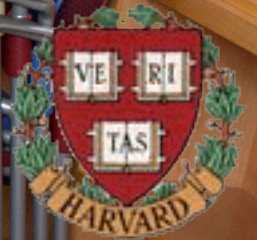


# Flat space, deep learning



Yale-NUS  
Singapore, 23 August 2016



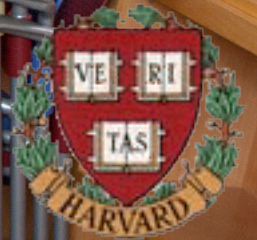


# Flat space, deep learning

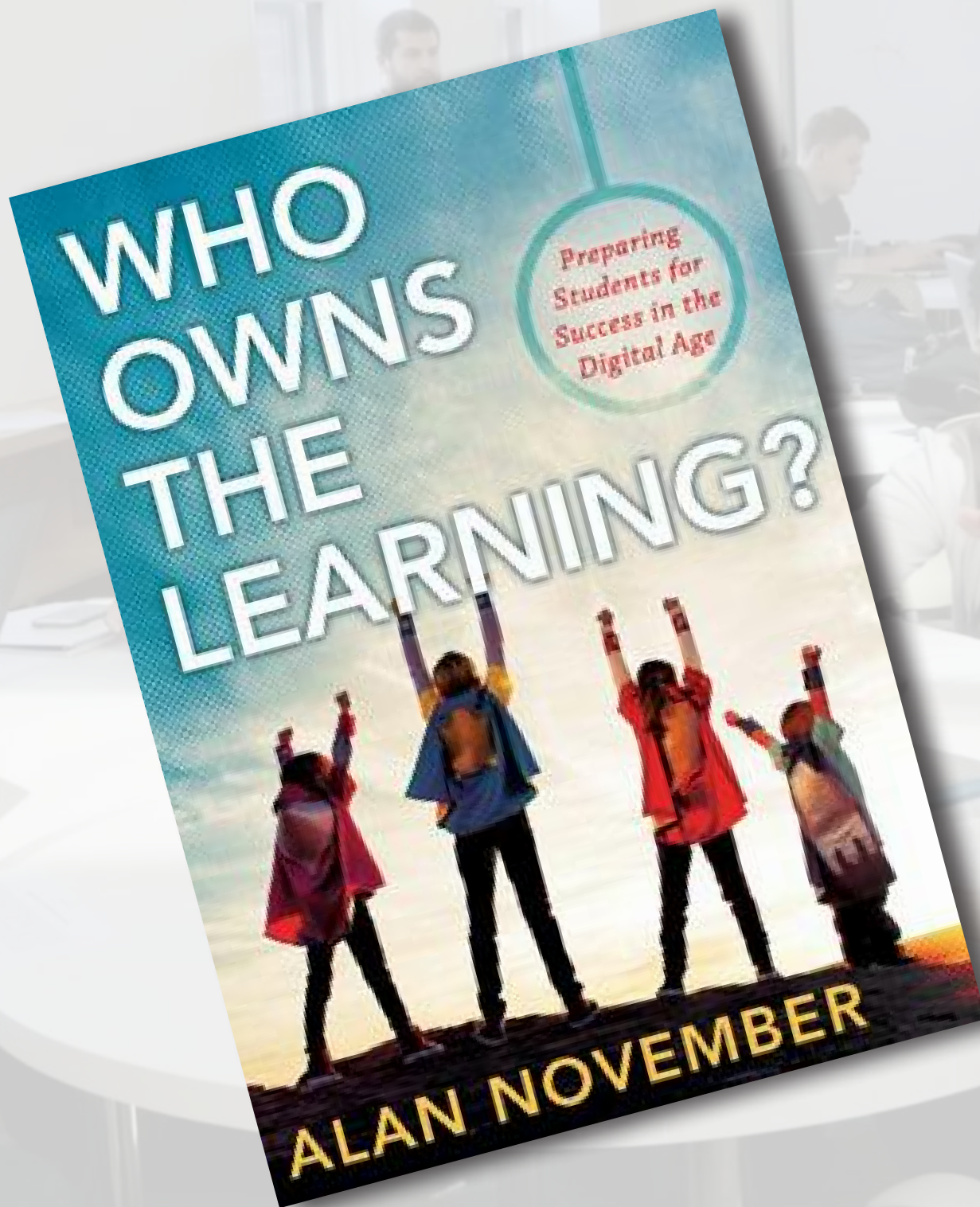


@eric\_mazur

Yale-NUS  
Singapore, 23 August 2016





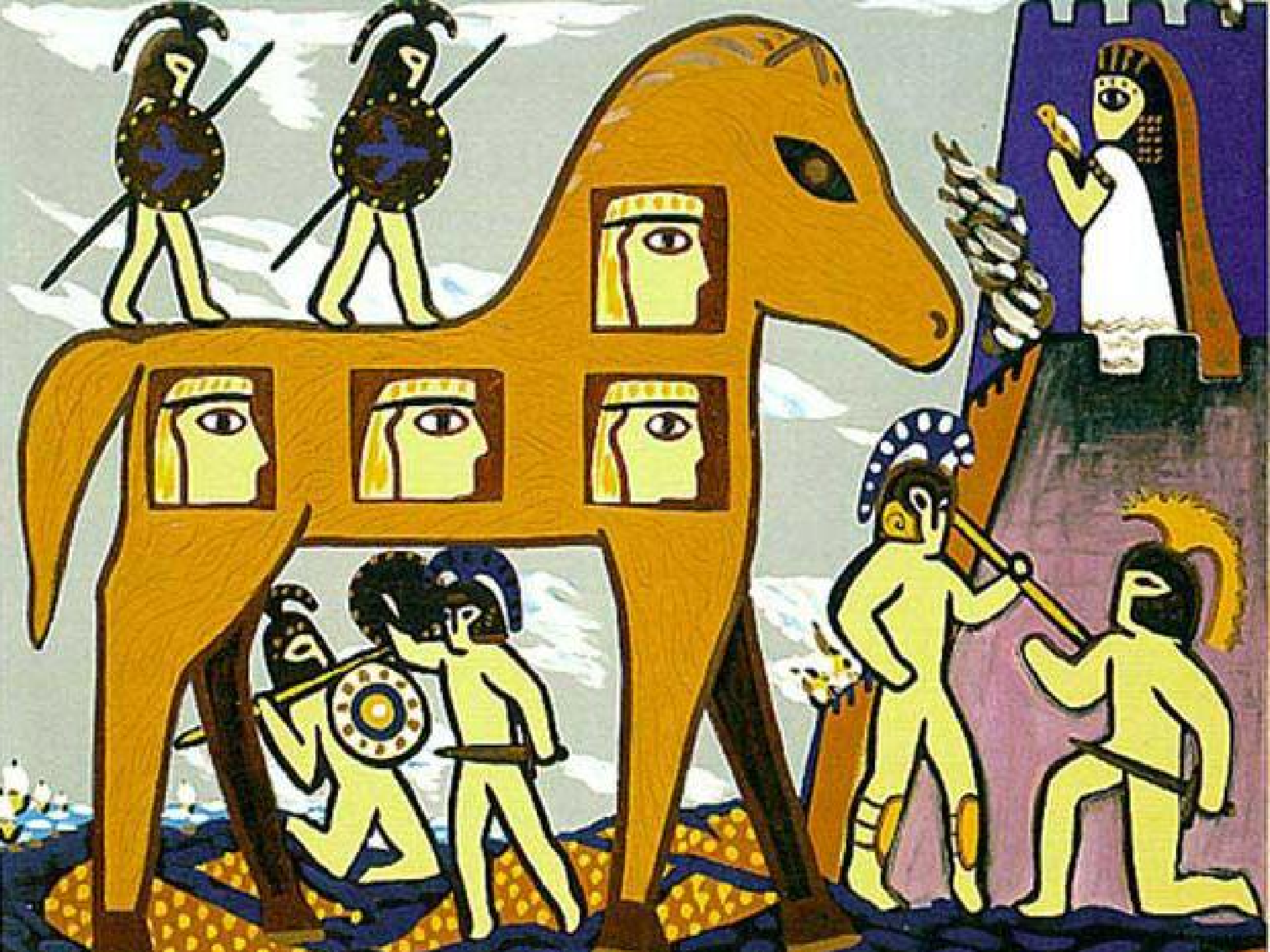






**Ownership of learning *physics*?**





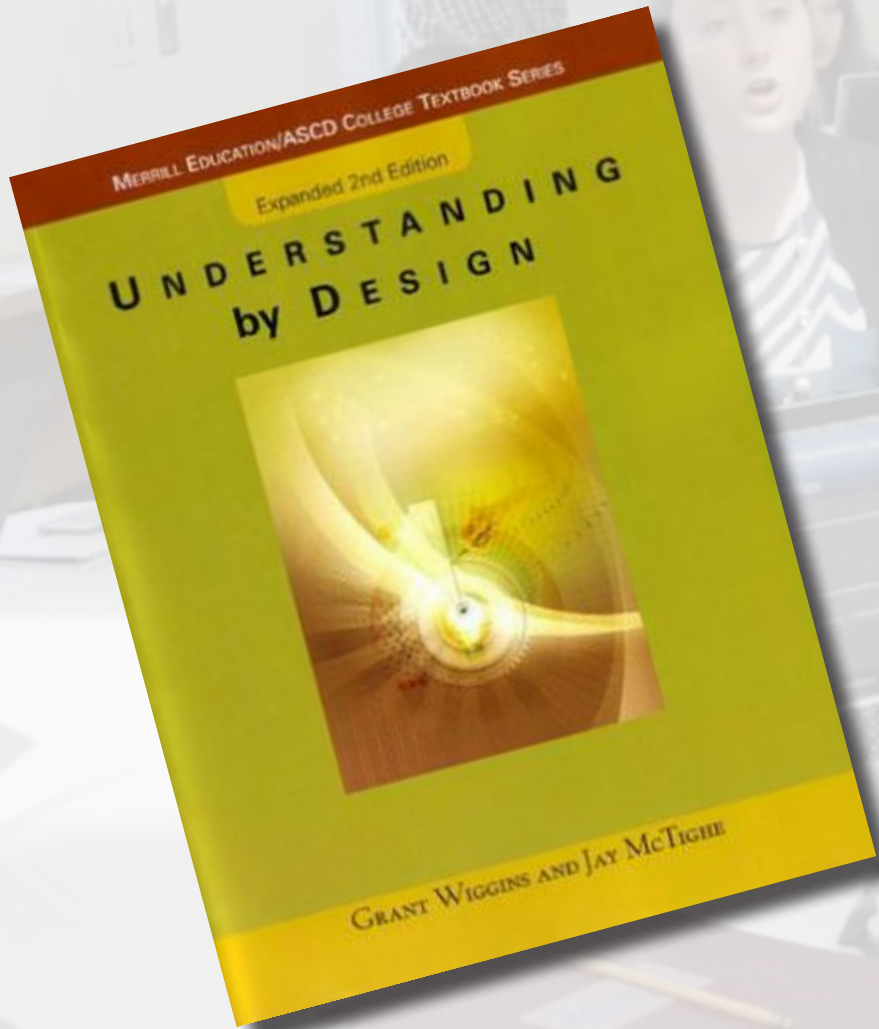


A stylized illustration of a Trojan Horse. The horse is a large, brown, horse-like shape with several rectangular windows or panels on its side, each containing a stylized face with a yellow headband and a large eye. Two figures in dark, patterned tunics and helmets stand on the horse's back, holding long spears. In the foreground, two figures in yellow tunics and helmets are engaged in combat; one is holding a shield with a circular pattern, and the other is holding a spear. To the right, a figure in a white tunic and a tall, pointed headdress stands on a dark, rocky outcrop, holding a staff or scepter. The background shows a city with a purple wall and a yellow tower. The overall style is reminiscent of ancient Greek or Roman art, with bold outlines and a limited color palette.

