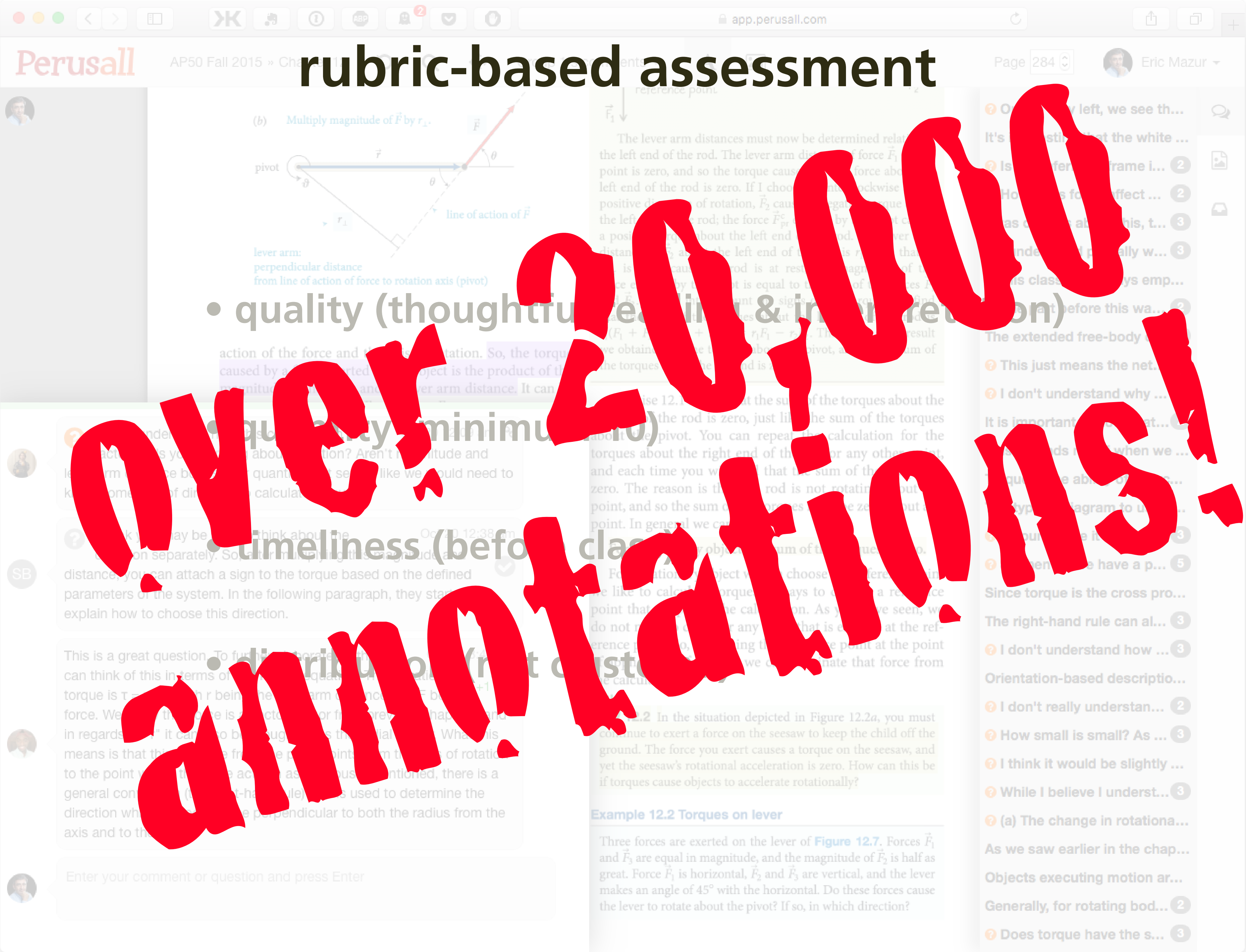


- quality (thoughtful reading & interpretation)
- quantity (minimum 10)
- timeliness (before class)
- distribution (not clustered)

rubric-based assessment



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Page 284

Eric Mazur

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

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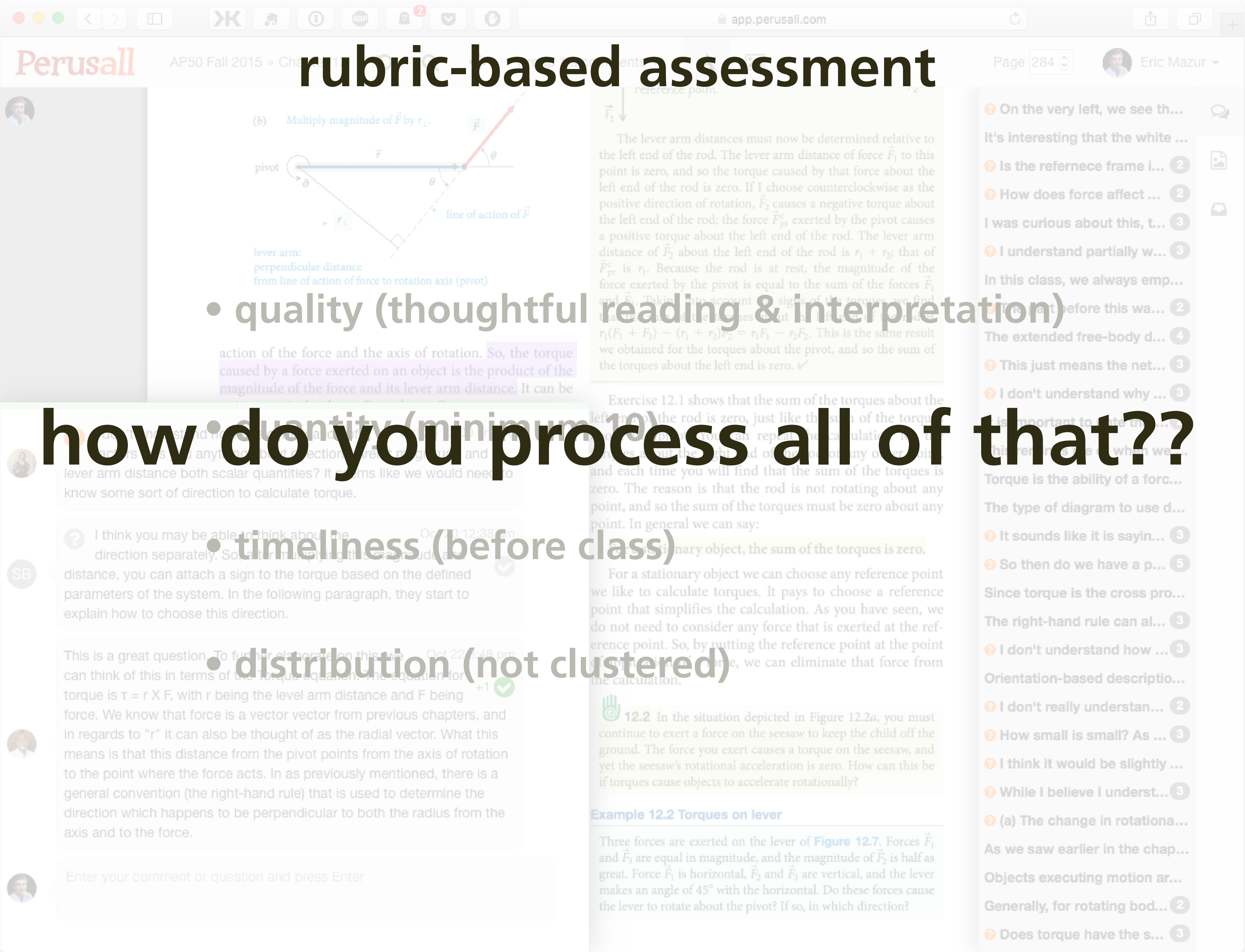

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how do you process all of that??

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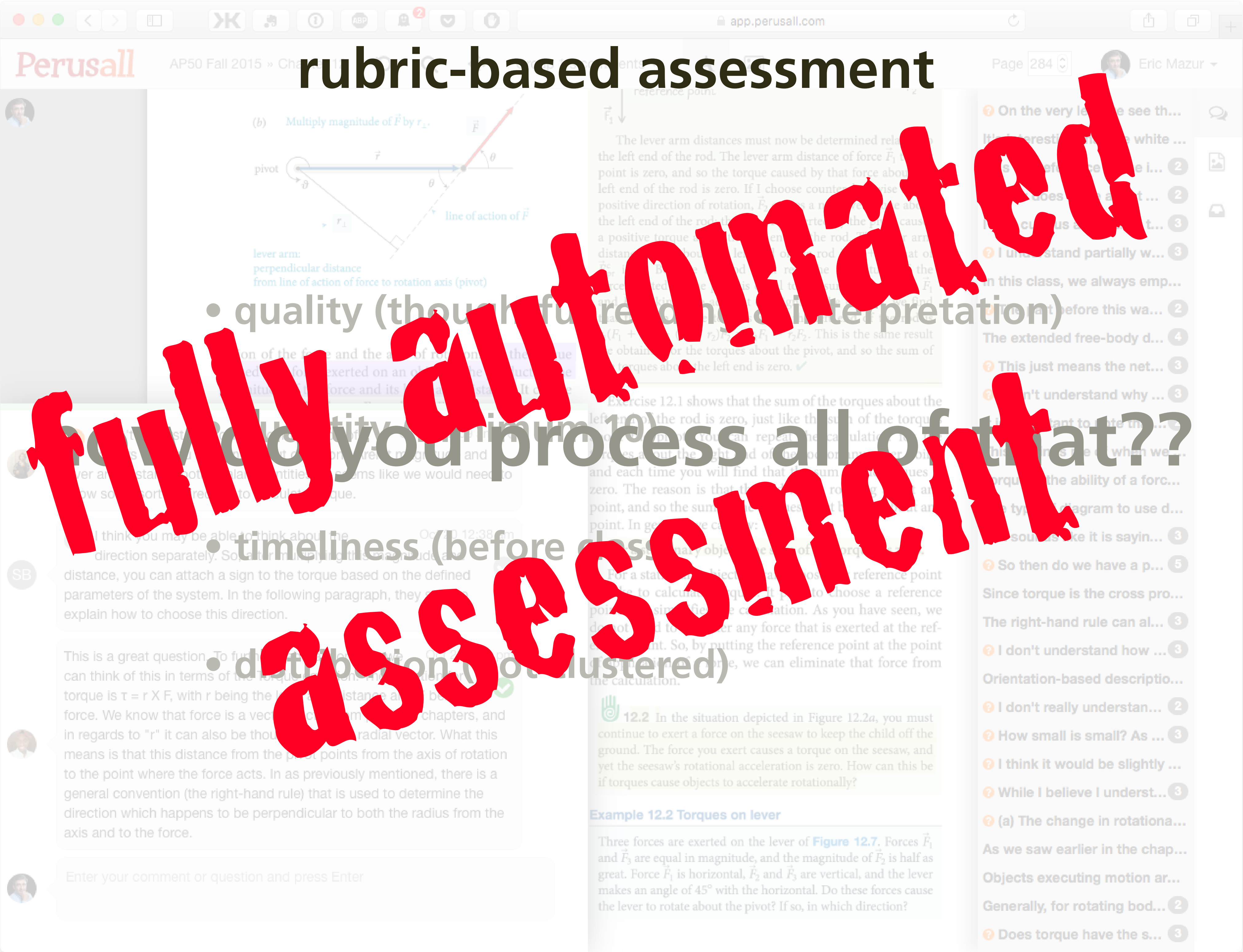

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fully automated assessment

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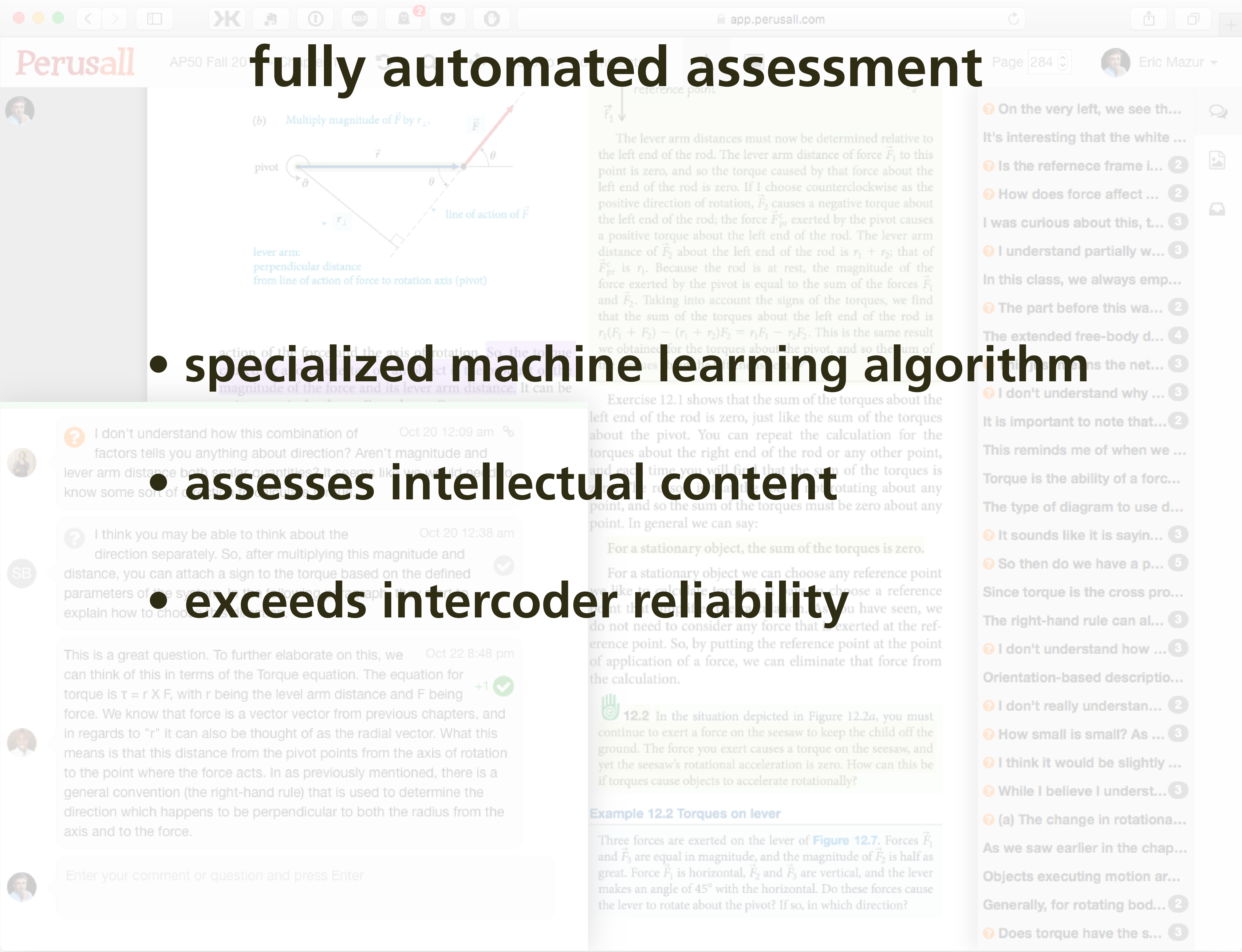
- specialized machine learning algorithm
- assesses intellectual content
- exceeds intercoder reliability



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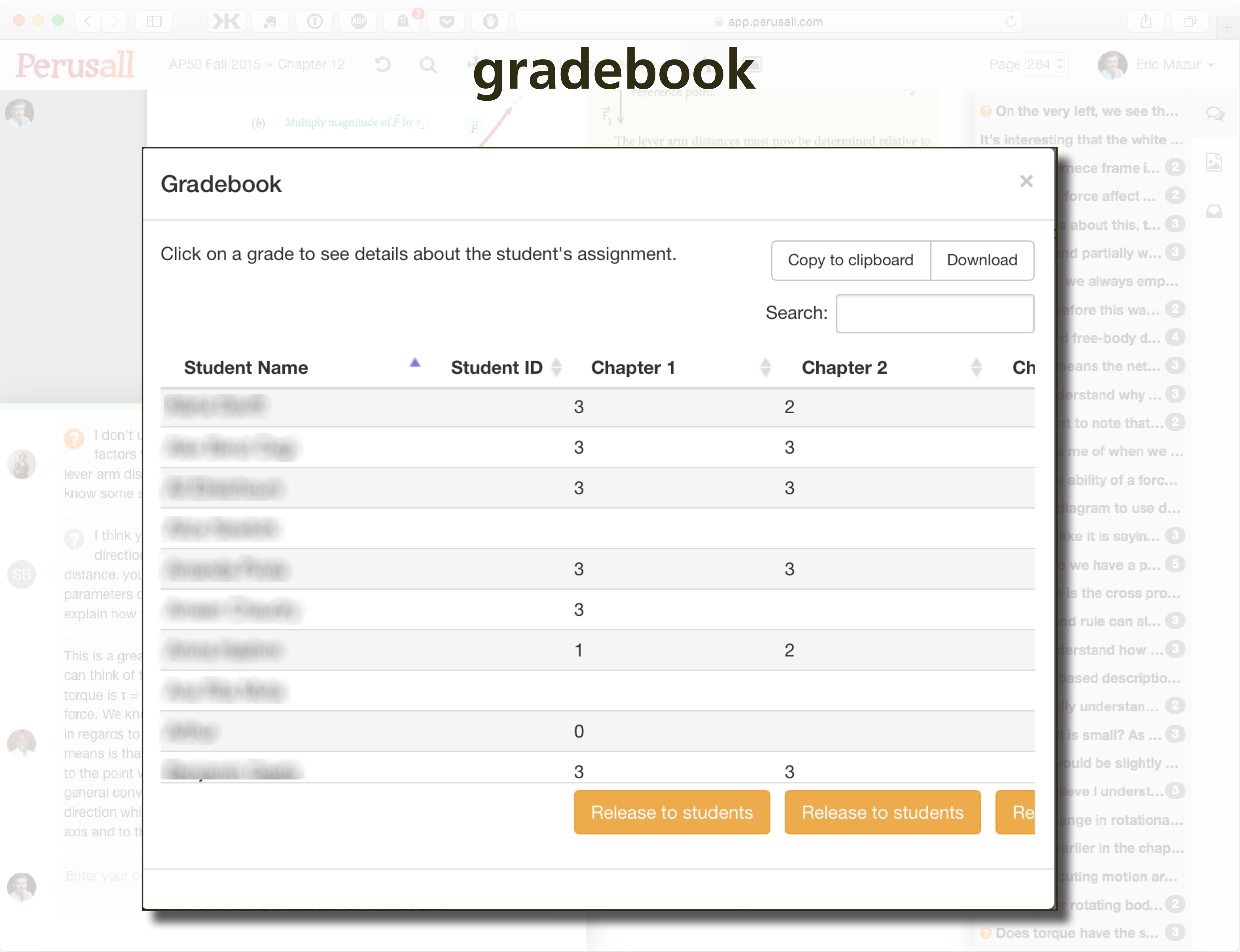
gradebook



Gradebook

Click on a grade to see details about the student's assignment.

Student Name	Student ID	Chapter 1	Chapter 2	Ch
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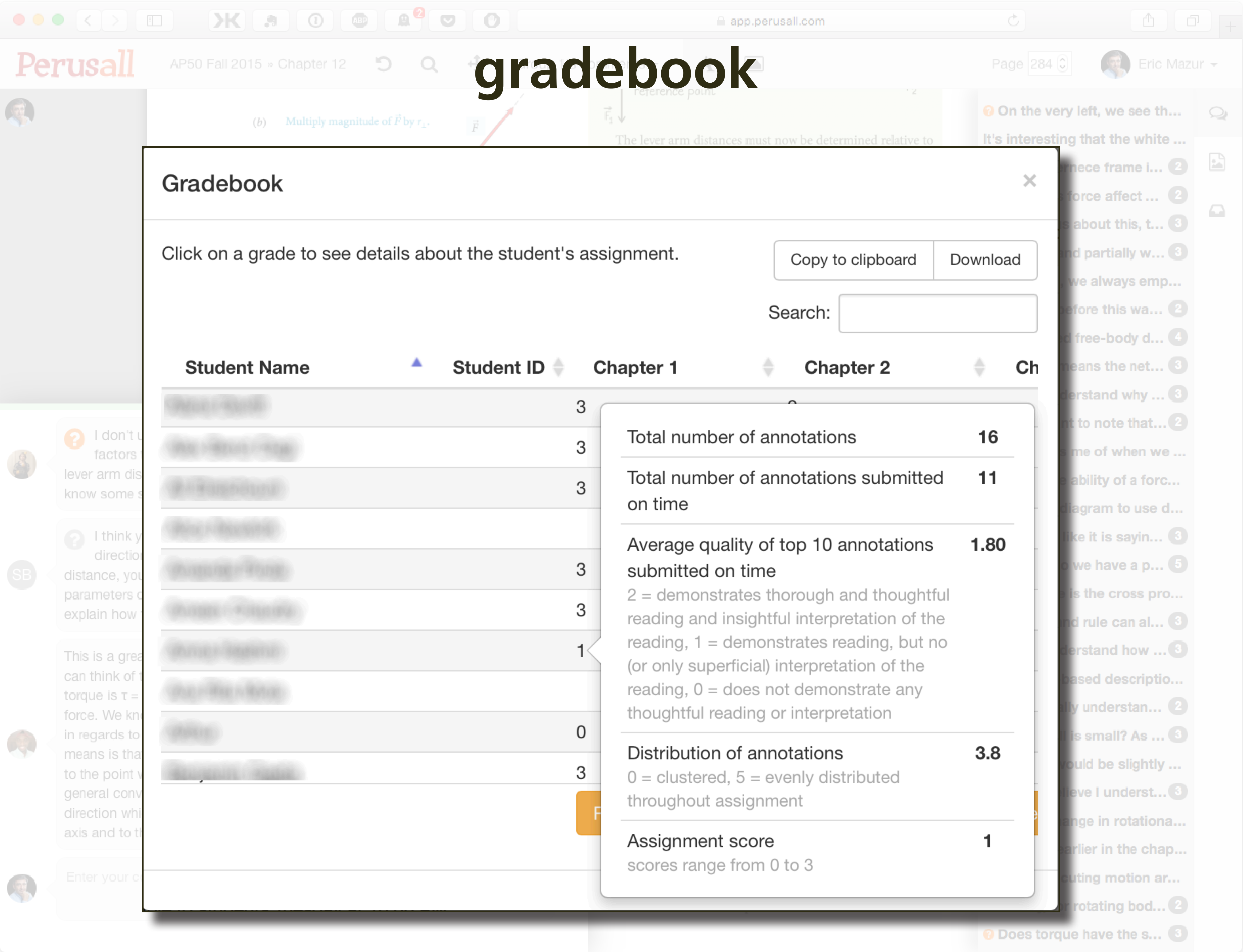

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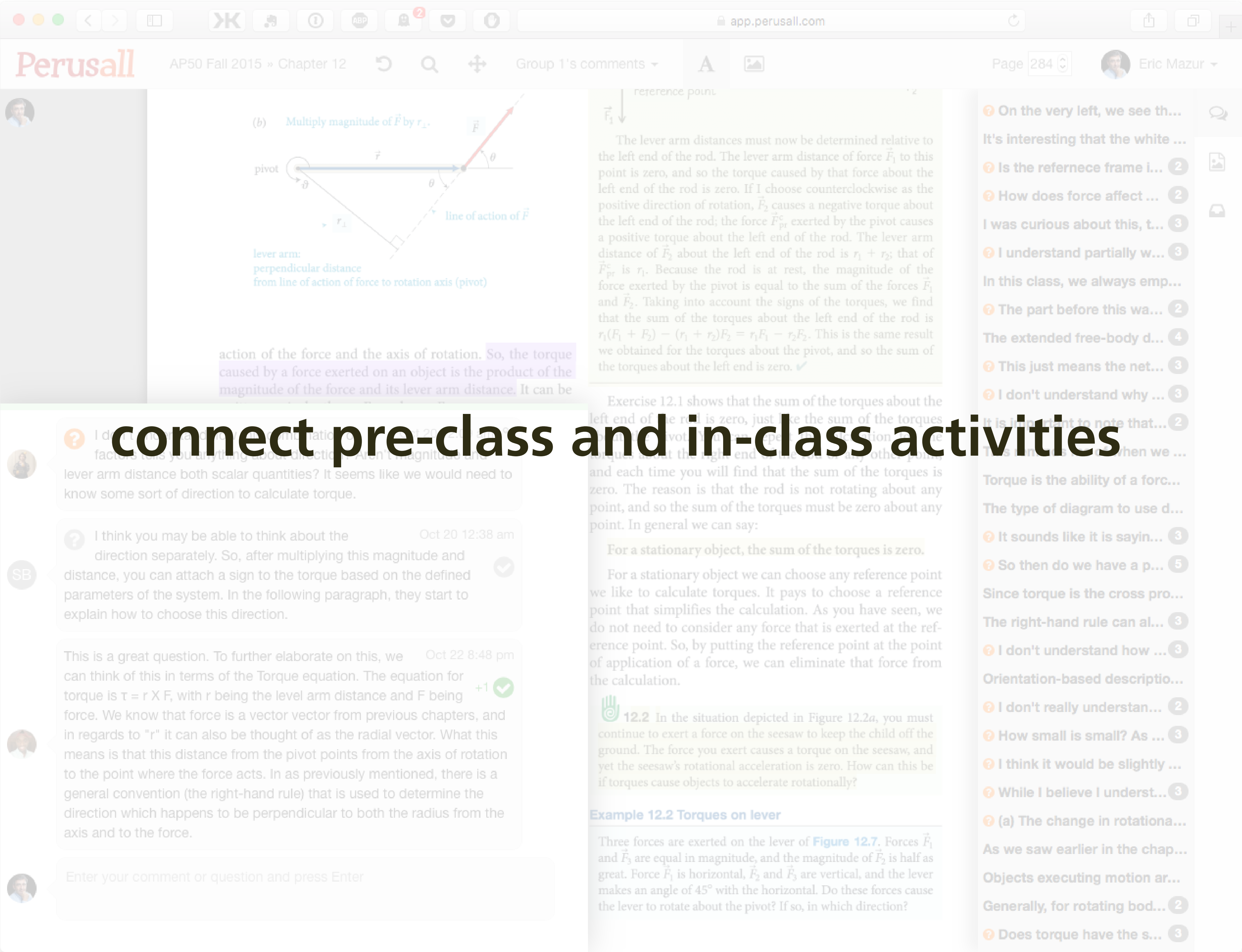
Total number of annotations	16
Total number of annotations submitted on time	11
Average quality of top 10 annotations submitted on time 2 = demonstrates thorough and thoughtful reading and insightful interpretation of the reading, 1 = demonstrates reading, but no (or only superficial) interpretation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

connect pre-class and in-class activities



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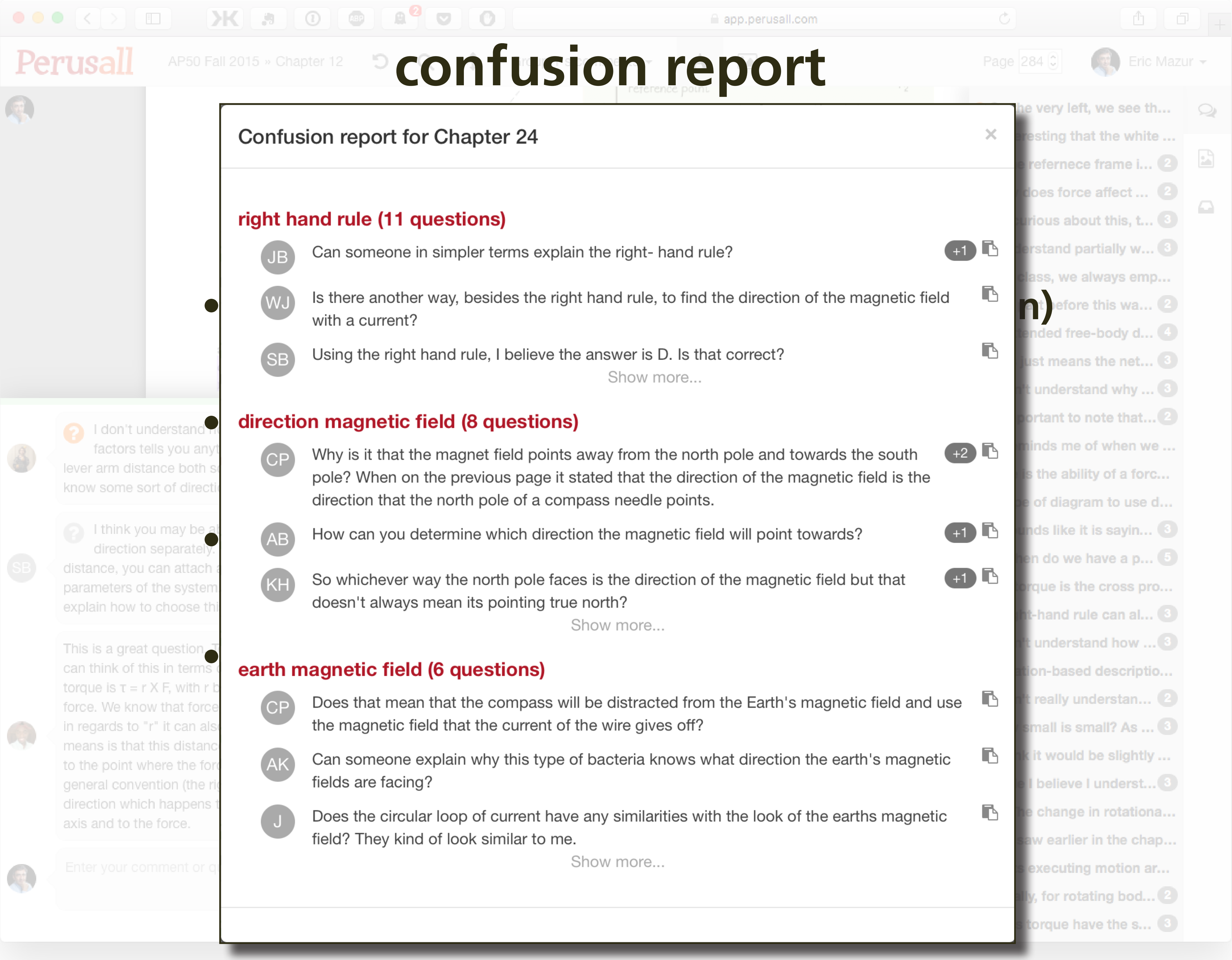
confusion report



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?

