

Flat space, deep learning



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



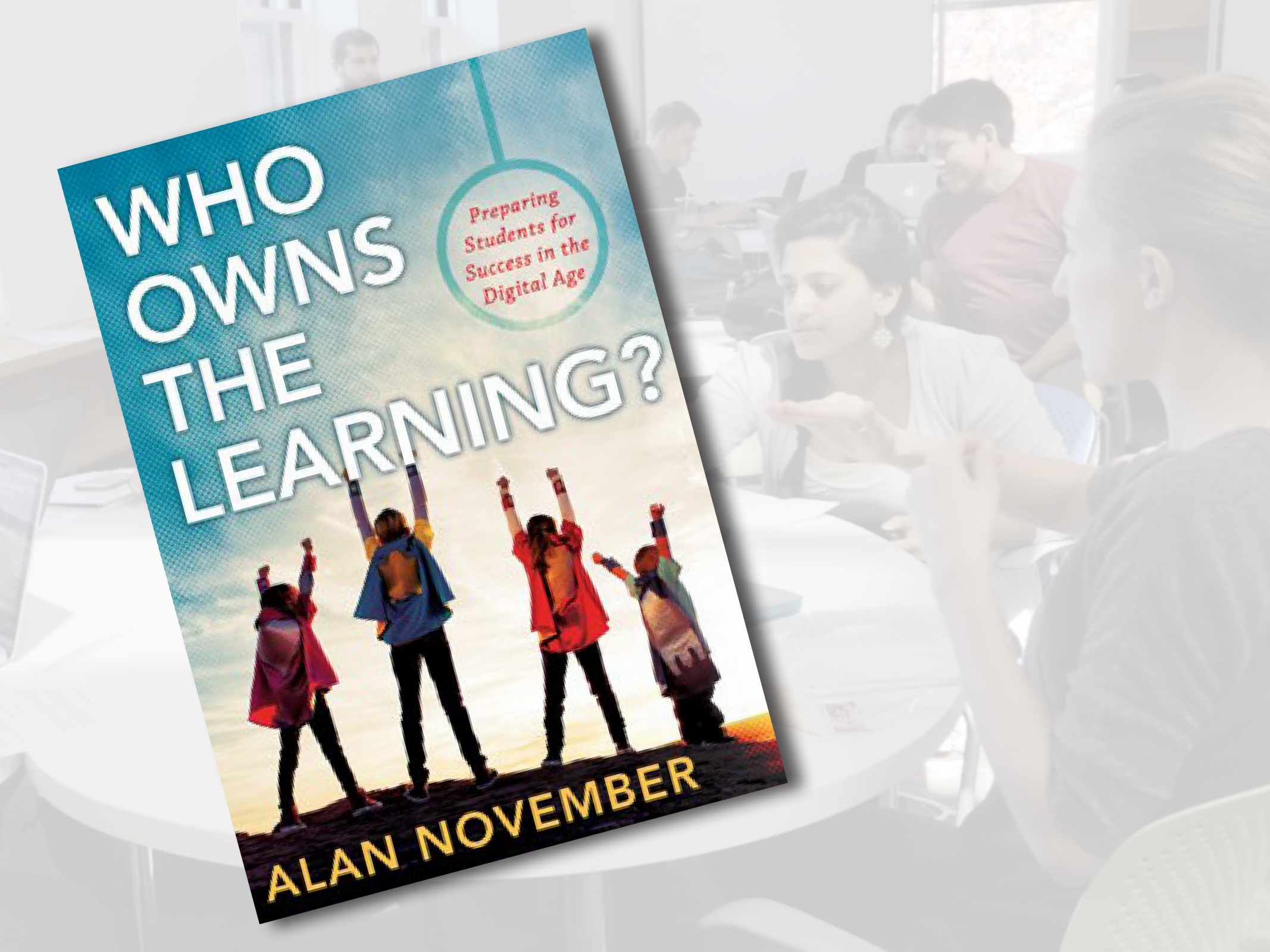
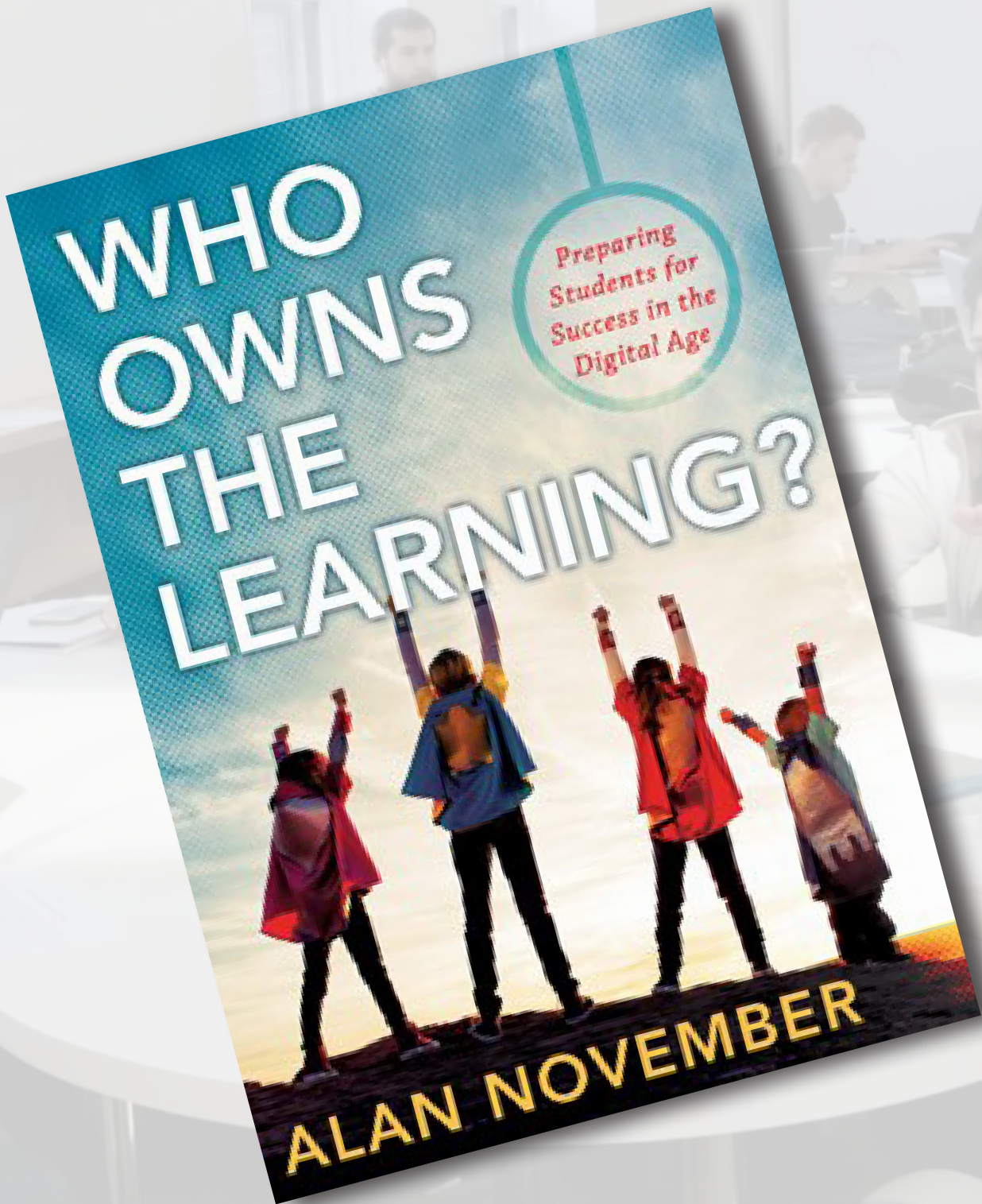
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A large white oval with a black border containing the Twitter logo and the handle "@eric_mazur".

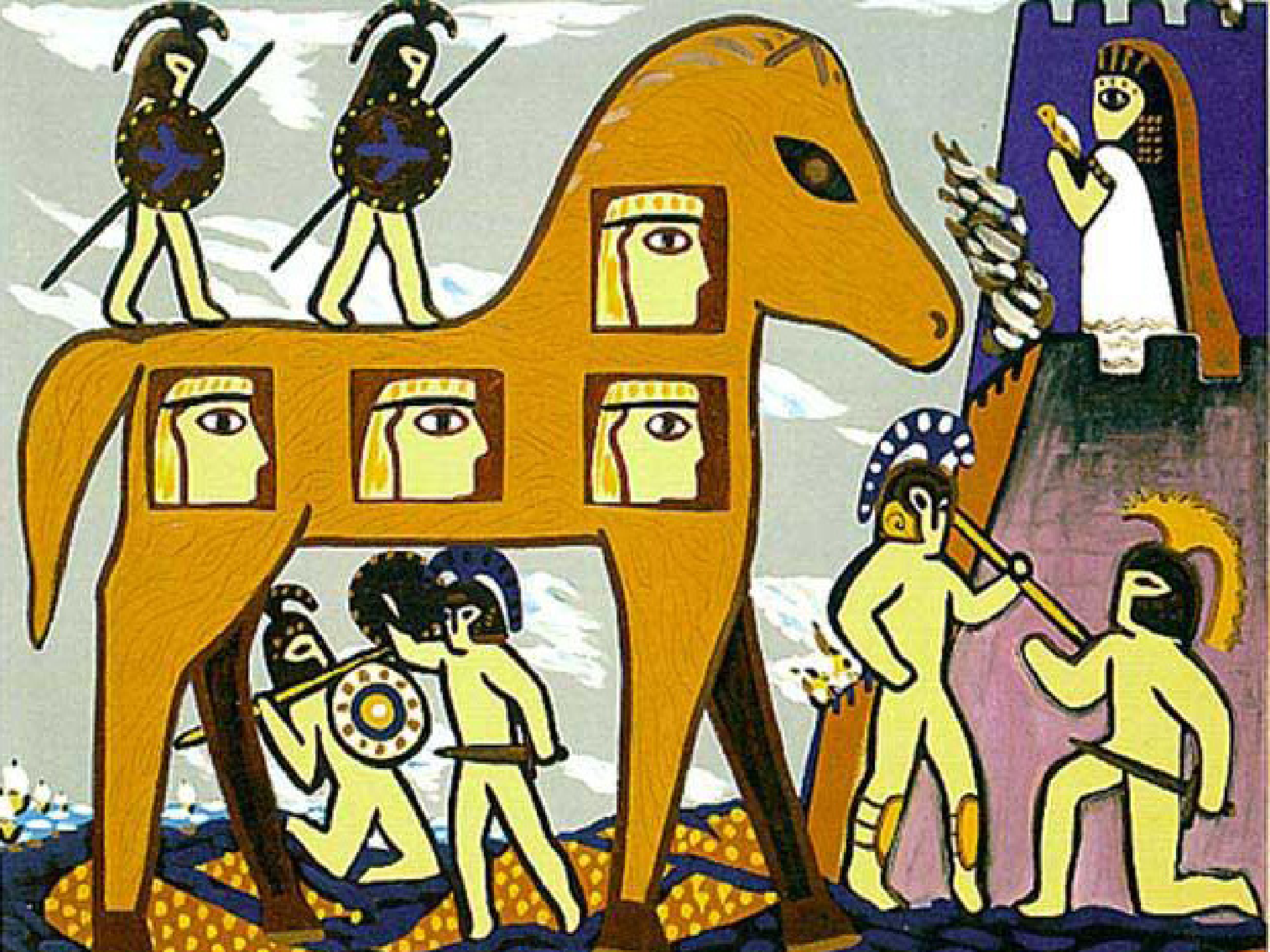
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Ownership of learning *physics*?





team & project-based approach

A stylized illustration of a brown horse with Egyptian-style faces on its body, surrounded by various figures in a desert setting. The horse is the central focus, with several faces integrated into its body. In the background, there are two figures with blue crosses on their chests, a figure holding a staff, and two figures in the foreground, one holding a shield and the other a staff. The scene is set in a desert with a purple sky and a yellow ground.