**team & project-based approach**



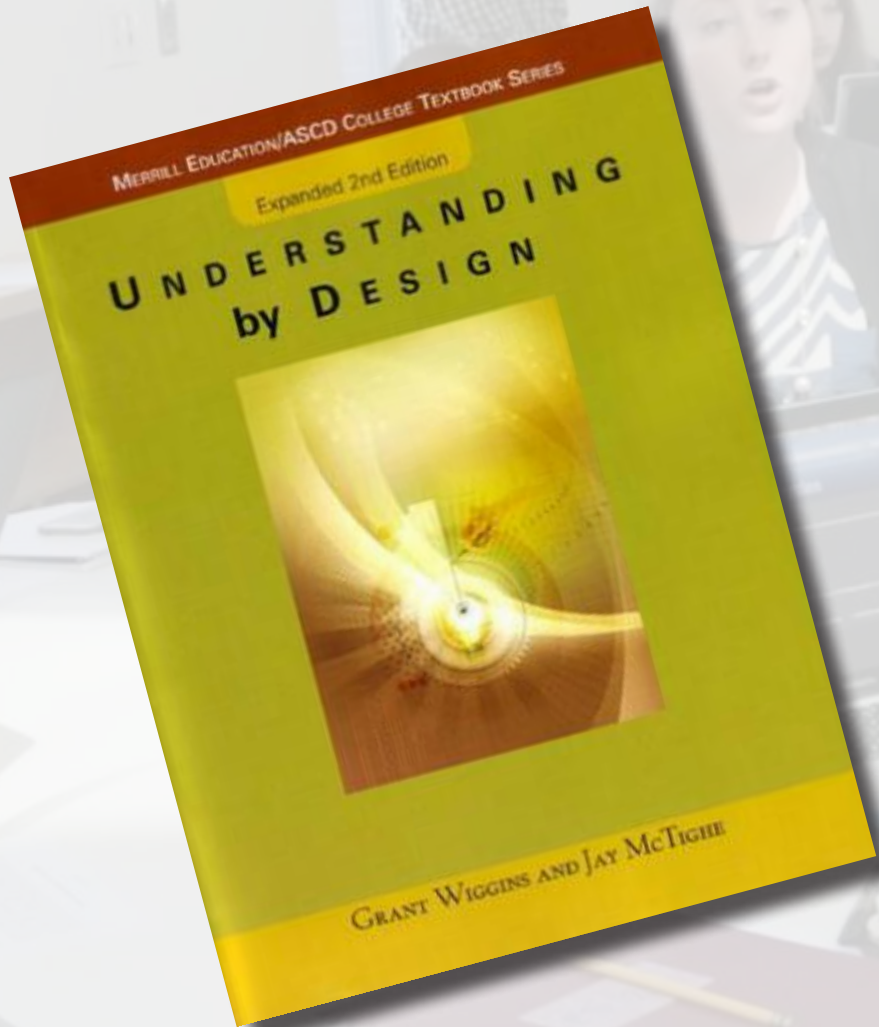
## Setting learning goals



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



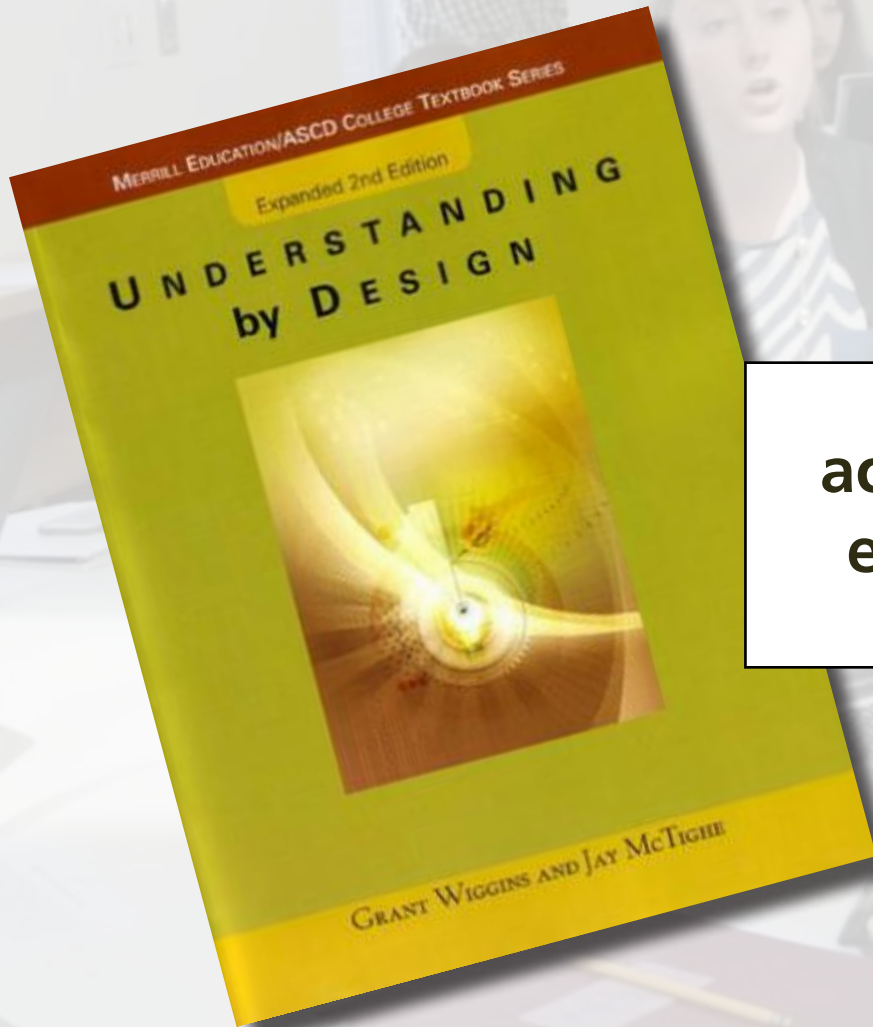
## Backward design



**desired  
outcomes**

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

## Backward design



acceptable  
evidence

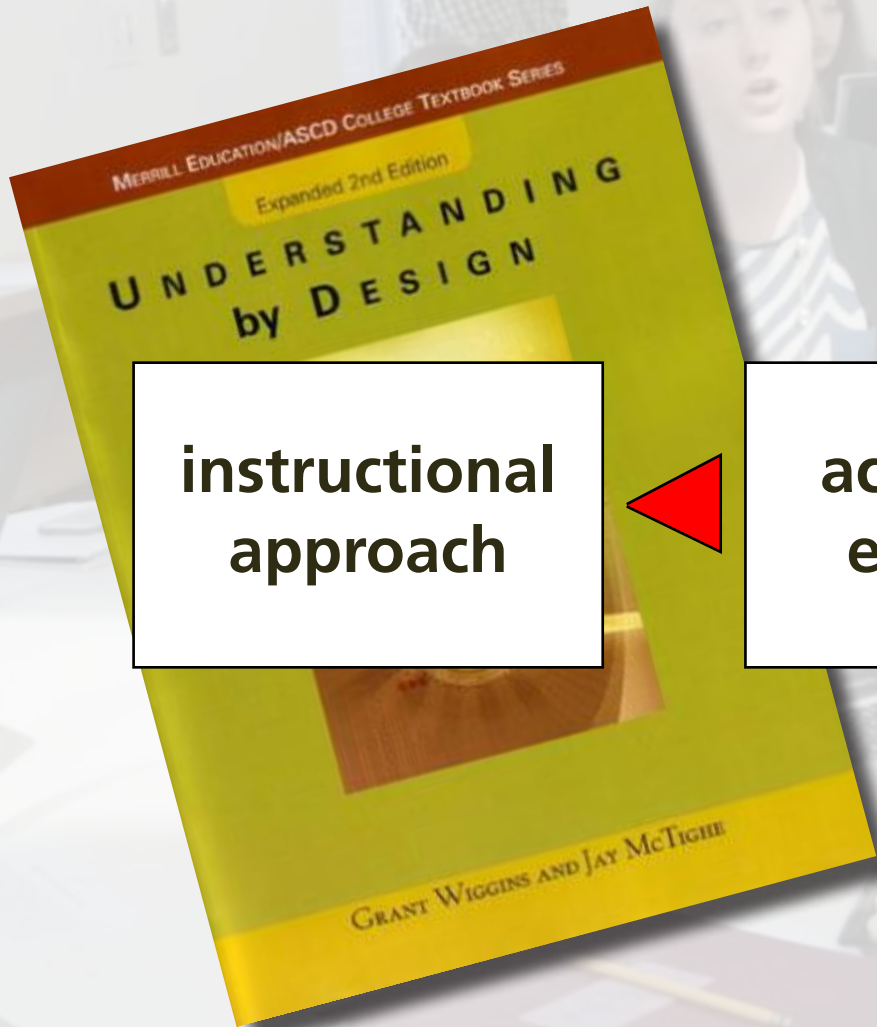


desired  
outcomes

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



## Backward design



**instructional  
approach**

**acceptable  
evidence**

**desired  
outcomes**

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

# competencies

- **Qualitative Analysis:** The ability to analyze and solve problems in science disciplines qualitatively, including estimation, analysis with uncertainty and visual thinking.
- **Quantitative Analysis:** The ability to analyze and to solve problems in science disciplines quantitatively, including use of appropriate tools, quantitative solving, and experimentation.
- **Diagnosis:** The ability to identify and resolve problems within identification, formation and testing of a hypothesis, and recommendation.
- **Design:** The ability to develop creative, effective designs that creation, problem formulation, application of other competencies which integrate knowledge, beliefs and modes of inquiry from contributing to contribute effectively in a variety of approaches and contributions. You will develop approaches and



# COURSE GOALS

After successful completion of this course, you

## course goals

1. Engage in **self-directed learning** by:

- identifying and addressing your own educational needs in a changing personal attributes, fluency in use of information sources, planning
- using independent study and research to tackle problems, especially using a variety of techniques to get a handle on problems: represent
- perform order of magnitude estimates, use dimensional analysis
- symmetries, evaluate limitations and/or relate the problem to cases
- explaining and justify any assumptions made
- “thinking critically,” both positively and negatively, about any
- evaluating the correctness of a solution

2. Demonstrate **content mastery** by:

- meeting the content learning goals specified in the project
- applying your knowledge of physics to solve problems
- using data, analyzing, and interpreting them

by: ... on diverse

# COURSE GOALS

After successful completion of this course, you

- **self-directed learning**
- **content mastery**
- **team work**
- **professionalism**

2. Demonstrate **content mastery** by:

- meeting the content learning goals specified in the project
- applying your knowledge of physics to solve problems
- using data, analyzing, and interpreting them



## content-specific goals

- Conduct fundamental experiments on electrostatic interaction and the two types of charge.
- Explain quantization and conservation of charge.
- Describe the observations supporting the quantization and conservation of charge.
- Define and give examples of insulators and conductors.
- Describe how the charge carriers behave in insulators and conductors.
- Explain polarization and how it gives rise to an electric force on a neutral object.
- Describe what happens at the atomic level when a conductor (insulator) is polarized by induction.
- Describe and explain the process of charging by induction.
- Use Coulomb's law to calculate or estimate the electric force that a given charge distribution exerts on a charged particle.
- Explain the conditions in which Coulomb's law is valid.
- Explain what a field is and give examples of scalar and vector fields.
- Draw vector field diagrams for a simple distribution of charged particles.
- Describe a vector field by means of vector diagrams and vector functions.
- Explain the electric field.
- Explain the relationship between the electric field concept and the insulating material.
- Determine the electric field.

<http://bit.ly/ap50visitor>







information transfer

faculty-centered








A large, bright, modern classroom with a high ceiling and exposed wooden beams. Students are seated at white tables, some using laptops. A teacher is standing and interacting with a group of students. The room has large windows and a high ceiling with exposed wooden beams and modern lighting fixtures. The text "interaction" and "student-centered" is overlaid in red, bold, sans-serif font.

**interaction**  
**student-centered**



**no lectures**

**no exams**





**CLASS**

**1st exposure**



**ROOM**

**deeper understanding**



**CLASS**

1st exposure



**ROOM**

deeper understanding



**ROOM**

1st exposure



**CLASS**

deeper understanding



**CLASS**

1st exposure

**ROOM**

deeper understanding

**ROOM**

1st exposure

**CLASS**

deeper understanding





**CLASS**

1st exposure

**ROOM**

deeper understanding

**ROOM**

1st exposure

**CLASS**

deeper understanding

**1** information transfer

**2** projects



**CLASS**

1st exposure

**ROOM**

deeper understanding

**ROOM**

1st exposure

**CLASS**

deeper understanding

**1** information transfer

**2** projects

**3** in-class activities



**1** information transfer



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, and purple. They are all facing forward, and some are holding pens or pencils. The desks are white, and the background is a light, neutral color.

**Solution**

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

**1 information transfer**

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

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



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



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

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

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



## 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. Eventually, it comes to rest. The rougher the surface, the sooner the block stops. On a very smooth 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 concrete.

the velocity of a wooden block sliding on three different surfaces. The rougher the surface, the more quickly the velocity decreases. The effect of friction is to bring two objects to rest with respect to each other—in this case the wooden block and the surface it is sliding on. The less friction there is, the longer it takes for the block to come to rest.

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



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



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, would continue to move forever. There is no such thing as a frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air creates a cushion on which a conventional cart with friction between the wheels and the track can move. Alternatively, one can use bearings on an ordinary cart. On the low-friction carts you may have encountered in physics labs, though there is still some friction. For the track shown in Figure 4.2, the friction is so small that it can be ignored.

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.

log in through social network



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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.

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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 distance can be quite different. If the surfaces are 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 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.



## 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.

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

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You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction track—a track whose surface is dotted with little holes through which pressurized air blows. The air serves as a cushion on which a conveniently shaped object can float, with friction between the object and the track all but eliminated. Alternatively, one can use wheeled carts with low-friction bearings on an ordinary track. Figure 4.2 shows the low-friction track and carts used in the experiments described in this chapter. In your book, you will find a photograph of the low-friction track and carts used in the experiments described in this chapter. In other words:

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

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

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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 compressed 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:

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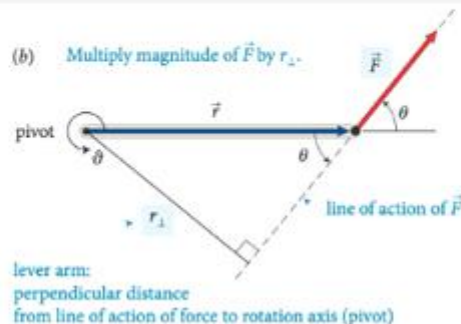
Another advantage of using such carts is that the track constrains the motion to being along a straight line. We can then use a high-speed camera to record the cart's position at various instants, and from that information determine its speed and acceleration.

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

Nov 1 4:41 pm

Enter your comment or question and press Enter





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

Like other rotational quantities, torque carries a sign that depends on the choice of direction for increasing  $\theta$ . 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  $\theta$  and so is positive; the torque caused by  $\vec{F}_2$  is negative. The sum of the two torques about the pivot is then  $r_1 F_1 + (-r_2 F_2)$ . As we've seen, the two torques are equal in magnitude when the rod is balanced, and so the sum of the torques is zero. When the sum of the torques is not zero, the rod's rotational acceleration is nonzero, and so its rotational velocity and angular momentum change.

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

#### Exercise 12.1 Reference point

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

**SOLUTION:** I begin by making a sketch of the rod and the three

reference point

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

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

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

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

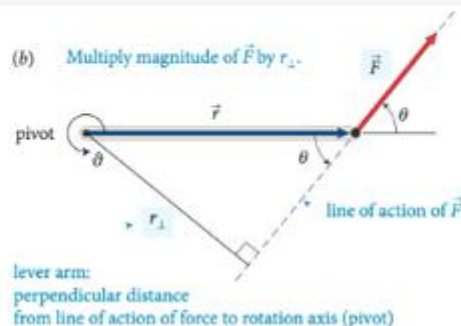


**12.2** In the situation depicted in Figure 12.2a, you must continue to exert a force on the seesaw to keep the child off the ground. The force you exert causes a torque on the seesaw, and yet the seesaw's rotational acceleration is zero. How can this be if torques cause objects to accelerate rotationally?