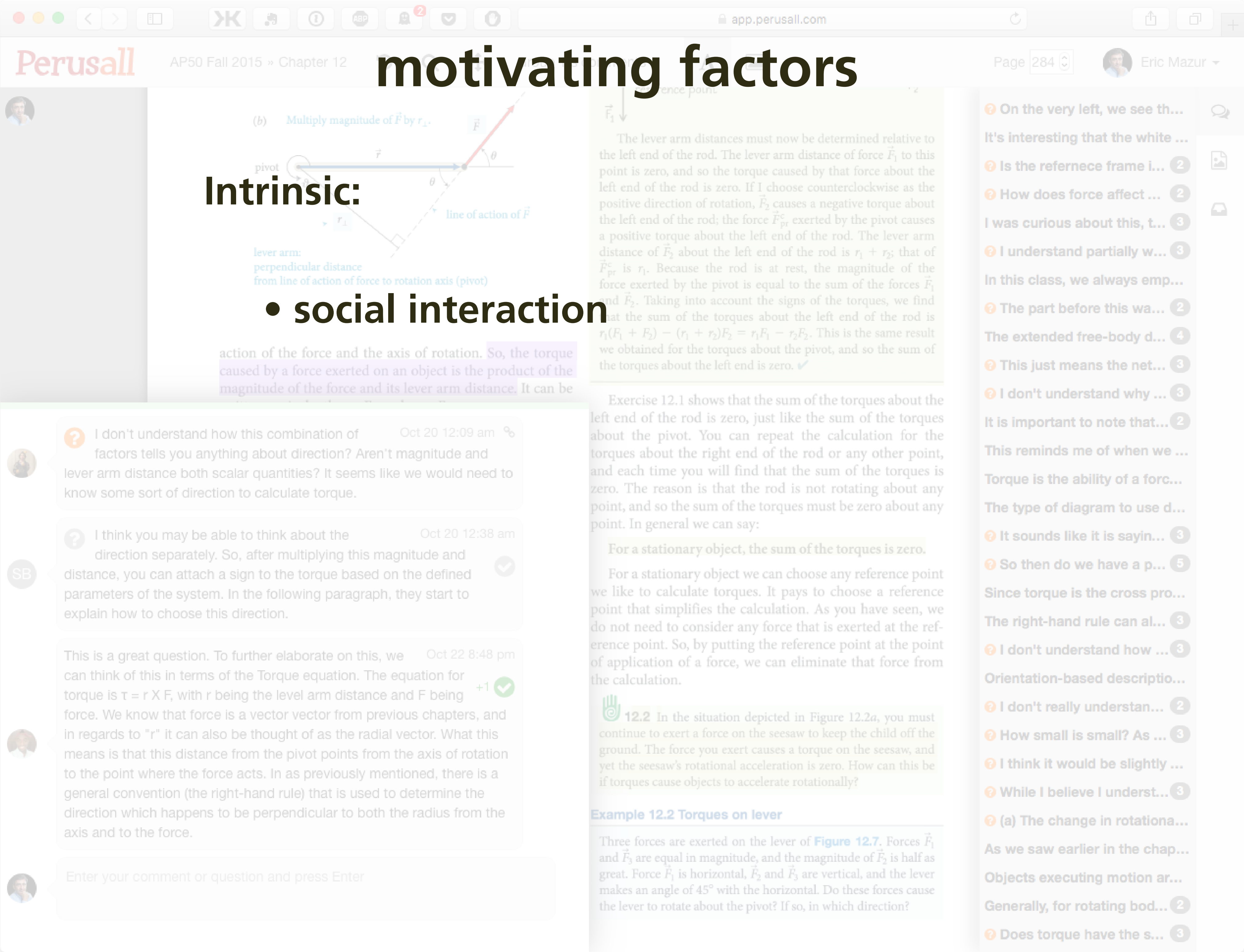
J Does the circular loop of current have any similarities with the look of the earths magnetic field? They kind of look similar to me.

Show more...

motivating factors

Intrinsic:

- social interaction



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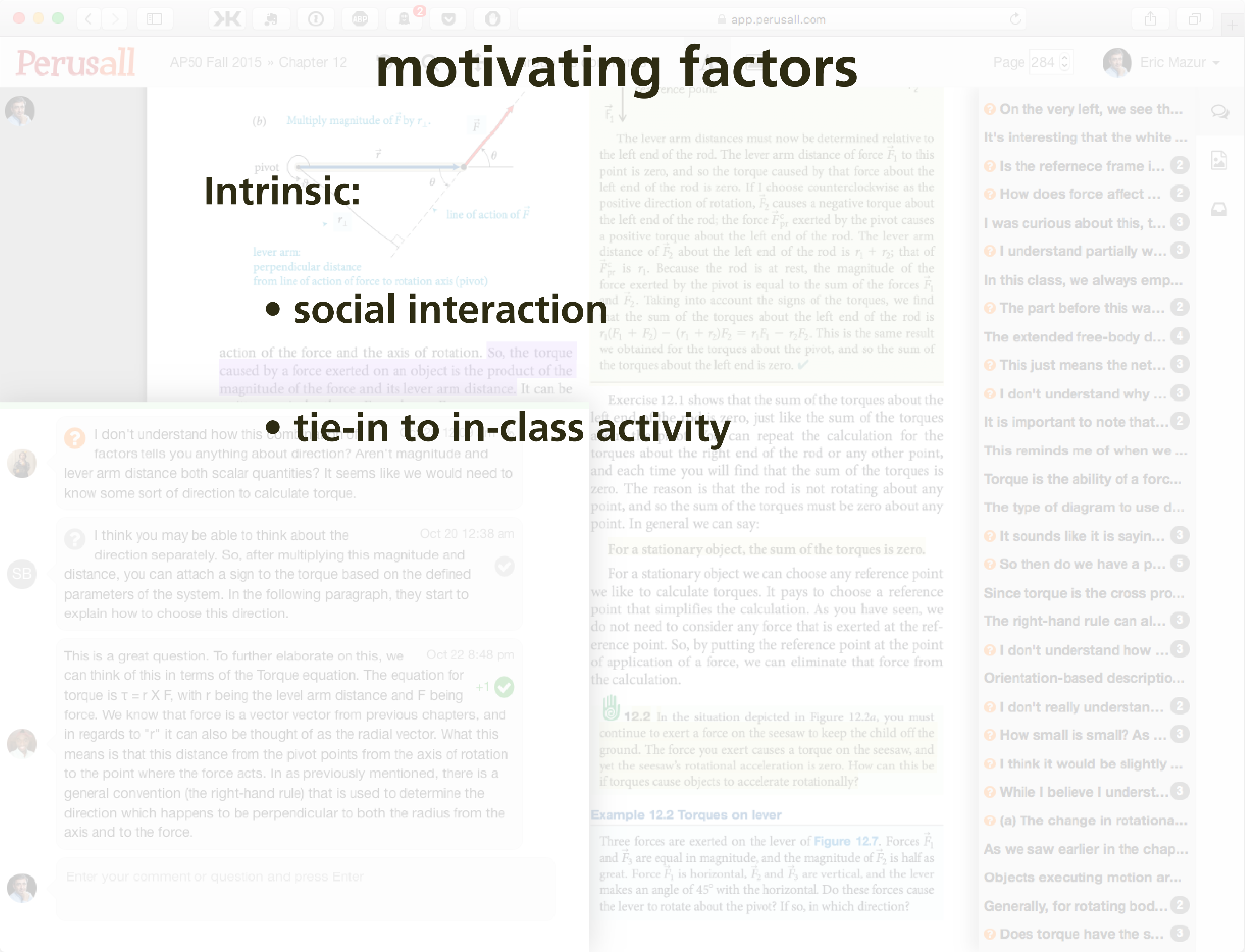
- tie-in to in-class activity



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motivating factors

Intrinsic:

- social interaction
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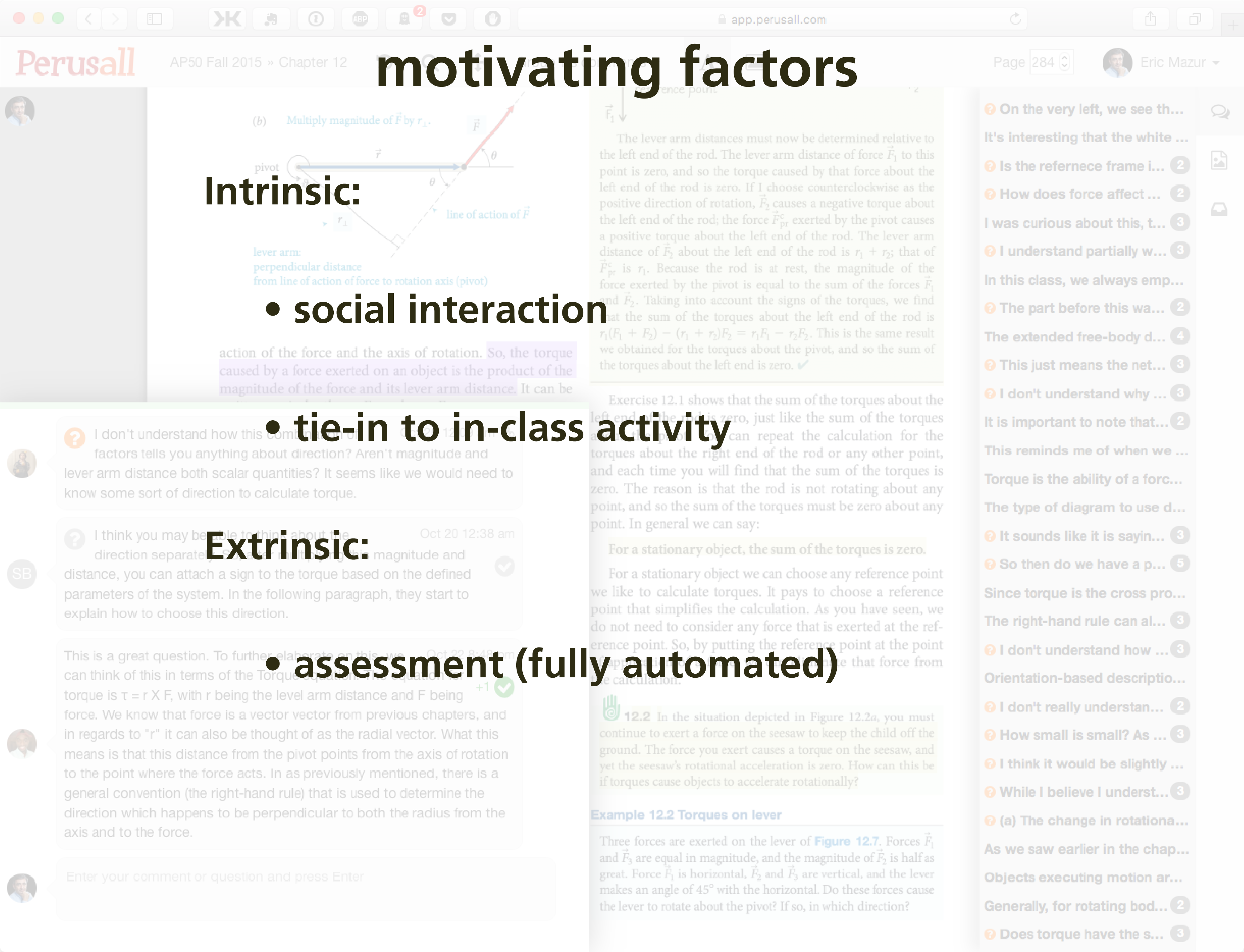
Extrinsic:

- assessment (fully automated)



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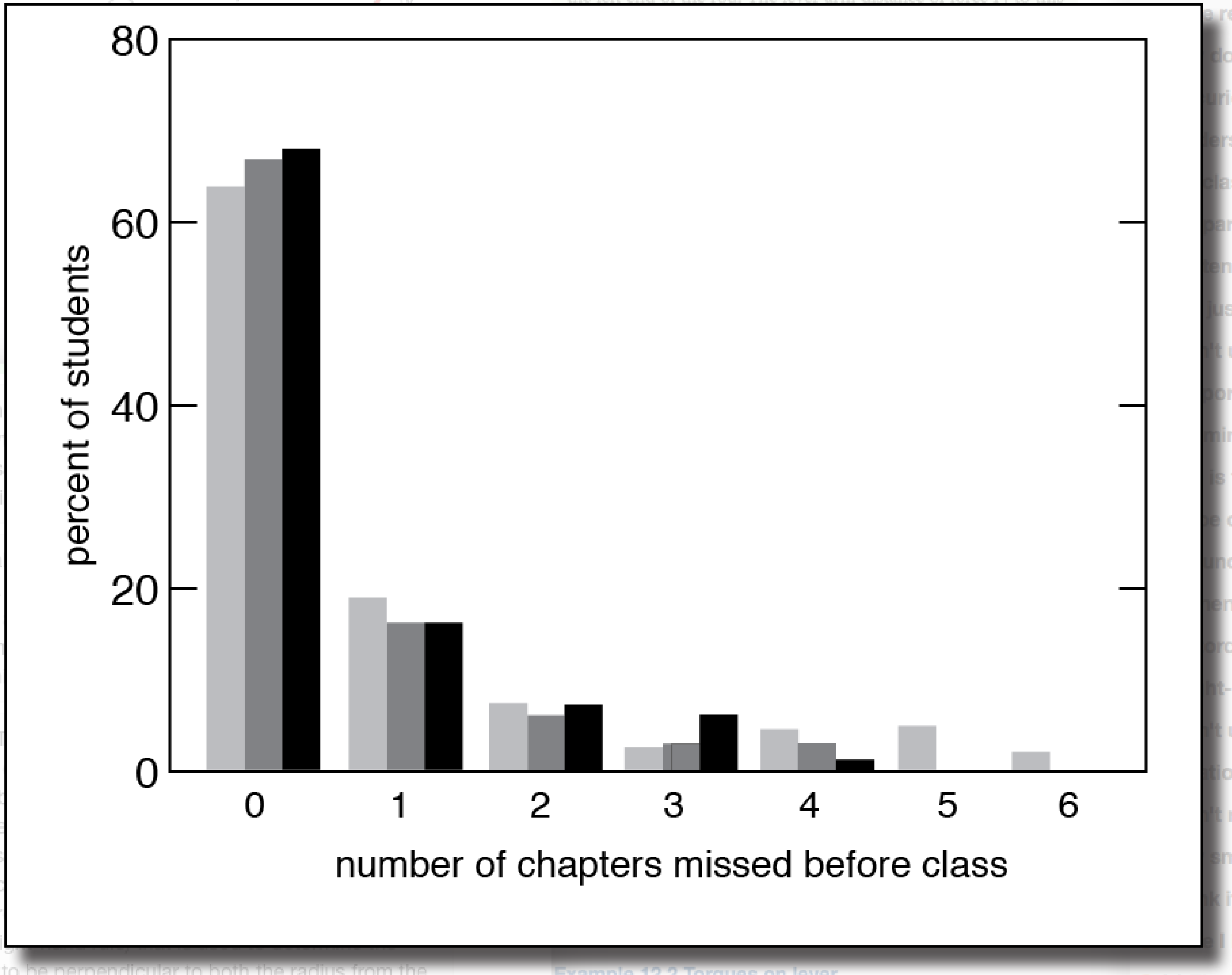
research data



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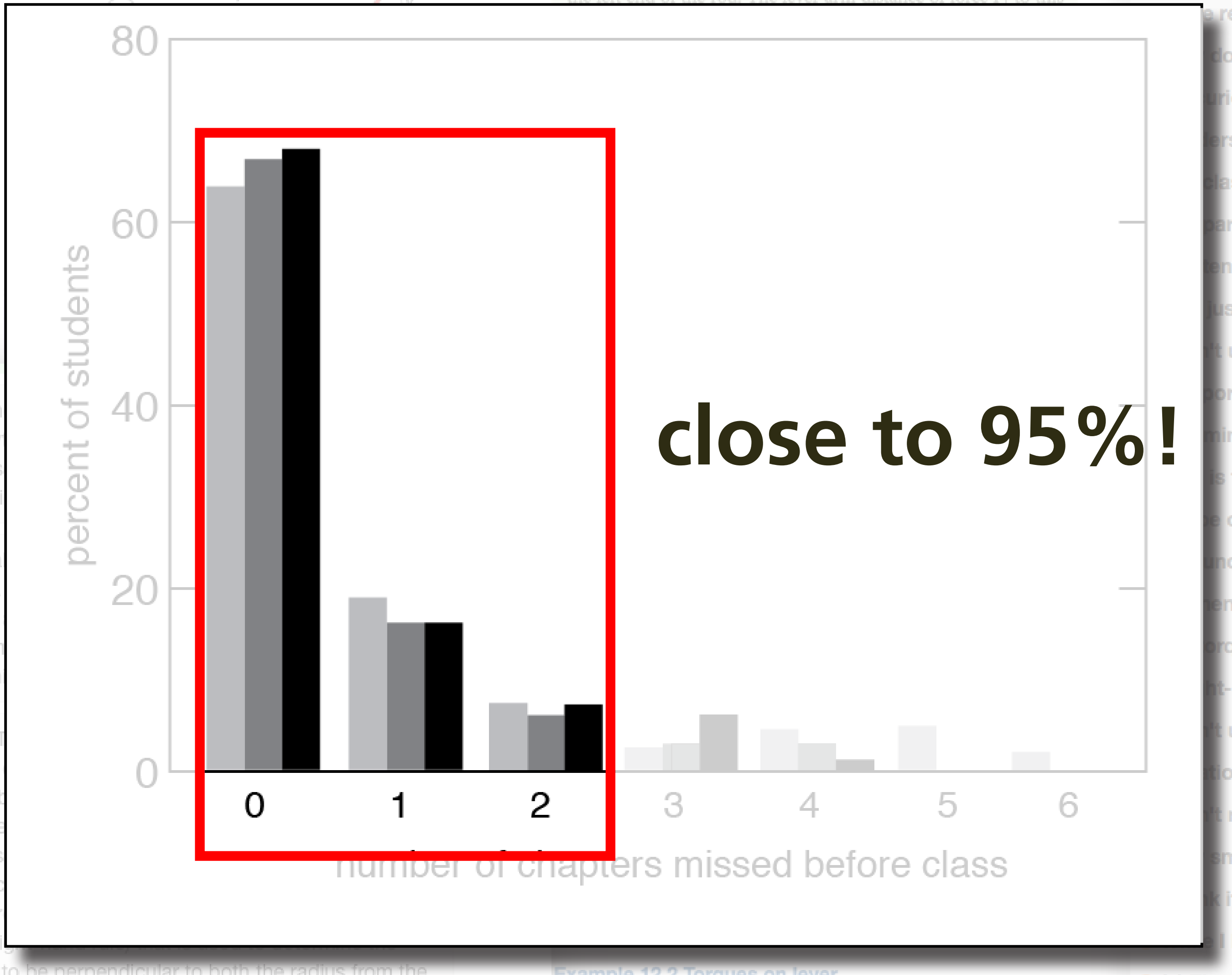
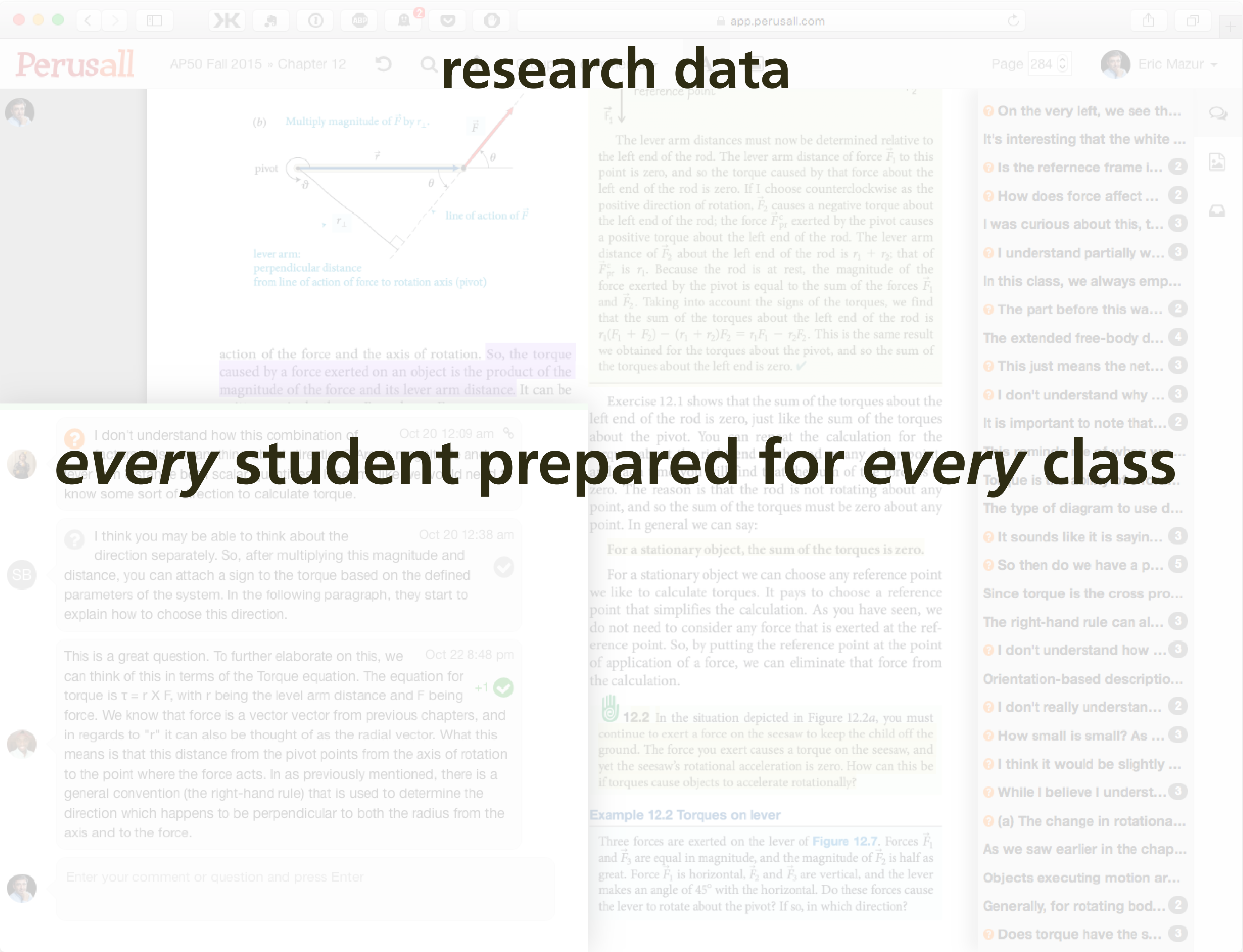


close to 95%!

research data



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 $\vec{F}^c_{pr}$ 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 $\vec{F}^c_{pr}$ 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 [illegible] 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 12.2*a*, 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° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

? I don't understand how this combination of [illegible] know some sort of direction to calculate torque. Oct 20 12:09 am

? I think you may be able to think about the direction separately. So, after multiplying this magnitude and distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they start to explain how to choose this direction. Oct 20 12:38 am

This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is τ = r X 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

- ? 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
- In this class, we always emp...
- ? The part before this wa... 2
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- This reminds me of when we...
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- ? So then do we have a p... 5
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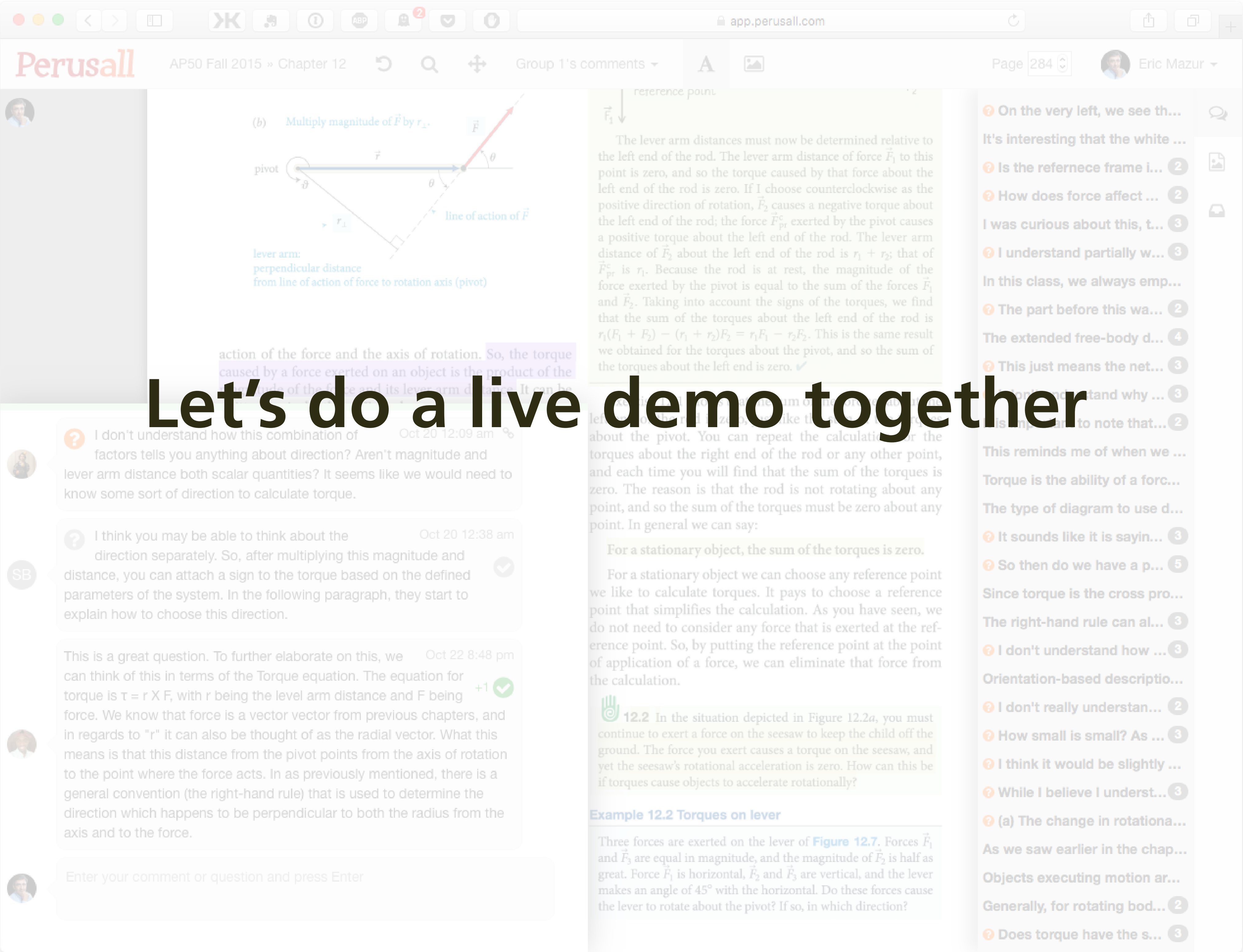