ProTeam Learning





1 design

2 approach

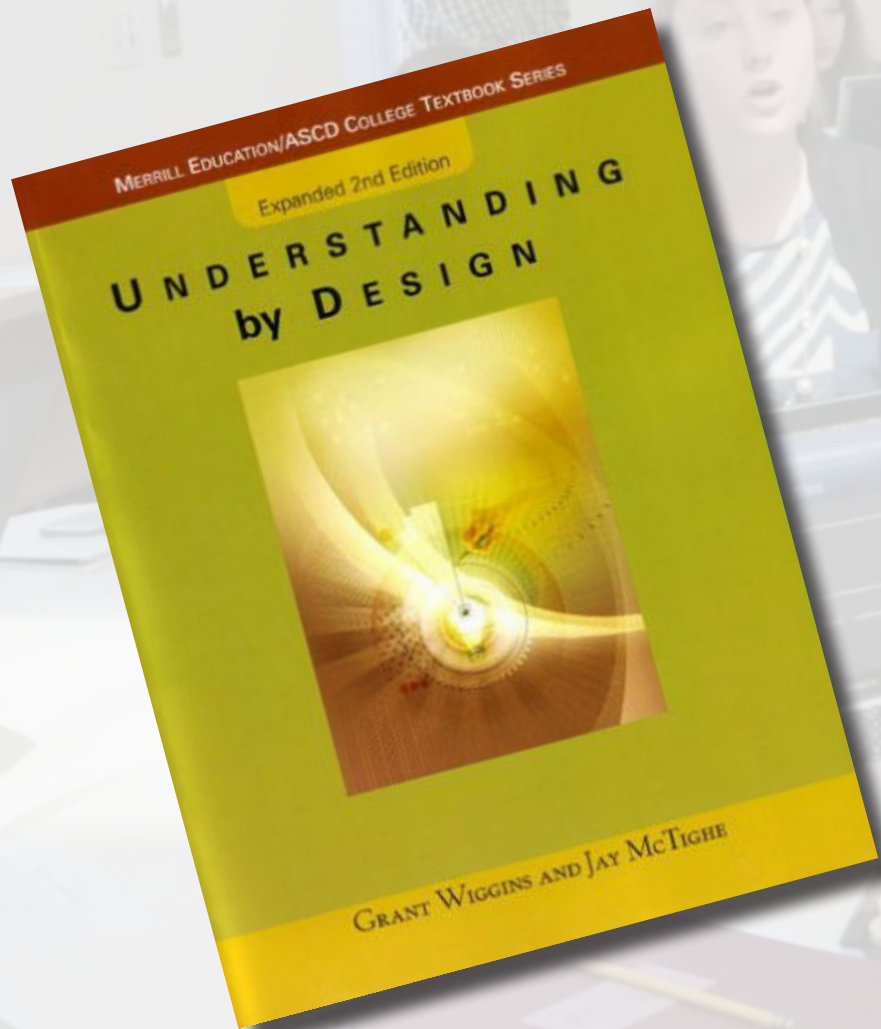


1 design

2 approach

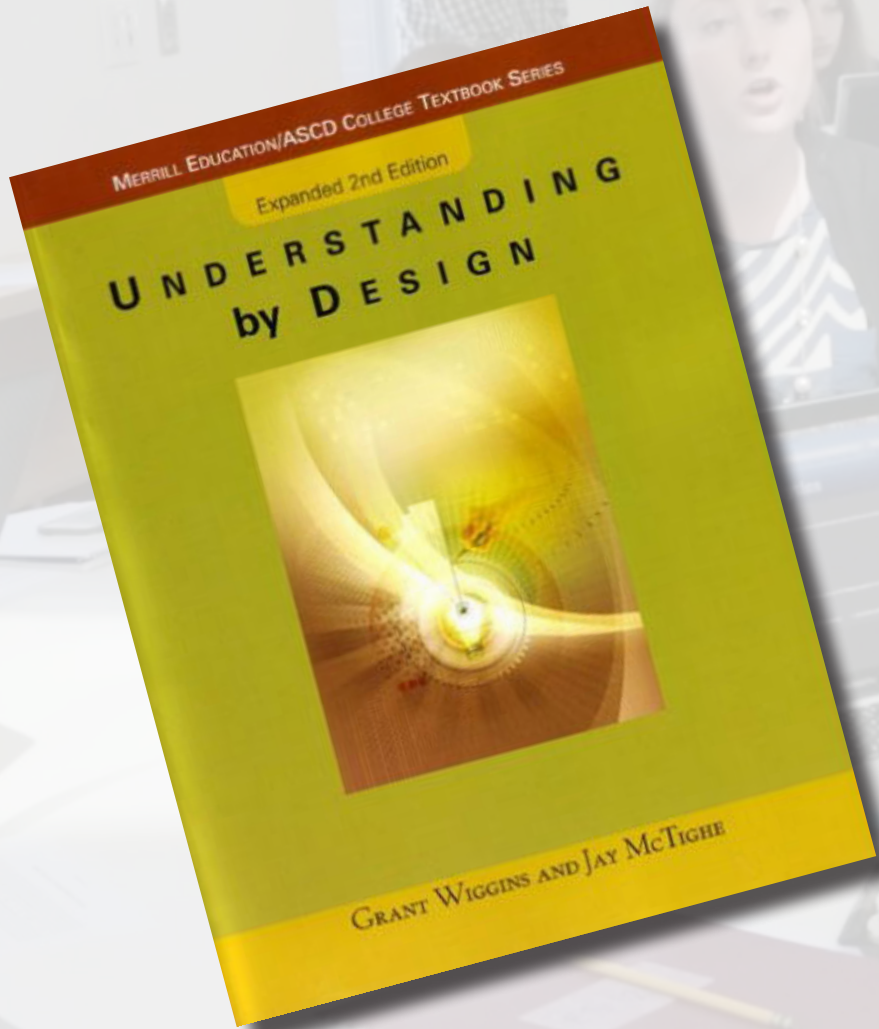
3 results

Setting learning goals



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

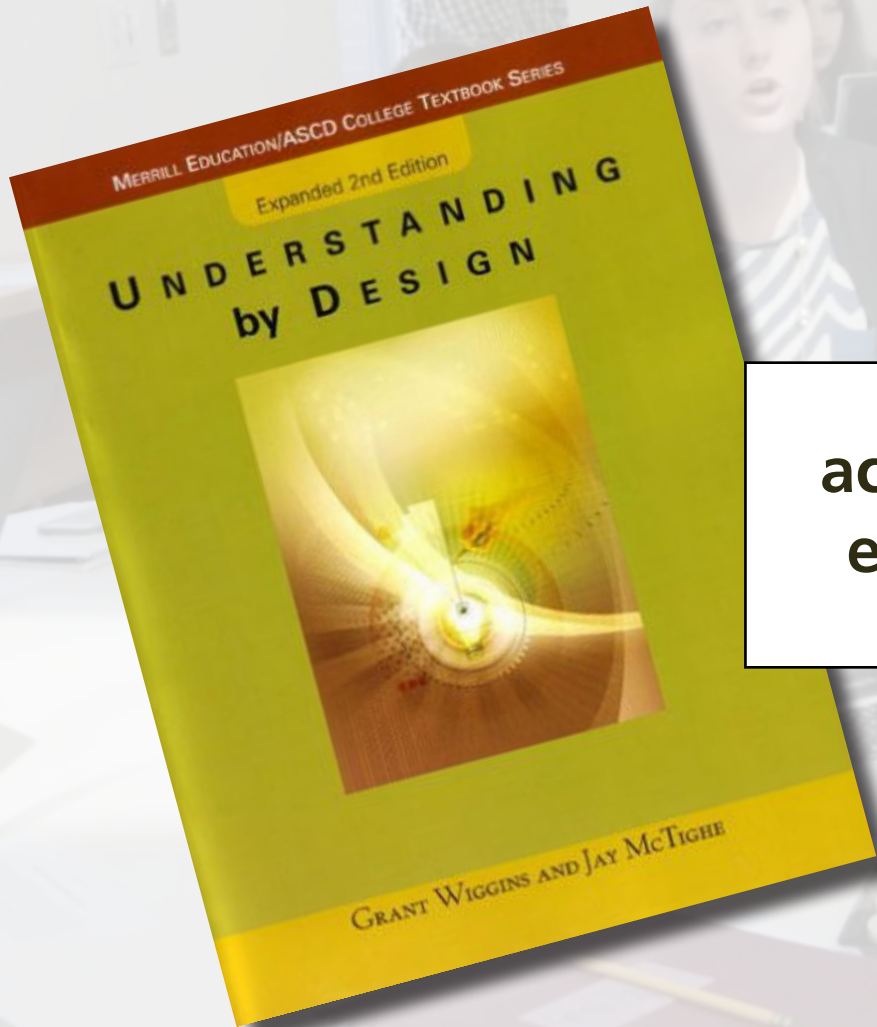
Backward design



**desired
outcomes**

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Backward design



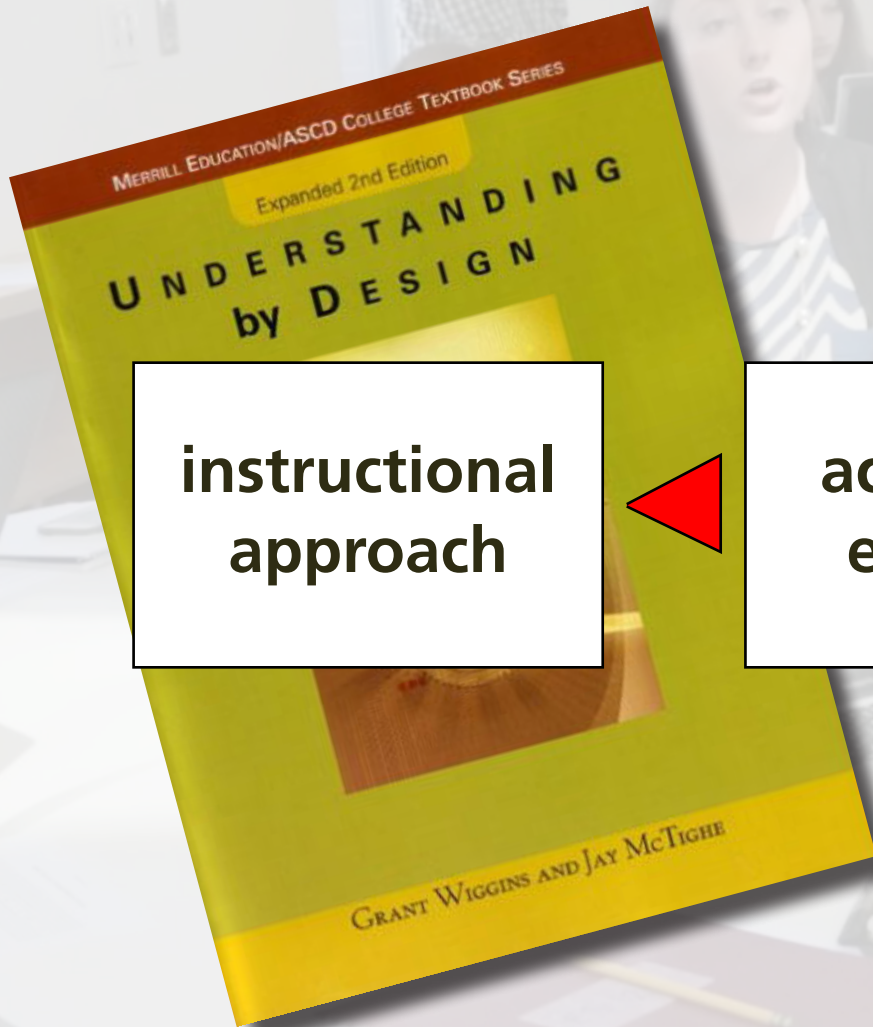
acceptable
evidence



desired
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Backward design



**instructional
approach**

**acceptable
evidence**

**desired
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also designed to

- **Qualitative Analysis:** The ability to analyze and to solve problems in scientific disciplines qualitatively, including estimation, and visual thinking.
- **Quantitative Analysis:** The ability to analyze and to solve problems in scientific disciplines quantitatively, including use of appropriate tools, quantitative solving, and experimentation.
- **Diagnosis:** The ability to identify and resolve problems within complex identification, formation and testing of a hypothesis, and recommending solutions.
- **Design:** The ability to develop creative, effective designs that solve creation, problem formulation, application of other competencies, balance and which integrate knowledge, beliefs and modes of inquiry from multiple perspectives.
- **Teamwork:** The ability to contribute effectively in a variety of roles while respecting everyone's contributions. You will develop communication, questioning, listening, and identifying multiple approaches and points of view.
- **Communication:** The ability to convey information and ideas effectively to identify and address your own needs, fluency in use of communication, and to contribute positively to the team.

competencies

COURSE GOALS

After successful completion of this course, you

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, especial
 - using a variety of techniques to get a handle on problems: repres
 - perform order of magnitude estimates, use dimensional analysis
 - symmetries, evaluate limits 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

course goals

2. Demonstrate **content mastery** by:
 - meeting the content learning goals specified in the project
 - knowledge of physics to solve problems
 - interpreting them

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content-specific goals

<http://bit.ly/ap50visitor>





information transfer

faculty-centered





interaction

student-centered



1 design

2 approach



CLASS

1st exposure



ROOM

deeper understanding

1 design

2 approach



1st exposure



deeper understanding



1st exposure



deeper understanding

no lectures

no exams

1 design

2 approach



Three major components:

- **information transfer (out of class)**
- **projects**
- **in-class activities**

PRINCIPLES & PRACTICE OF
PHYSICS

ERIC MAZUR

PRINCIPLES & PRACTICE OF
PHYSICS

ERIC MAZUR

1 design

2 approach

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

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



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



You may wonder whether it is possible to make surfaces that have no friction at all, such that an object, once given a shove, continues to glide forever. There is no totally frictionless surface over which objects slide forever, but there are ways to minimize friction. You can, for instance, float an object on a cushion of air. This is most easily accomplished with a low-friction surface. 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. All carts have some friction both for low-friction tracks and for ordinary tracks. This friction is ignored during an experiment. The track shown in Figure 4.2 is horizontal, carts move without slowing down appreciably. In the absence of friction, a cart moving along a horizontal track would continue to move without slowing down.

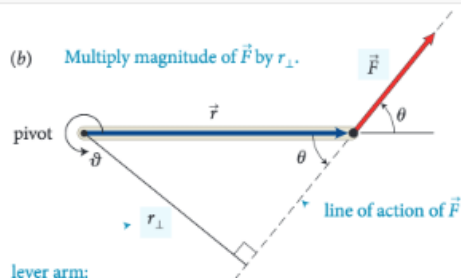
In the absence of friction, a cart moving along a horizontal track would continue to move without slowing down.

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.

social learning platform



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



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

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

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

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

Exercise 12.1 Reference point

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

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

reference point

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

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

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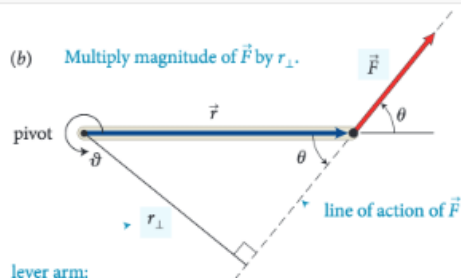


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Example 12.2 Torques on lever

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

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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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Information transfer

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over 20,000 annotations!

AP50 Spring 2015

Annotation Rubric

Your annotations of the textbook on NB will be evaluated on the basis of quality, quantity, and timeliness, as shown below. Your goal in annotating each chapter is to demonstrate *timely and thoughtful reading of the text*. When we look at your annotations we want them to reflect the effort you put in your study of the text. It is unlikely that that effort will be reflected by just a few annotations per chapter, unless your annotations are unusually thoughtful and stimulate a deep discussion. About 7–20 *thoughtful* annotations per chapter spread out over the chapter is about right, but keep in mind that quality is more important than quantity!

About 4 days after the deadline of the last chapter in each unit, we will provide an overall assessment of your annotations in that unit using the usual three-point scale (0–3), by combining your annotation scores for the three categories.

Quality The textbook replaces the lectures (us reading the textbook to you) so that we can do more interesting things in class. Therefore it is important you read the text thoughtfully and attempt to lay the foundation for the work in class.

2 = Demonstrates thorough and thoughtful reading AND insightful interpretation of the chapter

1 = Demonstrates reading, but no (or only superficial) interpretation of the chapter

0 = Does not demonstrate any thoughtful reading of the chapter

See the examples on the next page to see the quality criterion applied to sample annotations.

Quantity To lay the foundation for understanding the in-class activities, you must at least familiarize yourself with the entire chapter — not just the first few pages.

2 = 7–20 thoughtful annotations that cover each section of the chapter

1 = 7–20 thoughtful annotations, but not each section is annotated

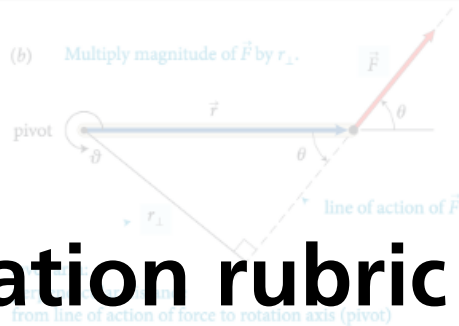
0 = 6 or fewer annotations

Timeliness The work done in class depends on you having done the reading in advance, so completing the reading on schedule is important. Your annotations can be questions, comments, or responses to existing questions or comments. Responses are allowed up to three days beyond the posted deadline.