#### Example 12.2 Torques on lever

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



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

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

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:

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

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



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

### Example 12.2 Torques on lever

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

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

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

? This is a great question. To further elaborate on this, we can think of this in terms of the Torque equation. The equation for torque is  $\tau = r \times F$ , with  $r$  being the level arm distance and  $F$  being force. We know that force is a vector from previous chapters, and in regards to " $r$ " it can also be thought of as the radial vector. What this means is that this distance from the pivot points from the axis of rotation to the point where the force acts. In as previously mentioned, there is a general convention (the right-hand rule) that is used to determine the direction which happens to be perpendicular to both the radius from the axis and to the force. Oct 22 8:48 pm

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

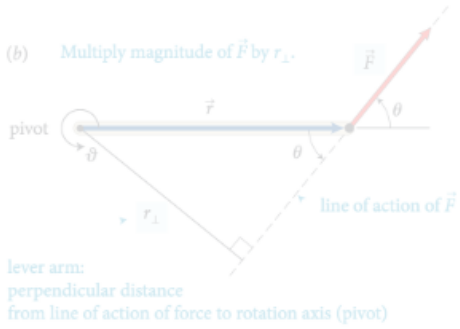
reference point

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



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

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

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 the lever arm distance.

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. ✓

use combination of intrinsic and extrinsic motivation drivers

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



## 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 rotation. So, the torque caused by a force  $\vec{F}$  is the product of the magnitude of the force and the lever arm distance. It can be written as

- quantity (minimum)

understand the concept of torque. Aren't the magnitude and direction of the force and the distance from the pivot to the point of application of the force enough to determine the torque? Why do we need to know the direction of the force and the distance from the pivot to the point of application of the force?

- timeliness (before class)

distance, you can attach a sign to the torque based on the defined parameters of the system. In the following paragraph, they state the sign convention for torque. Explain how to choose this direction.

- distribution (not consistent)

This is a great question. To further understand torque, we can think of this in terms of the lever arm distance. The torque is  $\tau = rF \sin \theta$ , where  $r$  is the lever arm distance,  $F$  is the magnitude of the force, and  $\theta$  is the angle between the lever arm and the force. We can think of the lever arm distance as the perpendicular distance from the pivot to the line of action of the force. In regards to the sign convention, it can be thought of as the direction of rotation. What this means is that the sign of the torque depends on the direction of rotation. The sign convention for torque is that a positive torque causes a counter-clockwise rotation, and a negative torque causes a clockwise rotation. 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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It's interesting that the white ...

Is it a reference frame i...

How does force affect ...

As we saw earlier in this, t...

Understand the physical w...

This class is a very emp...

Before this wa...

The extended free-body ...

This just means the net ...

I don't understand why ...

It is important to ...

It's important to ...

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It's important to ...


It's important to ...



1 information transfer

2 projects



- 
- A young man in a grey t-shirt with 'TWINSBURG FOOTBALL CAMP' printed on it is focused on a wooden mechanical project on a table. He is surrounded by a large group of diverse students in a bright, modern workshop or classroom setting. In the foreground, there are various tools and materials, including a pink ball, a pair of orange-handled scissors, and a stack of colorful interlocking blocks. A laptop is also visible on the table.
- 1 project/month (6 over 2 semesters)
  - new team formation for each project

**1** information transfer

**2** projects



# Projects

**To be successful, the projects must**

- require practical application of skills**
- be linked to real world problems**
- have compelling narrative (help/do good)**

# Projects

---

**Fall**

**Drag Race**

**Rube Goldberg**

**Symphosium**

---

**Spring**

**Ecotricity**

**Crack-a-Thon**

**inSPECT Fair**

---

**1** information transfer

**2** projects





**AP50 FALL 2014**

**Project Brief**

---

**Drag**

**Rube G**

**Sympho**

---

**Symphosium**

**1 information transfer**





**1** information transfer

**2** projects

# Projects



**1** information transfer

**2** projects



# Projects

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



# Projects

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

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

# Projects

## Milestones:

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

# Projects

## Milestones:

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



# Projects

## Milestones:

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

# Projects

## Milestones:

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

# Projects

## Milestones:

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



# Projects

## Milestones:

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



**1** information transfer

**2** projects



**1** information transfer

**2** projects



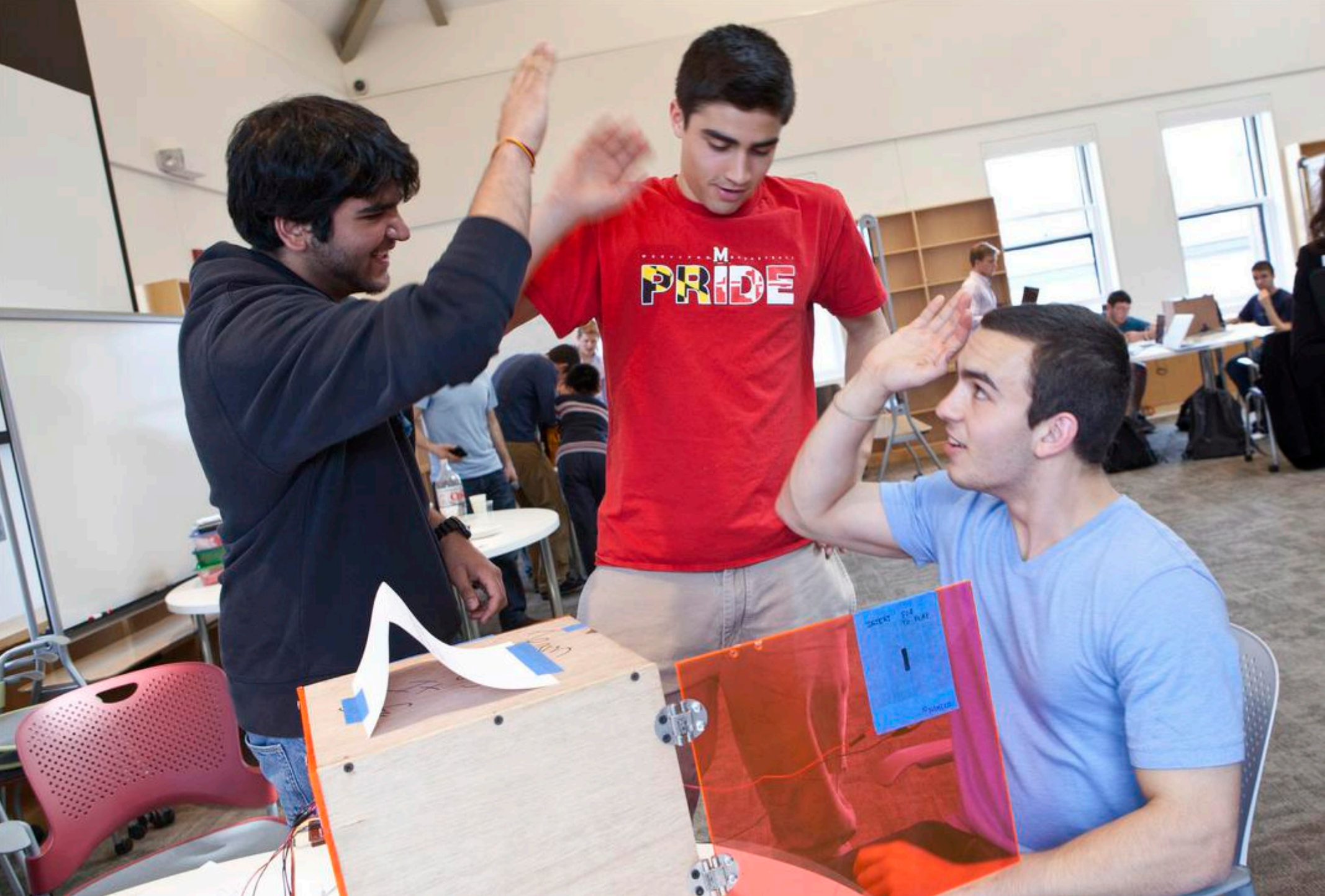
A group of students are gathered around a table in a classroom, working on a project. A male student in a black hoodie with 'unicef' on it is leaning over the table, looking at a white paper structure. A female student with glasses and a red and black striped shirt is also looking at the project. Another male student in a red shirt is visible in the background. The project appears to be a white paper structure, possibly a model or a prototype, with some blue tape and wires attached. The background shows a typical classroom setting with windows and other students.

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

**1** information transfer

**2** projects





**1** information transfer

**2** projects





**2 weekly 3-hour class periods**

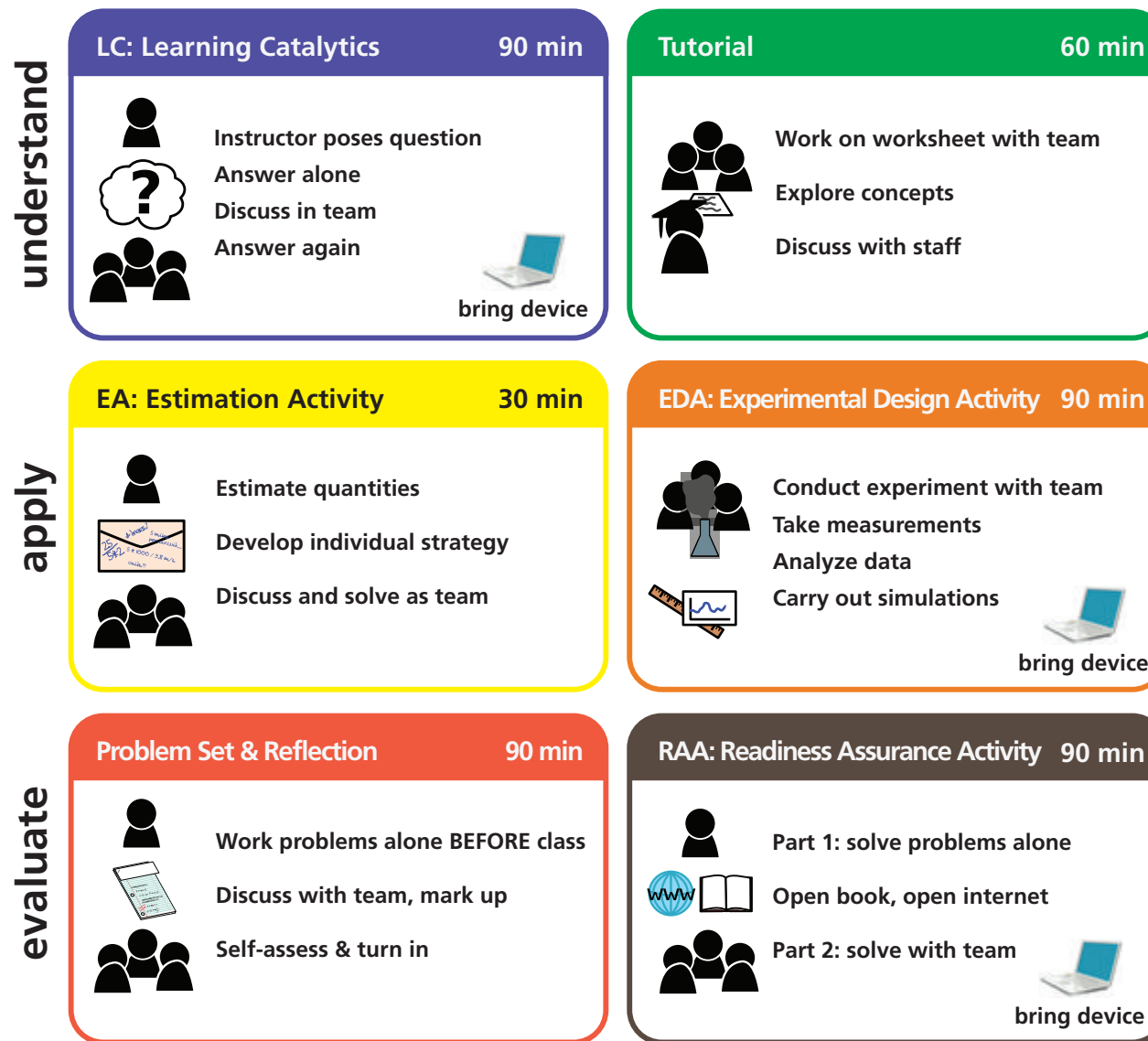
**1 information transfer**

**2 projects**

**3 in-class activities**



# blend of 6 scaffolded “best practices”



1 information transfer

2 projects

3 in-class activities

JAN	FEB								MAR								APR								
27	29	3	5	10	12	17	19	24	26	3	5	10	12	24	26	31	2	7	9	14	16	21	23	28	
intro	6	T 6	6	6	7	7	7	ECOTRICITY	T 8	8	8	8	9	9	9			CRACKATHON	T 10	10	10	10	10	inSPECT FAIR	
	6	6	6	7	7				8	9	8	9P	9						10	10		P			