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I don't understand how this combination of factors tells you anything about direction? Aren't magnitude and lever arm distance both scalar quantities? It seems like we would need to know some sort of direction to calculate torque. Oct 20 12:09 am

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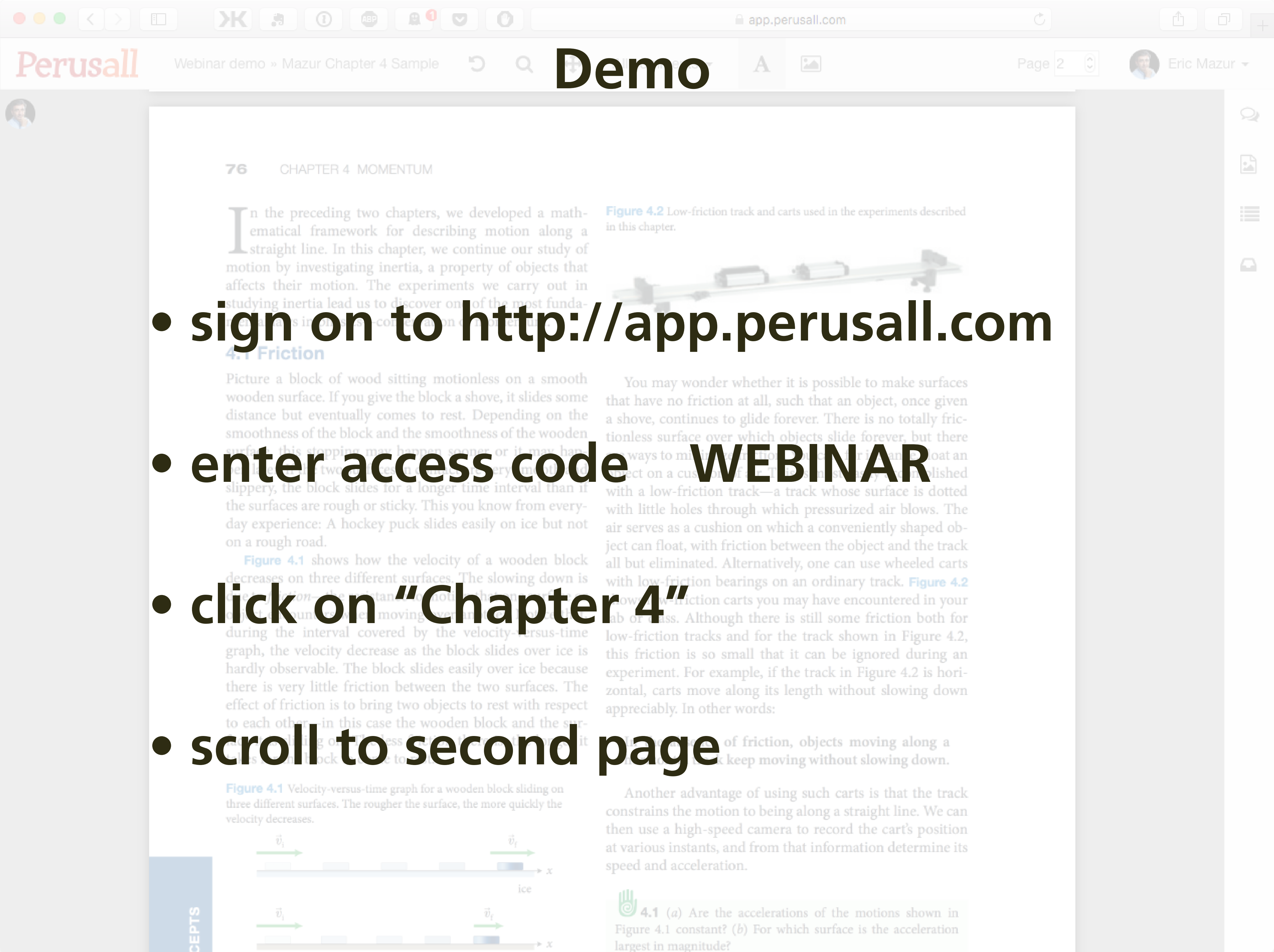
Demo



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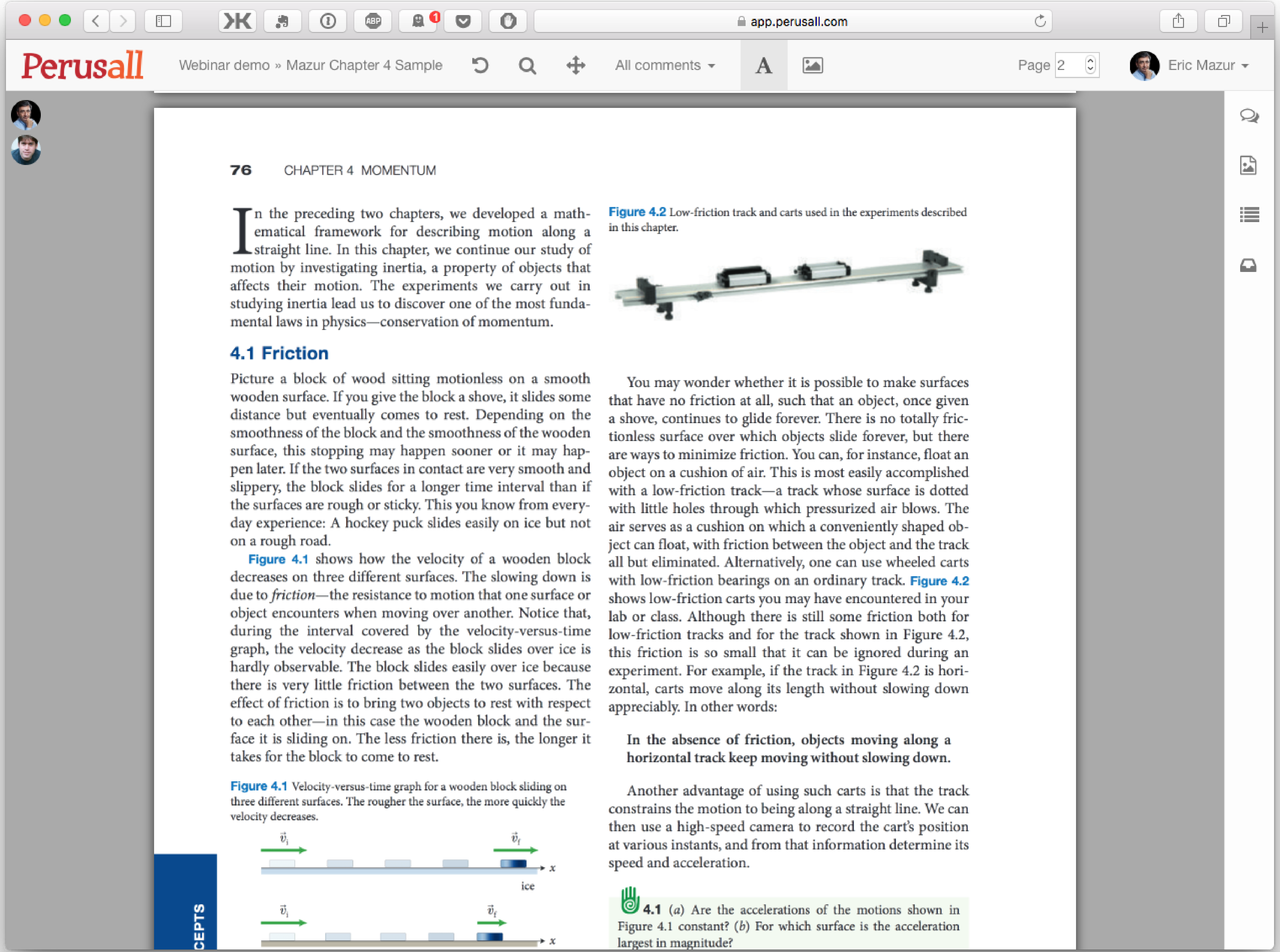
- click on “Chapter 4”
- scroll to second page



76 CHAPTER 4 MOMENTUM

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

4.1 Friction

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

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

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

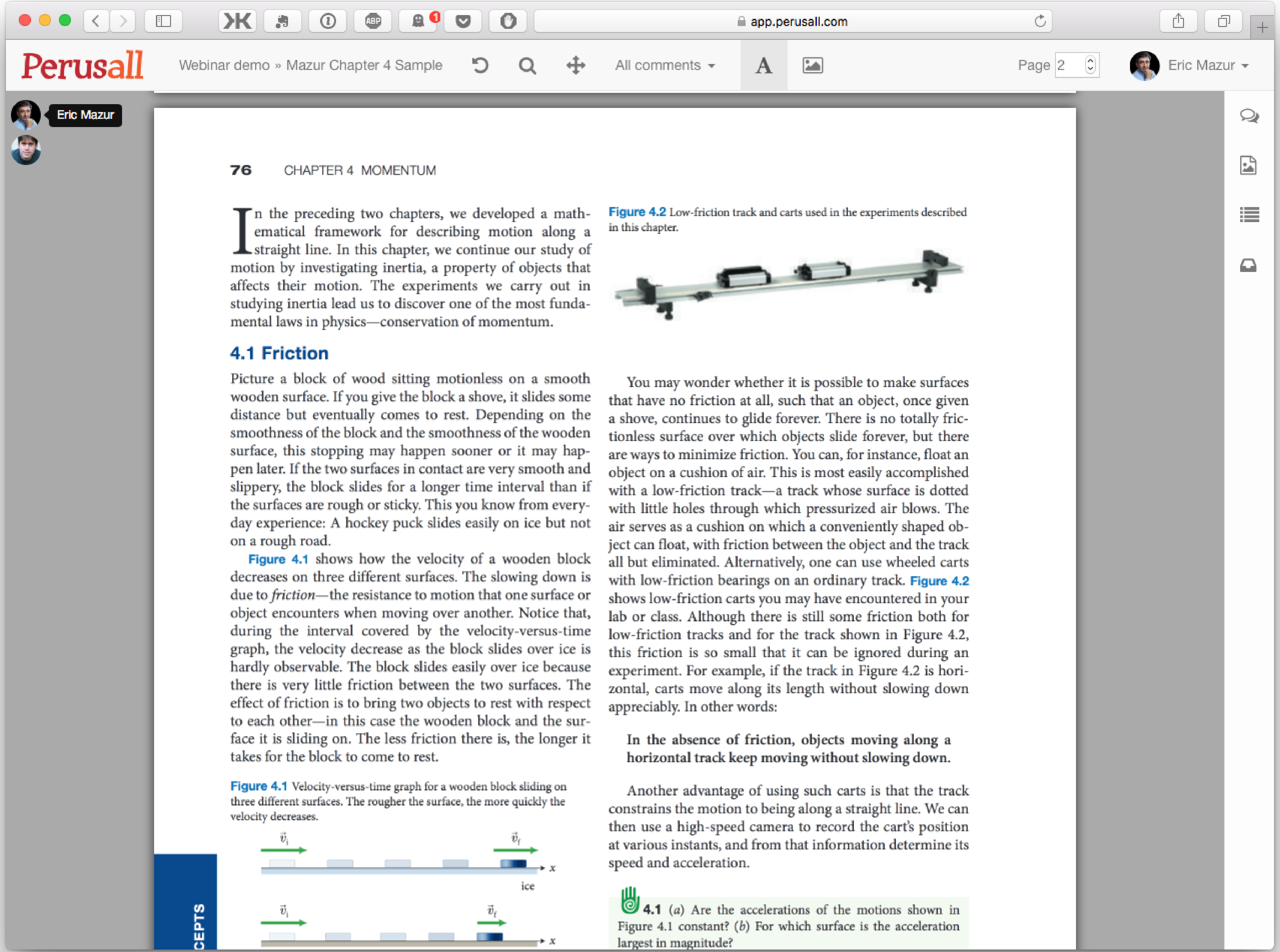
Figure 4.2 Low-friction track and carts used in the experiments described in this chapter.

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

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

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

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



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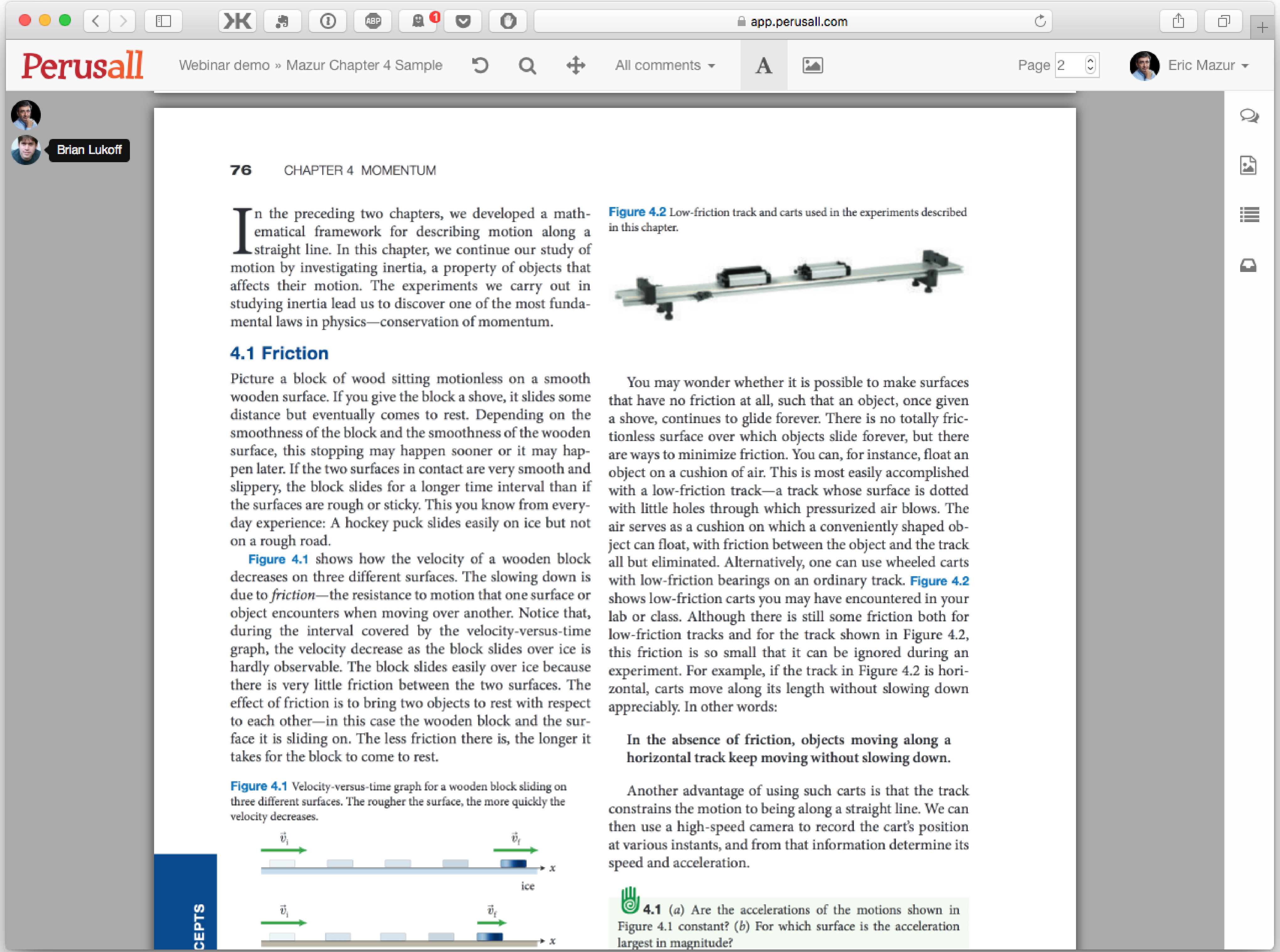

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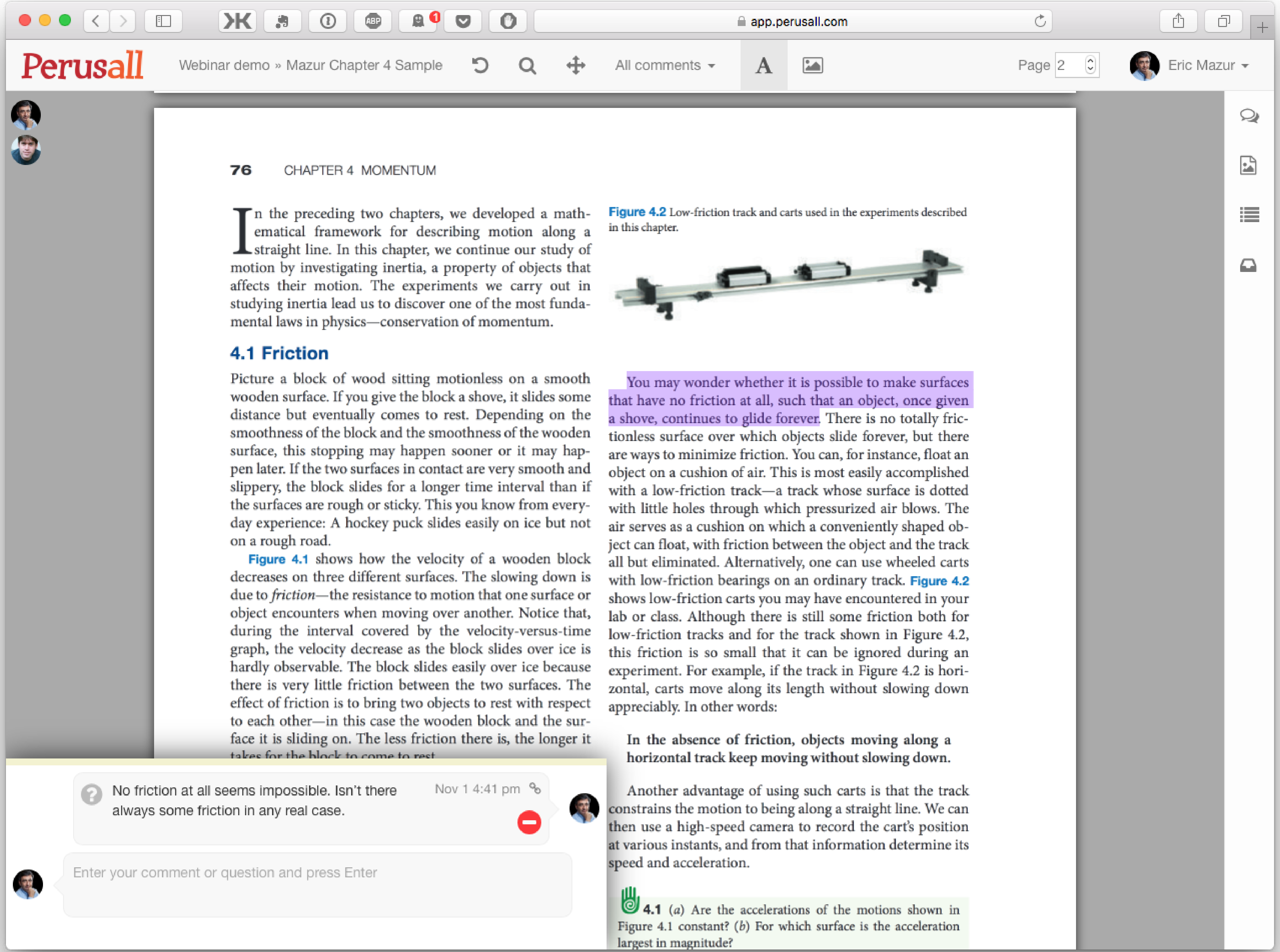

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Nov 1 4:41 pm

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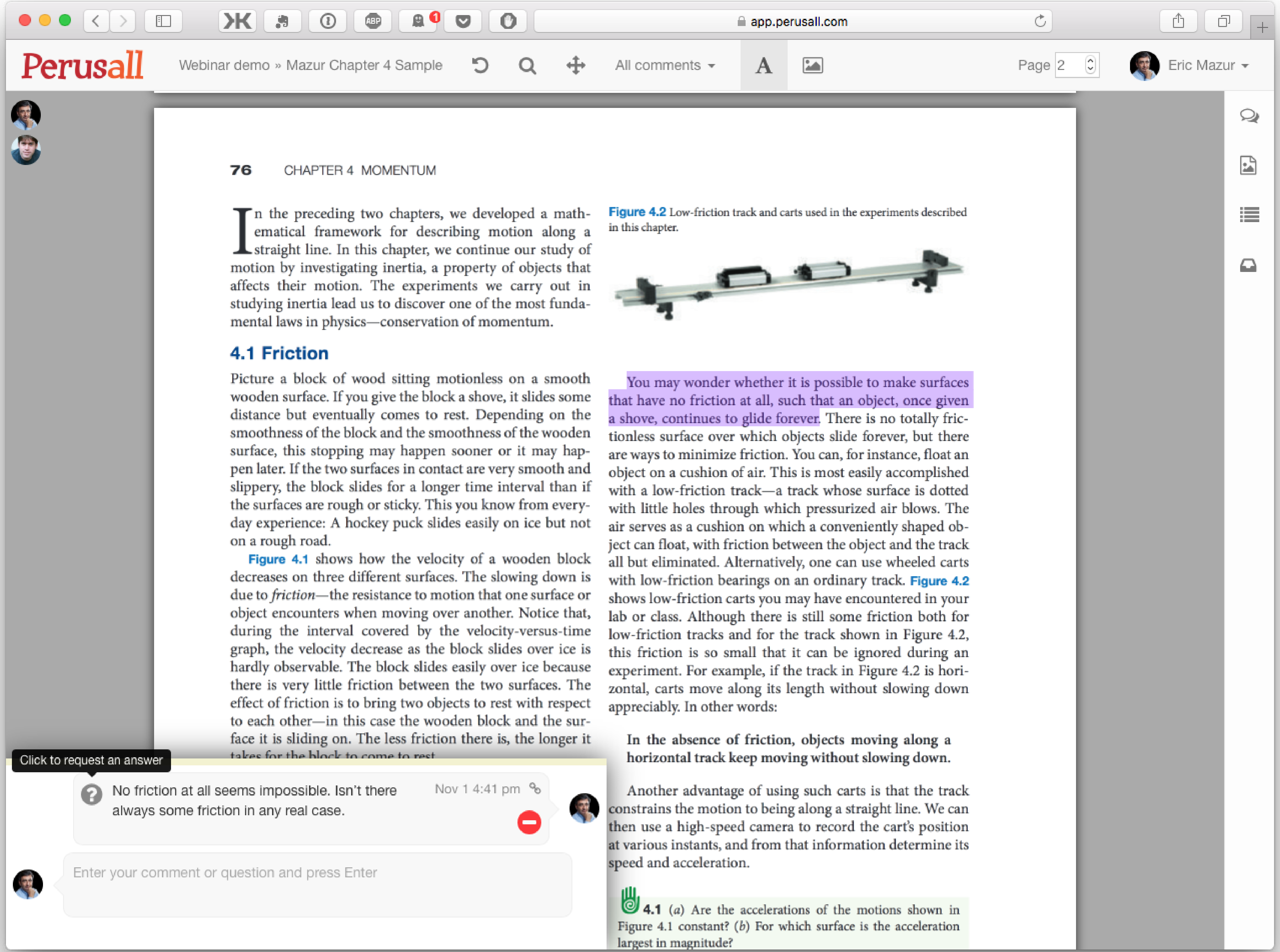

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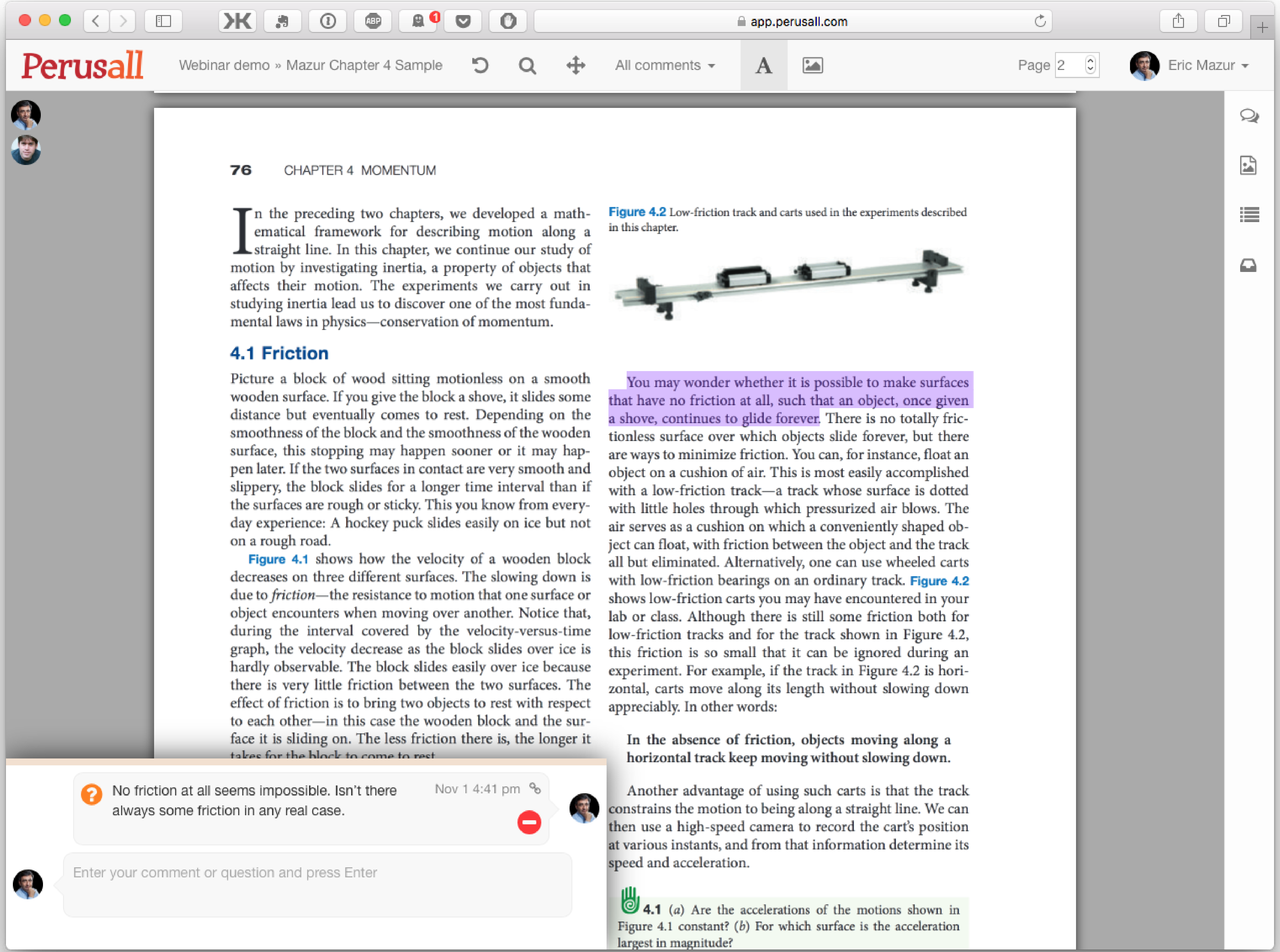

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In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