Annotation rubric

- Quality (thoughtful reading & interpretation)
- Quantity (10)
- Timeliness (before class)
- Distributed

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



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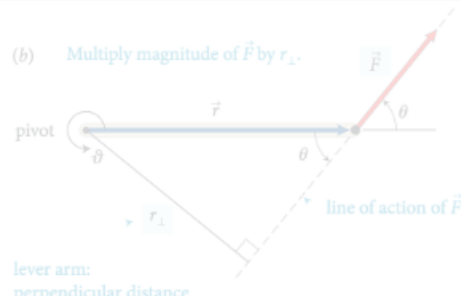
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Information transfer



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READING SCHEDULE

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	
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sections 27.4 and 27.8 optional

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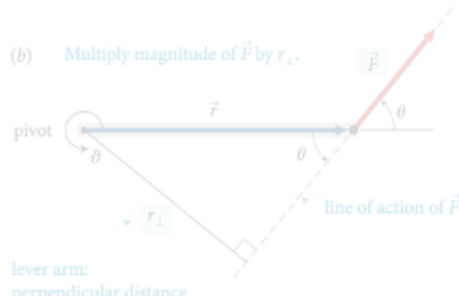
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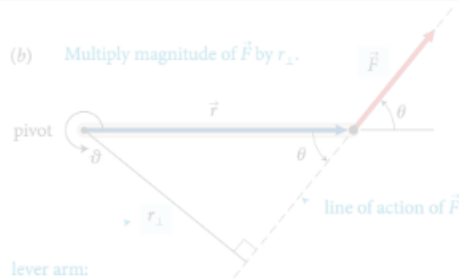
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from line of action of force to rotation axis (pivot)

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

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

Exercise 12.1 shows that the sum of the torques about the left end of the rod is zero, just like the sum of the torques about the pivot. This is true for any point on the rod. For any point on the rod, 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}_2 are equal in magnitude, and the magnitude of \vec{F}_3 is half as great. Forces \vec{F}_1 is horizontal, \vec{F}_2 and \vec{F}_3 are vertical, and the lever

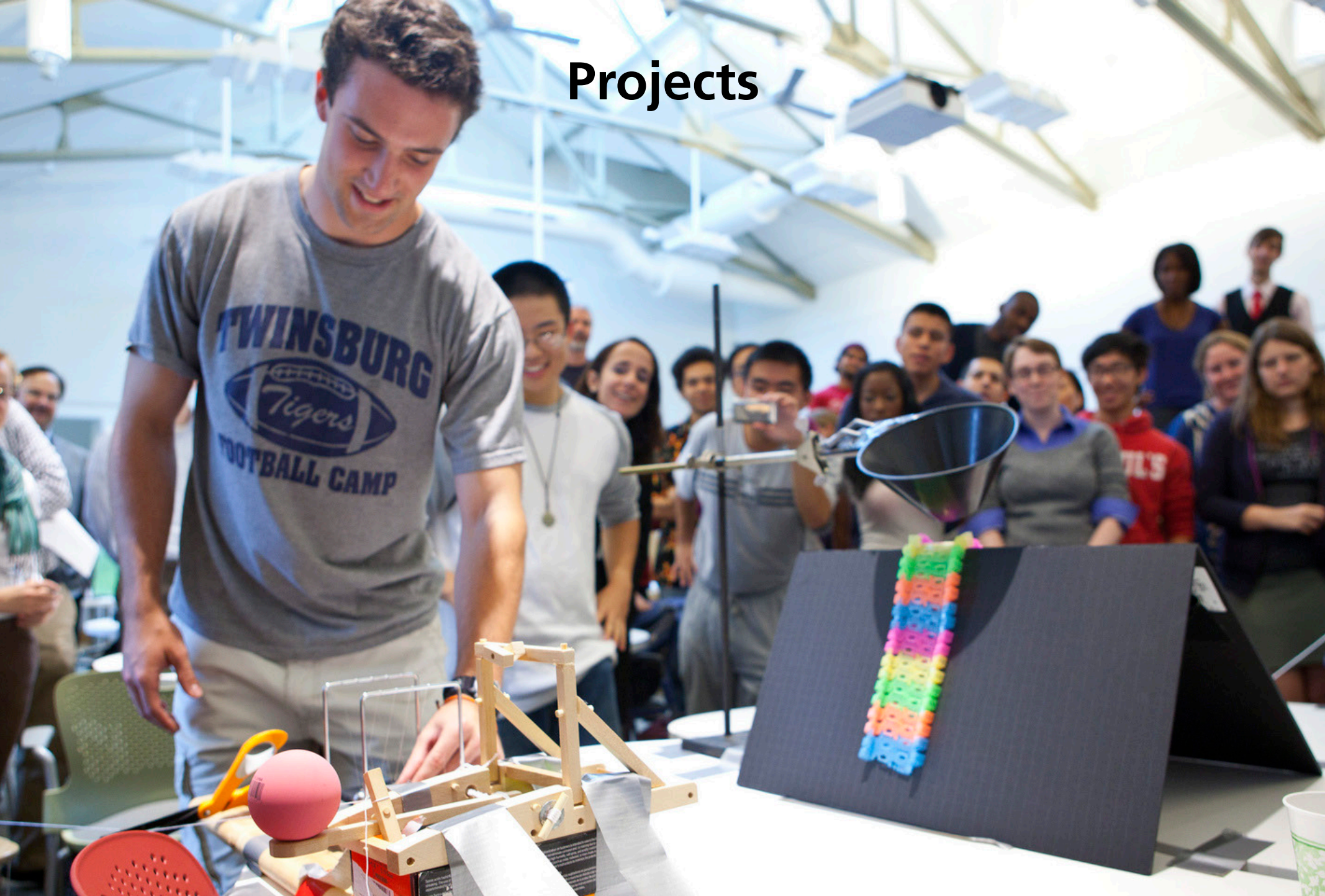
virtually all students complete all readings!

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

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

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

Projects



1 design

2 approach

Projects

- 1 project/month (6 over 2 semesters)
- new team formation for each project
- projects not prescriptive, but open-ended
- 3 types of project “fairs”
- external evaluators

Projects

Rule-based team formation using GroupEng

www.GroupEng.org

1 design

2 approach

Projects

Rule-based team formation using GroupEng

- gender
- year
- self-efficacy & learning attitude
- class performance
- exclude previous team mates

www.GroupEng.org

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 design

2 approach

AP50 FALL 2014

Project Brief

Drag

Rube G

Sympho

Symphosium



1 design

2 approach

Projects



1 design

2 approach

Projects

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

1 design

2 approach

Projects

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

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

Milestones:

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

Projects

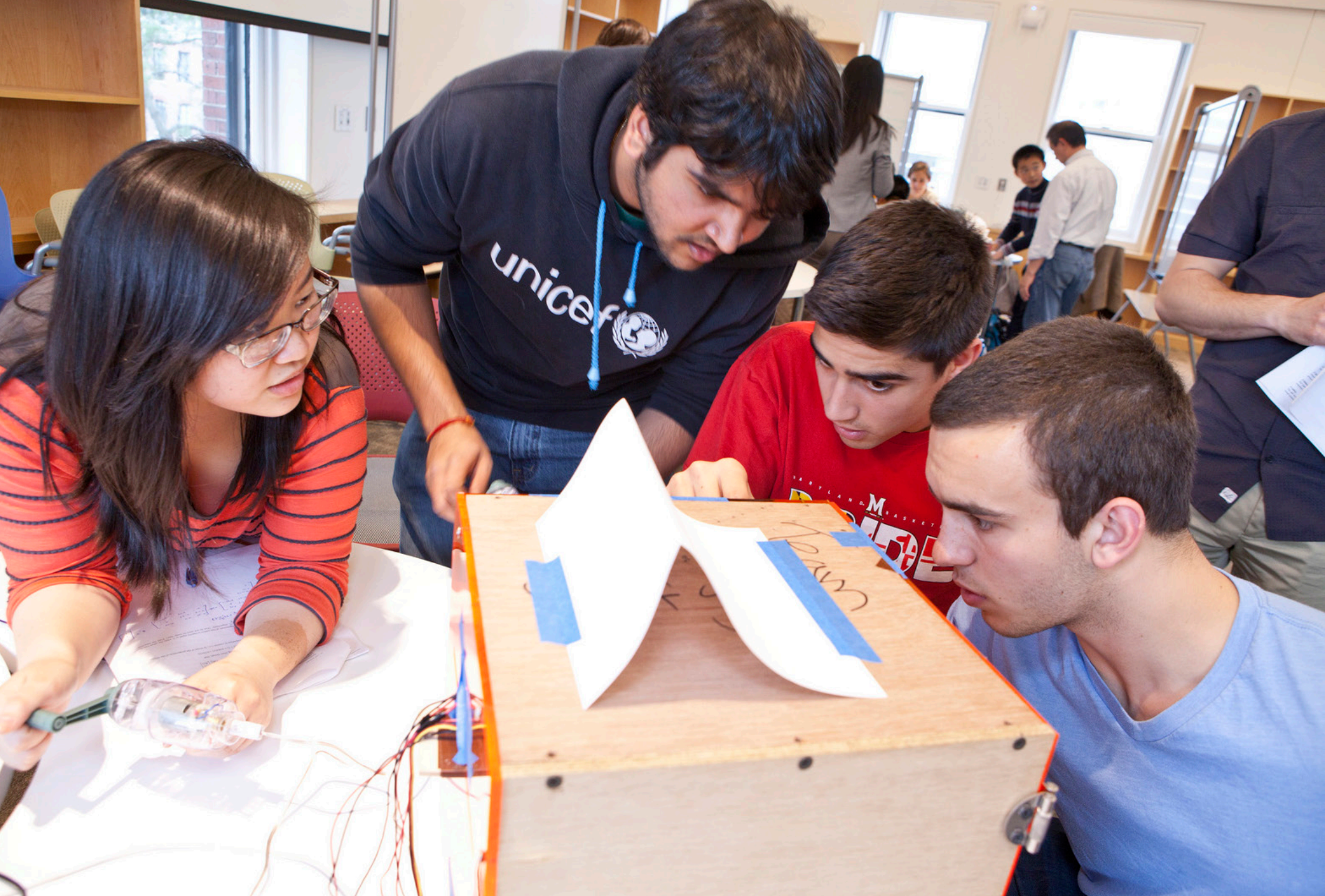
Milestones:

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



1 design

2 approach



1 design

2 approach

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

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

1 design

2 approach



1 design

2 approach

In-class activities



1 design

2 approach

In-class activities

2 weekly 3-hour class periods

1 design

2 approach

In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question
Answer alone
Discuss in team
Answer again



bring device

Tutorial 60 min



Work on worksheet with team
Explore concepts
Discuss with staff

blend of 6 "best practices"

apply



Estimate quantities
Develop individual strategy
Discuss and solve as team



Conduct experiment with team
Take measurements
Analyze data
Carry out simulations



bring device

evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class
Discuss with team, mark up
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone
Open book, open internet
Part 2: solve with team