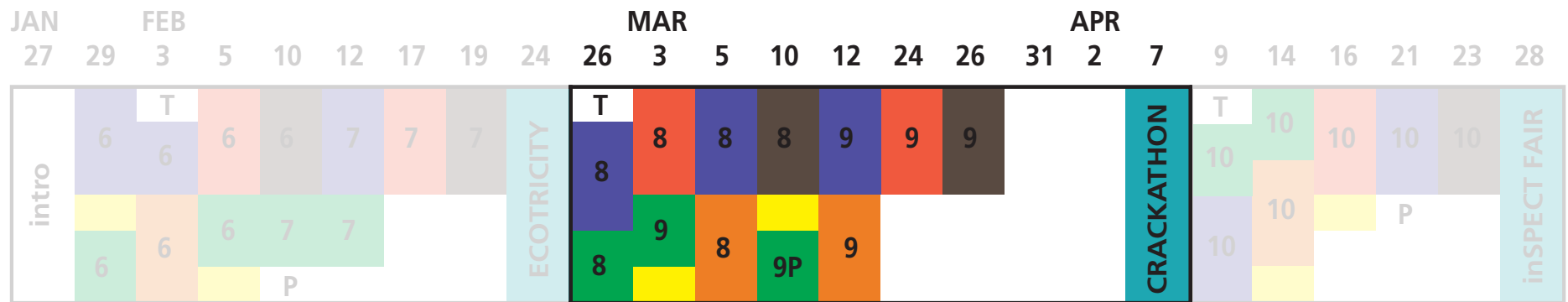
1 information transfer

2 projects

3 in-class activities

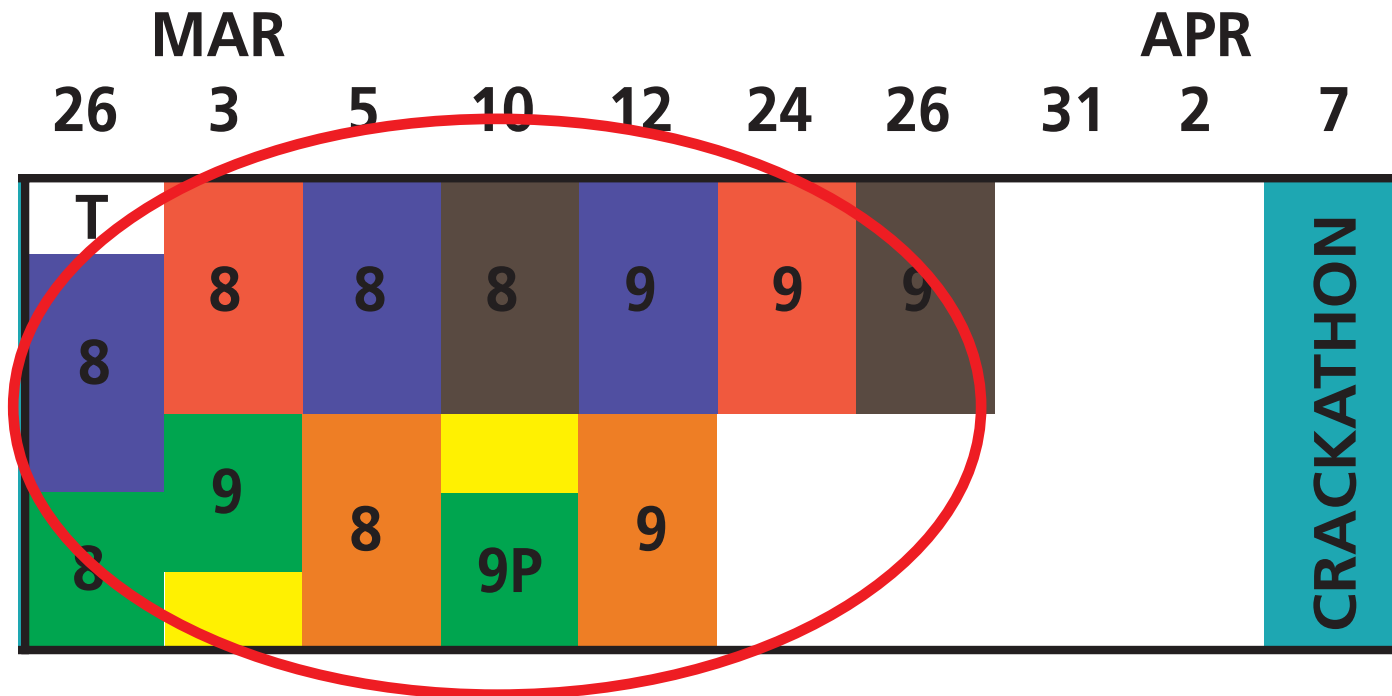


# one project





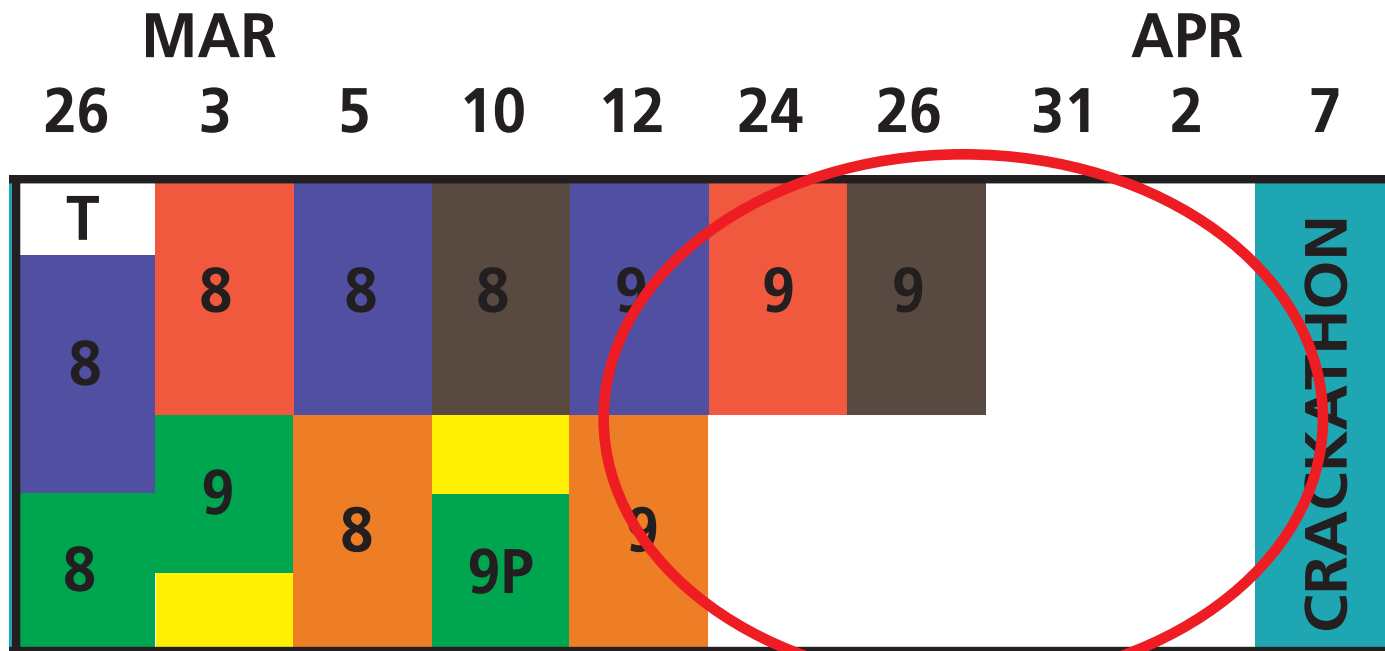
## 2/3 scaffolded, guided



1 information transfer

2 projects

3 in-class activities



1/3 unguided

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

# team intro

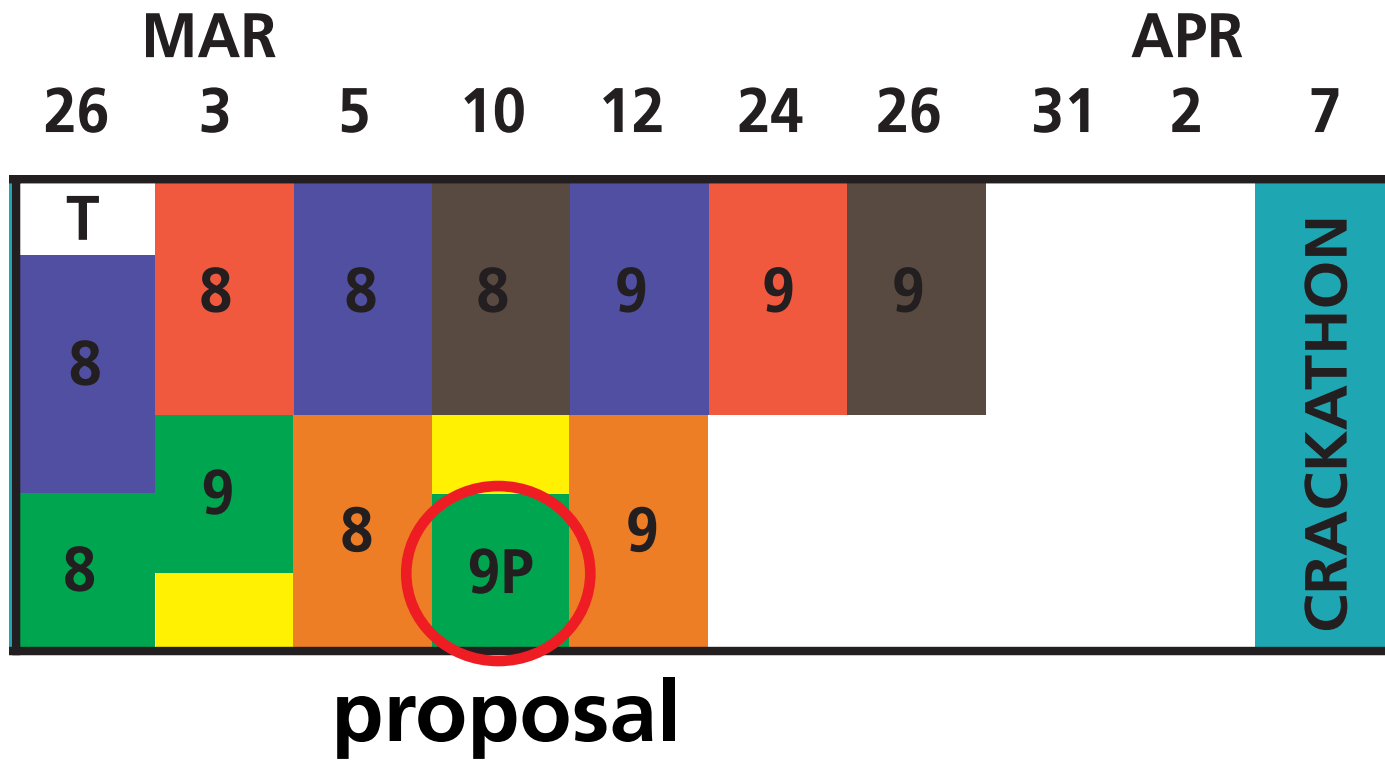


## 1 information transfer

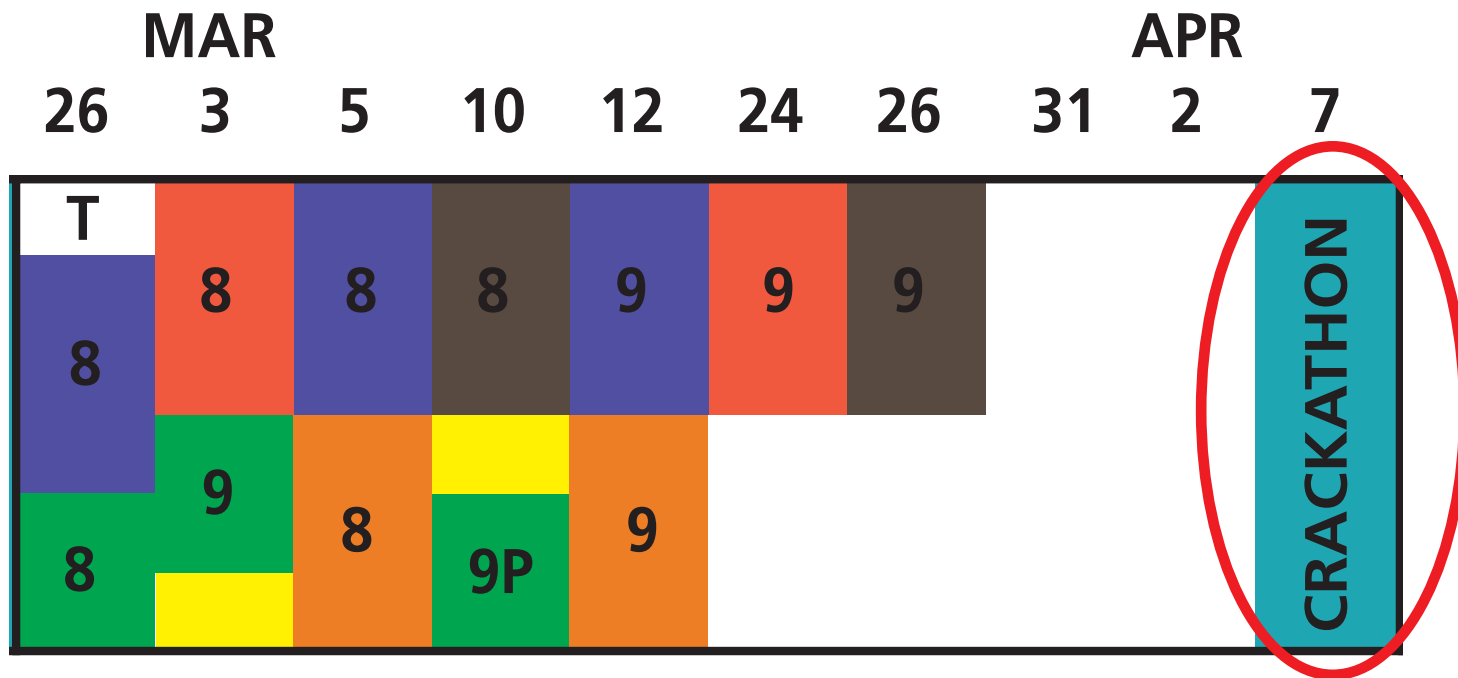
## 2 projects

### 3 in-class activities





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



project fair

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







# Course outcomes

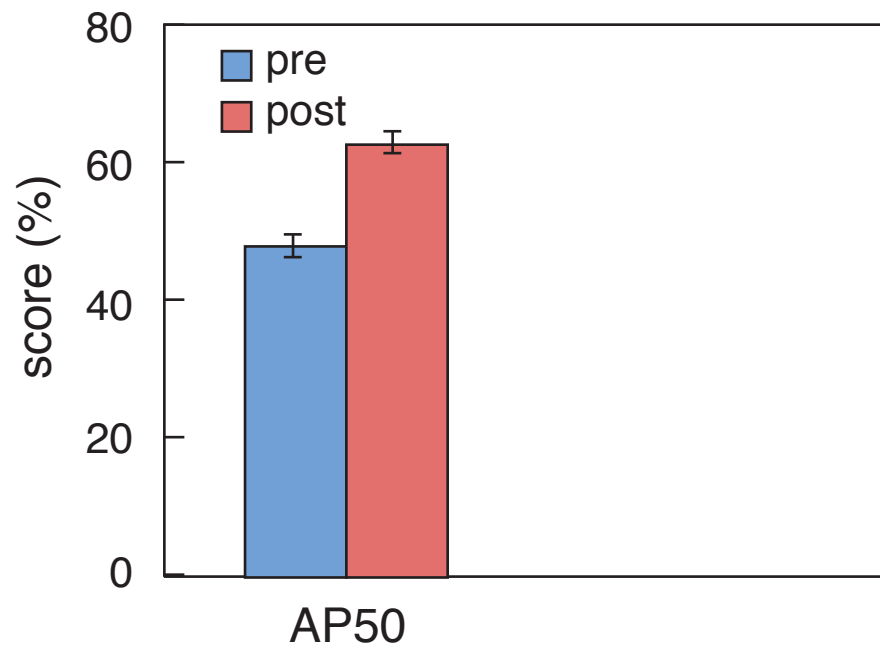
- **self-directed learning**
- **content learning goals**
- **teamwork**
- **professionalism**