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

Nov 1 4:41 pm

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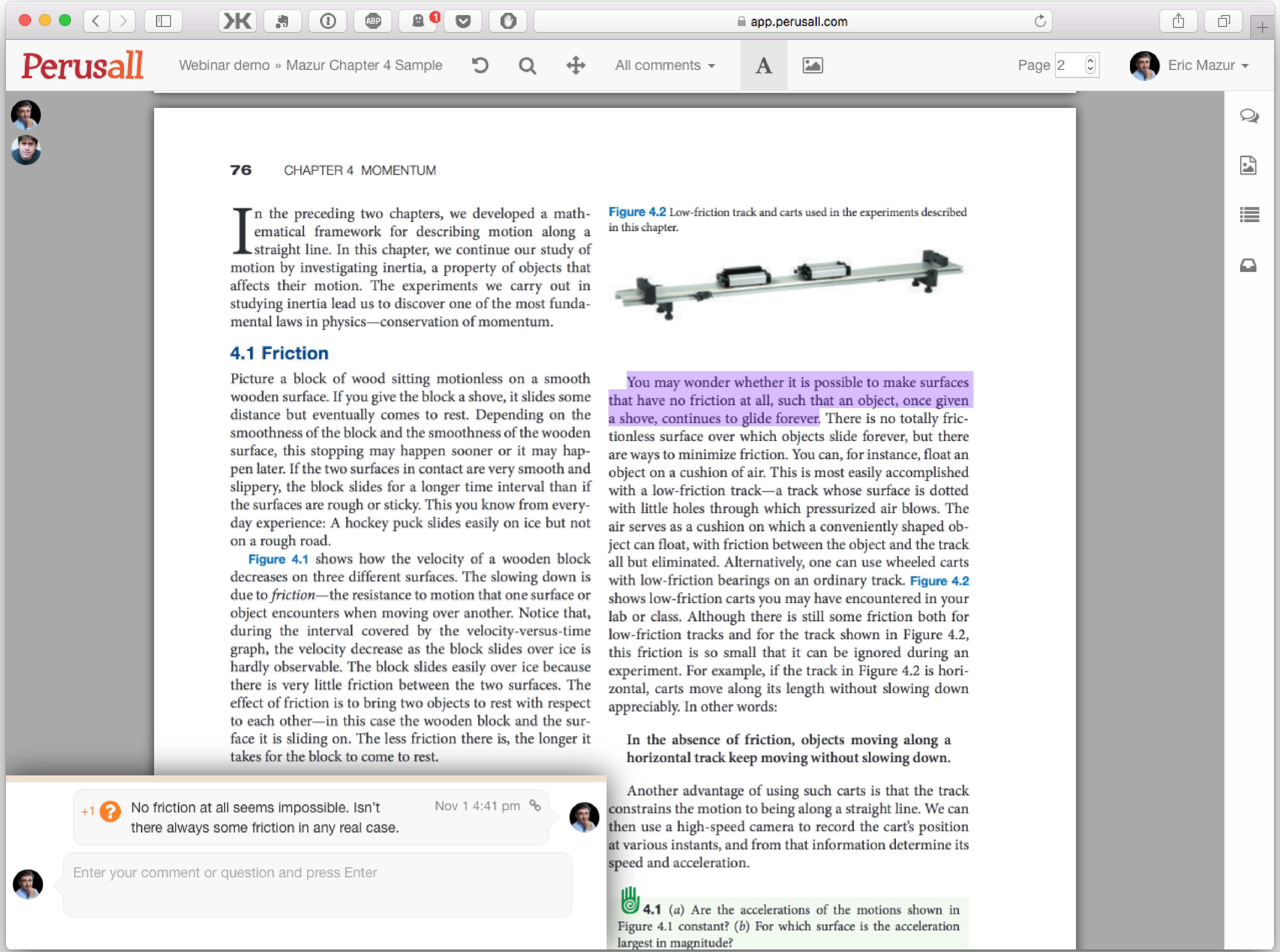

76 CHAPTER 4 MOMENTUM

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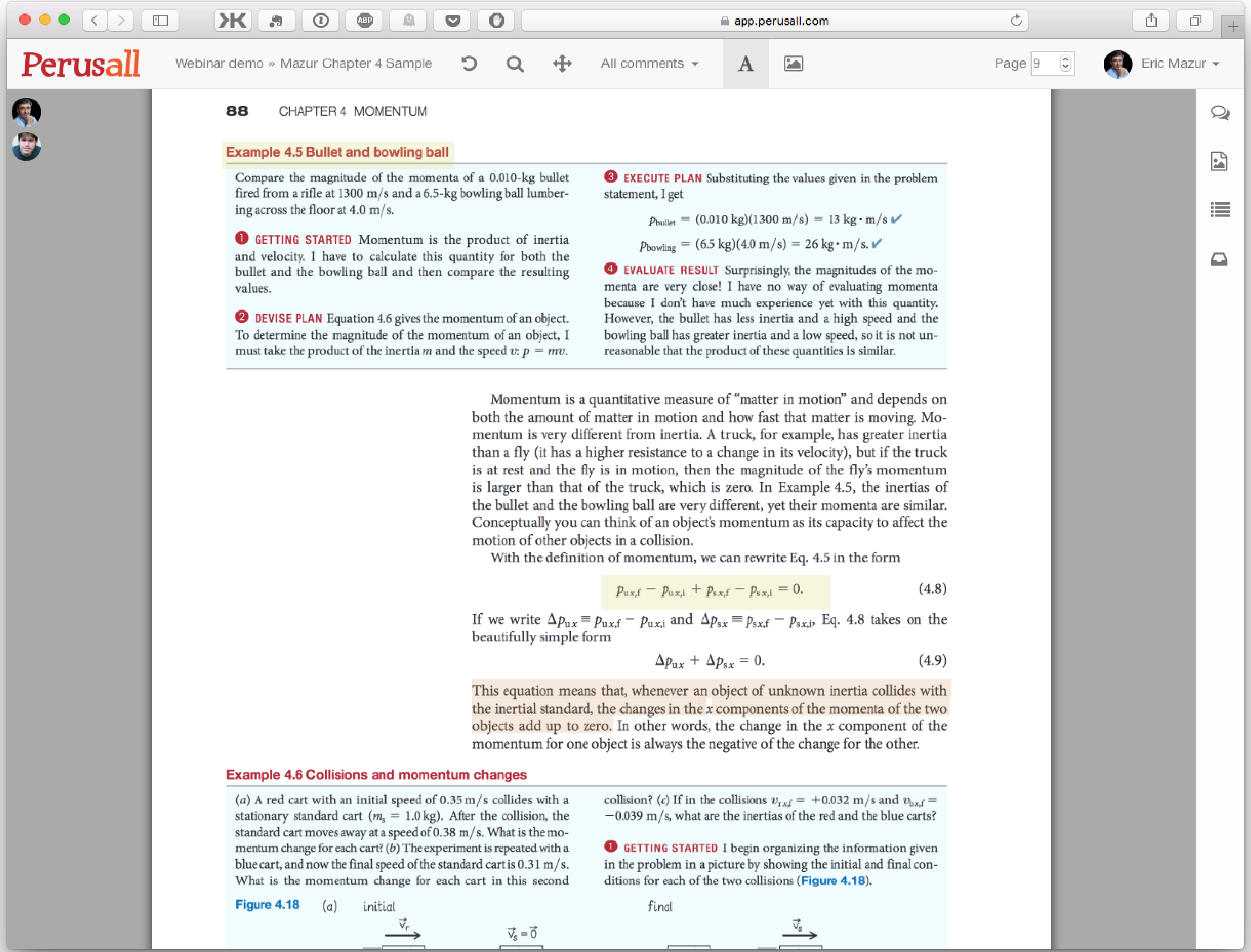

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Compare the magnitude of the momenta of a 0.010-kg bullet fired from a rifle at 1300 m/s and a 6.5-kg bowling ball lumbering across the floor at 4.0 m/s.

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With the definition of momentum, we can rewrite Eq. 4.5 in the form

$$p_{\mathrm{u}x,\mathrm{f}} - p_{\mathrm{u}x,\mathrm{i}} + p_{\mathrm{s}x,\mathrm{f}} - p_{\mathrm{s}x,\mathrm{i}} = 0. \tag{4.8}$$

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(*a*) A red cart with an initial speed of 0.35 m/s collides with a stationary standard cart ($m_s = 1.0$ kg). After the collision, the standard cart moves away at a speed of 0.38 m/s. What is the momentum change for each cart? (*b*) The experiment is repeated with a blue cart, and now the final speed of the standard cart is 0.31 m/s. What is the momentum change for each cart in this second collision? (*c*) If in the collisions $v_{\mathrm{r}x,\mathrm{f}} = +0.032$ m/s and $v_{\mathrm{b}x,\mathrm{f}} = -0.039$ m/s, what are the inertias of the red and the blue carts?

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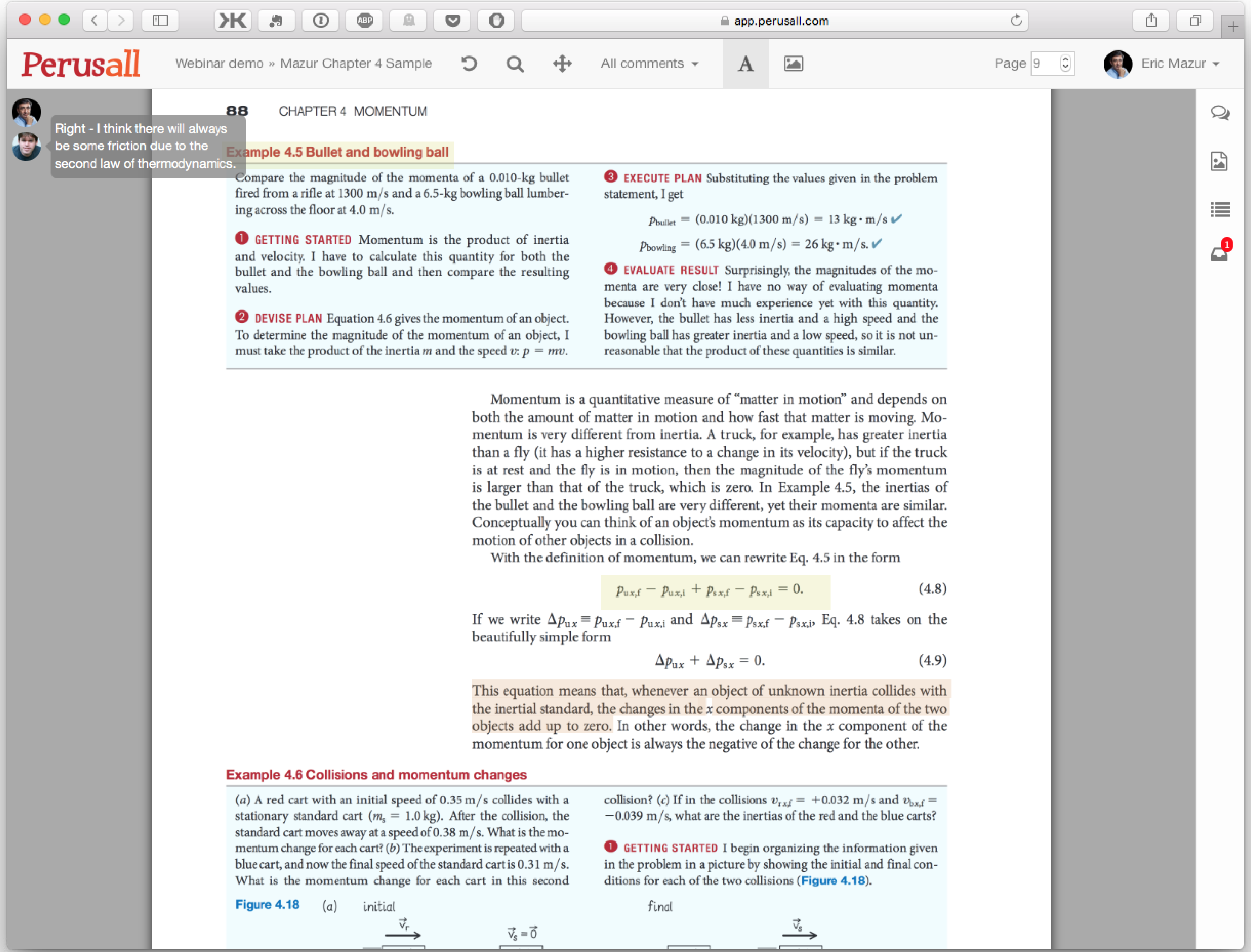

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88 CHAPTER 4 MOMENTUM

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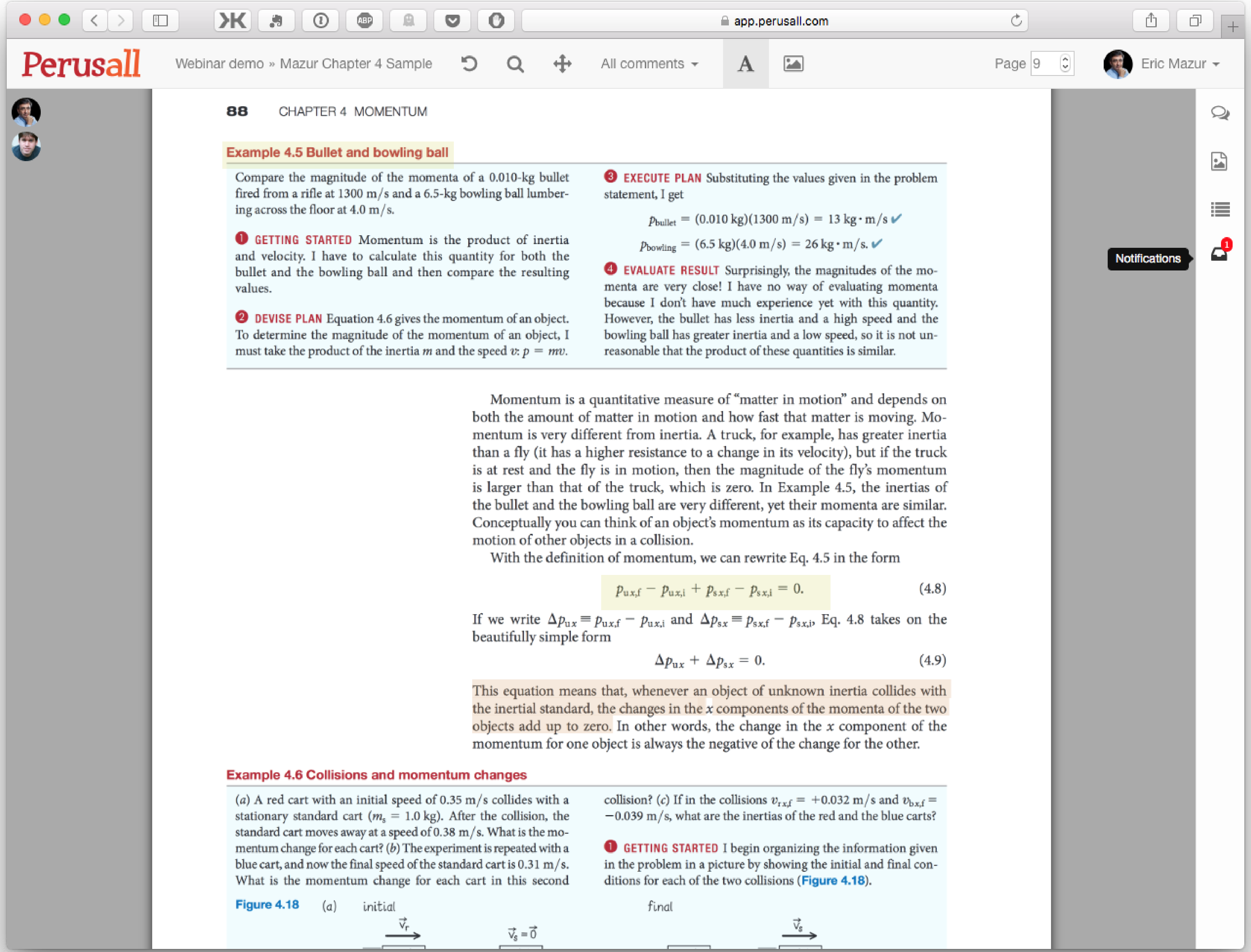

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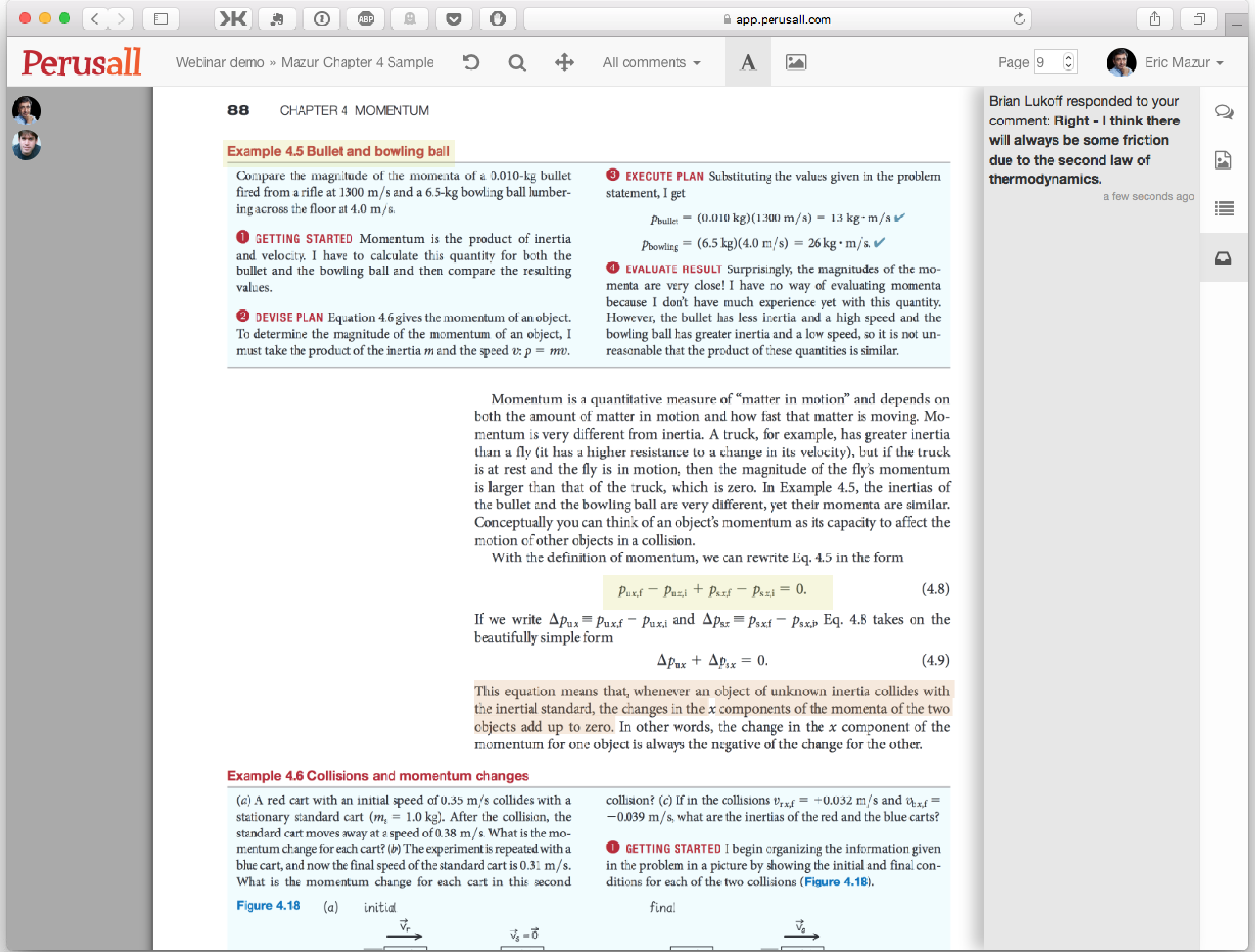

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a few seconds ago

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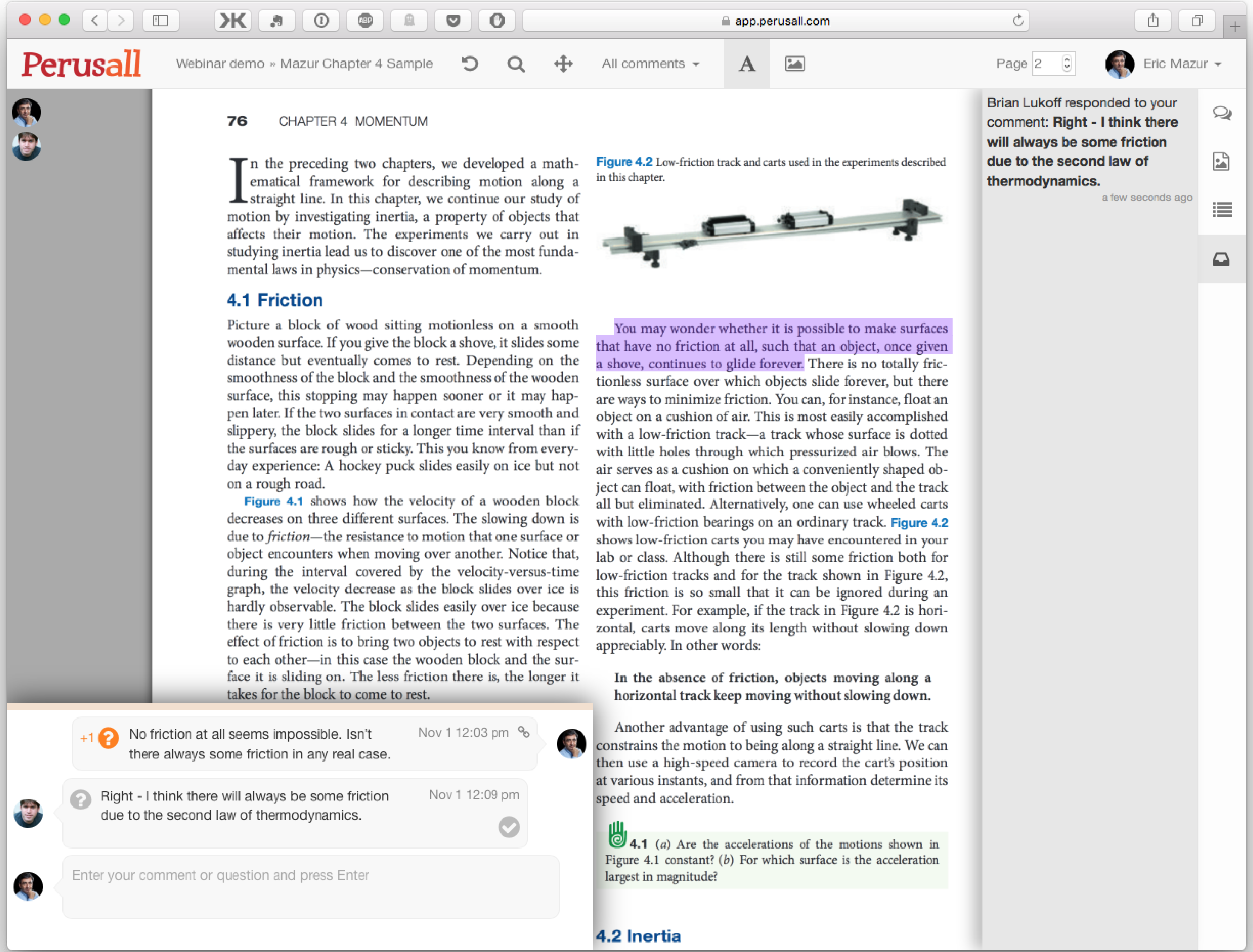

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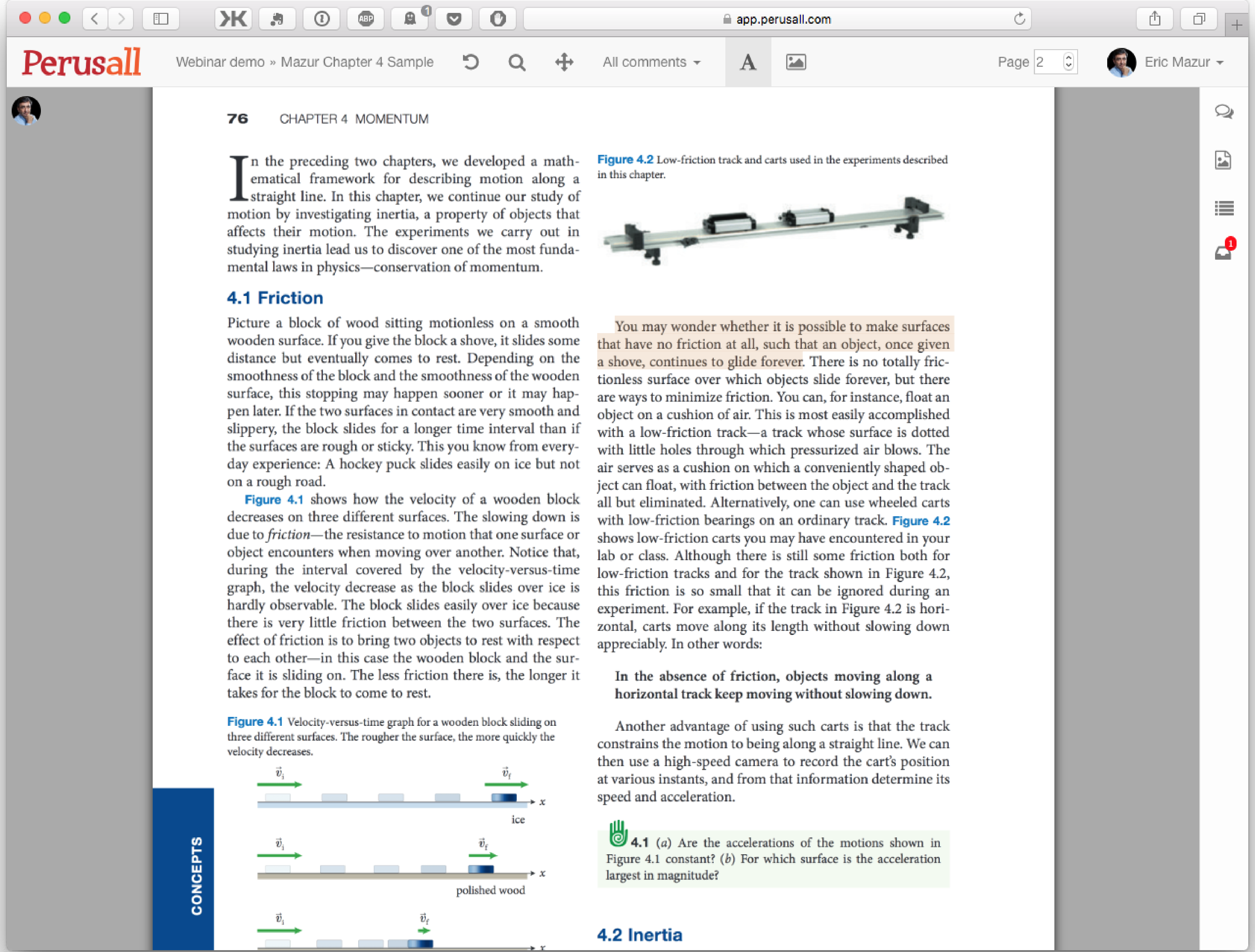

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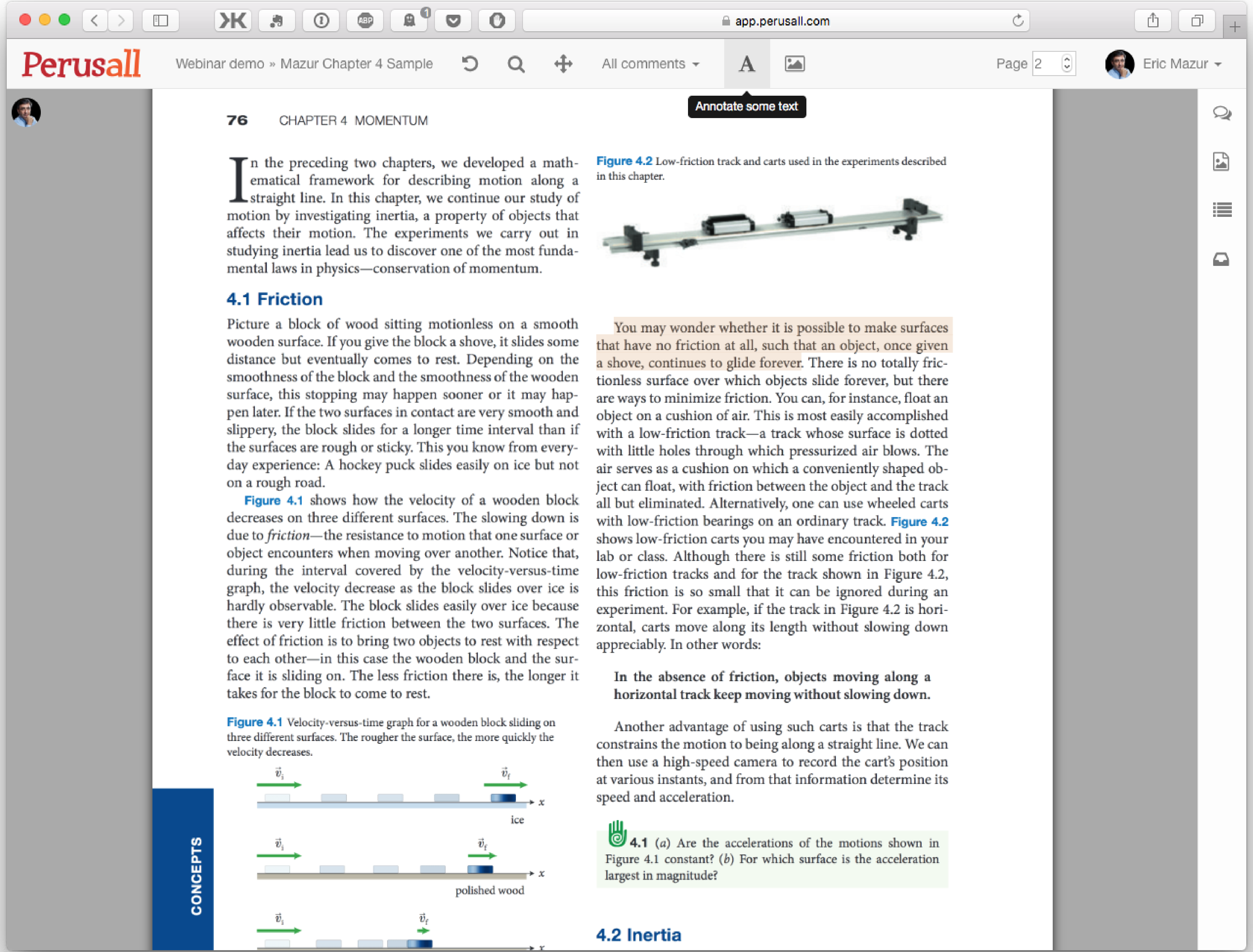

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In the absence of friction, objects moving along a horizontal track keep moving without slowing down.