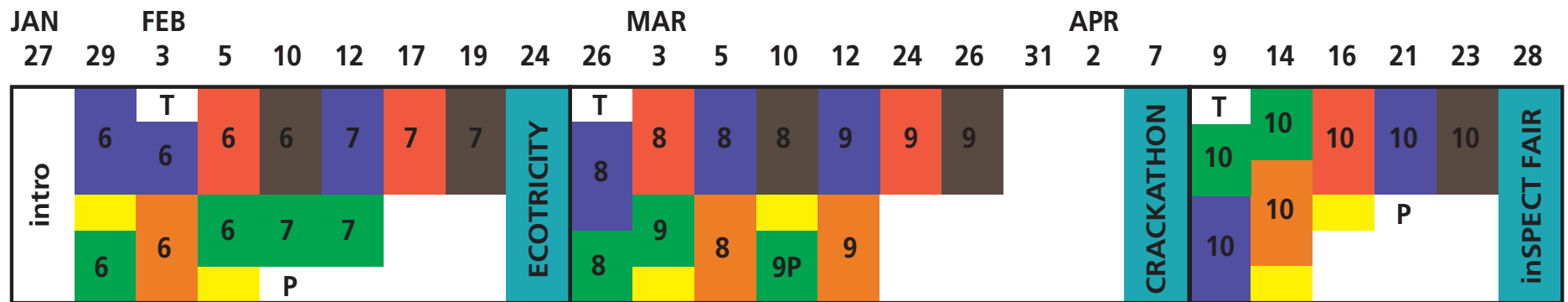


bring device

1 design

2 approach

In-class activities

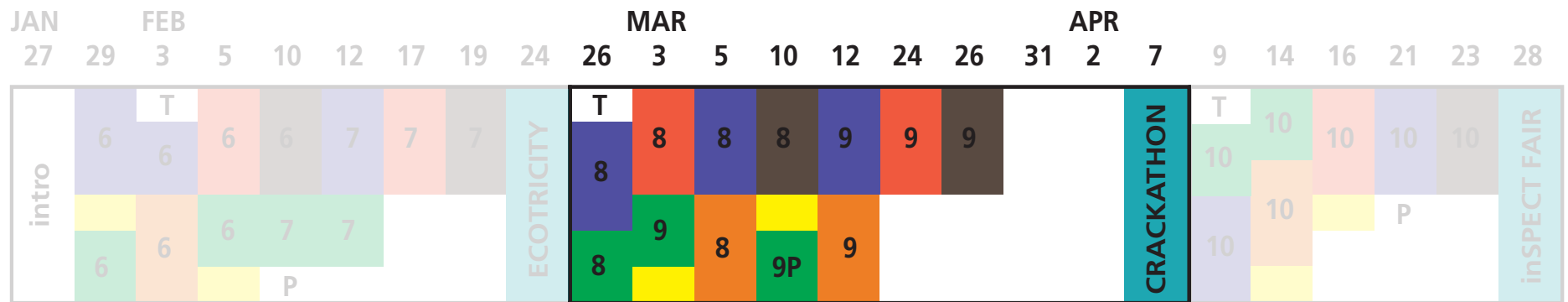


1 design

2 approach

In-class activities

one project

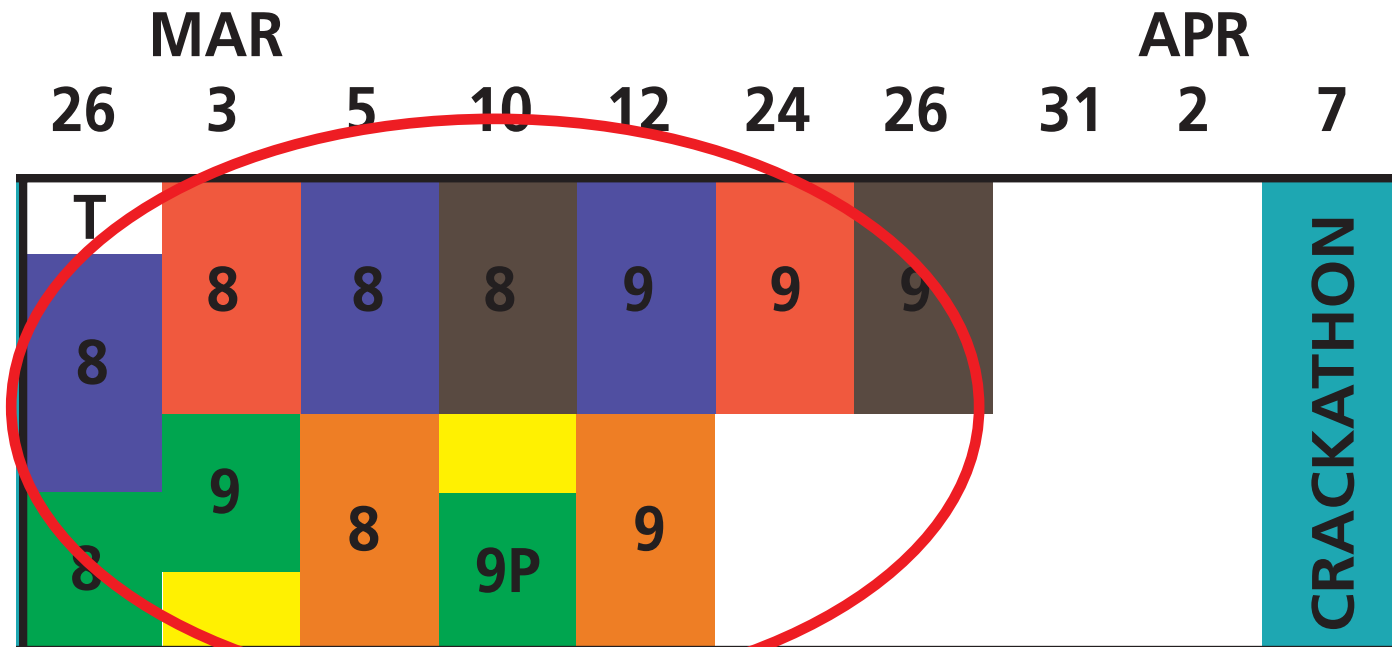


1 design

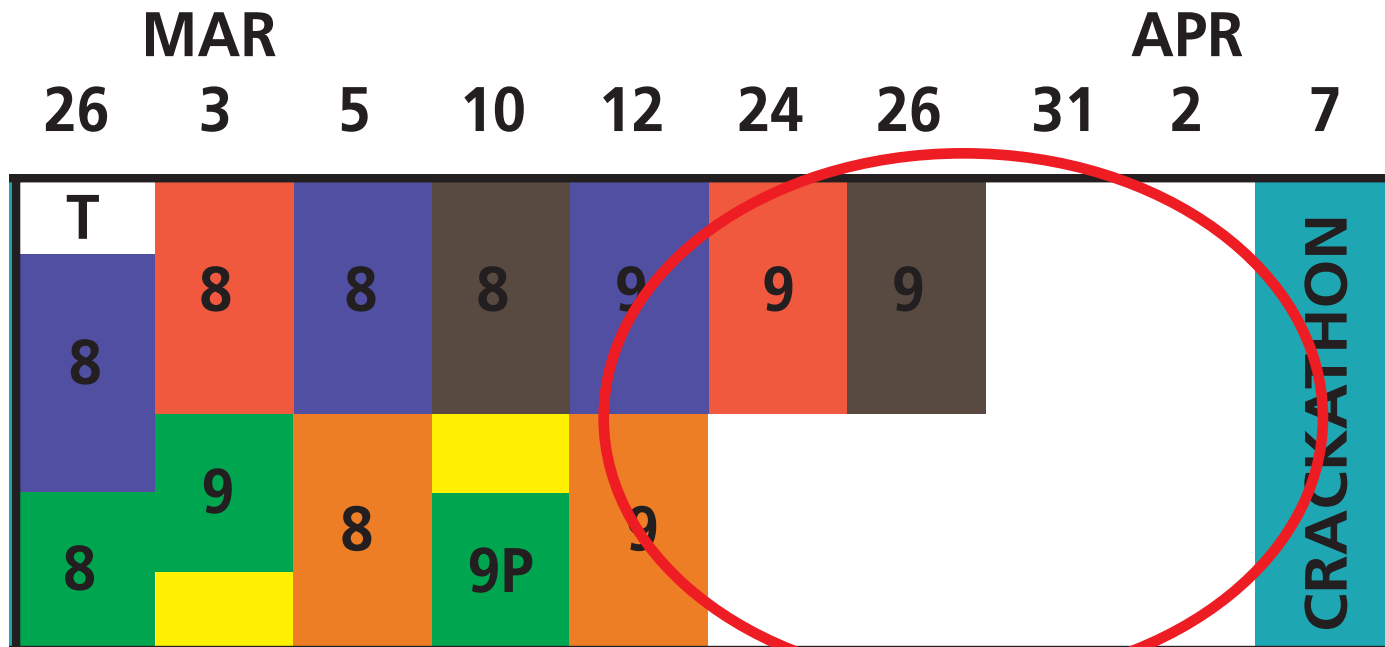
2 approach

In-class activities

2/3 scaffolded, guided



In-class activities



1/3 unguided

1 design

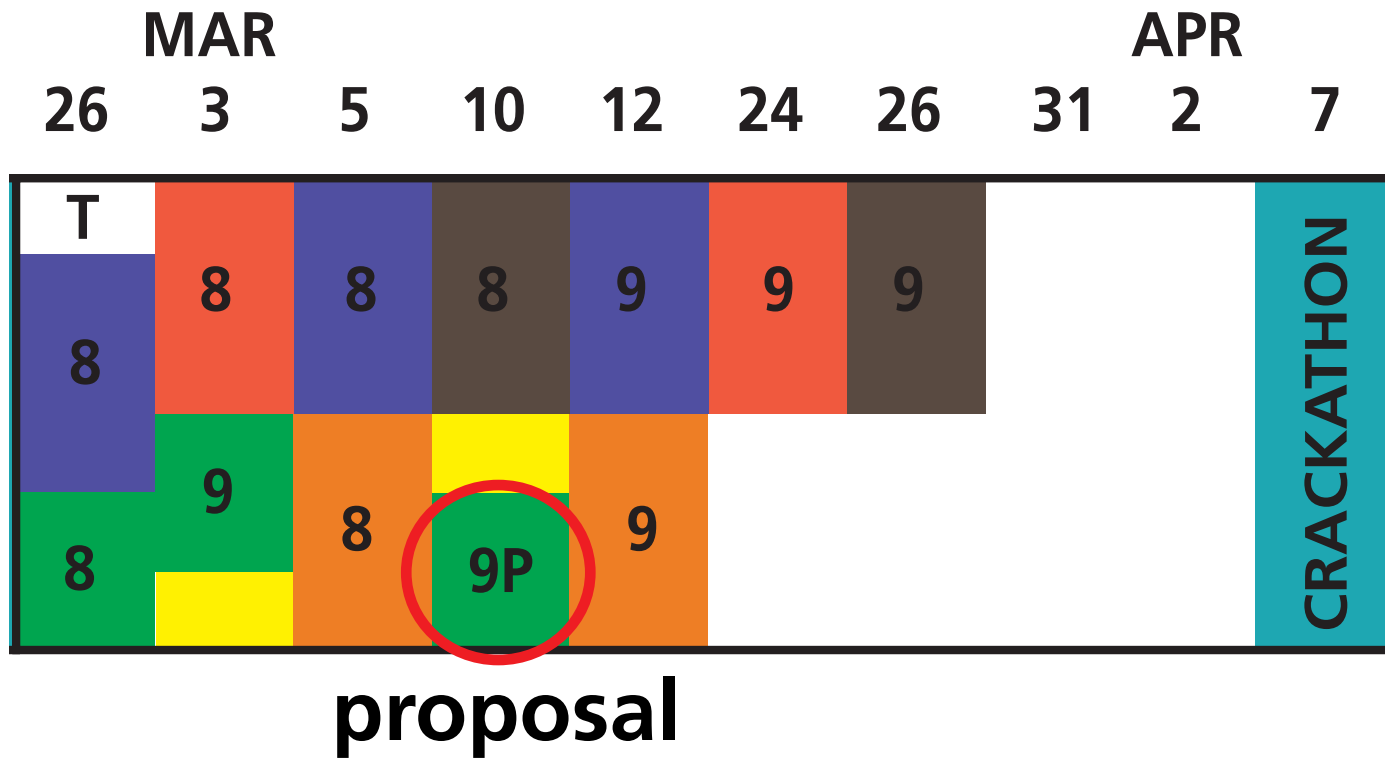
2 approach

In-class activities

team intro



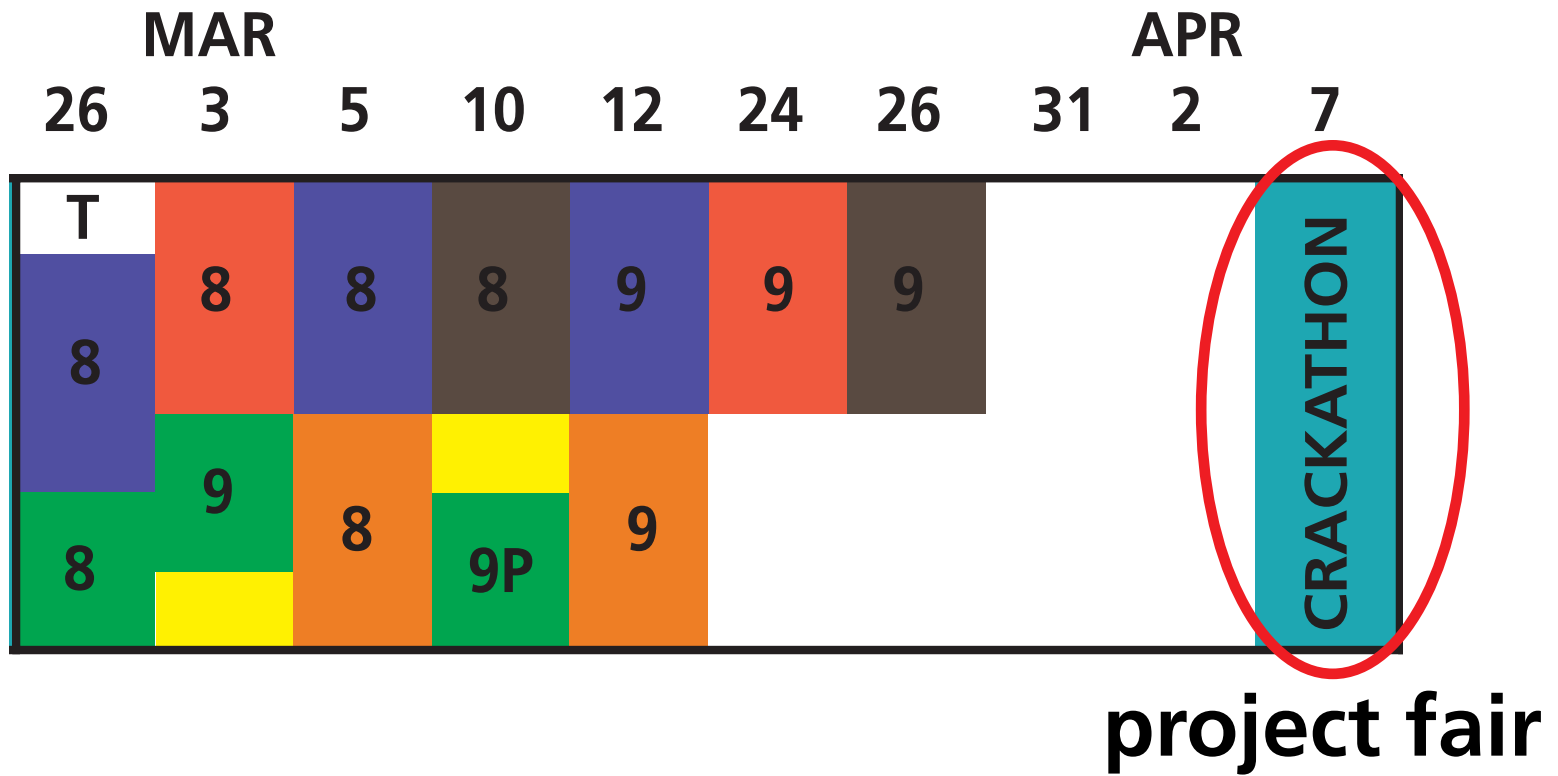
In-class activities



1 design

2 approach

In-class activities



1 design

2 approach

In-class activities

understand

LC: Learning Catalytics

90 min



Instructor poses question
Answer alone
Discuss in team
Answer again



bring device

Tutorial

60 min

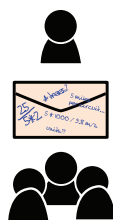


Work on worksheet with team
Explore concepts
Discuss with staff

apply

EA: Estimation Activity

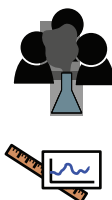
30 min



Estimate quantities
Develop individual strategy
Discuss and solve as team

EDA: Experimental Design Activity

90 min



Conduct experiment with team
Take measurements
Analyze data
Carry out simulations



bring device

evaluate

Problem Set & Reflection

90 min



Work problems alone BEFORE class
Discuss with team, mark up
Self-assess & turn in

RAA: Readiness Assurance Activity

90 min



Part 1: solve problems alone
Open book, open internet
Part 2: solve with team



bring device

In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question
Answer alone
Discuss in team
Answer again



bring device

Tutorial 60 min



Work on worksheet with team
Explore concepts
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities
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Conduct experiment with team
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bring device

evaluate

Problem Set & Reflection 90 min



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Self-assess & turn in

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Open book, open internet
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bring device

1 design

2 approach

In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question
Answer alone
Discuss in team
Answer again



Tutorial 60 min



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Explore concepts
Discuss with staff

apply

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Problem Set & Reflection 90 min



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In-class activities

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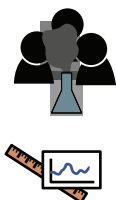
apply

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Part 2: solve with team



AP50b Fall 2013

Problem Set 1

due W Feb 6 in class

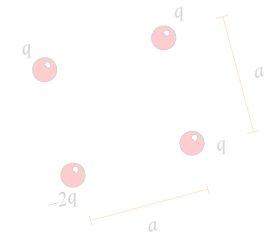
Instructions: We need to quickly scan your work so we can return it before the end of class, please:

- use a pen or ballpoint pen
- no-dog ears or tabs
- dark ink (no light pencils)
- no staples
- name on each page
- single-sided
- leave margins

goal: develop problem solving and metacognitive skills

1. **Ink-Jet Printing.** In an inkjet printer, ink is ejected by squirting drops of ink at a piece of paper. The drops are ejected from a rapidly moving nozzle. The ink drops leave a positive charge by removing electrons. The drops then pass through a charging unit that gives each drop a positive charge by removing electrons. The drops then pass between two parallel deflecting plates where there is a uniform vertical electric field. The drops then pass between two parallel plates. Estimate the number of atoms present in a droplet of ink.
2. **Levitation.** One possible way of levitating an object might be to use the forces associated with charged objects. For example, you have two charged particles that are fixed on a vertical pole 0.5 m apart. The lower one has a fixed charge of $-3.0 \mu\text{C}$. The upper one has a charge q_A that can be adjusted. A 30-mg particle with a charge of $+8.0 \mu\text{C}$ can move freely on the pole below the other two. You wish to levitate (i.e., float) this particle at a distance of 1.0 m below the lower fixed charge. What should the adjustable charge q_A be to achieve this feat?

3. **Charge Square.** Four charged particles are arranged in a square as shown in the figure to the right, with $q = 3.9 \times 10^{-4} \text{ C}$ and $a = 6.9 \text{ mm}$. What is the net force on the particle at the upper right corner due to the other three?



1 design

2 approach

Problem Set Rubric

The goal of the problem sets is to develop problem-solving skills, not just to test your ability to obtain the right answer. You will receive the problem sets a week before they are due. Each problem set involves both individual and team work.

Individual phase (at home): From the time you receive a problem set to the time it is due in class at 10 am, you are to work on the problem set **alone**. The work you complete during this phase will be evaluated on effort, not correctness. You may only use **blue or black ink** and you must attempt to solve each problem using the following 4-step procedure (see Section 1.8 in the textbook for additional details)

Getting Started

State the important information and summarize the problem. If possible, include a diagram. Note any assumptions you're making.

Devise Plan

Devise a plan of attack before diving into the solution. Break down the problem into smaller, manageable segments. Identify which physical relationships you can apply.

Execute Plan

Carry out your plan, explaining each step. The argument should be easy to follow. Articulate your thought process at each step (including roadblocks). Any variables should be clearly defined, and your diagrams should be labeled.

Evaluate Answer

Check each solution for reasonableness. There are many ways to justify your reasoning: check the symmetry of the solution, evaluate limiting or special cases, relate the solution to situations with known solutions, check units, use dimensional analysis, and/or check the order of magnitude of an answer.

You can consult the textbook and online resources, and you may consult the teaching staff by posting questions to the Problem Set Discussion on the course Web site. However, you may not consult other people, nor collaborate with your peers. It's ok to try hard and not succeed at first (only your effort is evaluated), but you must attempt every problem. If you reach the Evaluate stage and find that your answer does not seem reasonable, try to describe your thought process so you are prepared for a discussion with your team in class.

Team/Reflect phase (in class): On the due date of the problem set, you will work with your team in class to improve and/or correct your solutions, reflect on your work, and determine what you need to review. In this stage, you may only use **red ink** to write on your problem sets (pens will be provided in class to review. In additional 45 minutes, your team will be provided with a solution set which you may use to review. In the final additional 45 minutes, your team must submit the marked-up problem sets to the teaching staff. You will receive sheets for the entire team and a team scoring sheet.