# Content learning goals

# **Content learning goals**

## **conceptual mastery**

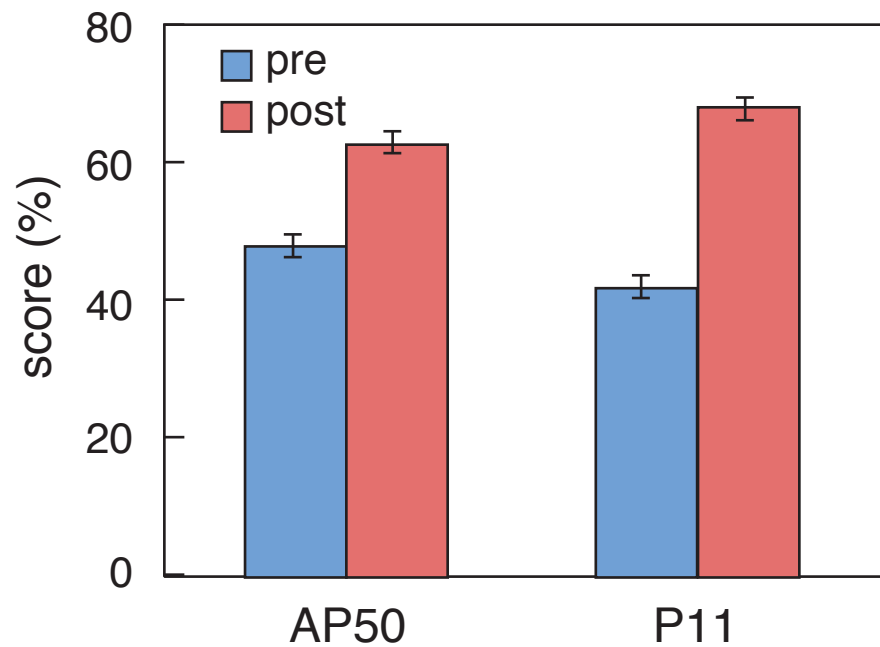


**similar to lecture based course**



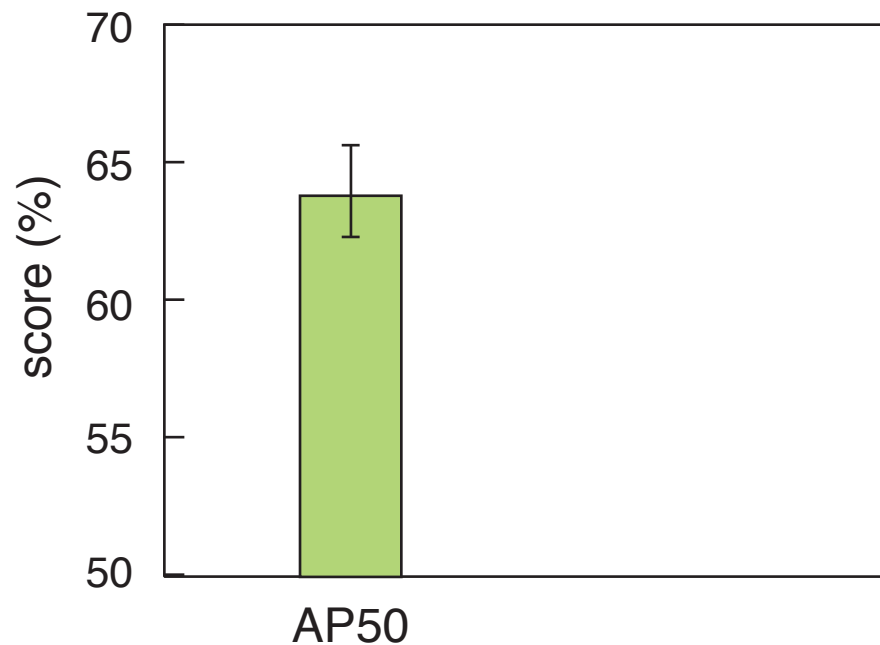
# Content learning goals

## conceptual mastery



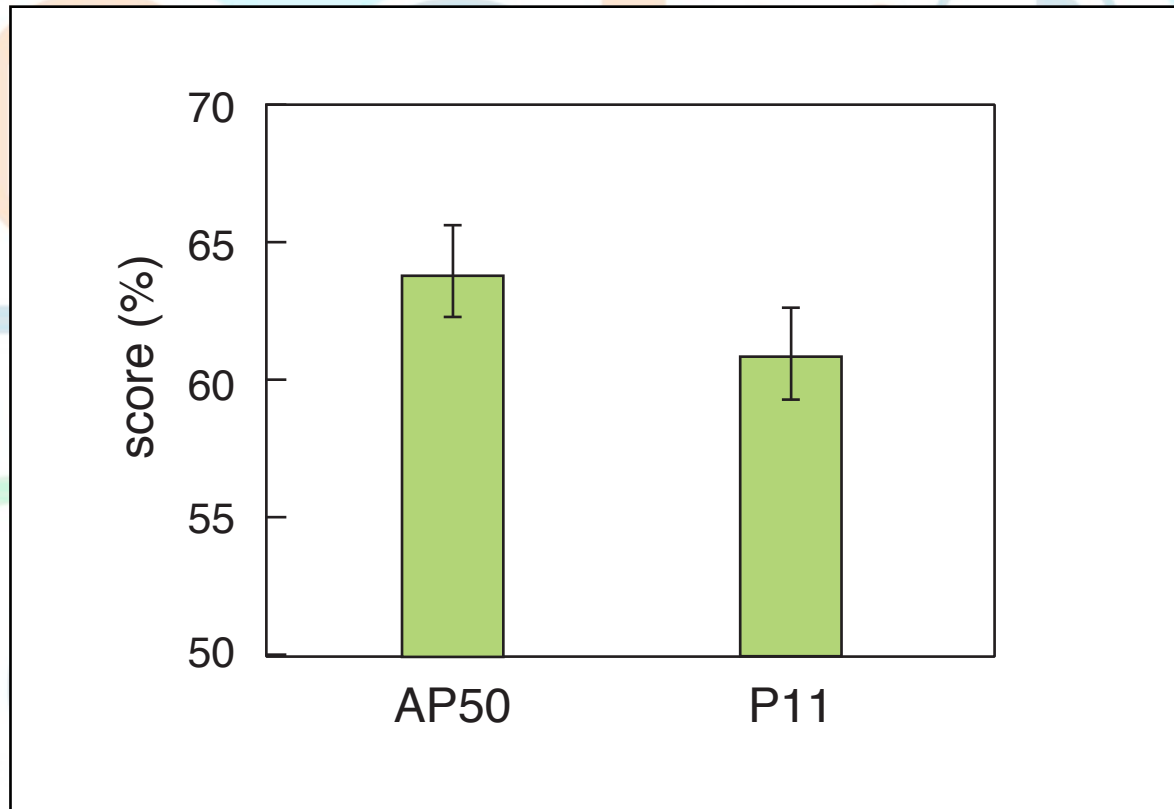
# **Content learning goals**

## **exam problem performance**



# **Content learning goals**

## **exam problem performance**



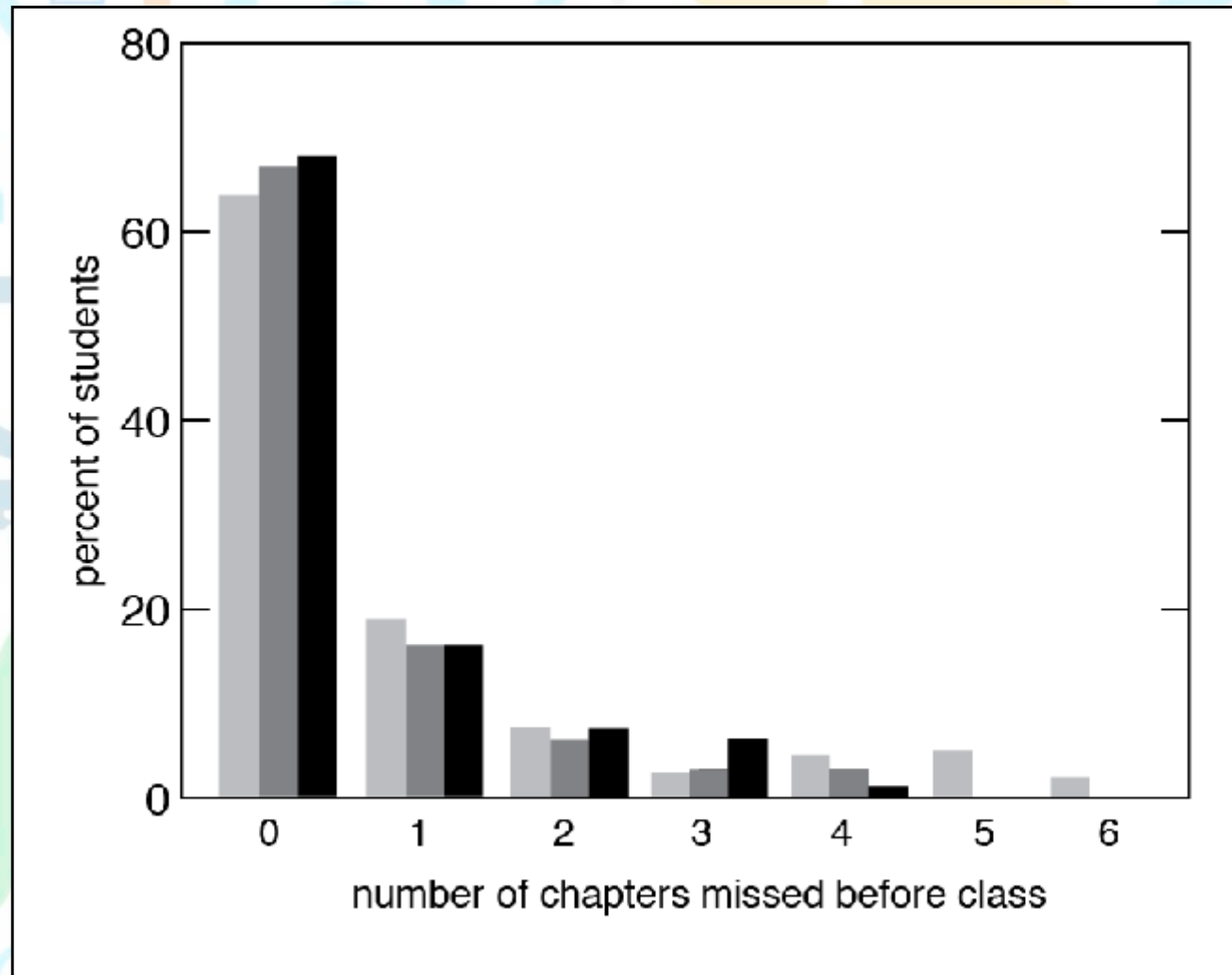
**similar to lecture based course**



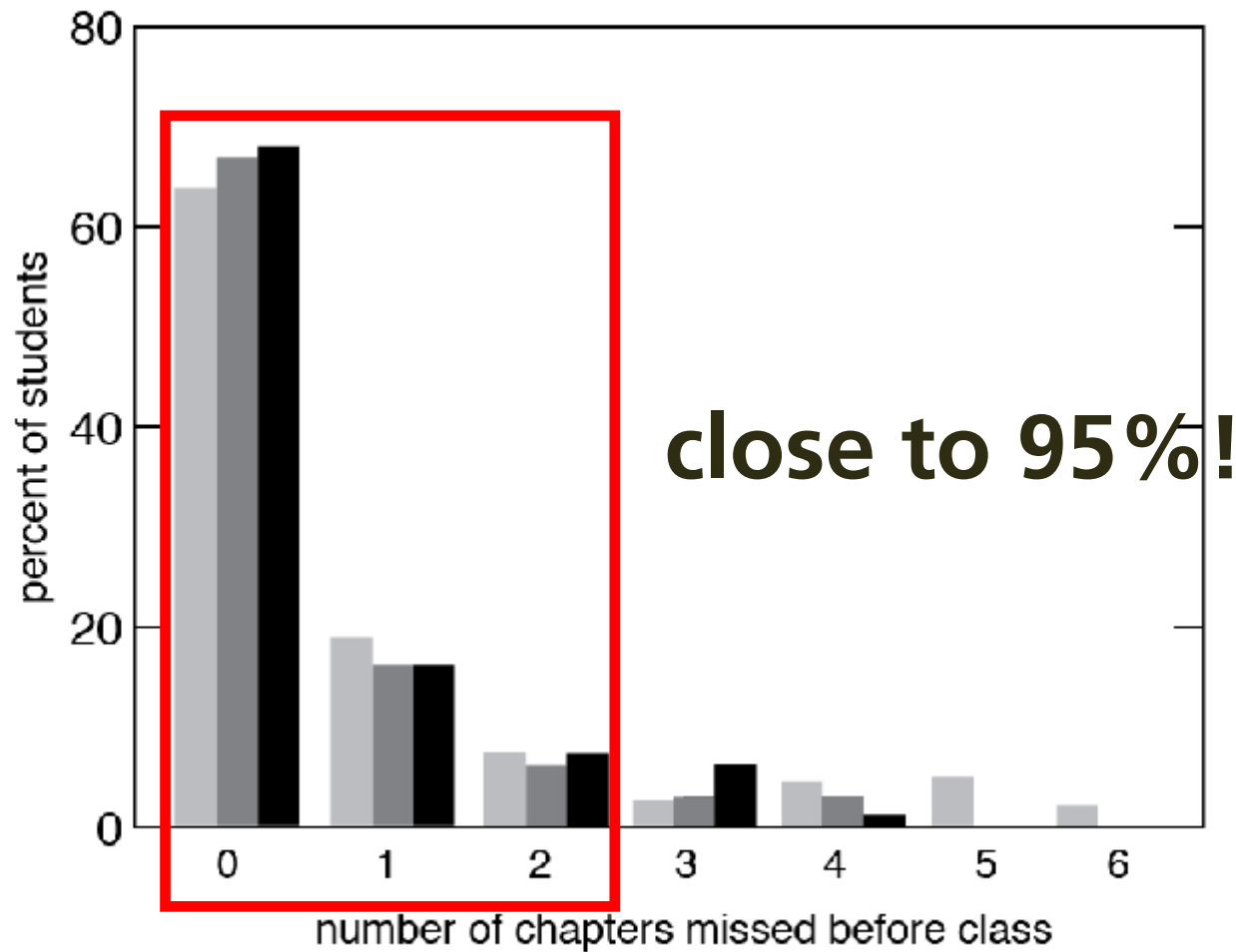
# Self directed learning



# Self directed learning



# Self directed learning





# **Self directed learning**

**81% spend 2–6 hrs/wk reading**

# Self directed learning

***"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"***

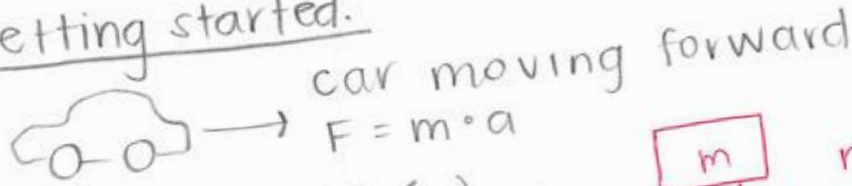


# Applied Physics 50a

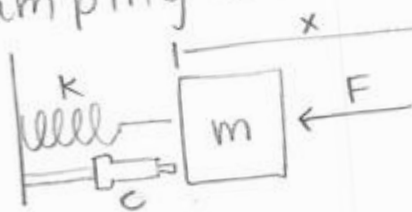
## Self directed learning

- ① Estimate damping coefficient for a shock absorber on a midsize car.

Getting started.

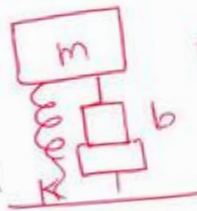


Damping coeff (c)

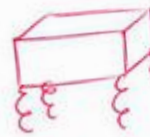


$$F_s = -kx$$

$$F_d = -cV$$



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