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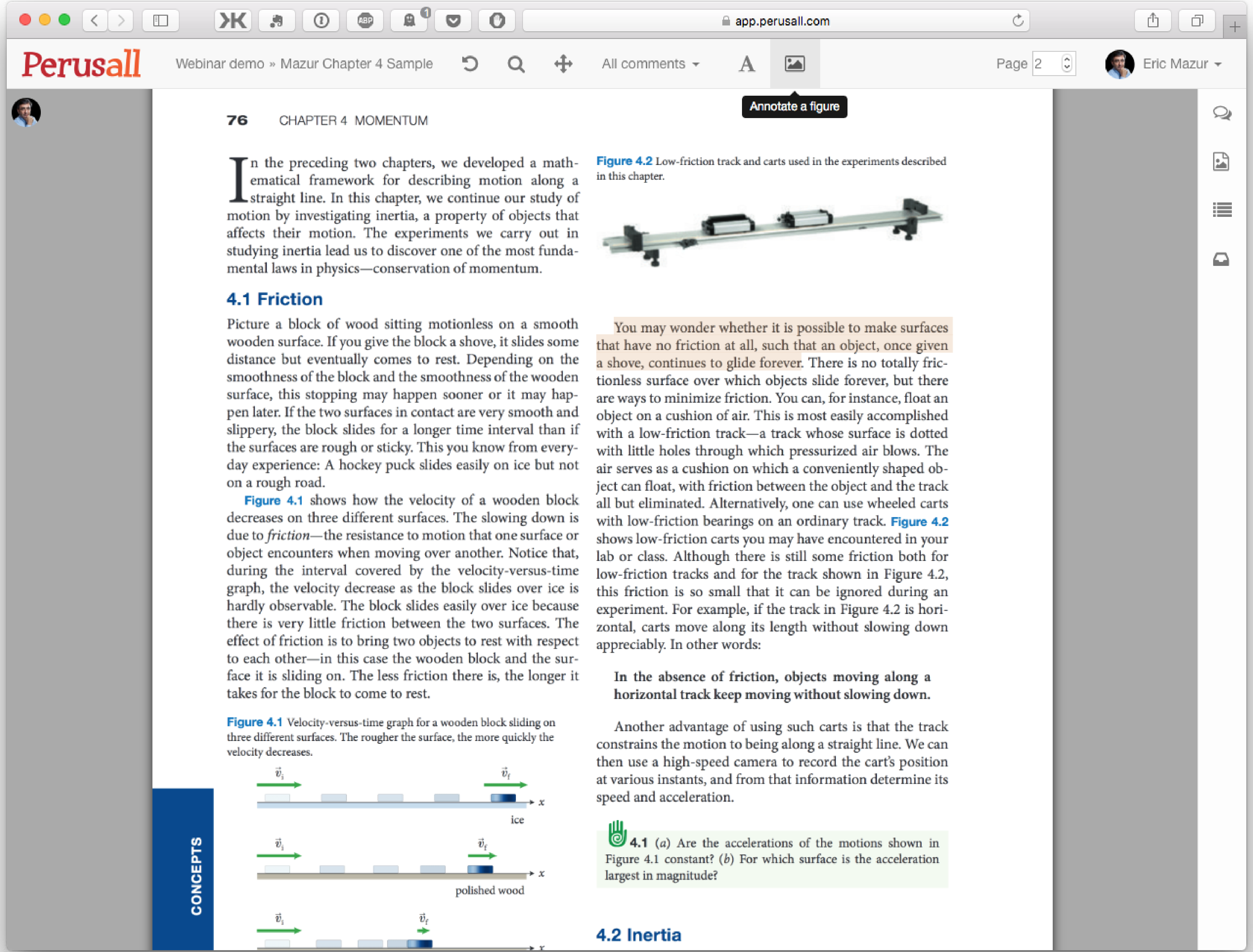
4.1 (*a*) Are the accelerations of the motions shown in Figure 4.1 constant? (*b*) For which surface is the acceleration largest in magnitude?

4.2 Inertia



76 CHAPTER 4 MOMENTUM

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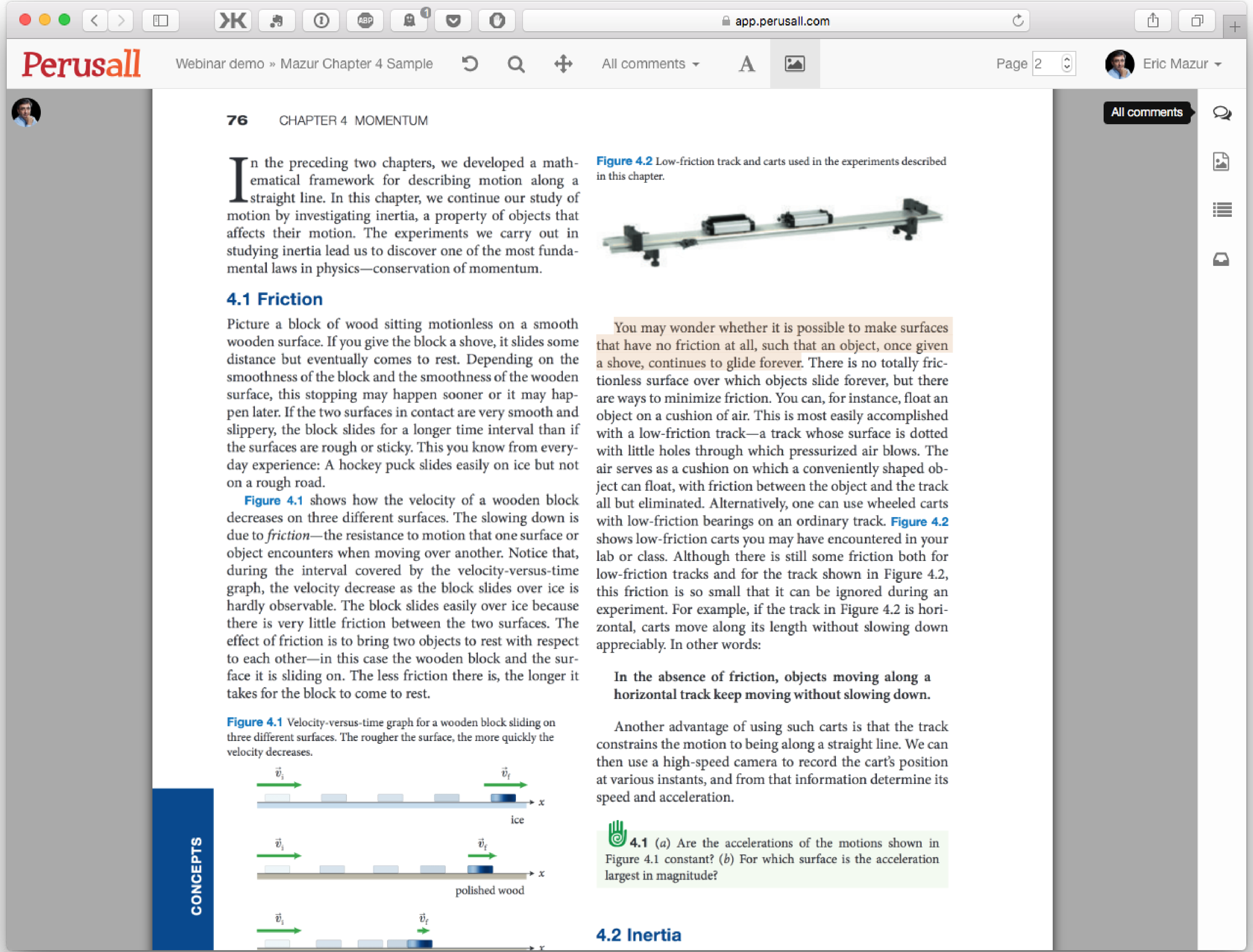

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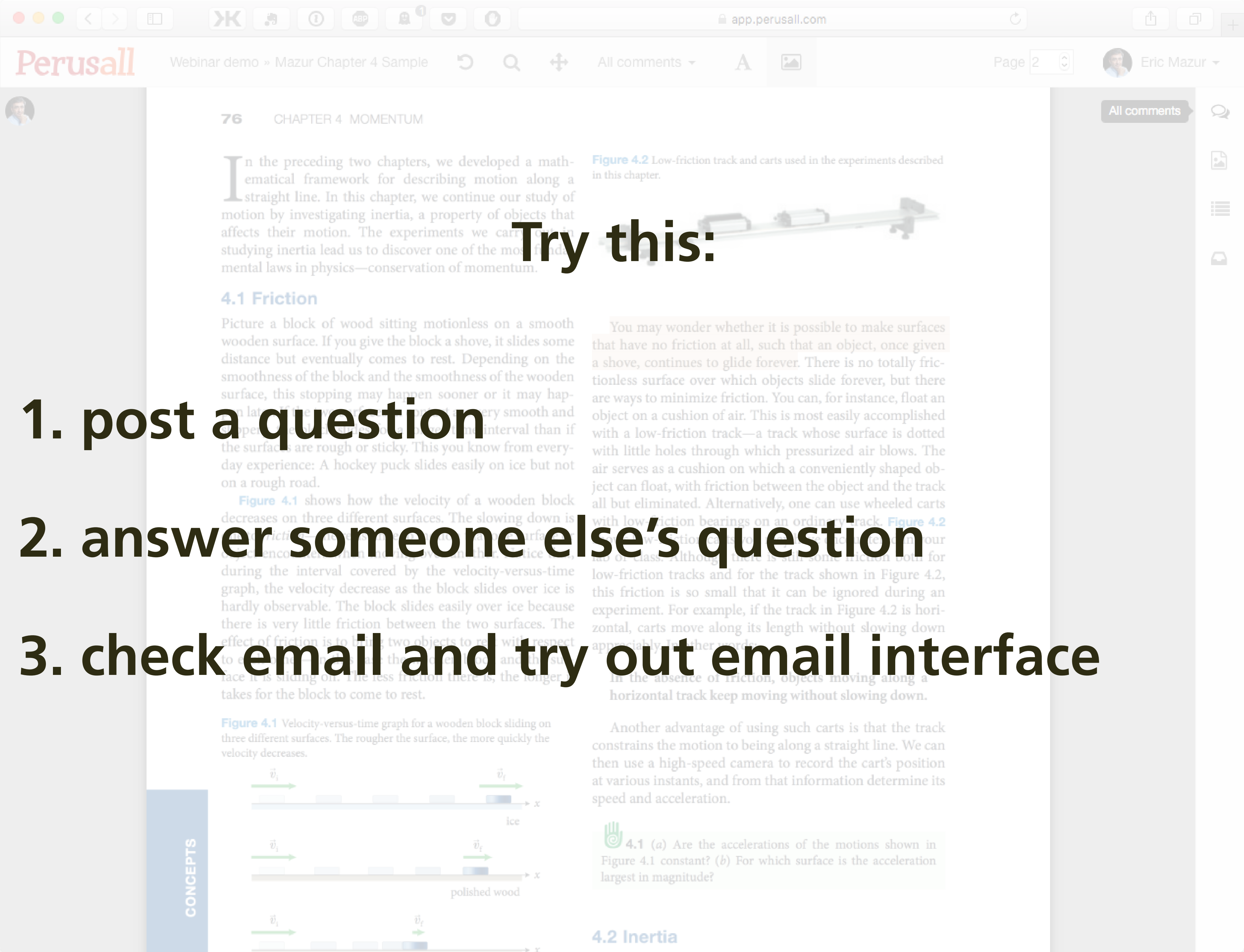
4.2 Inertia

Try this:

1. post a question

2. answer someone else's question

3. check email and try out email interface



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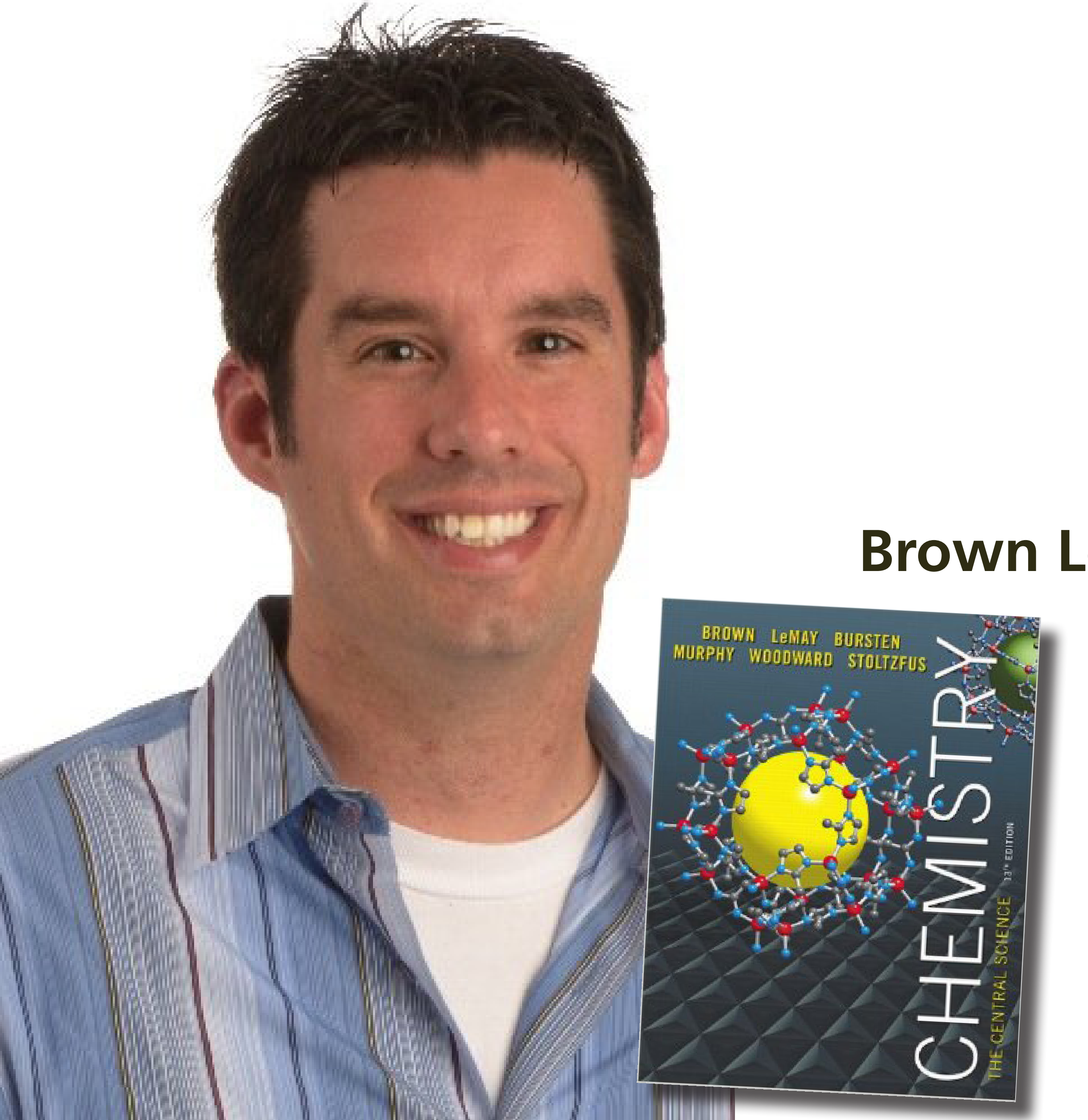
CHEM1210: General Chemistry



Matt Stoltzfus

Ohio State University

525 students

Brown Lemay 13th ed (Pearson)

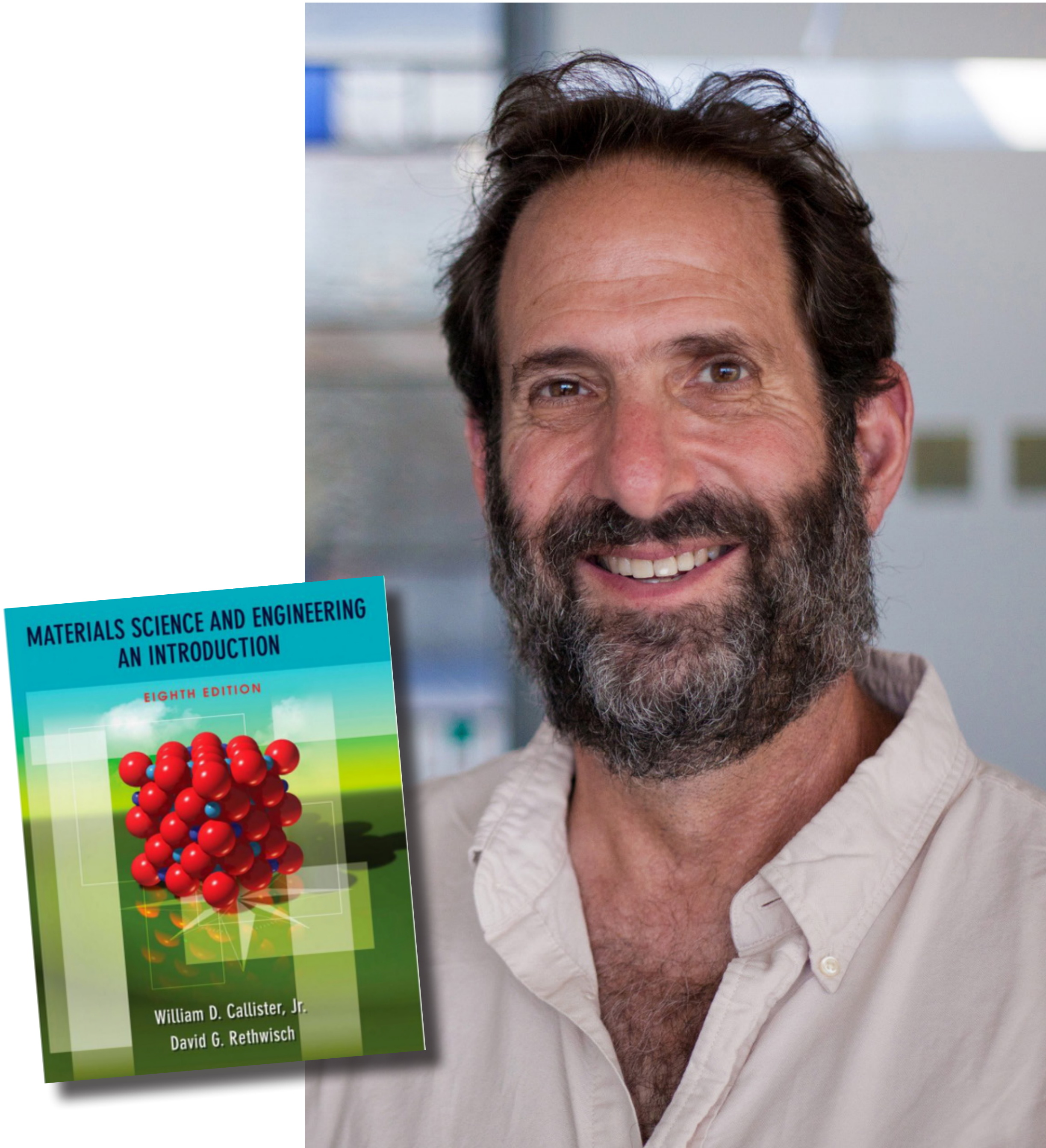
MSE220 : Introduction to Materials and Manufacturing

Steve Yalisove

University Michigan

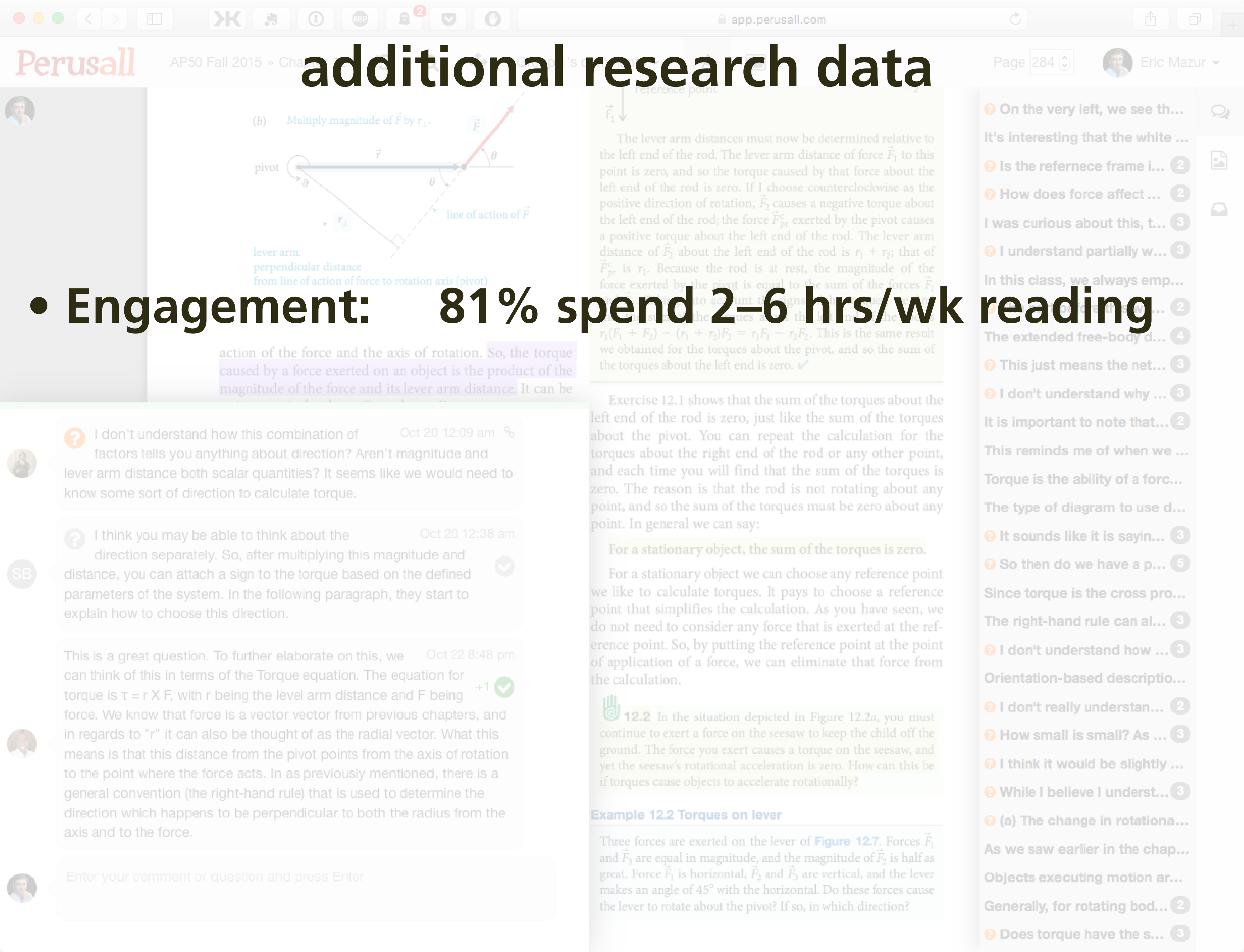
74 students

McCallister 8th ed (Wiley)



additional research data

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



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additional research data

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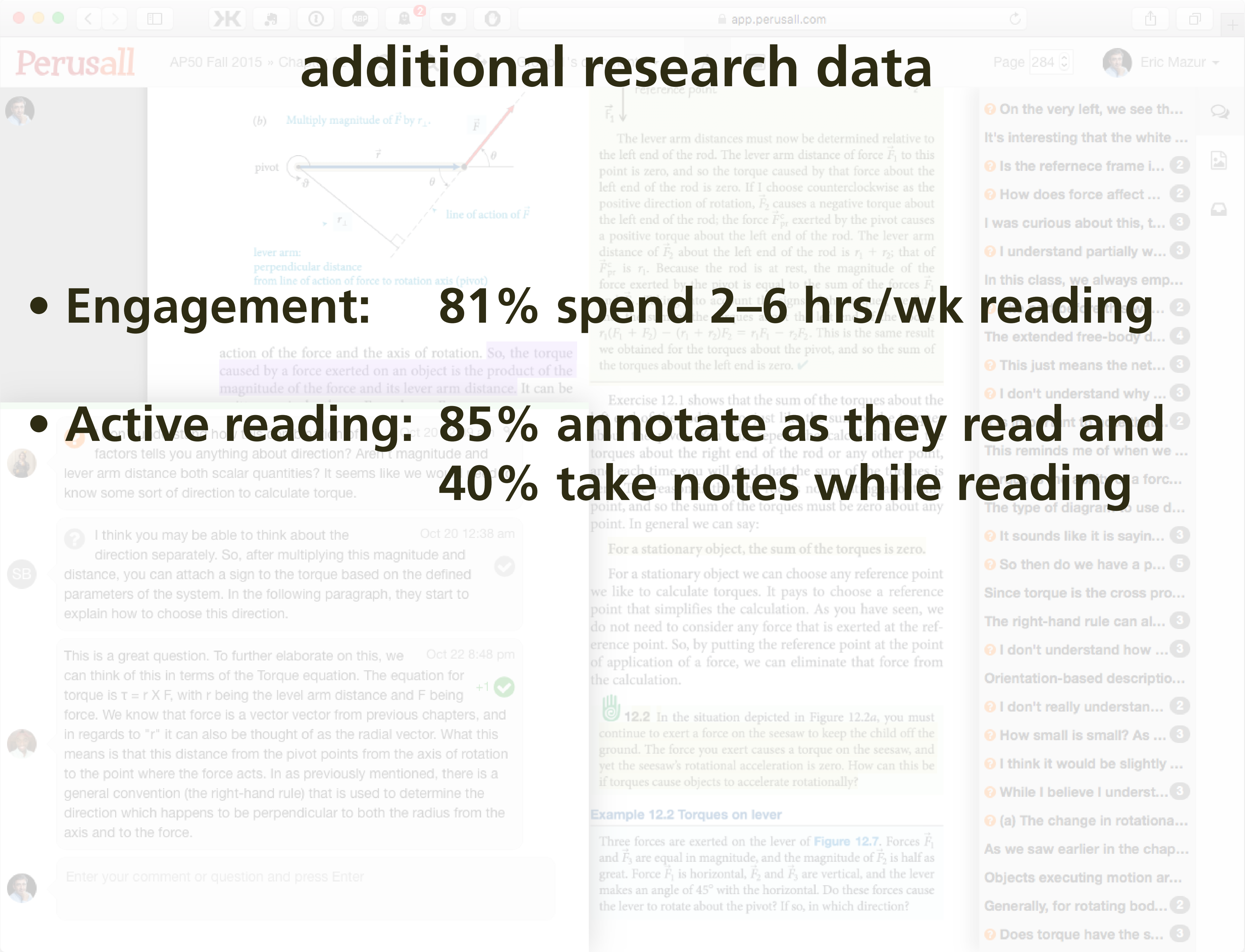