It is the team's responsibility to ensure that all team members have their own copy of the problem sets and solutions together with a team score. This is only for the team's use.

Individual phase (at home): From the time you receive a problem set to the time it is due to work on the problem set **alone**. The work you complete during this phase will be correctness. You may only use **blue or black ink** and you must attempt to solve each problem using a 4-step procedure (see Section 1.8 in the textbook for additional details)

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Execute Plan Carry out your plan, explaining each step. The argument should be your thought process at each step (including roadblocks). Any variables should be defined, and your diagrams should be labeled.

Evaluate Answer Check each solution for reasonableness. There are many ways to justify the symmetry of the solution, evaluate limiting or special cases, compare to similar situations with known solutions, check units, use dimensional analysis, and check the magnitude of an answer.

You can consult the textbook and online resources, and you may consult the teaching staff for help.

Individual phase (at home): From the time you receive a problem set to the time it is due to work on the problem set **alone**. The work you complete during this phase will be evaluated on correctness. You may only use **blue or black ink** and you must attempt to solve each problem using a 4-step procedure (see Section 1.8 in the textbook for additional details)

Getting Started

State the important information and summarize the problem. If possible, note any assumptions you're making.

at home:

Devise Plan

Devise a plan of attack before diving into the solution. Break down the problem into manageable parts. Determine why a particular approach you can attempt will work.

implement 4-step procedure

Execute Plan

Carry out your plan, explaining each step. The argument should be your thought process at each step (including roadblocks). Any variables should be defined, and your diagrams should be labeled.

(evaluated on effort)

Evaluate Answer

Check each solution for reasonableness. There are many ways to justify the symmetry of the solution, evaluate limiting or special cases, compare situations with known solutions, check units, use dimensional analysis, and check the magnitude of an answer.

You can consult the textbook and online resources, and you may consult the teaching staff for help.

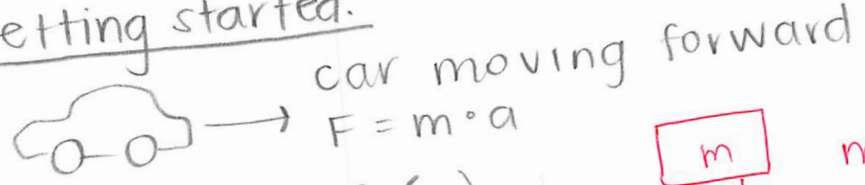
1 design

2 approach

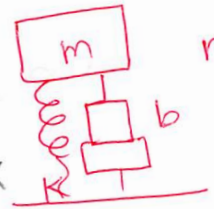
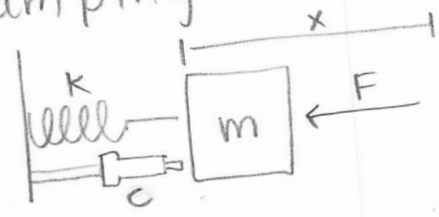
Applied Physics 50a

① Estimate damping coeff. for a shock absorber on a midsize car.

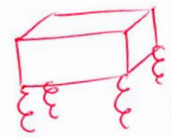
Getting started.



Damping coeff (c)



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



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

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.

$$F = m \cdot a$$

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

Translational eq = $\sum F_x = 0$

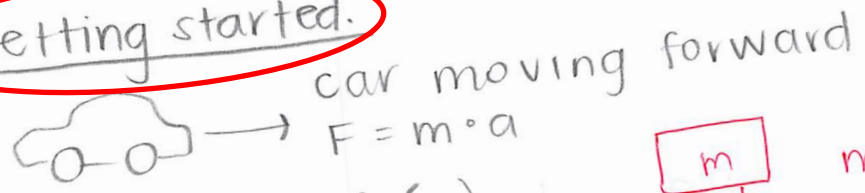
- Estimate mass of mid-size car = 1500 kg
- Est. accel. of midsize car: 5 m/s

$$k = \frac{\Delta mg}{x}$$

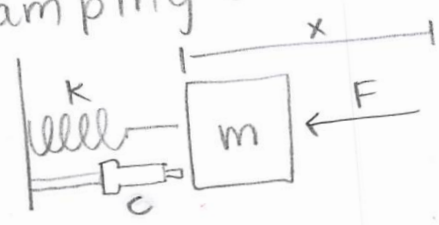
Applied Physics 50a

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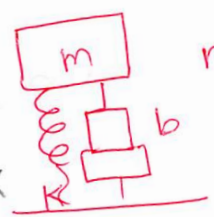
Getting started.



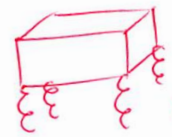
Damping coeff (c)



$F_s = -kx$
 $F_d = -cv$



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



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

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

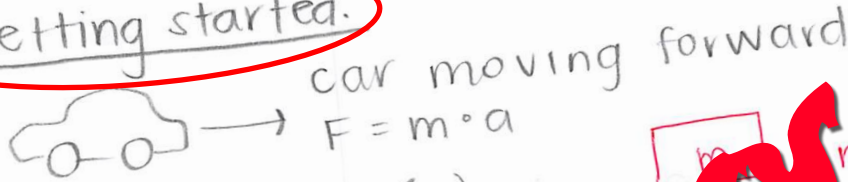
$\sum F_x = F_{Ec}^G - F_{sc}^c = \Delta mg - k(x_{eq} - x_0)$
 Translational eq = $\sum F_x = 0$

$k = \frac{\Delta mg}{x}$

Applied Physics 50a

① Estimate damping coeff. for a shock absorber on a midsize car.

Getting started.



Damping coeff (c)



25 pages!

Create a plan.

Let 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^2

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

F_{Ec}^G Translational eq = $\Sigma F_x = 0$

$k = \frac{\Delta mg}{x}$

with your peers. It's ok to try hard and not succeed at first (only your effort is evaluated every problem. If you reach the Evaluate stage and find that your answer does not describe your thought process so you are prepared for a discussion with your team in class.

Team/Reflect phase (in class): On the due date of the problem set, you will work with your team to improve and/or correct your solutions, reflect on your work, and determine what you need to learn. During this stage, you may only use **red ink** to write on your problem sets (pens will be provided in class). In the final 15 minutes, your team will be provided with a solution set which you may use to confirm your answers. In the additional 45 minutes, your team must submit the marked-up problem sets together with your reflection sheets for the entire team and a team scoring sheet.

It is the team's responsibility to ensure that *all* team members hand-in complete answers and solutions together with a completed reflection sheet, because your team's submitted work will determine your team score. This means that if you do not put in adequate effort before the Team/Reflect phase, you will only receive your own score, but also that of your team members. Likewise, it is important to ensure that your team marks his/her work up correctly during the Team/Reflect phase.

Important: Writing on the problem set in class in any other color but red will be considered a violation of the rules.

with your peers. It's ok to try hard and not succeed at first (only your effort is evaluated every problem. If you reach the Evaluate stage and find that your answer does not describe your thought process so you are prepared for a discussion with your team in class

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in class:

mark up/improve solutions

complete reflection sheet

It is the team's responsibility to ensure that *all* team members hand-in complete and accurate solutions together with a completed reflection sheet because your team's score is based on the team score. This means that if you do not put in adequate effort before the Team/Reflect phase, you will receive only your own score, but also that of your team members. Likewise, it is important to ensure that your team marks his/her work up correctly during the Team/Reflect phase.

Important: Writing on the problem set in class in any other color but red will be considered a violation of the rules.

② continued.

c) Maximum transverse speed.

Use $\lambda = \frac{v}{f}$; solve for v.

d) Length would have to be λ or $1/2$ wavelength, etc.

Execute plan.

a) $y = 0.2 \sin[\pi(0.5x - 100t)] = 0.5\pi(x - 200t)$

~~$x(t) = A \sin(\omega t + \phi)$~~ $y = A \sin[k(x - ct)]$

• amplitude = 0.2 cm

200 cm/s

k = wave #

c = wave speed

A = amplitude

• $\omega = \text{rotational speed} = 0.5\pi$

~~$0.5\pi = \frac{2\pi}{T} \Rightarrow T = 4 \text{ sec} = \text{period}$~~ $\frac{1}{50}$

$k = \frac{2\pi}{\lambda} \rightarrow \lambda = \frac{2\pi}{k}$

• $f = \frac{1}{T} = 50 \text{ sec}^{-1} = \text{Hz}$ 0.02 sec

$\lambda = \frac{v}{f}$

• $\lambda = \frac{v}{f} = \frac{200}{50} = 4 \text{ cm}$

$T = \frac{1}{f}$

$4 f = \frac{v}{\lambda}$

• wave number = $\frac{2\pi}{\lambda} = \frac{1}{2}\pi = 0.5\pi$

$= \frac{200}{4} = 50$

(shifted right)

$y = 0.2 \sin[\pi(0.5x - 100(\frac{1}{200}))]$

$y = 0.2 \sin[\pi(0.5x - 100(0))]$

Problem Set Reflection

Describe what you **learned** from working on this problem set before coming to class and reviewing it in class. (Do you think you would be able to take the concepts you explored in this problem set and transfer those concepts in a whole new context?) For example, would you be able to solve a problem involving the same physics concepts, but of a form you have never seen before?). You may complete this part before coming to class in blue or black ink.

Before coming to class, I learned a lot about waves in music and frequency. I feel really comfortable with concepts of wave speed, amplitude, frequency, and period. I understand beat frequency (although I made a clerical error by forgetting to use the speed of sound (twice)). I also feel like I now understand how decibels are calculated - before, I didn't know they were exponential! I know what the concept of intensity means and how to use it.

Based on your overall experience with this problem set, describe what you need to review.

I definitely need to review torque! I had no idea how to use that concept for #3 and I'll probably need to go over the solutions before I really understand it. Similarly with the damping coefficient estimation problem → I started off in the wrong direction and never really fixed where I went wrong. I also need to review some calculus. The last time I really understood calculus was high school and it's becoming an issue.

Problem Set Reflection

Describe what you learned from working on this problem set before coming to class and reviewing it in class. (Do you think you would be able to take the concepts you explored in this problem set and transfer those concepts in a whole new context?) For example, would you be able to solve a problem involving the same physics concepts, but of a form you have never seen before?). You may complete this part before coming to class in blue or black ink.

Before coming to class, I learned a lot about waves in music and frequency. I feel really comfortable with concepts of wave speed, amplitude, frequency, and period. I understand beat frequency (although I made a clerical error by forgetting to use the speed of sound). I also feel like I now understand how decibels are calculated - before, I didn't know they were exponential! I know what the concept is, but I don't know how to use it.

phase

credit

solve (at home/individual)


50%

reflect (in class/team)

50%

Based on your overall experience with this problem set, what do you need to review.

I definitely need to review torque! I had a hard time with that concept for #3 and I'll probably need to go back to my notes before I really understand it. Similarly with the damping coefficient estimation problem - I started off in the wrong direction and never really fixed where I went wrong. I also need to review some calculus. The last time I really understood calculus was high school and it's becoming an issue.



“I was inspired and encouraged to do these problems on my own with the promise of collaborative work [the next day]”



**“I felt less pressure to find the right answer
and more freedom to explore”**

1 design

2 approach

In-class activities

understand

LC: Learning Catalytics 90 min



Instructor poses question
Answer alone
Discuss in team
Answer again



Tutorial 60 min



Work on worksheet with team
Explore concepts
Discuss with staff

apply

EA: Estimation Activity 30 min



Estimate quantities
Develop individual strategy
Discuss and solve as team

EDA: Experimental Design Activity 90 min



Conduct experiment with team
Take measurements
Analyze data
Carry out simulations



evaluate

Problem Set & Reflection 90 min



Work problems alone BEFORE class
Discuss with team, mark up
Self-assess & turn in

RAA: Readiness Assurance Activity 90 min



Part 1: solve problems alone
Open book, open internet
Part 2: solve with team





1 design

2 approach

A group of students in a classroom or computer lab, working on laptops and discussing their work. The scene is brightly lit with large windows in the background. Several students are seated at desks, some looking at their laptops, while others are engaged in conversation. The overall atmosphere is collaborative and focused.

**goal: formative assessment
collaborative learning**

1 design

2 approach

Session 389314

This is the individual round; work on these questions on your own.



Jump to ▼

1

2

3

4

5

expression question

What is the derivative of $f(x) = 3x^2 - 6x$?

Submit response

Enter an expression, e.g., x^2 for x^2 , $\ln(y) - \sin(x)$ for $\ln y - \sin x$, $x/(y+1)$ for $\frac{x}{y+1}$, $(1/2)x$ for $\frac{1}{2}x$. Do not enter a complete equation.

Current team: **Blue team** [Change team](#)

[Change seat](#)

[Send a message to the instructor](#)

[Join another](#)

This is the individual round;

expression question

What is the derivative of $f(x) = 3x^2 - 6x$?

Submit response

Enter an expression, e.g., x^2 for x^2 , $\ln(y) - \sin(x)$ for $\ln y - \sin$

This is the individual round;

expression question

What is the derivative of $f(x) = 3x^2 - 6x$?

Submit response

Enter an expression, e.g., x^2 for x^2 , $\ln(y) - \sin(x)$ for $\ln y - \sin$

$6x - 6$

Brian Lukoff

$6x$

Brent Jones

$6x - 6$

Beth Sawyer

$6x^2 - 6$

Kip Harmon

expression question

What is the derivative of $f(x) = 3x^2 - 6x$?