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

Create a plan.

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

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

Execute plan.

$$F = m \cdot a$$

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

$$F = (1500 \text{ kg})(5 \text{ m/s}) = 7500 \text{ N}$$

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

Translational eq =  $\sum F_x = 0$

$$k = \frac{\Delta mg}{x_{eq} - x_0}$$

$$k = \frac{mg}{\Delta x} = \frac{(35 \text{ kg})(9.8 \text{ m/s}^2)}{5 \text{ cm}}$$

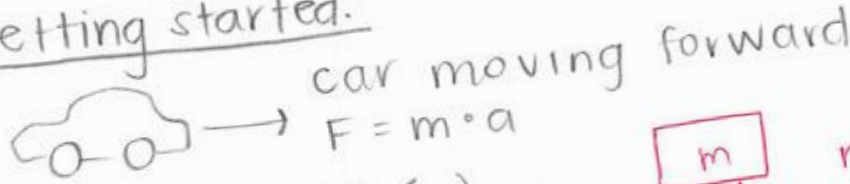


# Applied Physics 50a

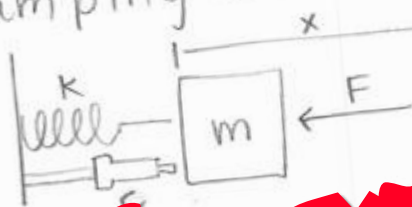
## Self directed learning

- ① Estimate damping coefficient for a shock absorber on a midsize car.

Getting started.



Damping coeff (c)



$$F_s = -KX$$

$$F_d = -cV$$



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

# 25 pages!

Execute plan.

$$F = m \cdot a$$

- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s<sup>2</sup>

$$F = (1500 \text{ kg})(5 \text{ m/s}^2) = 7500 \text{ N}$$

$\uparrow F_{sc}^c$   $\downarrow F_{Ec}^G$

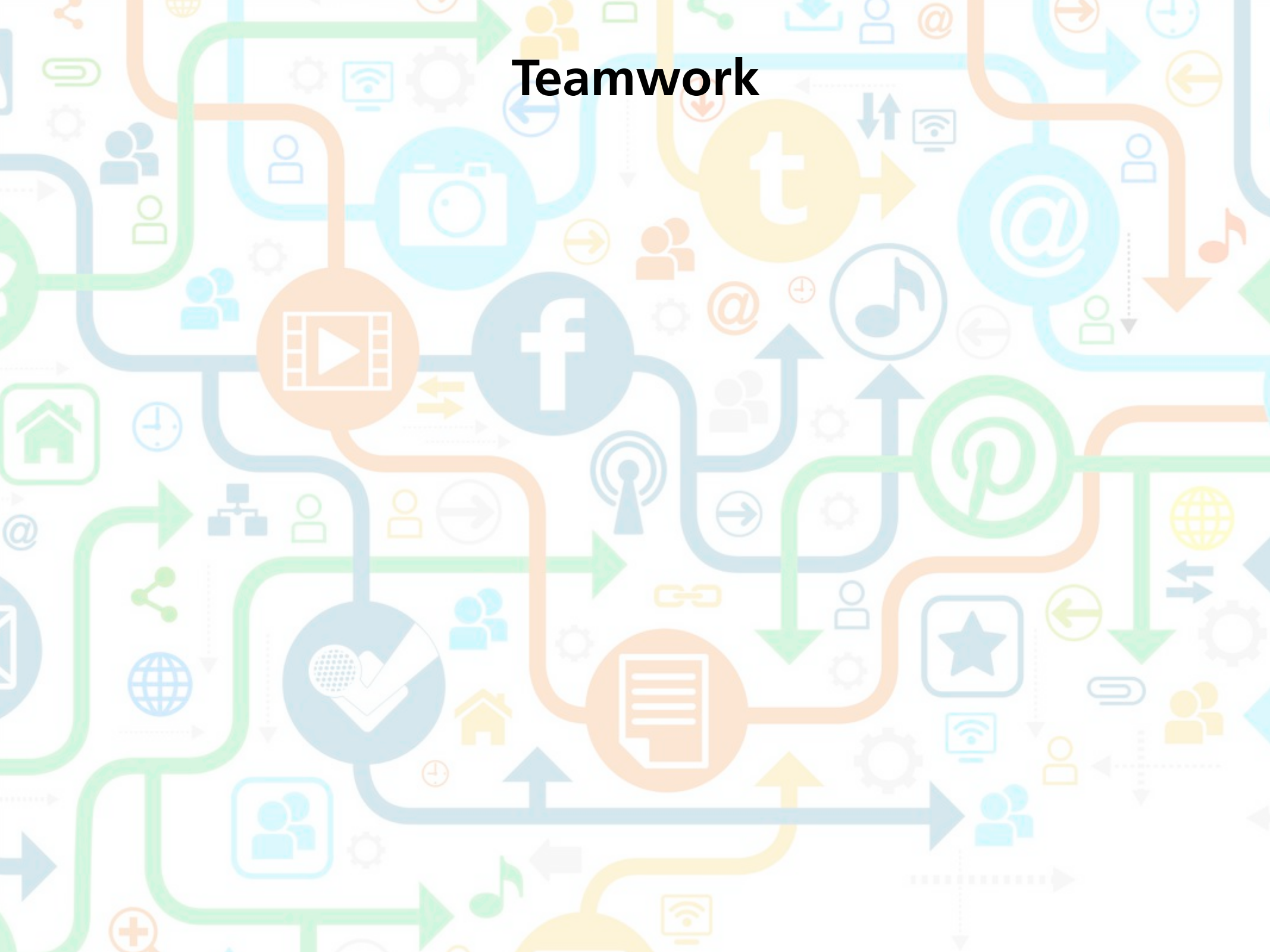
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# Teamwork