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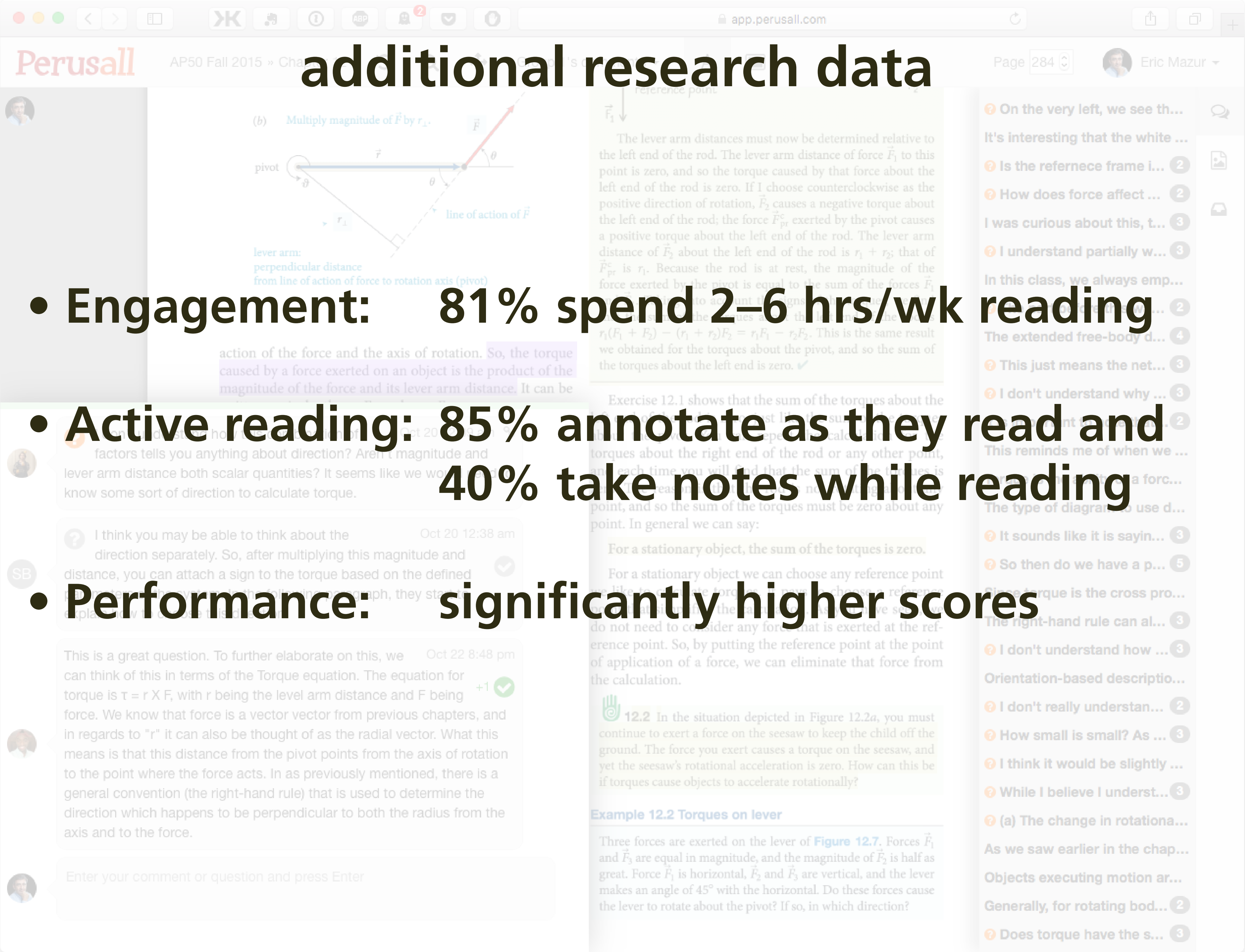

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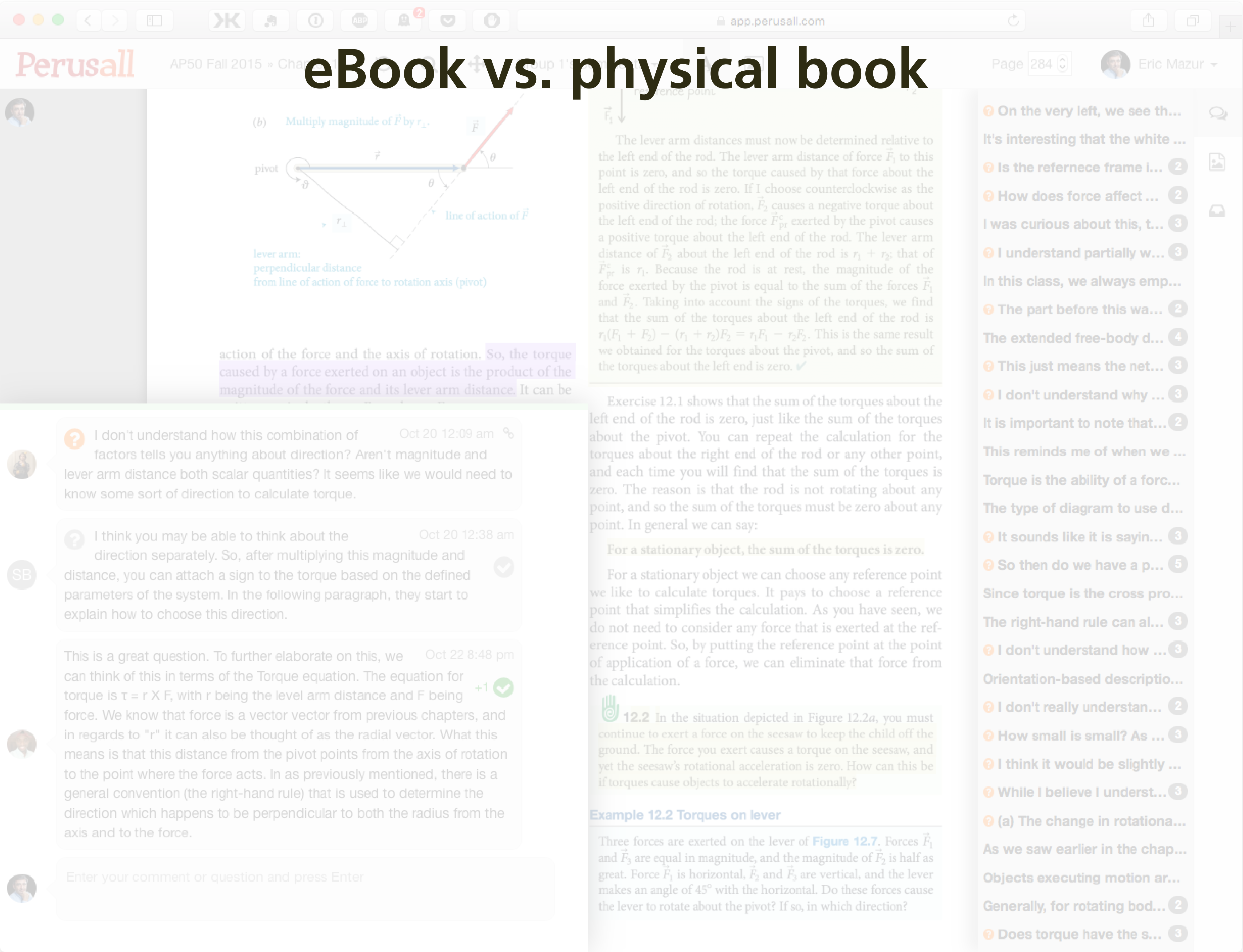

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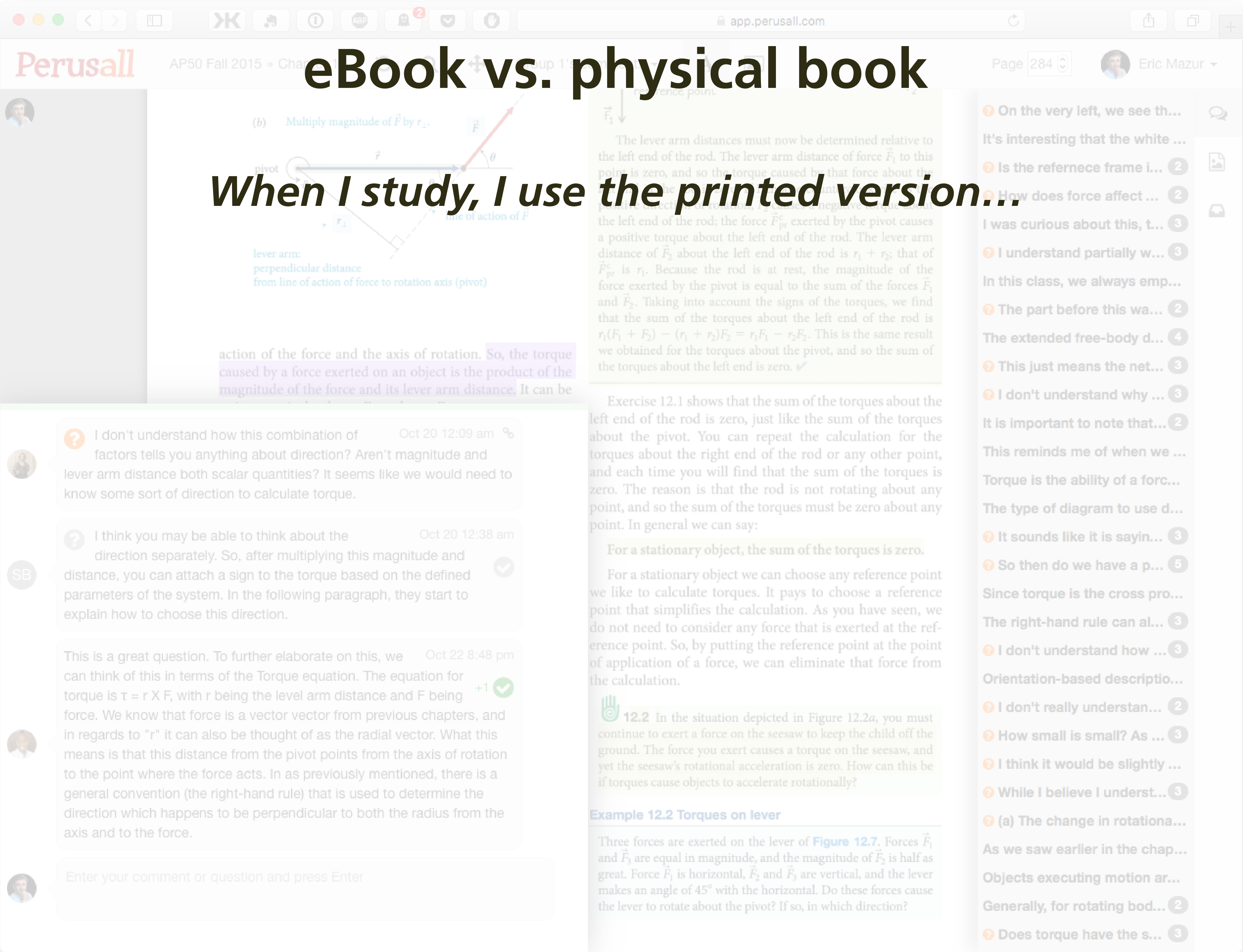

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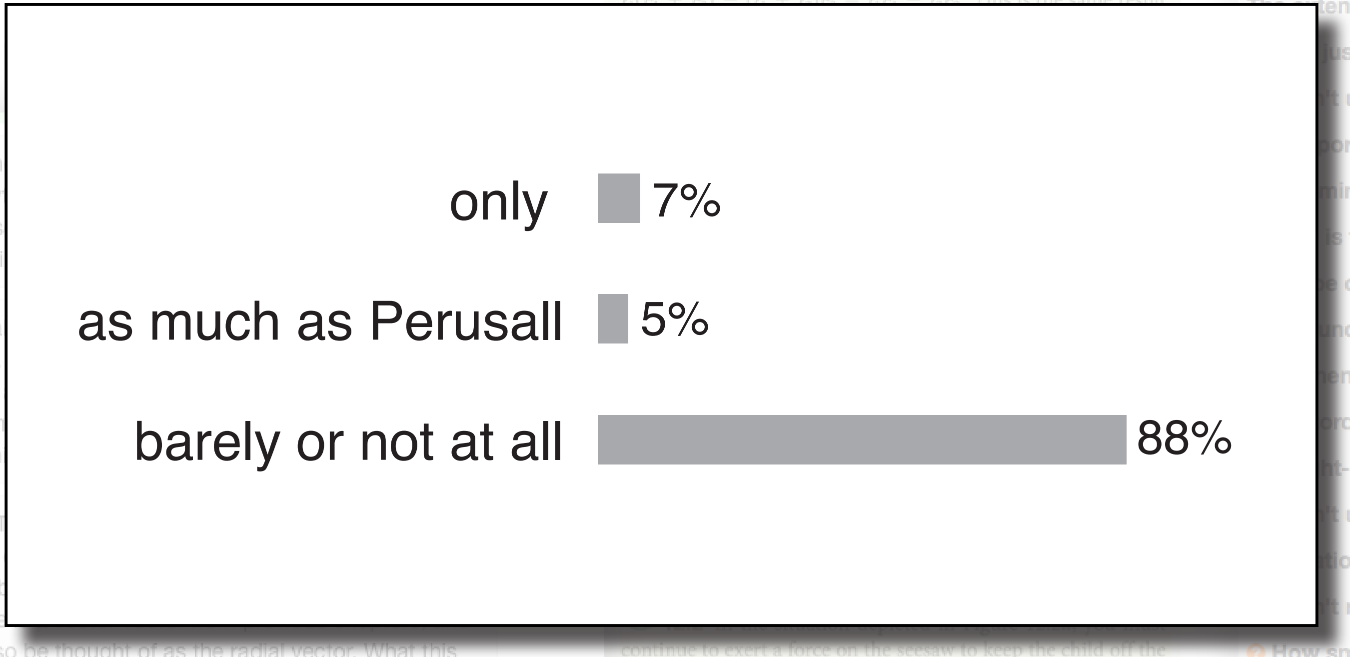

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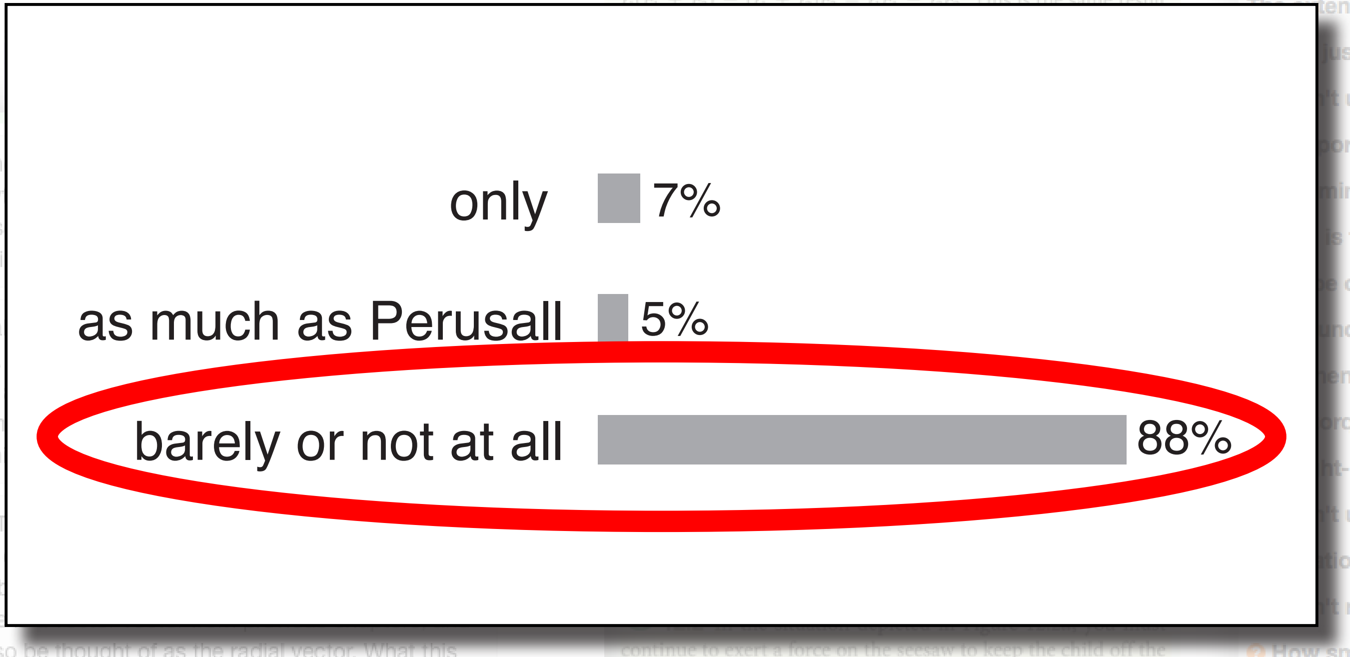

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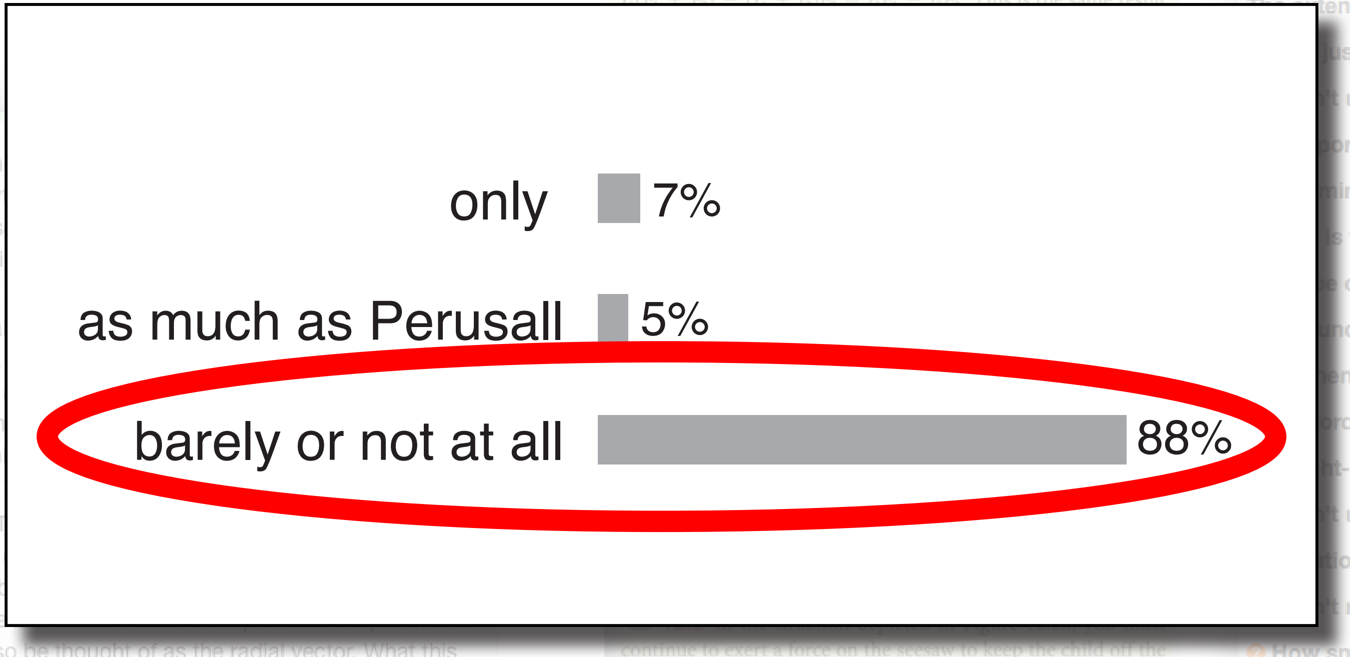

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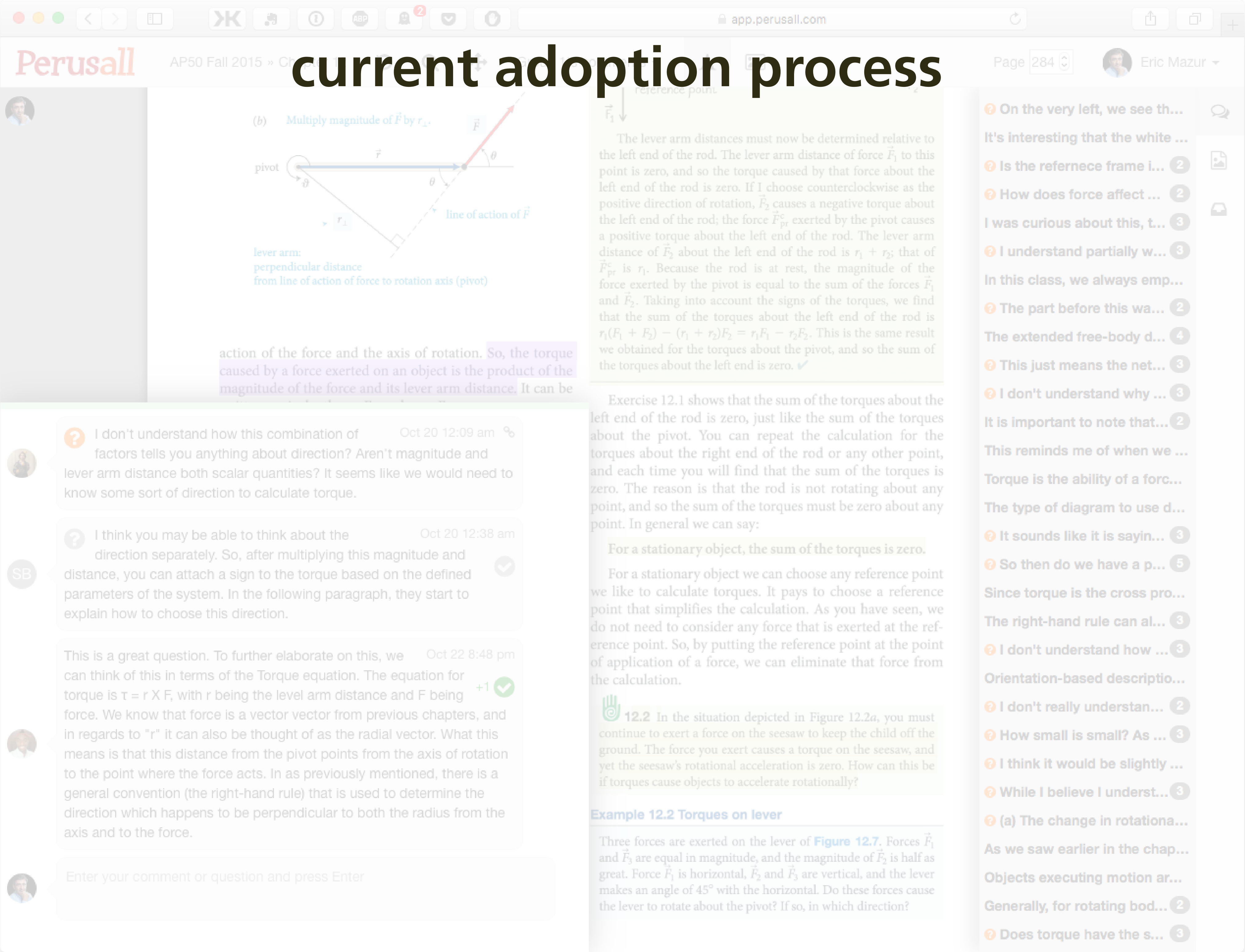

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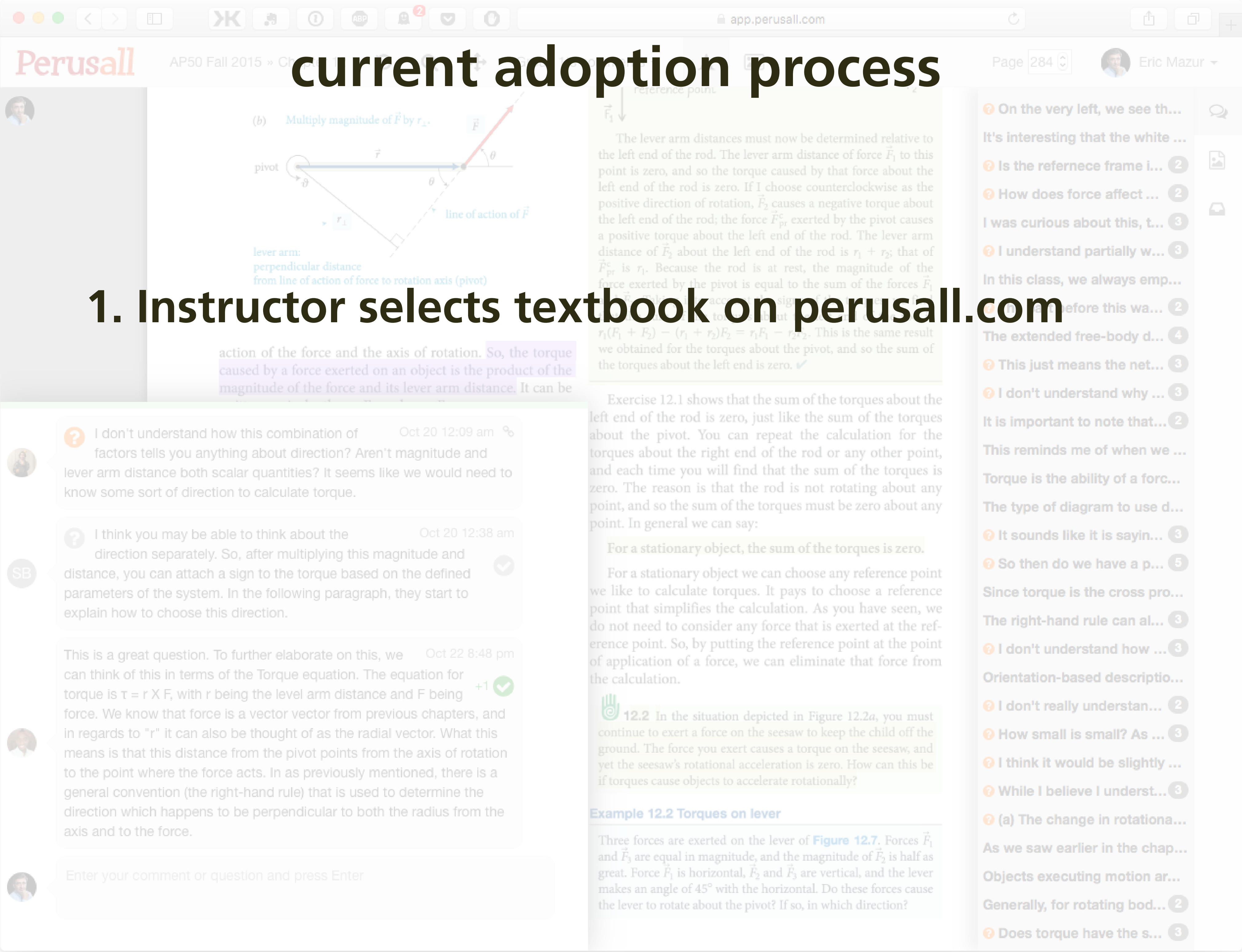