Submit response

Enter an expression, e.g., x^2 for x^2 , $\ln(y) - \sin(x)$ for $\ln y - \sin$



1 design

2 approach

round

credit

individual

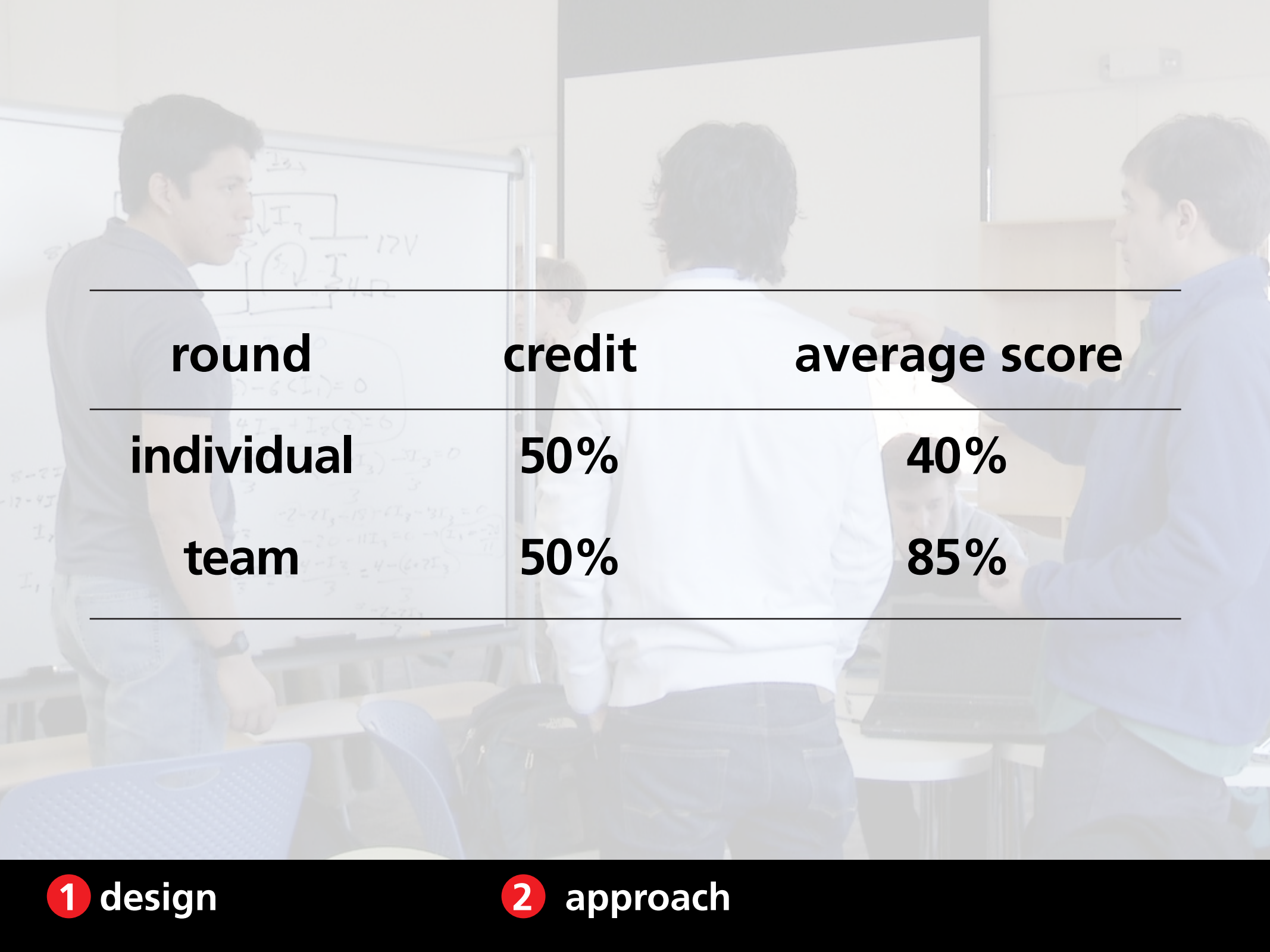
50%

team

50%

1 design

2 approach



round

credit

average score

individual

50%

40%

team

50%

85%

1 design

2 approach

Self, Peer, and Team assessment



1 design

2 approach

Team, Peer, and Self assessment

Self Assessment

Self Assessment (you!)		Never	Rarely	Sometimes	About half the time	Most of the time	All of the time
1.	I participate fully in team activities						
2.	I come to class well-prepared for all team activities						
3.	I communicate effectively and respectfully with team members: <ul style="list-style-type: none"> • I express my opinions respectfully and with clarity • I listen respectfully to the perspectives and contributions of others • I collaborate effectively with team members to make decisions and resolve conflicts 						
4.	Attendance: <ul style="list-style-type: none"> • I am present for team activities • I am on time/punctual 						
5.	I take responsibility for my own part of team work and decision-making						
6.	I am open to change and willing to re-evaluate my own position in light of new information from others						

7. Please describe one thing that you think you do well, that helps to make your team more effective

--	--

Team, Peer, and Self assessment

4. Relative contributions

How much did each team member contribute to the overall goals? Please note that the **sum of all relative contributions must be zero** — if one person did more than his/her fair share, then others must have done less.

	RELATIVE CONTRIBUTION						
	Less than fair share			Fair share	More than fair share		
	Almost nothing	Much less	Somewhat less		Somewhat more	Much more	Almost everything
Self							
Member 1							
Member 2							
Member 3							
Member 4							

Team, Peer, and Self assessment

Assessment Report

Assessment of You	Average Peer Assessment	Self Assessment
You	4.67	4
1. Participate fully in team activities	4.67	4
2. Come to class well-prepared for all team activities	4.83	4
3. Communicate effectively and respectfully with team members: <ul style="list-style-type: none"> Express your opinions respectfully and with clarity Listen respectfully to the perspectives and contributions of others Collaborate effectively with team members to make decisions and resolve conflicts 	4.83	5
4. Attendance: <ul style="list-style-type: none"> You are present for team activities On time/punctual 	4.83	4
5. Take responsibility for your own part of team work and decision-making	4.67	4
6. Are open to change and willing to re-evaluate your own position in light of new information from others		

Scale: 0 = Never, 1 = Rarely, 2 = Sometimes, 3 = About half the time, 4 = Most of the time, 5 = All of the time

helping make your team more effective in the following ways (the quotes

Team, Peer, and Self assessment

- You were great to work with and a true team player!
- Your ideas were a great contribution to our team
- You come up with good ideas
- You were really easy to work with and had a contagious enthusiasm

Assessment Report

Assessment of You	Average Peer	Self Assessment
1. Participate fully in team activities	4.67	4
2. Come to class prepared for team activities	4.67	4
3. Communicate effectively and respectfully with team members	4.83	4
4. Attendance: <ul style="list-style-type: none">• You are present for team activities• On time/punctual	4.83	5
5. Take responsibility for your own part of team work and decision-making	4.83	4
6. Are open to change and willing to re-evaluate your own position in light of new information from others	4.67	4

Scale: 0 = Never, 1 = Rarely, 2 = Sometimes, 3 = About half the time, 4 = Most of the time, 5 = All of the time

...being make your team more effective in the following ways (the quotes

Team, Peer, and Self assessment

- You were great to work with and a true team player!
- Your ideas were a great contribution to our team
- You come up with good ideas
- You were really easy to work with and had a contagious enthusiasm

“I felt as if I was able to effectively communicate my ideas, even though they may have been wrong... (still good for discussion, right?)”

Team, Peer, and Self assessment

- I would suggest being more responsive throughout the project process.
- Sometimes you're not engaged in activities
- It was hard to understand what you actually thought about an idea or project
- You could be more reasonable about what is actually feasible and what isn't

Assessment Report

Assessment of You	Average Peer	Self Assessment
You	4.67	4
1. Participate fully in team activities	4.67	4
2. Come to class with prepared work	4.83	4
3. Express your opinion clearly and with clarity	4.83	5
4. Listen respectfully to the perspectives of others	4.83	4
5. Take responsibility for your own work and decision-making	4.67	4
6. Are open to change and willing to re-evaluate your own position in light of new information from others		

Scale: 0 = Never, 1 = Rarely, 2 = Sometimes, 3 = About half the time, 4 = Most of the time, 5 = All of the time