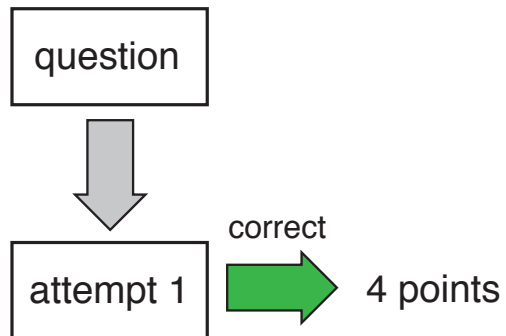


# Teamwork

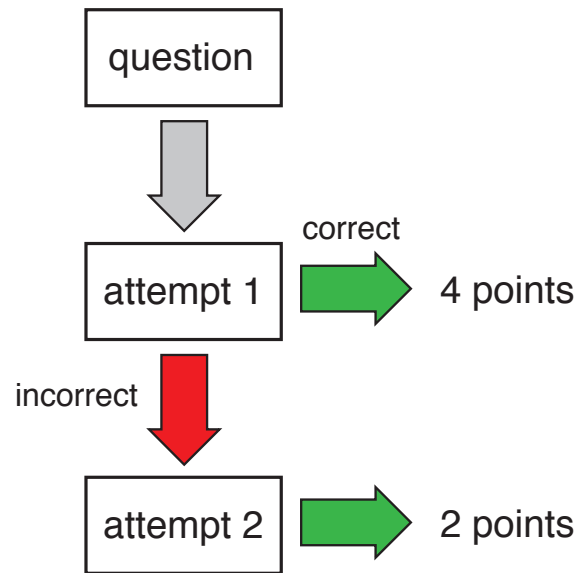
question



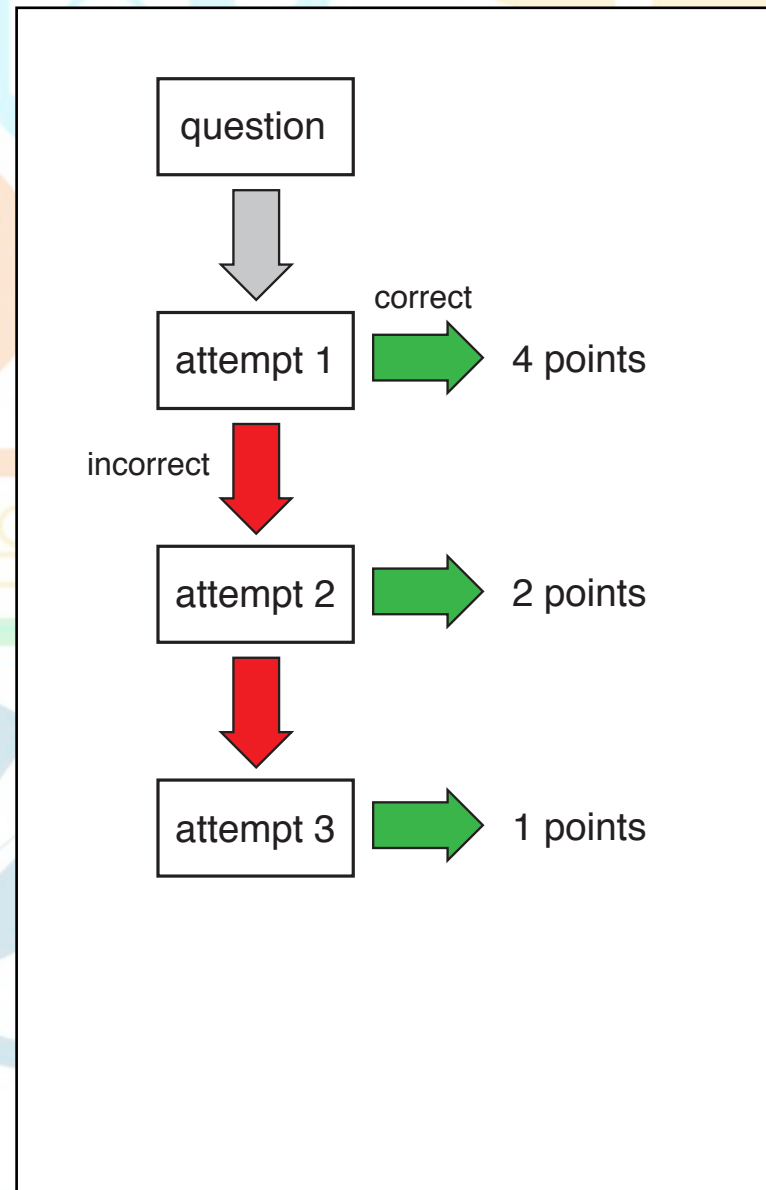
# Teamwork



# Teamwork

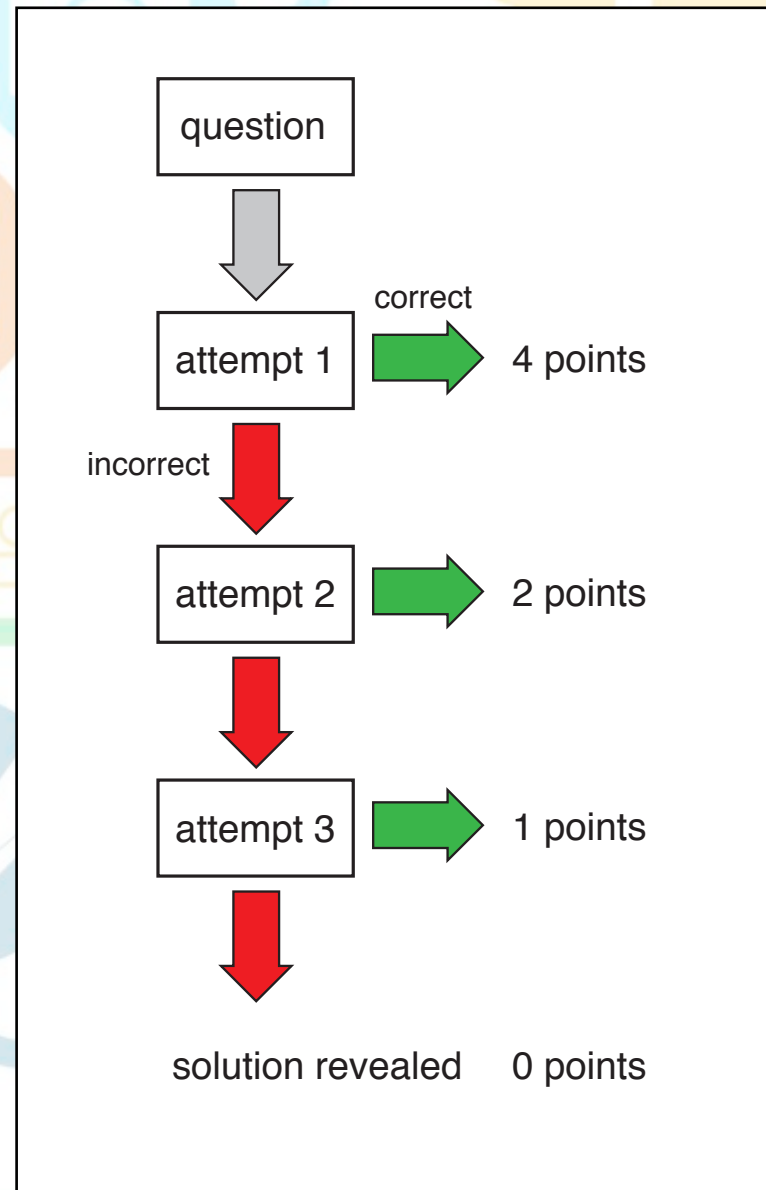


# Teamwork

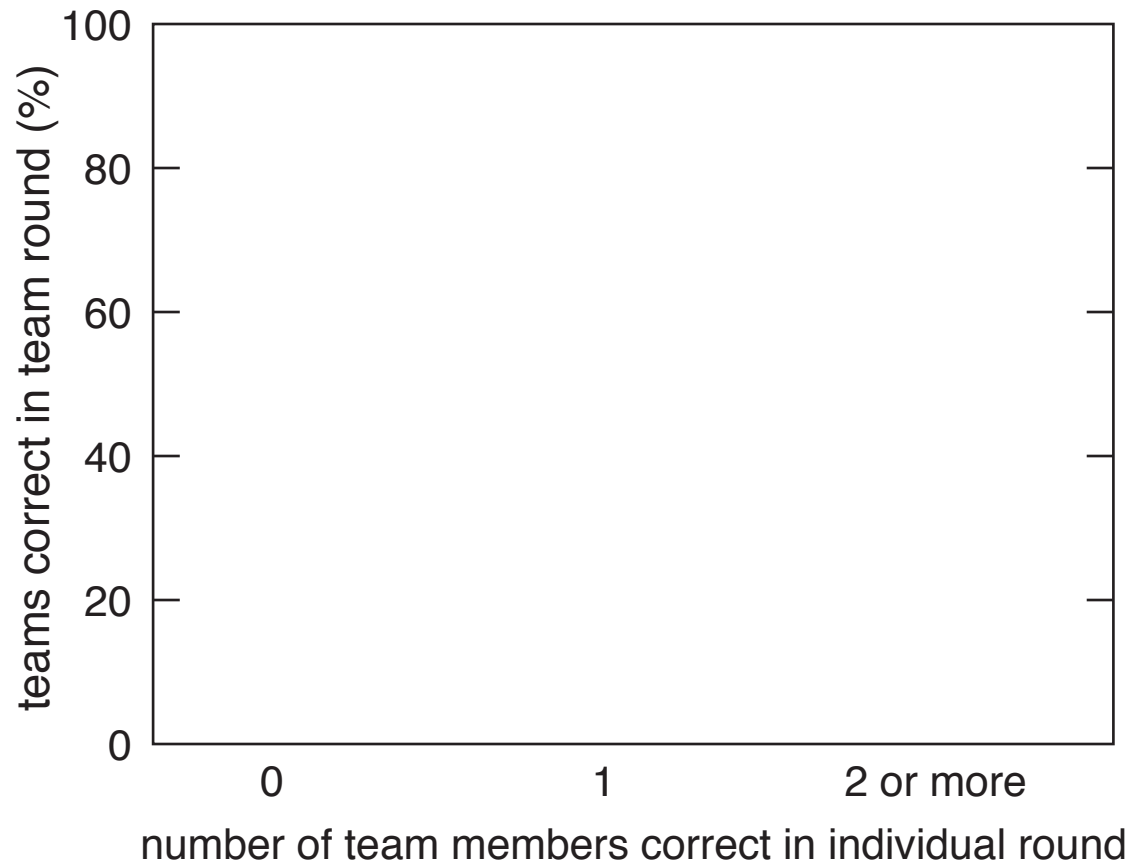




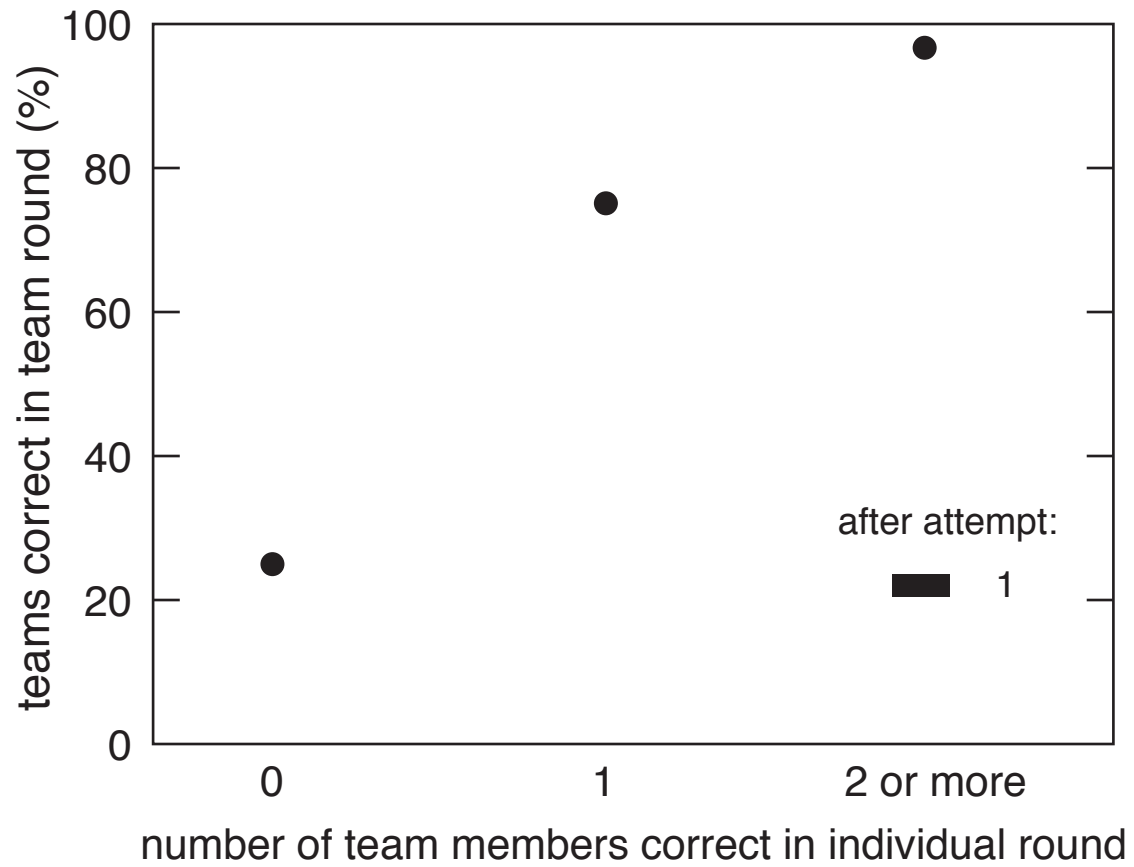
# Teamwork



# Teamwork

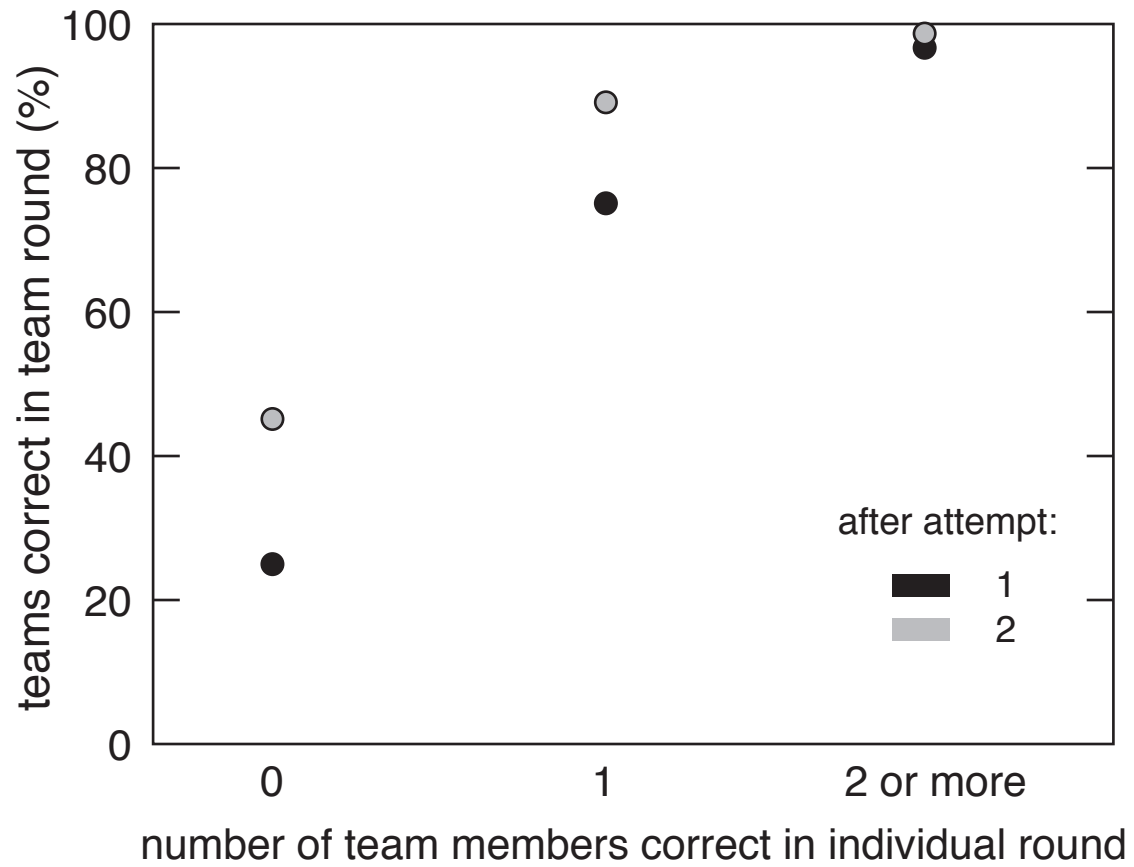


# Teamwork

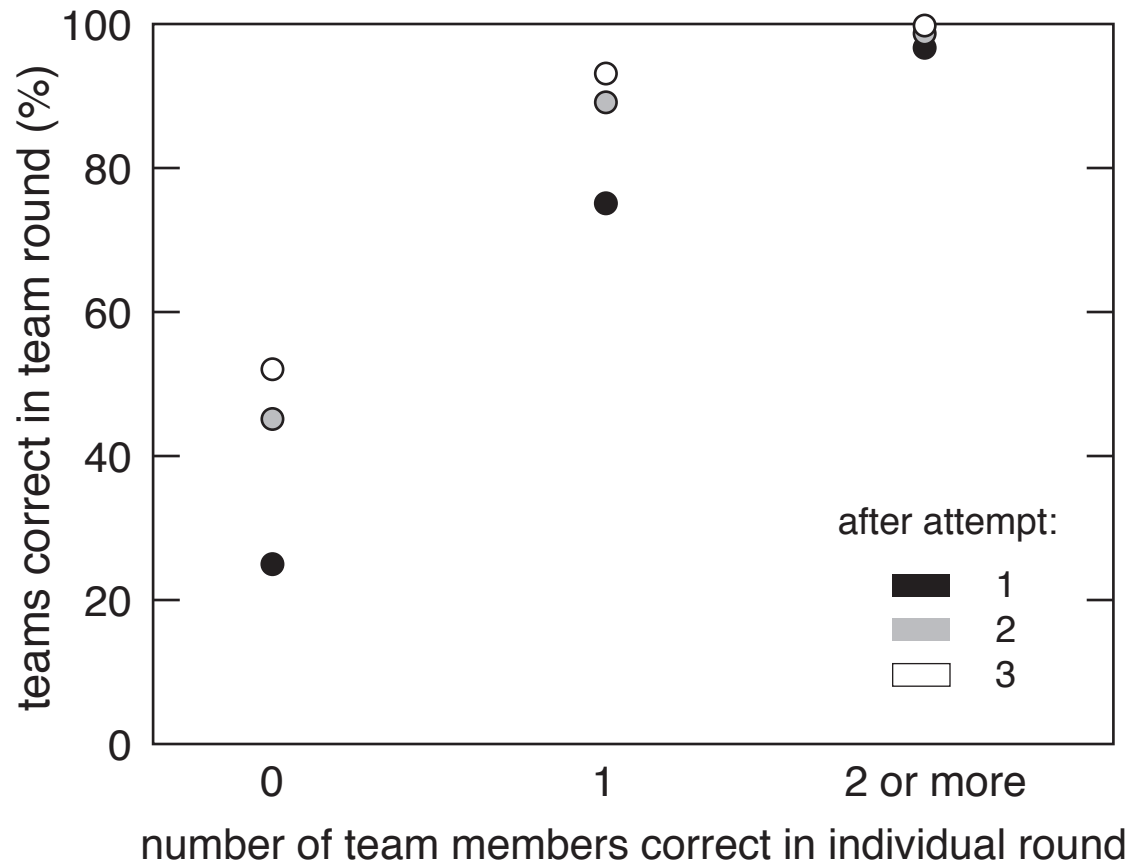




# Teamwork



# Teamwork



# Teamwork

**“We were all very committed to pulling our own weight, so when someone knew they hadn’t done as much work on one part, they volunteered to take on more the next time”**



## **Teamwork**

**“I think the fact that we all had experience working in groups like these was very helpful especially since we had less time to form team identity given the shorter time frame of this project. We all recognized each others’ strengths and weaknesses without needing to spell them out, and I think we capitalized on those effectively throughout the project.”**

# Professionalism

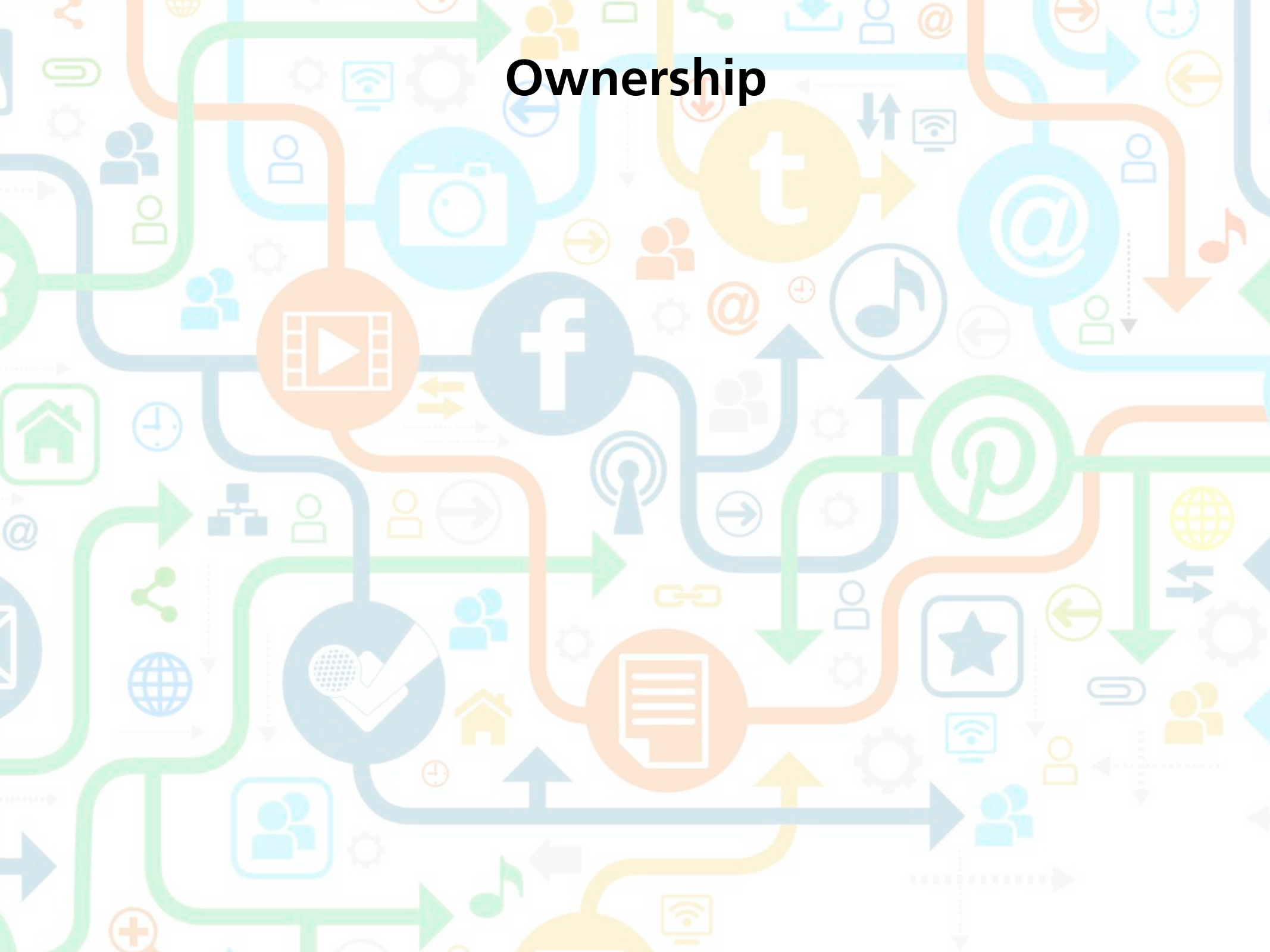


# Professionalism

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



# Ownership



# Ownership

**Course evaluation: 3.9–4.2/5**

# Ownership

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



## **Ownership**

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

# Ownership

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

# Ownership

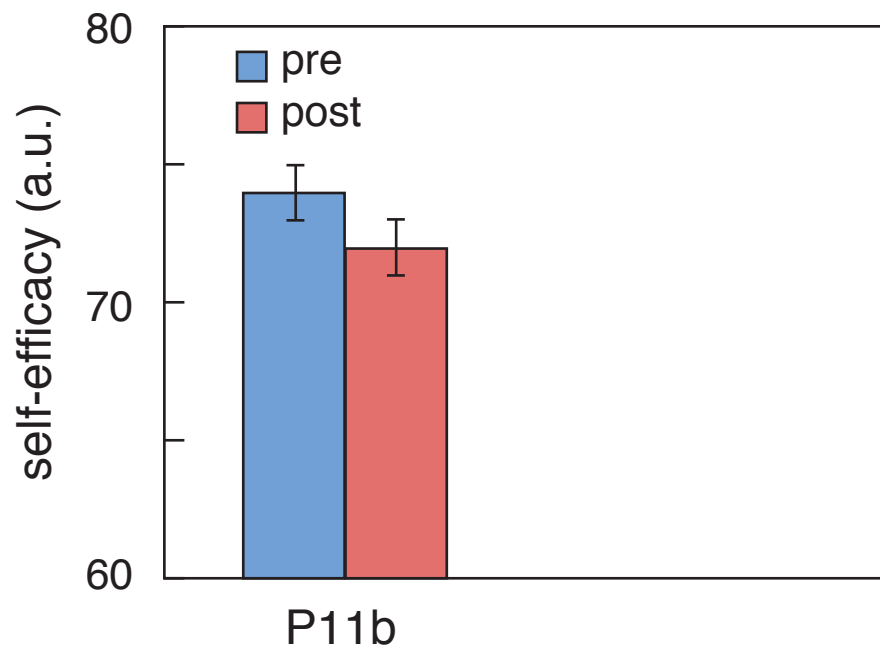
**3 hours and they don't *leave*!**



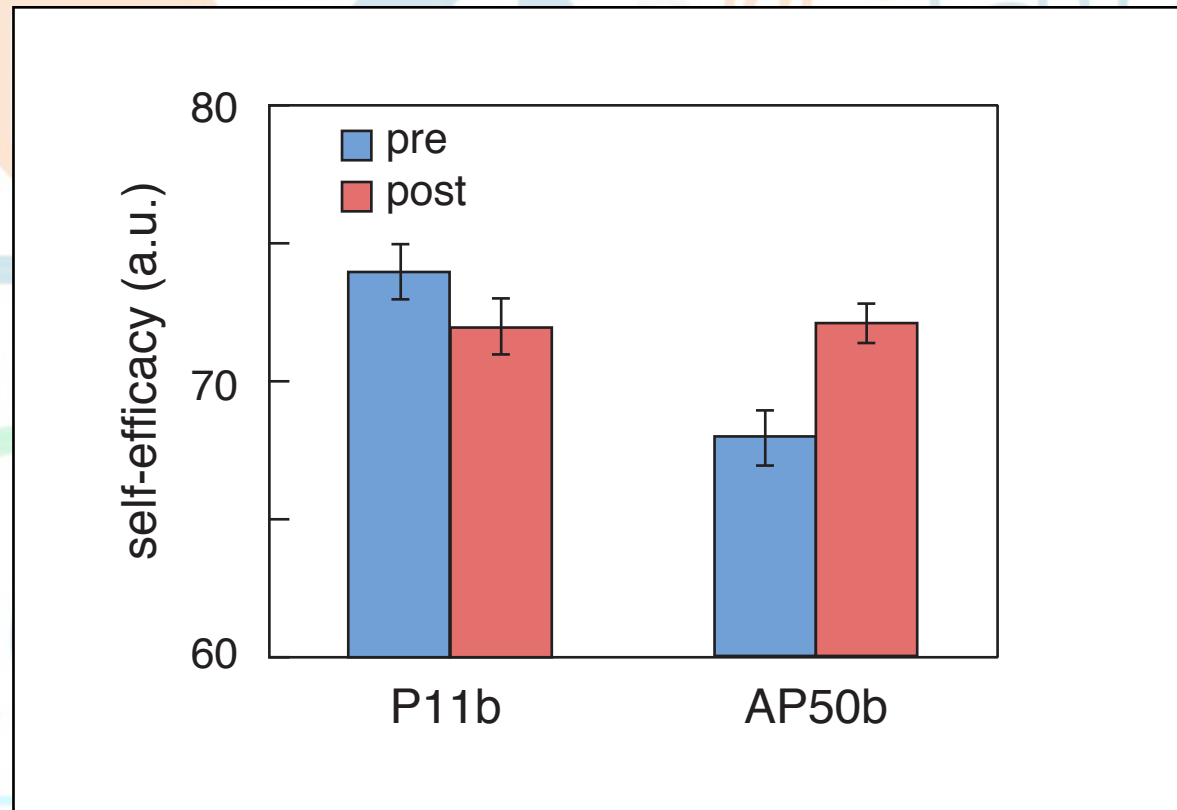
The background is a dense, colorful web of lines and icons. The lines are primarily blue, green, and orange, weaving across the frame. Interspersed among these lines are various icons: social media logos like Facebook (f), Twitter (t), and Pinterest (p); communication symbols like email (@), music notes, and video play buttons; and general digital icons like gears, Wi-Fi signals, and people silhouettes. The overall effect is one of a highly interconnected digital network.