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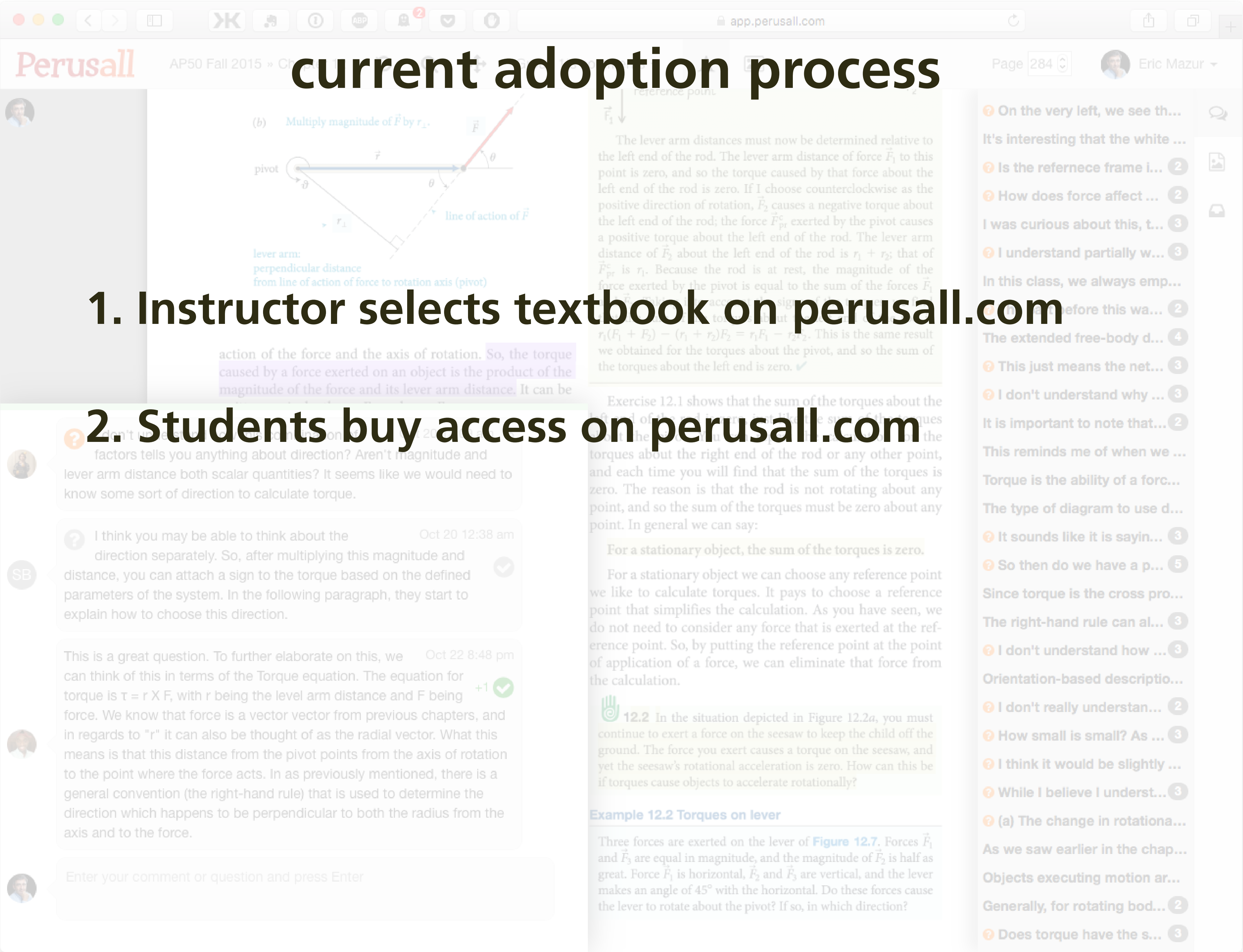

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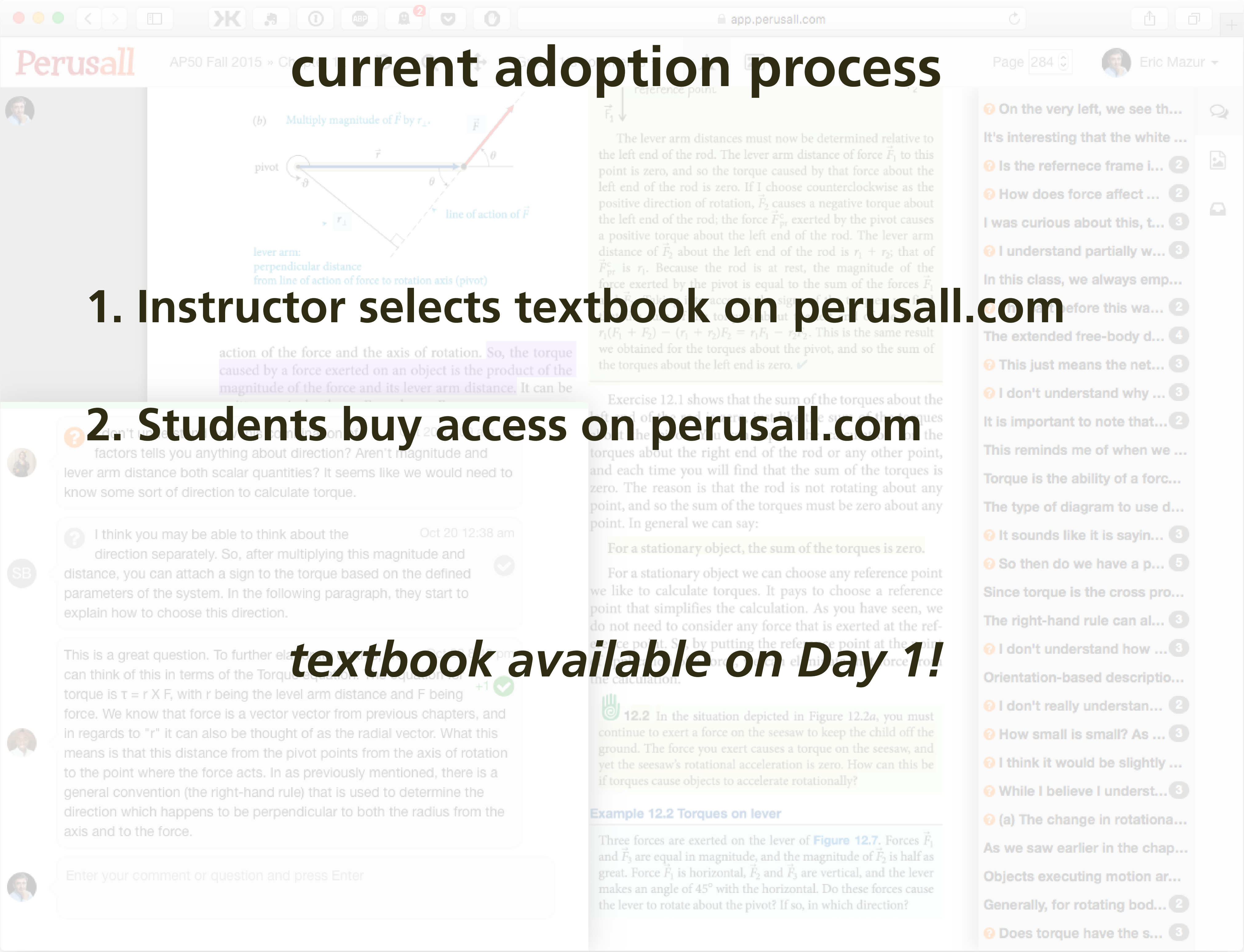

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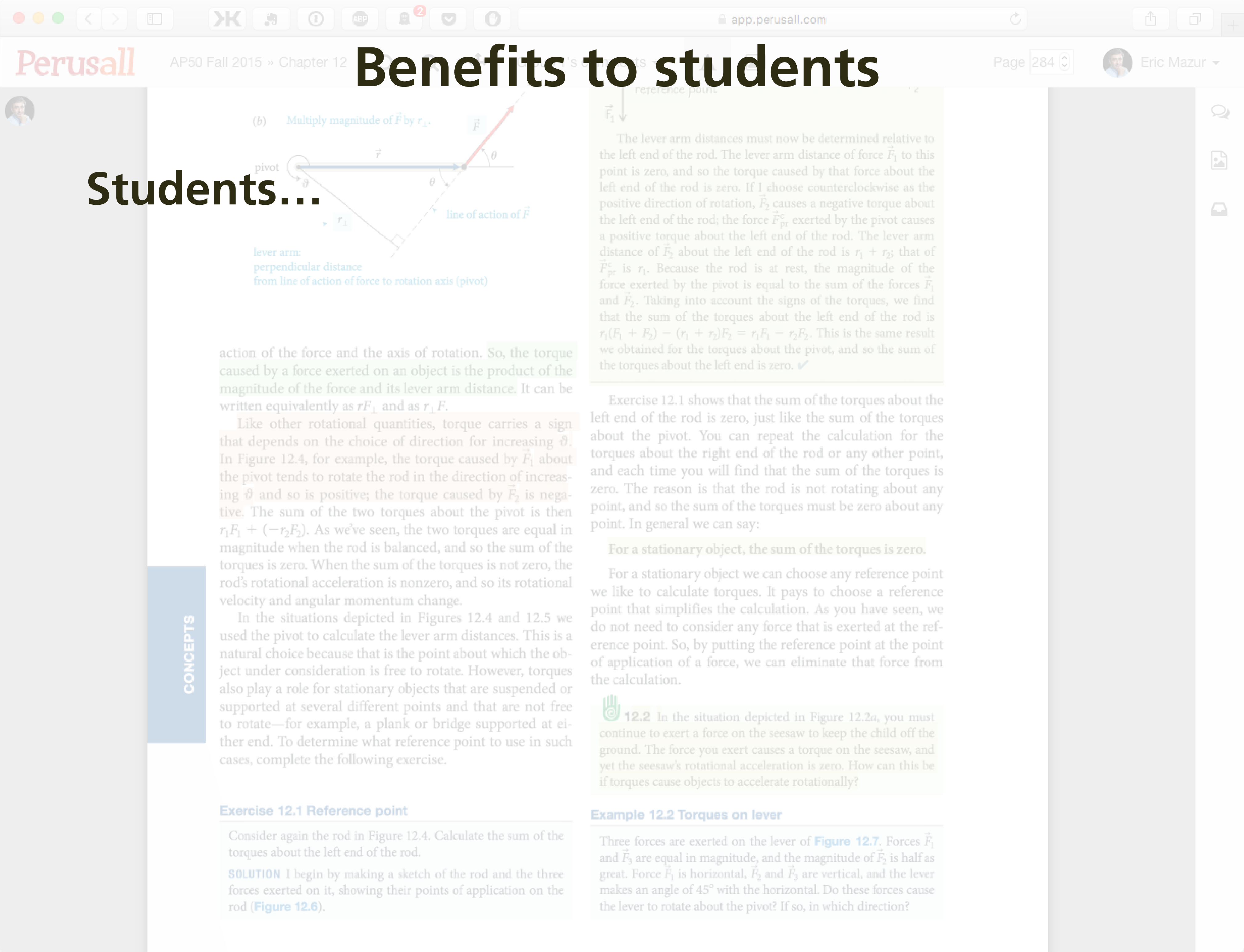

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Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing ϑ. In Figure 12.4, for example, the torque caused by $\vec{F}_1$ about the pivot tends to rotate the rod in the direction of increasing ϑ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

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

Exercise 12.1 Reference point

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

SOLUTION I begin by making a sketch of the rod and the three 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 $\vec{F}^c_{pr}$ 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 $\vec{F}^c_{pr}$ 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 12.2*a*, 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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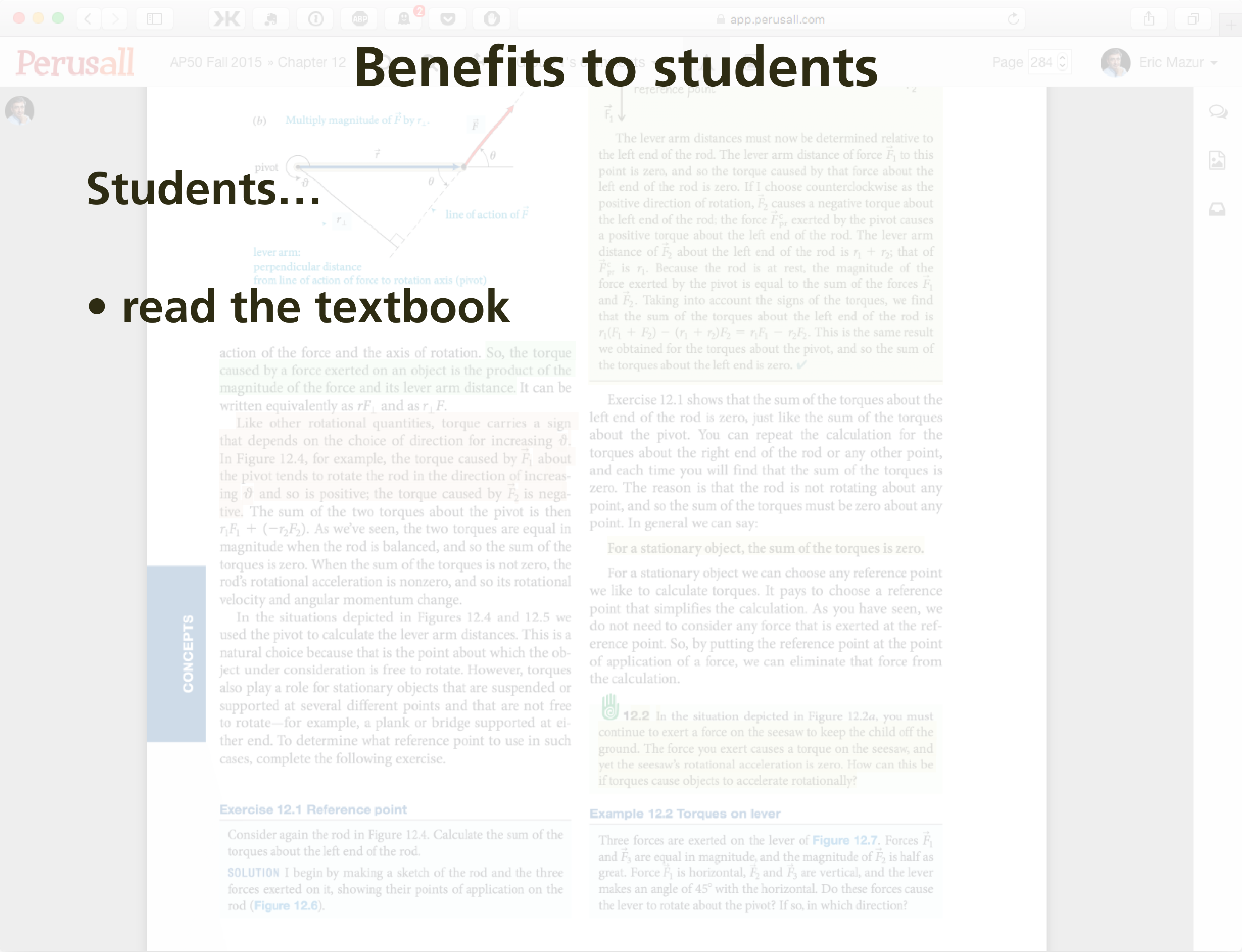
Three forces are exerted on the lever of **Figure 12.7**. Forces $\vec{F}_1$ and $\vec{F}_3$ are equal in magnitude, and the magnitude of $\vec{F}_2$ is half as great. Force $\vec{F}_1$ is horizontal, $\vec{F}_2$ and $\vec{F}_3$ are vertical, and the lever makes an angle of 45° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

Benefits to students

Students…

- read the textbook



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

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

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

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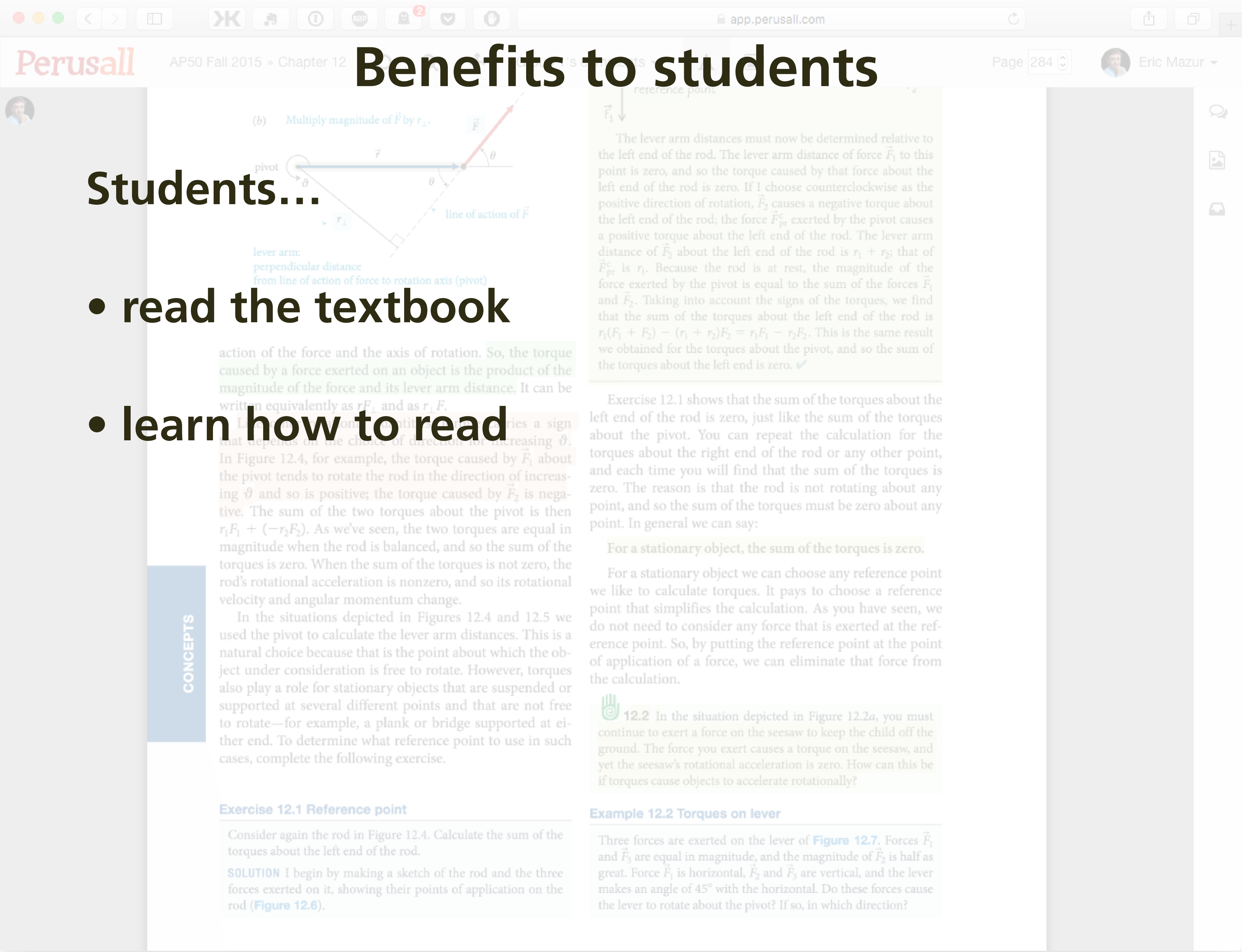
Benefits to students

Students…

- read the textbook
- learn how to read



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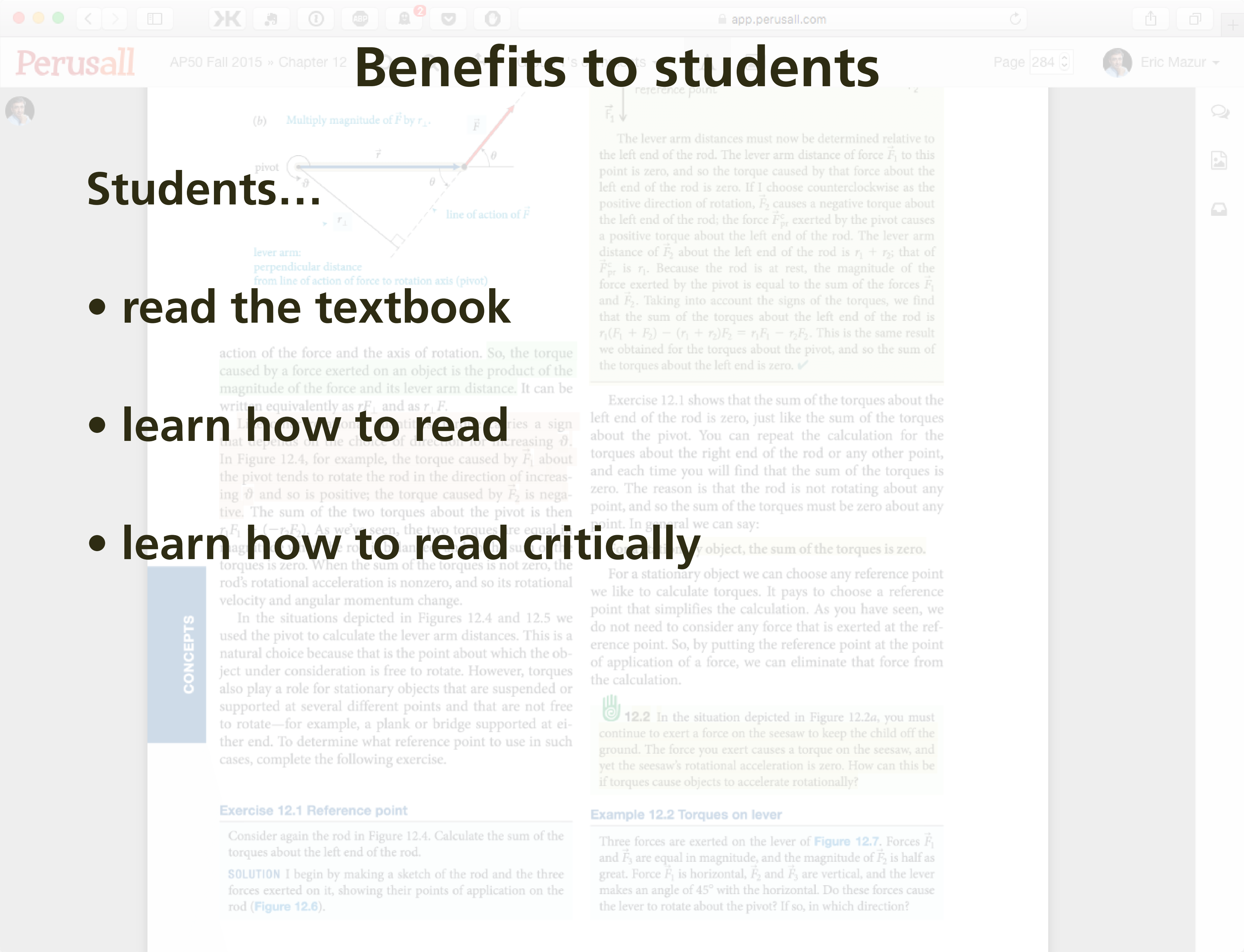
Benefits to students

Students…

- read the textbook
- learn how to read
- learn how to read critically



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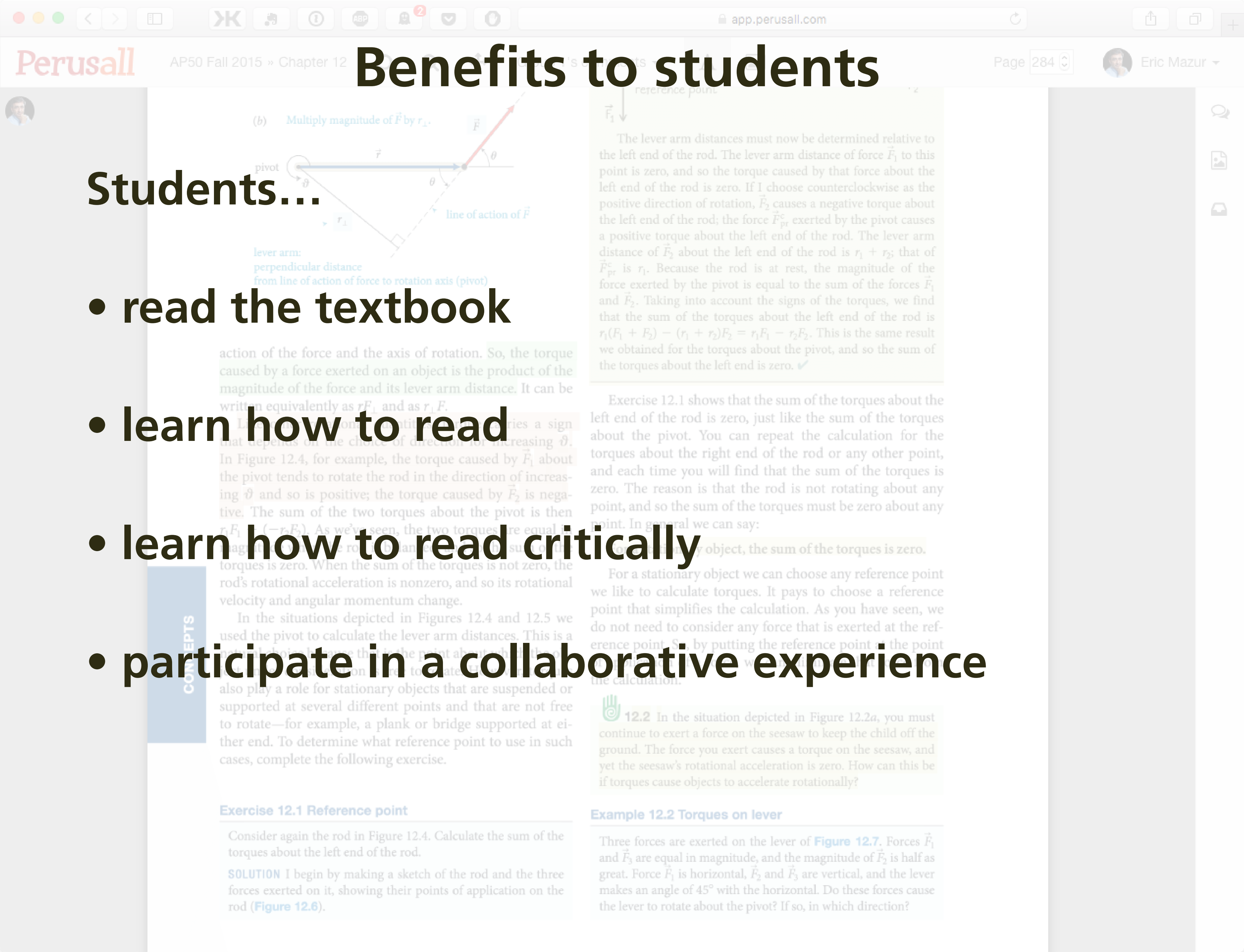
Benefits to students

Students…

- read the textbook
- learn how to read
- learn how to read critically
- participate in a collaborative experience