Assessment

self-directed learning

learning goals

team work

professionalism

1 design

2 approach

Assessment

Scale: 3-0

self-directed learning

learning goals

team work

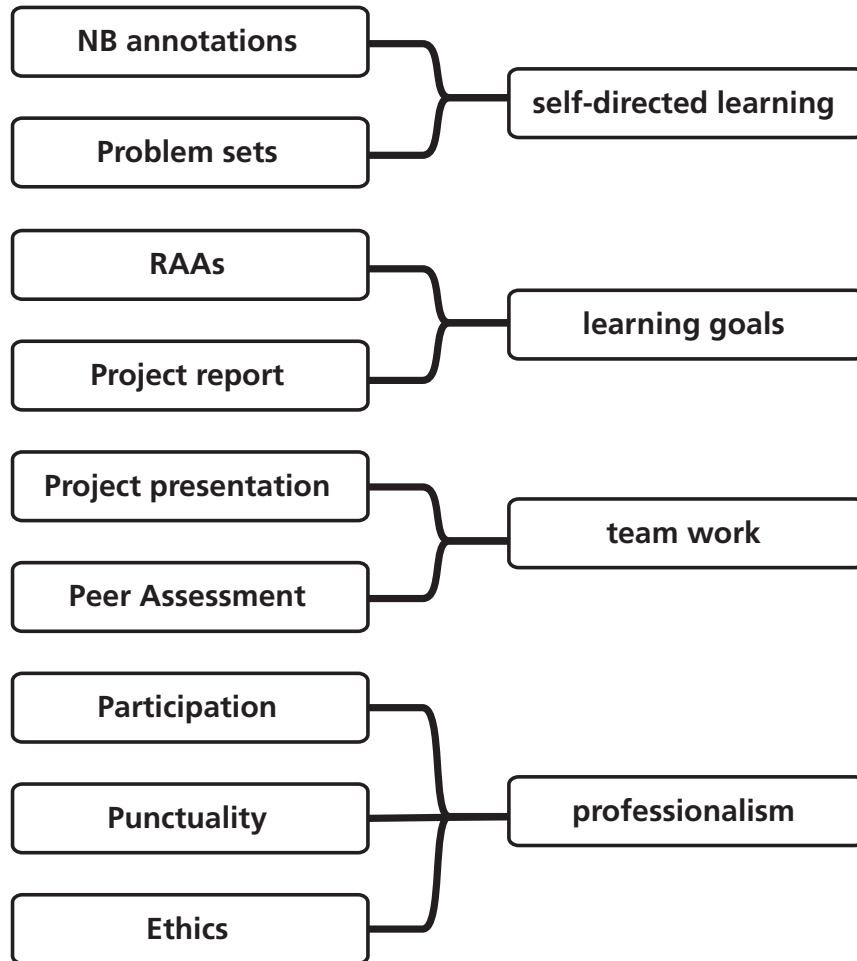
professionalism

1 design

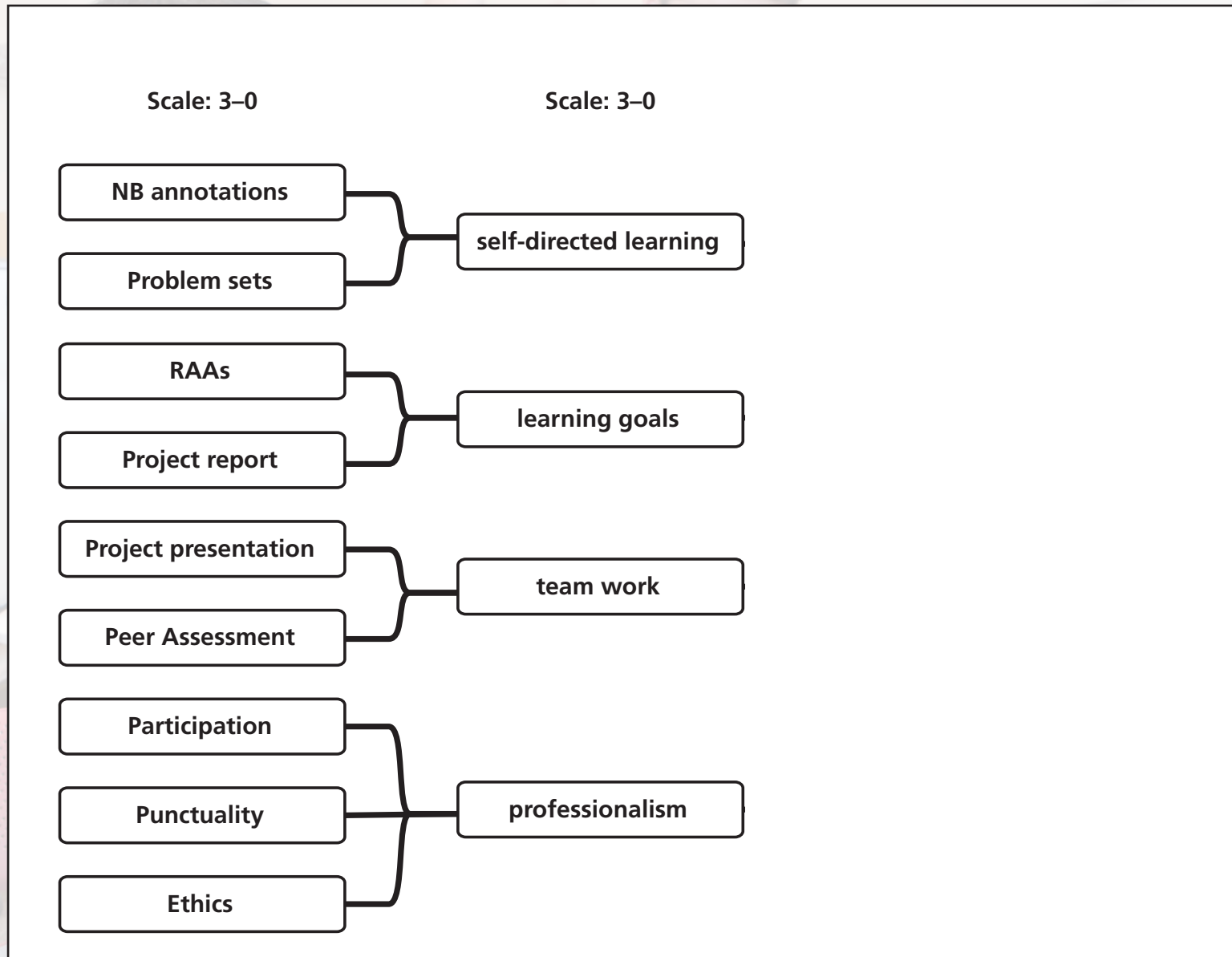
2 approach

Assessment

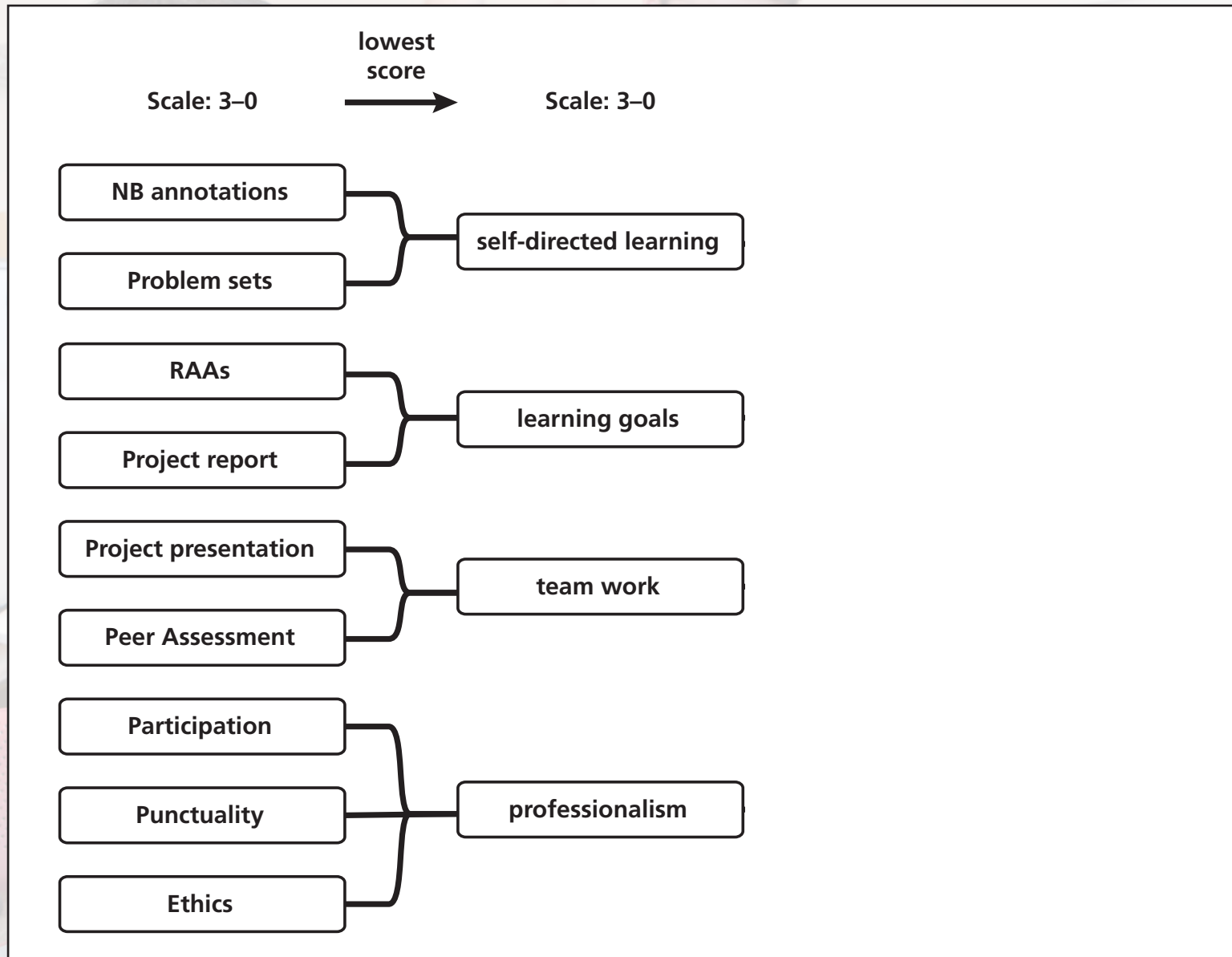
Scale: 3-0



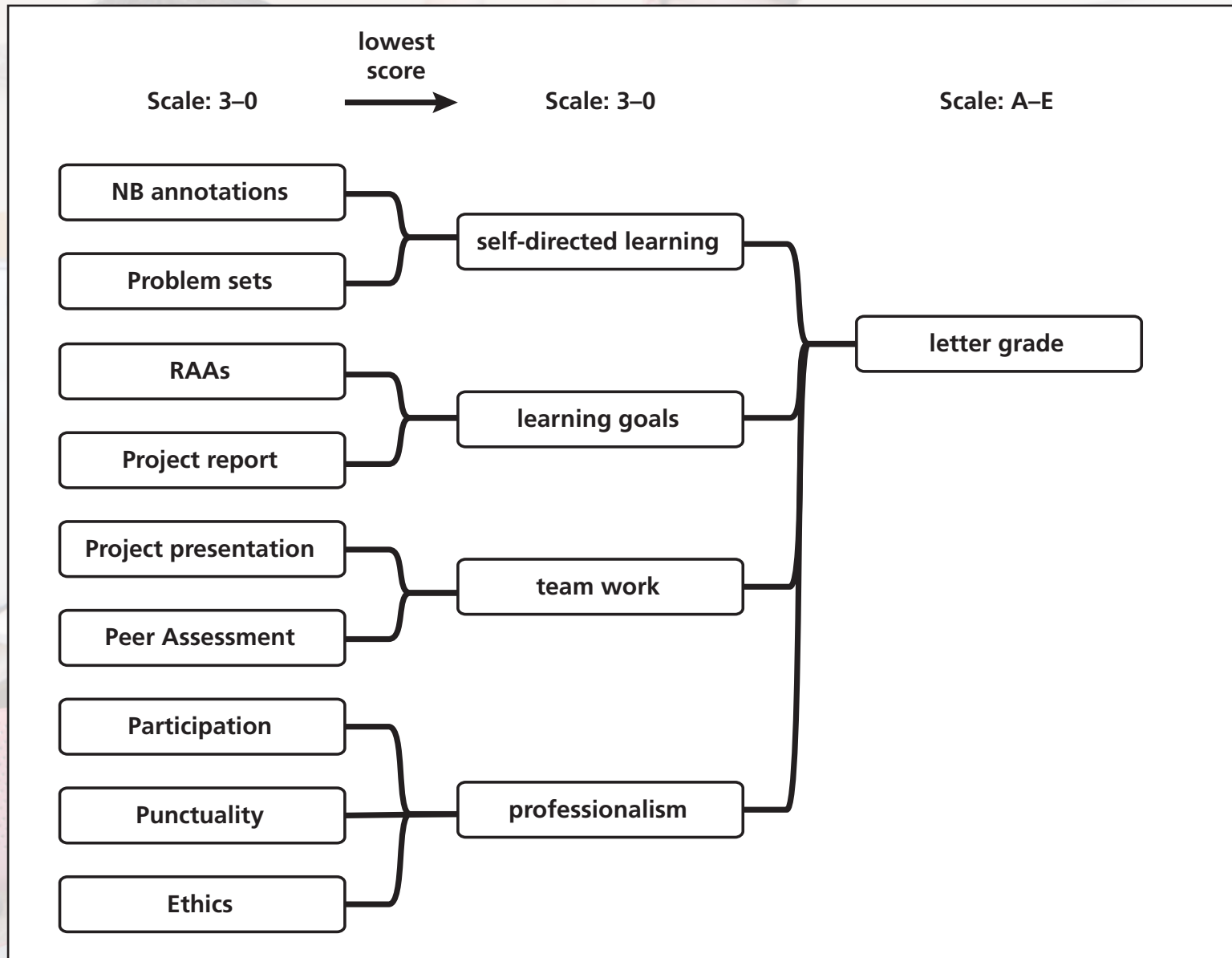
Assessment



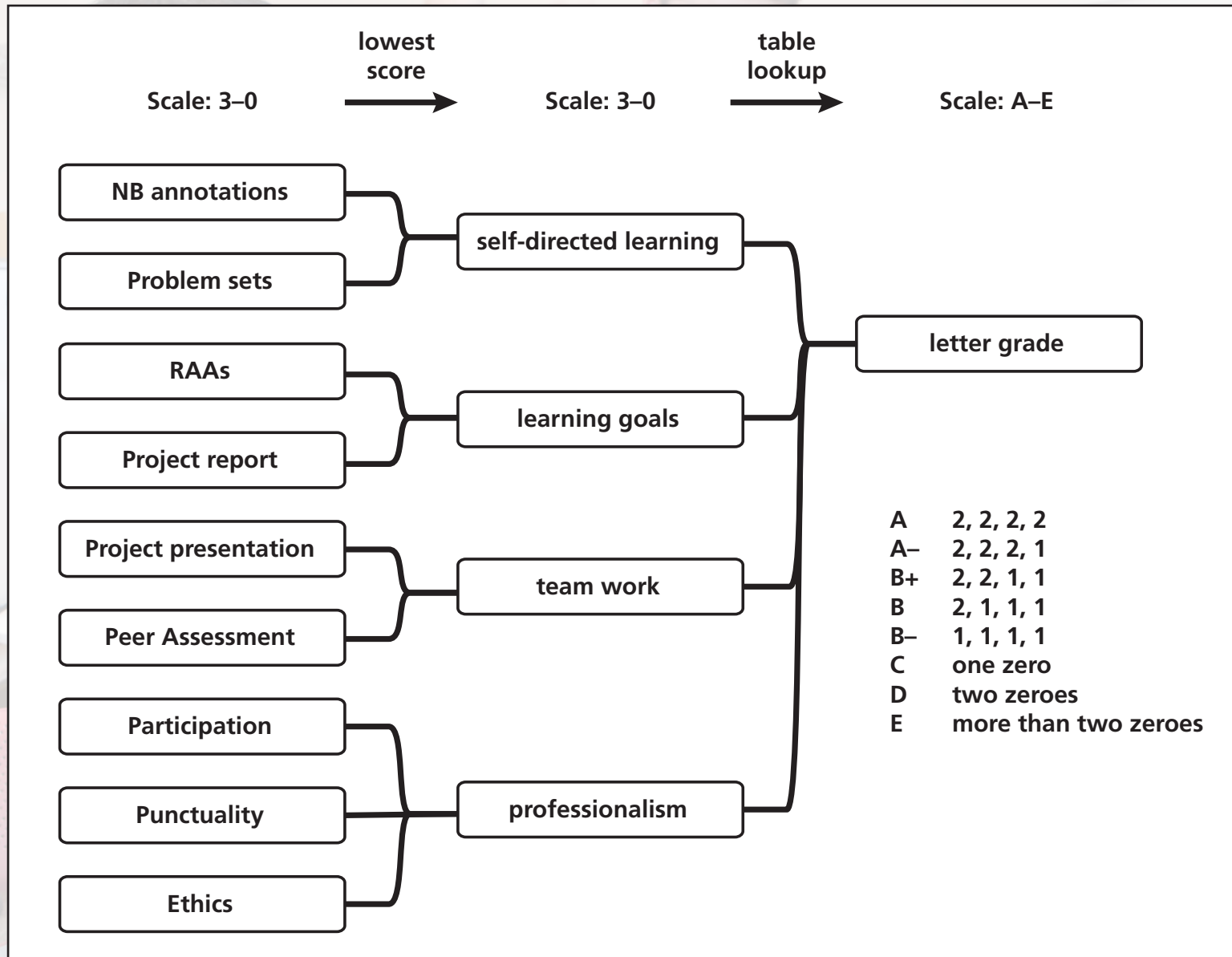
Assessment



Assessment



Assessment





1 design

2 approach

3 results

Ownership



1 design

2 approach

3 results

Ownership

Course evaluation: 4.2/5

1 design

2 approach

3 results

Ownership

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

1 design

2 approach

3 results

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!!!!!!”

1 design

2 approach

3 results

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.”

1 design

2 approach

3 results

Ownership

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

1 design

2 approach

3 results

Ownership

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

3 hours and they don't *leave!*

1 design

2 approach

3 results

Ownership

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

(via email)

1 design

2 approach

3 results

Self-efficacy

1 design

2 approach

3 results

Self-efficacy

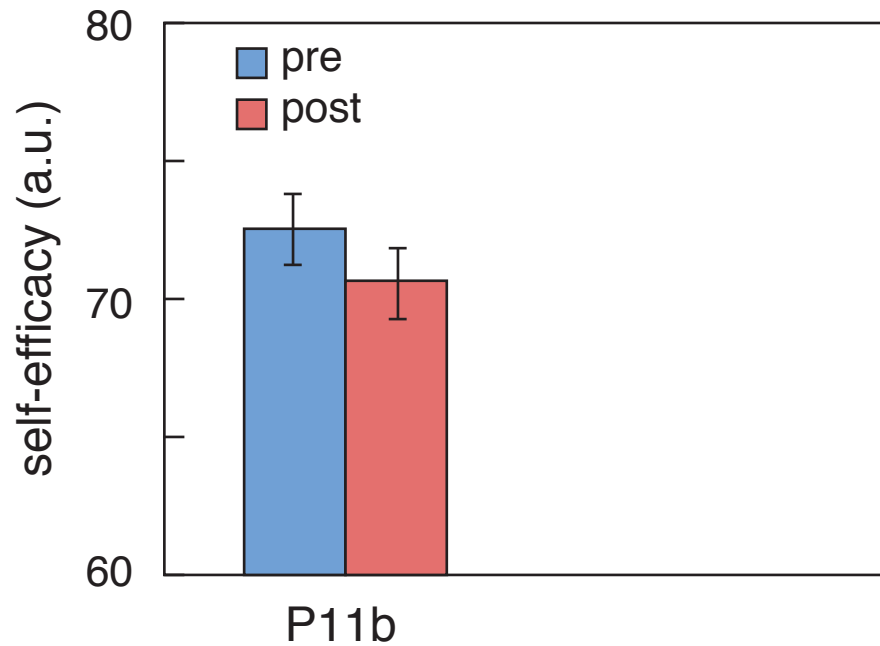
(students' belief in their ability to succeed)

1 design

2 approach

3 results

Self-efficacy

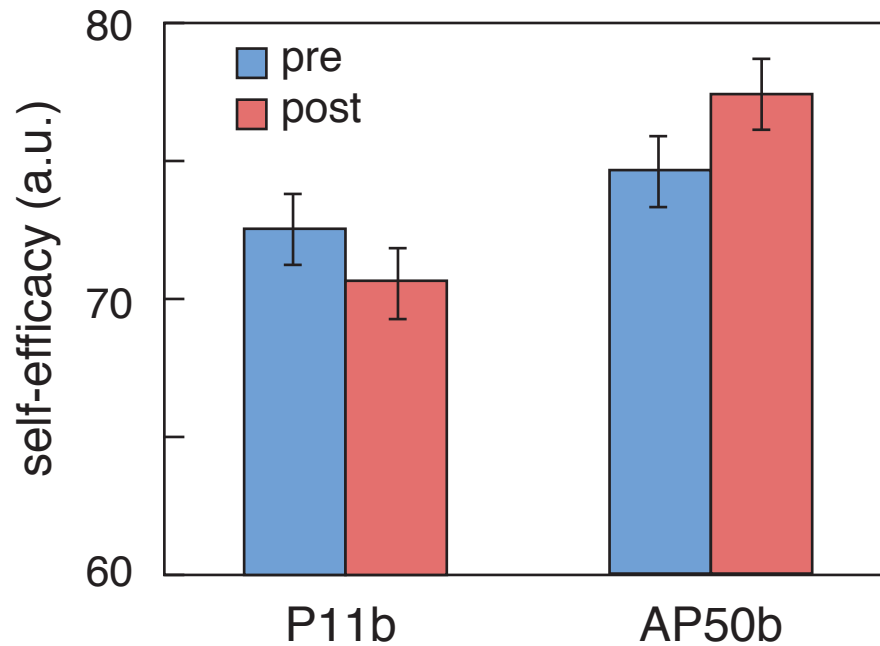


1 design

2 approach

3 results

Self-efficacy



1 design

2 approach

3 results

Self-directed learning



1 design

2 approach

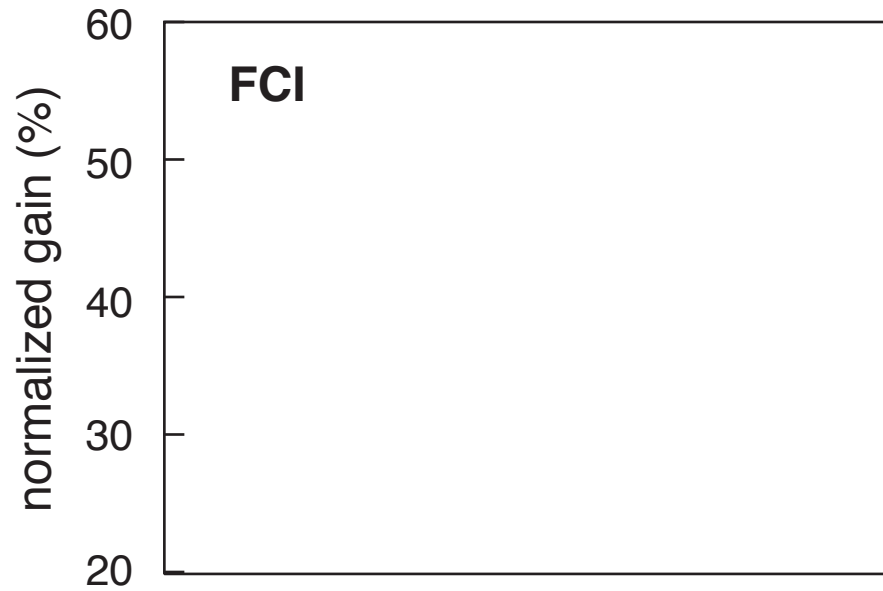
3 results

Self-directed learning

NB data shows:

- **student spend on average 2.3 hrs/chapter**
- **600–700 annotations/chapter (8–10/stu)**