**Ownership**  
**self-efficacy**

# Ownership self-efficacy



# Ownership self-efficacy










A group of four students are gathered around a wooden box containing a physics experiment. A female student with long dark hair and glasses is leaning over the box, using a tool to adjust a component. Another female student with long dark hair is standing behind her, smiling. A male student with short blonde hair is standing to the right, also smiling. A female student with short blonde hair is sitting in the foreground, looking up at the experiment with a smile. The box contains various electronic components, including a breadboard, wires, and a small motor. The background shows a laboratory setting with other equipment and a window.

***Can create ownership of learning physics!***

A group of four students are gathered around a wooden table in a classroom or lab setting. A female student with glasses and long dark hair is leaning over the table, smiling and pointing at a circuit board. Another female student with long dark hair is looking at the same area. A male student with short brown hair is sitting at the table, looking up at the female student with glasses. A male student with short brown hair is standing next to him, looking on. On the table is a circuit board with various components, a blue bowl, and other tools. The background shows a classroom with a whiteboard and a door.

***Can create ownership of learning physics!***



A group of four students are gathered around a wooden box containing electronic components. A woman with glasses is leaning over the box, pointing at something inside. A man in a plaid shirt is standing next to her, smiling. A woman with long dark hair is also looking at the box. A man in a maroon hoodie is sitting in front of the box, looking up at the woman with glasses. The box contains a breadboard, wires, and other electronic components. The background shows a laboratory setting with various equipment and a window.

**“you come out with so much knowledge  
and experience and fun”**

A background image showing a group of students in a laboratory or classroom setting. A female student with glasses is pouring liquid from a beaker into a container on a wooden table. Two other female students are looking on with interest. A male student in a plaid shirt stands to the right, smiling. The table has various lab equipment, including a beaker, a container with colorful beads, and some electronic components.

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