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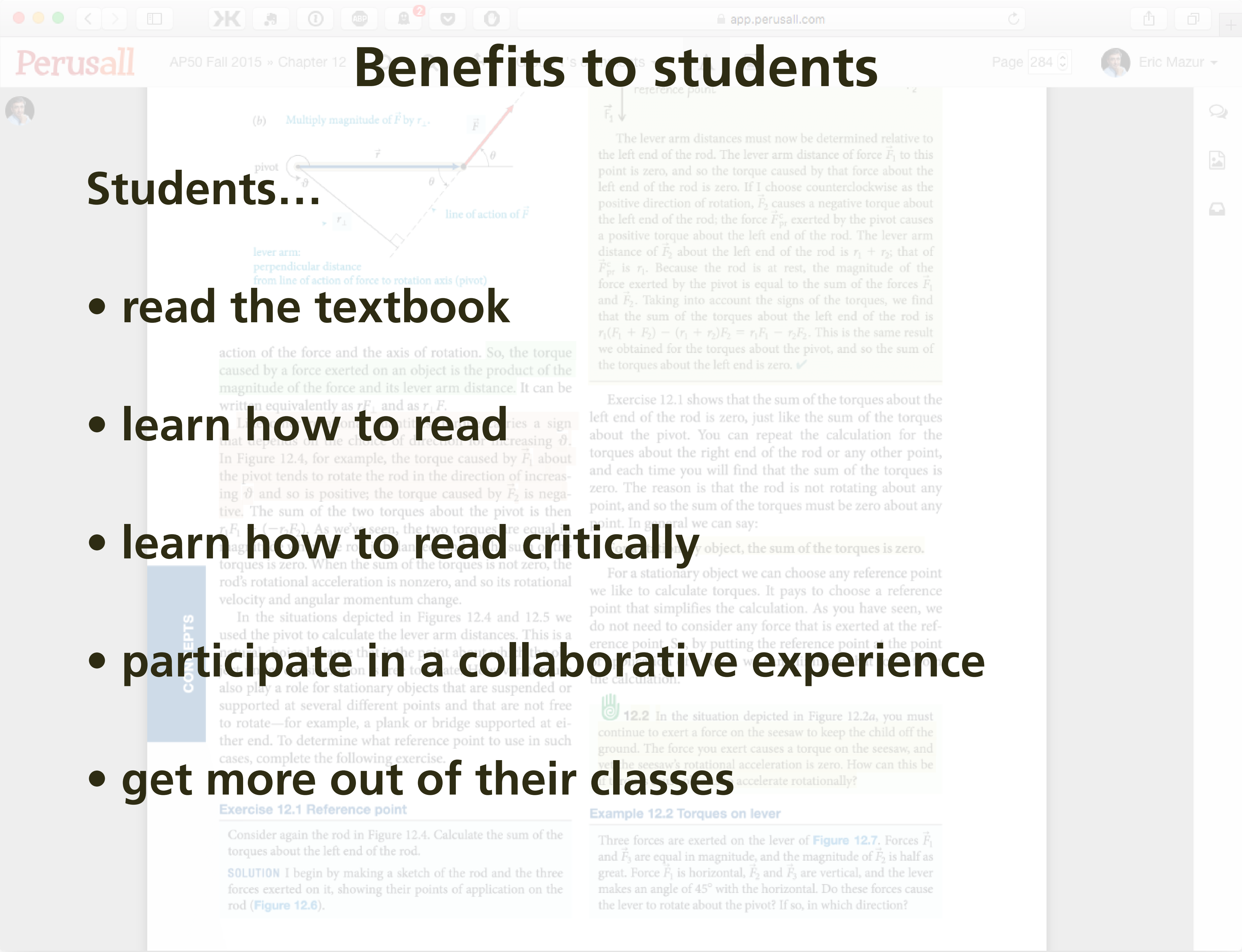
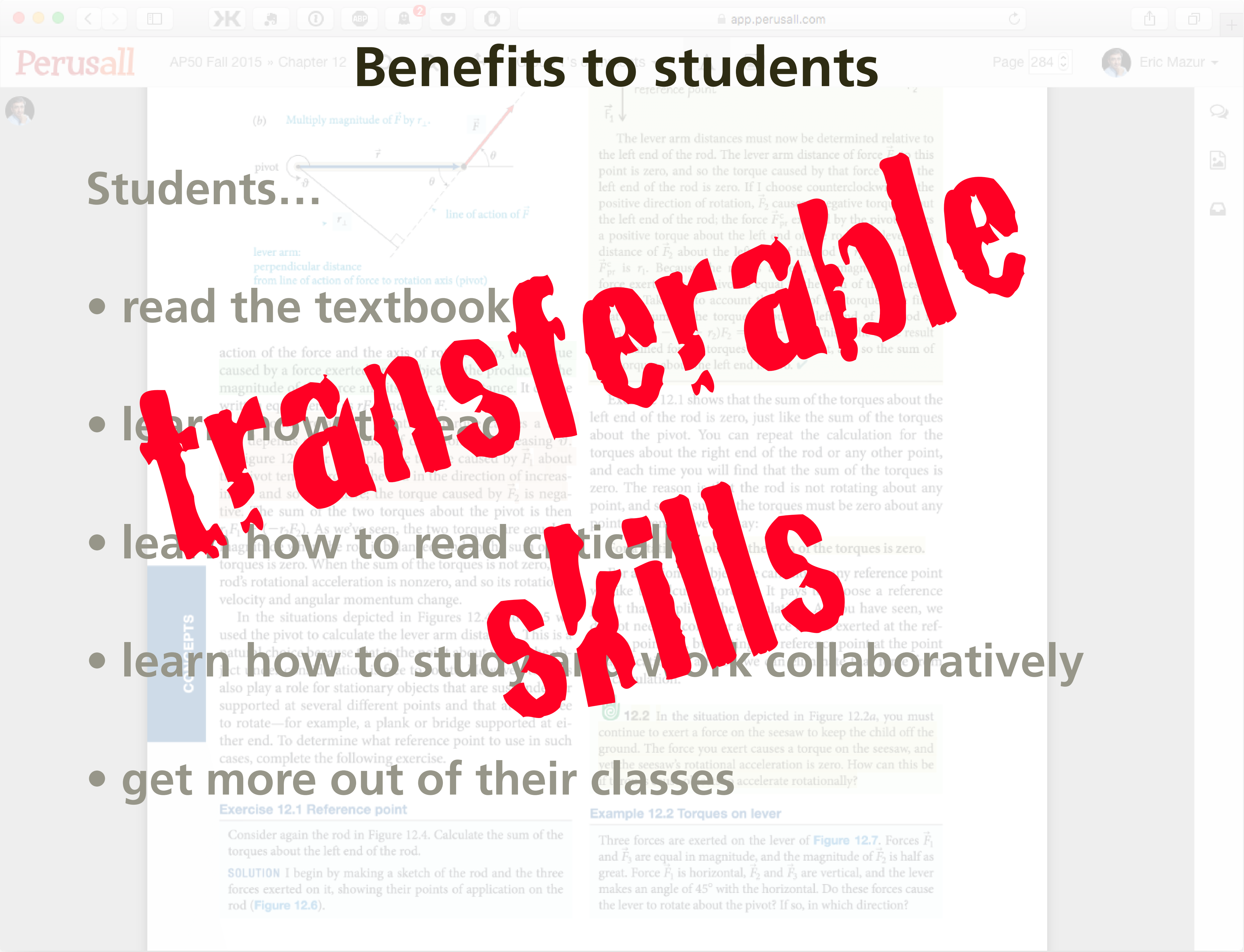
Benefits to students



Students…

- read the textbook
- learn how to read
- learn how to read critically
- participate in a collaborative experience
- get more out of their classes

Benefits to students



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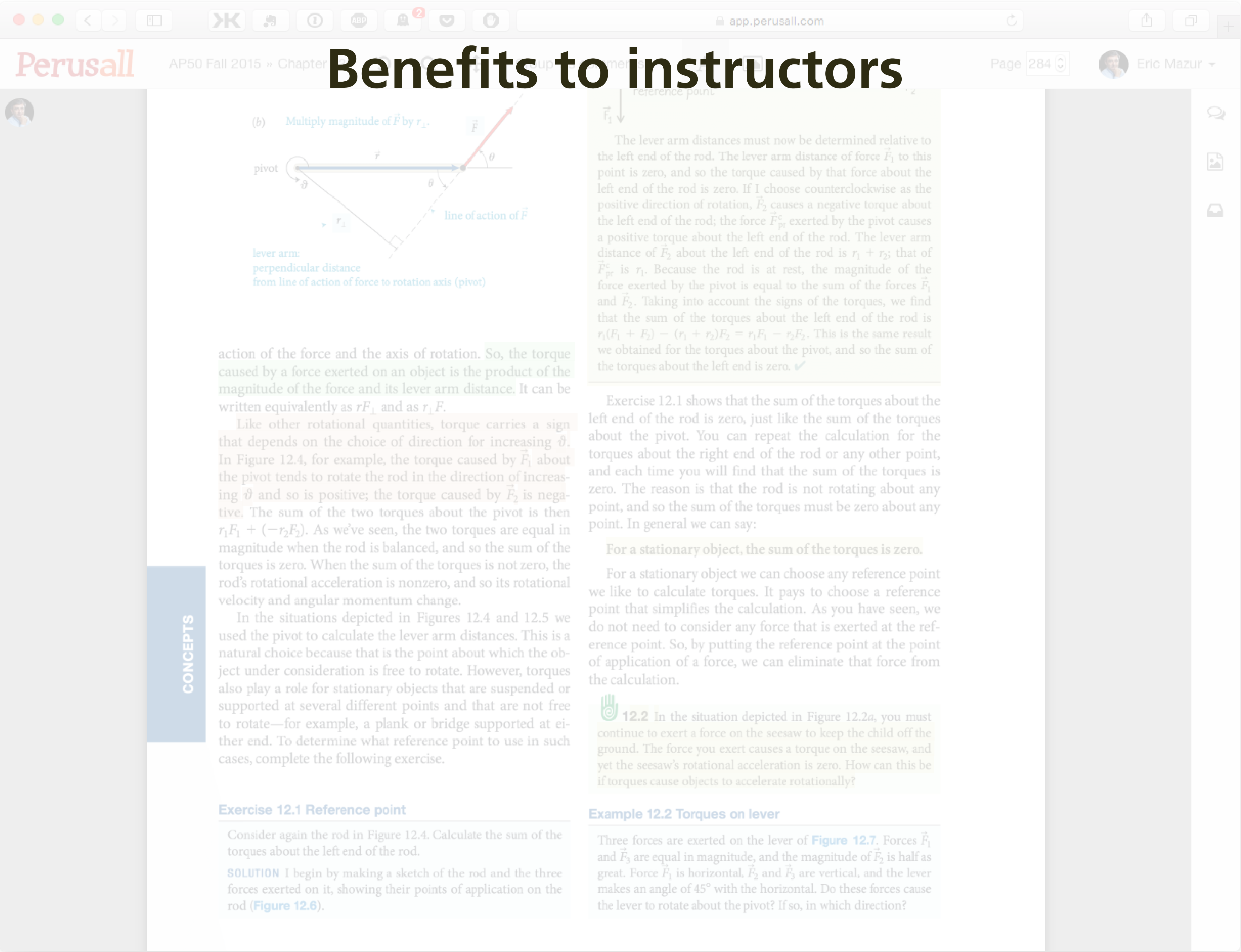
transferable skills

Benefits to instructors



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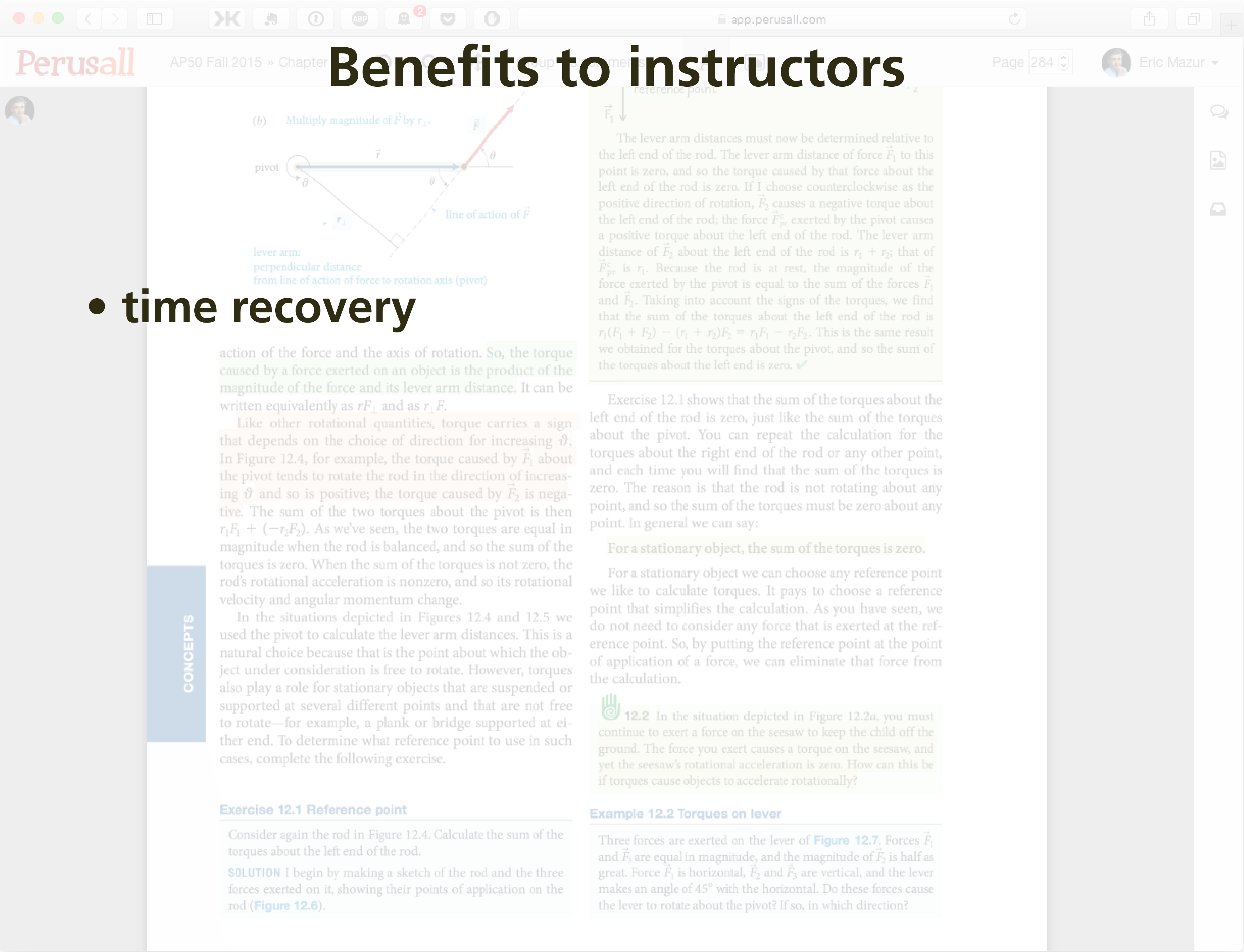
Benefits to instructors

- time recovery



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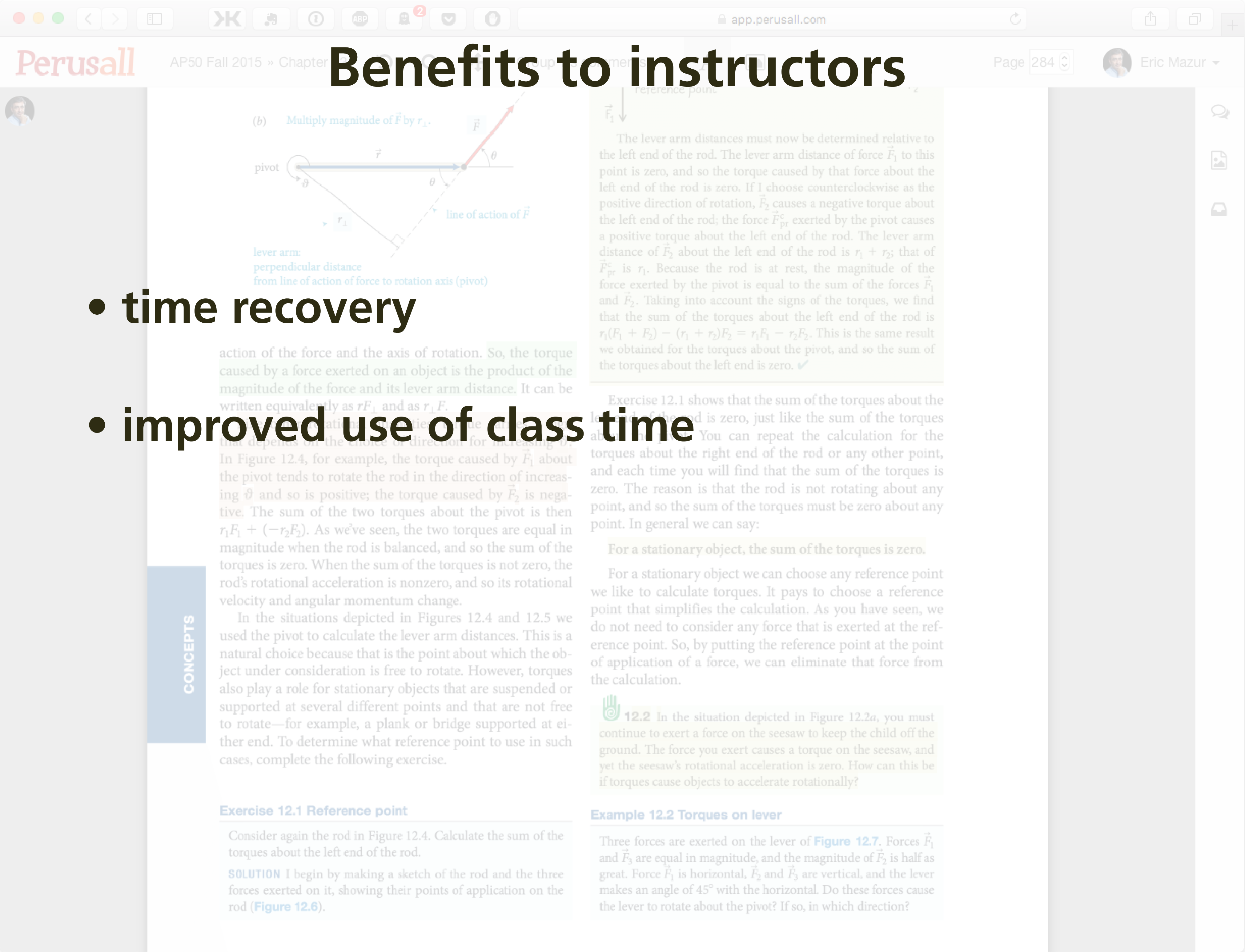
12.2 In the situation depicted in Figure 12.2*a*, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

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° with the horizontal. Do these forces cause the lever to rotate about the pivot? If so, in which direction?

Benefits to instructors

- time recovery
- improved use of class time



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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 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 $\vec{F}^c_{pr}$ 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 $\vec{F}^c_{pr}$ 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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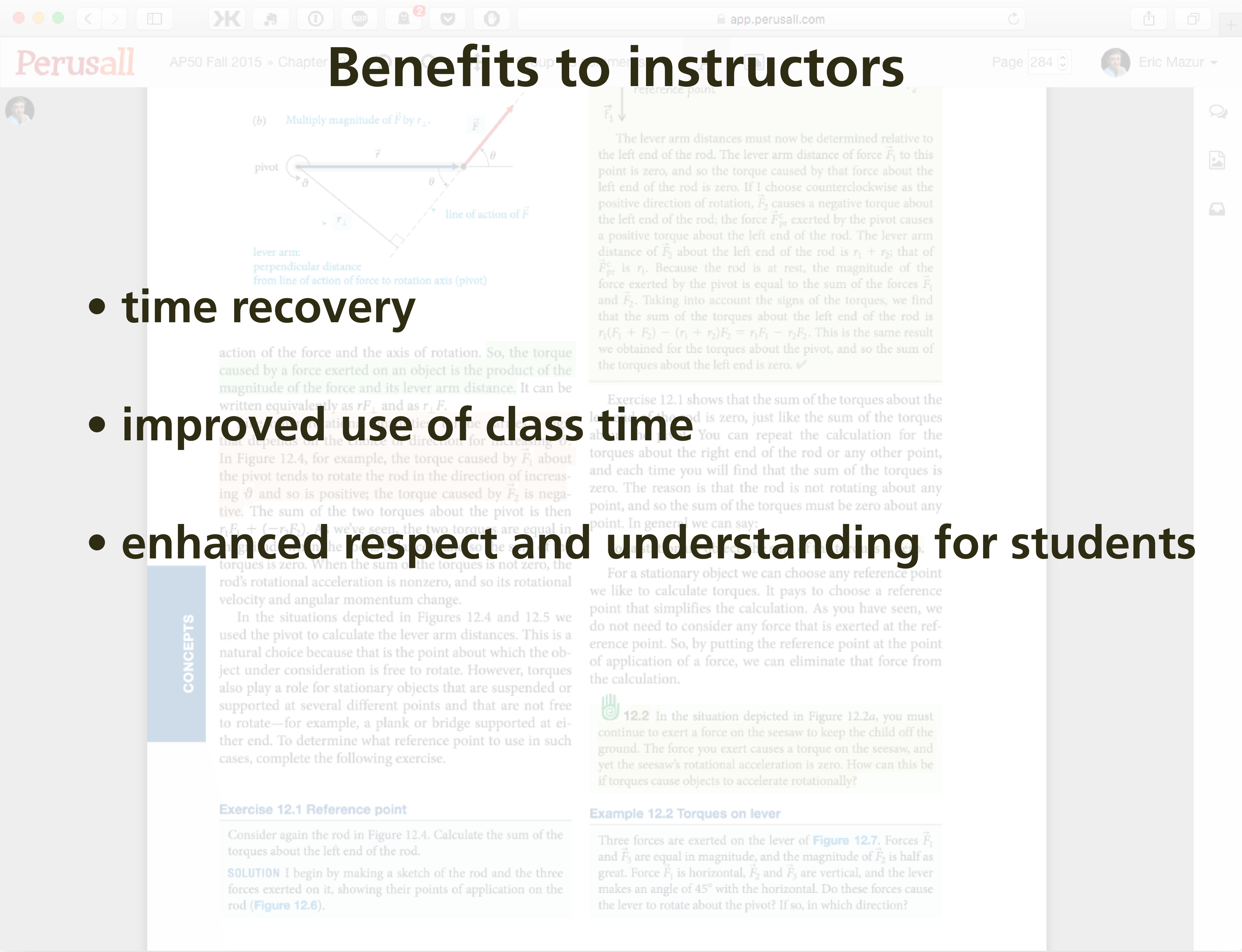
Benefits to instructors

- time recovery
- improved use of class time
- enhanced respect and understanding for students



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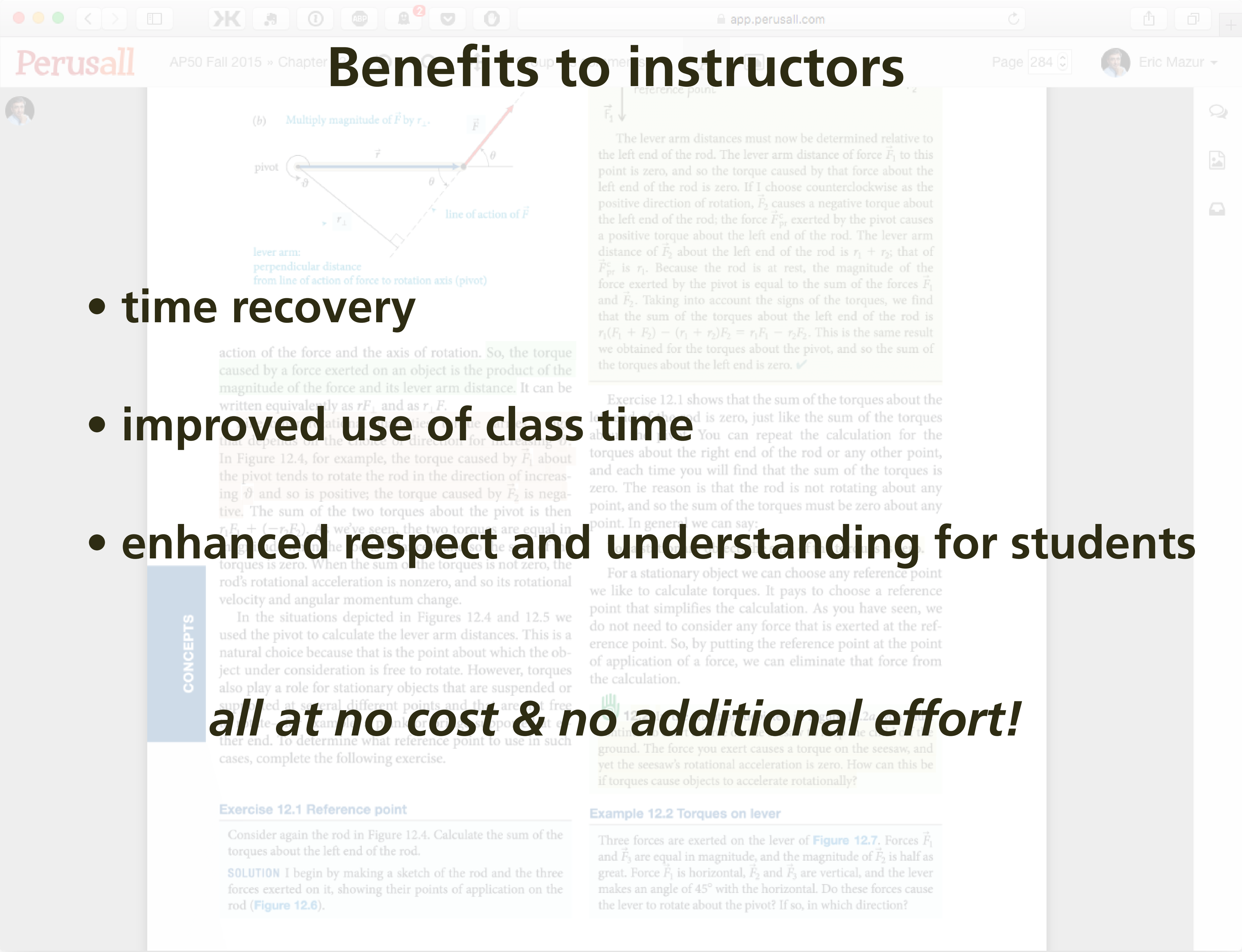
all at no cost & no additional effort!



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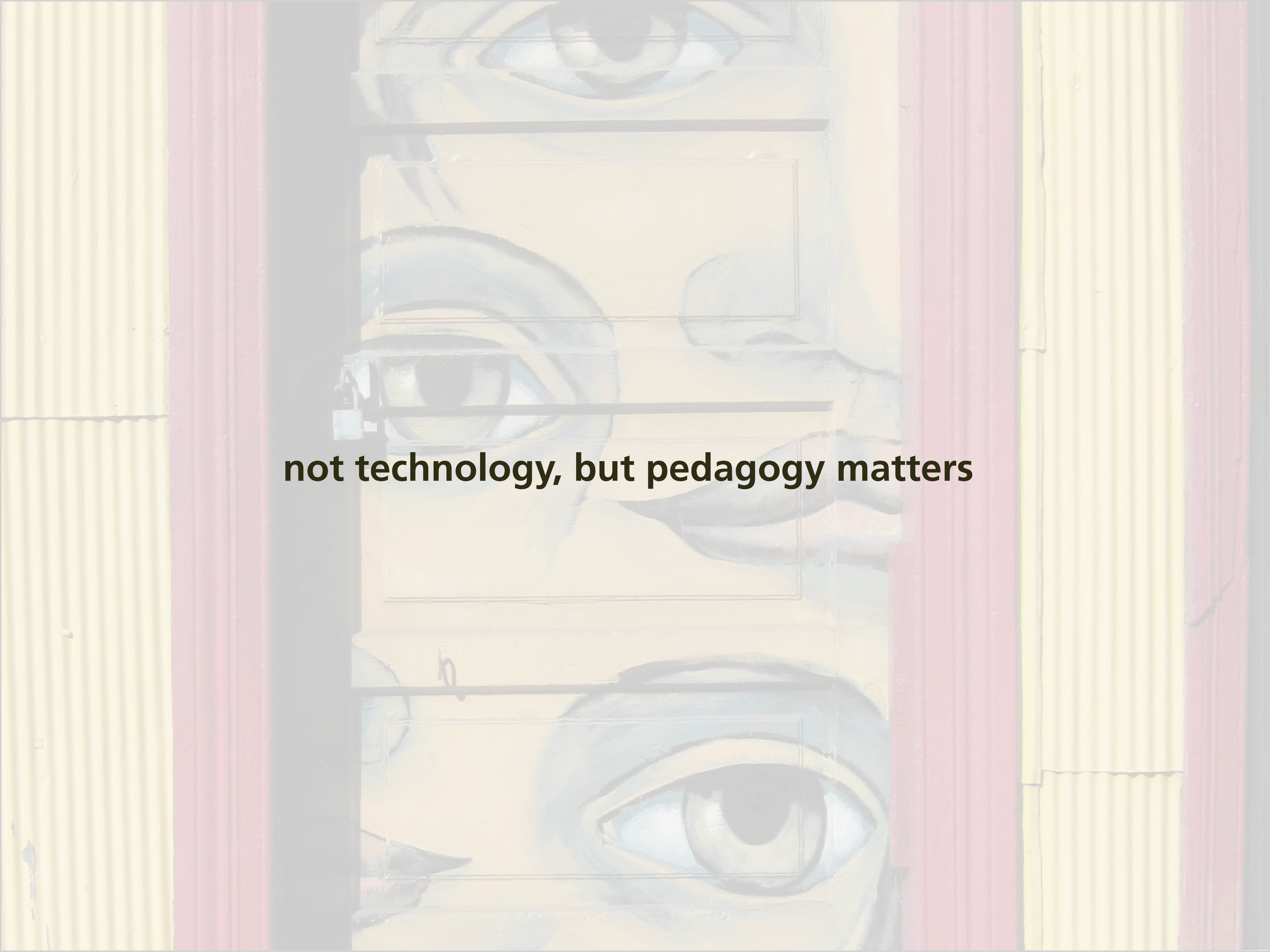

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