Conceptual Mastery

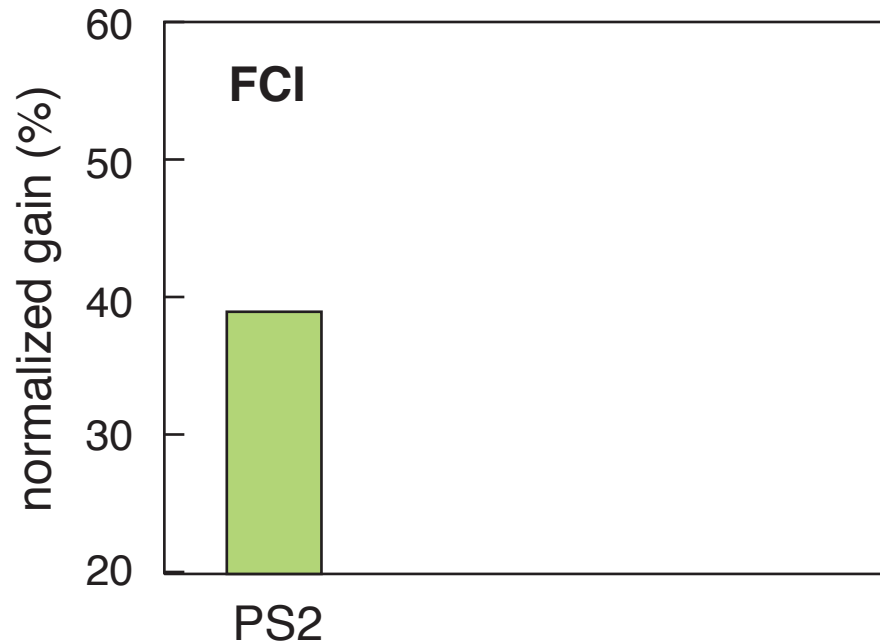


1 design

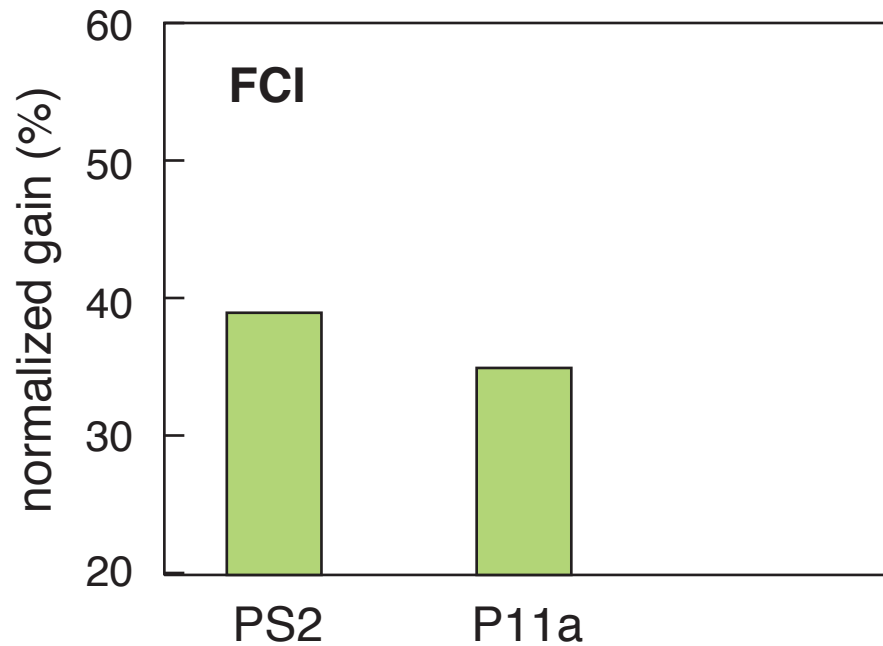
2 approach

3 results

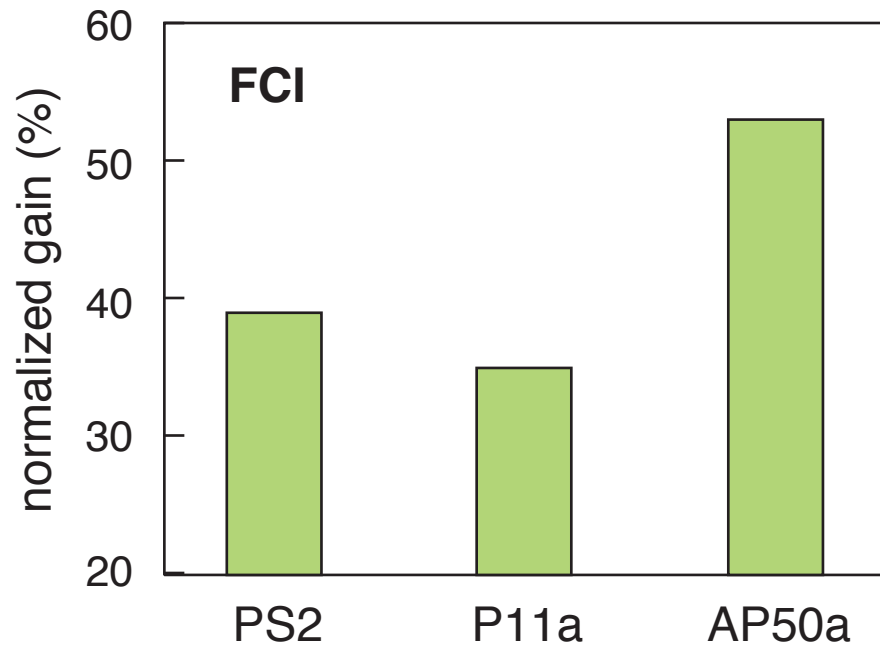
Conceptual Mastery



Conceptual Mastery



Conceptual Mastery

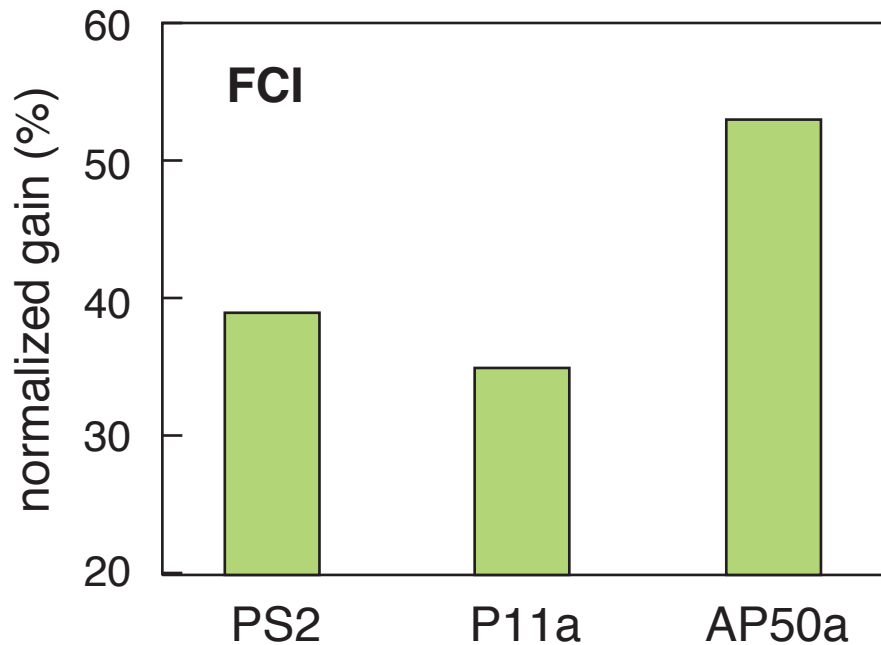


1 design

2 approach

3 results

Conceptual Mastery



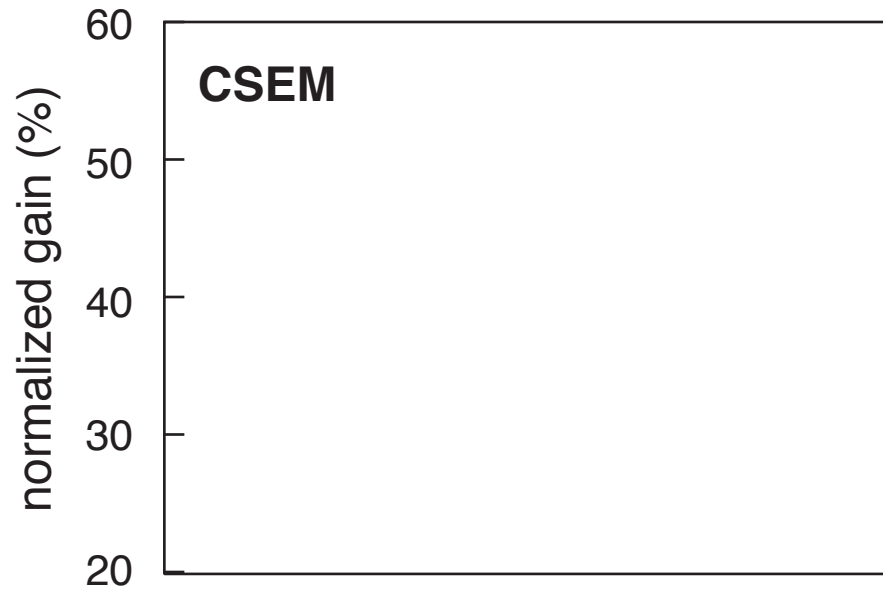
largest conceptual gain in *any* course past 6 yrs!

1 design

2 approach

3 results

Conceptual Mastery

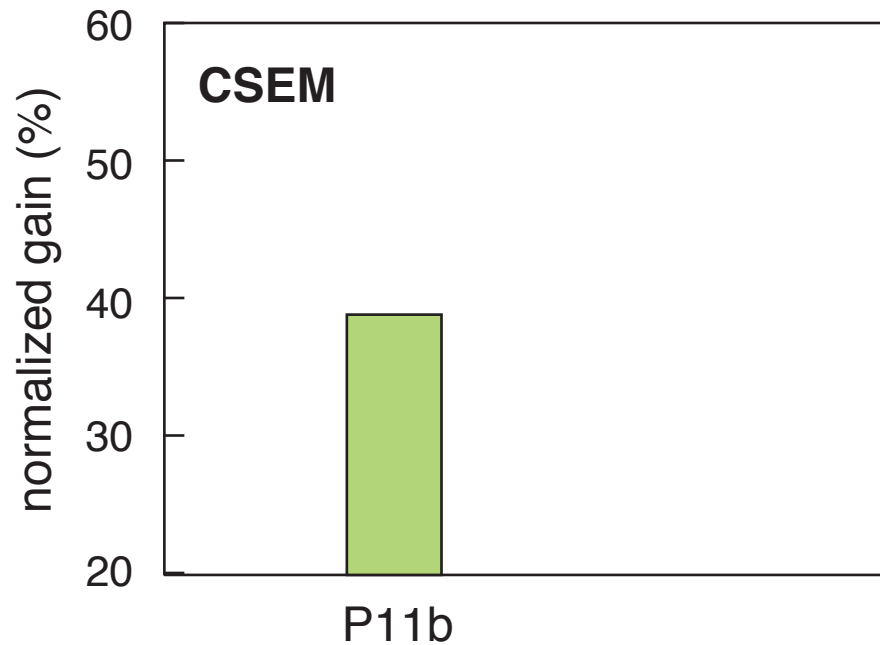


1 design

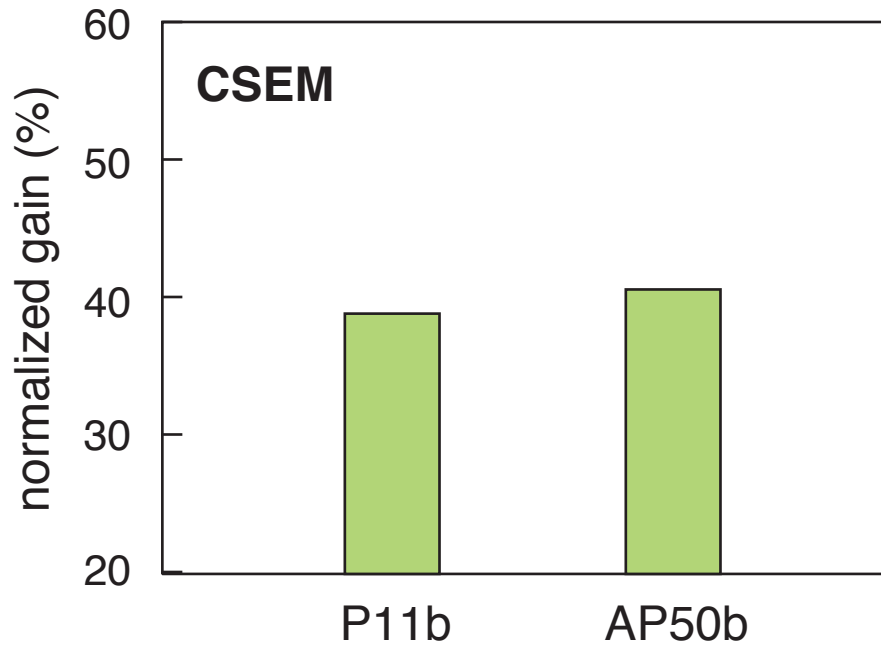
2 approach

3 results

Conceptual Mastery



Conceptual Mastery

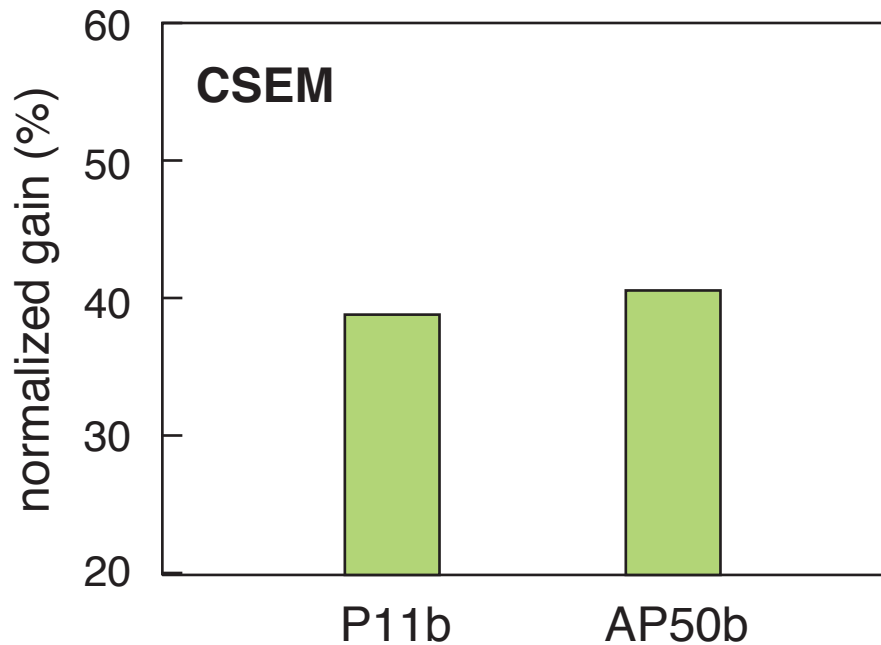


1 design

2 approach

3 results

Conceptual Mastery



as good as when I do my best teaching!

1 design

2 approach

3 results



1 design

2 approach

3 results

A photograph of four students in a physics laboratory. A woman with glasses is leaning over a wooden box containing a circuit board with many small lights. She is smiling and pointing at the board. Two other women and one man are looking at the board with interest and smiles. The man is wearing a plaid shirt and yellow pants. The woman in the foreground is wearing a maroon hoodie. The background shows a typical lab setting with whiteboards and equipment.

Can create ownership of learning physics!

1 design

2 approach

3 results



Can create ownership of learning physics!

1 design

2 approach

3 results




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

1 design

2 approach

3 results

A photograph of four students in a laboratory setting. A woman with glasses is leaning over a wooden box containing electronic equipment, pointing at it. A man in a plaid shirt stands to the right, smiling. Two other women are looking at the equipment. The background shows a typical lab environment with whiteboards and equipment.

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1 design

2 approach

3 results