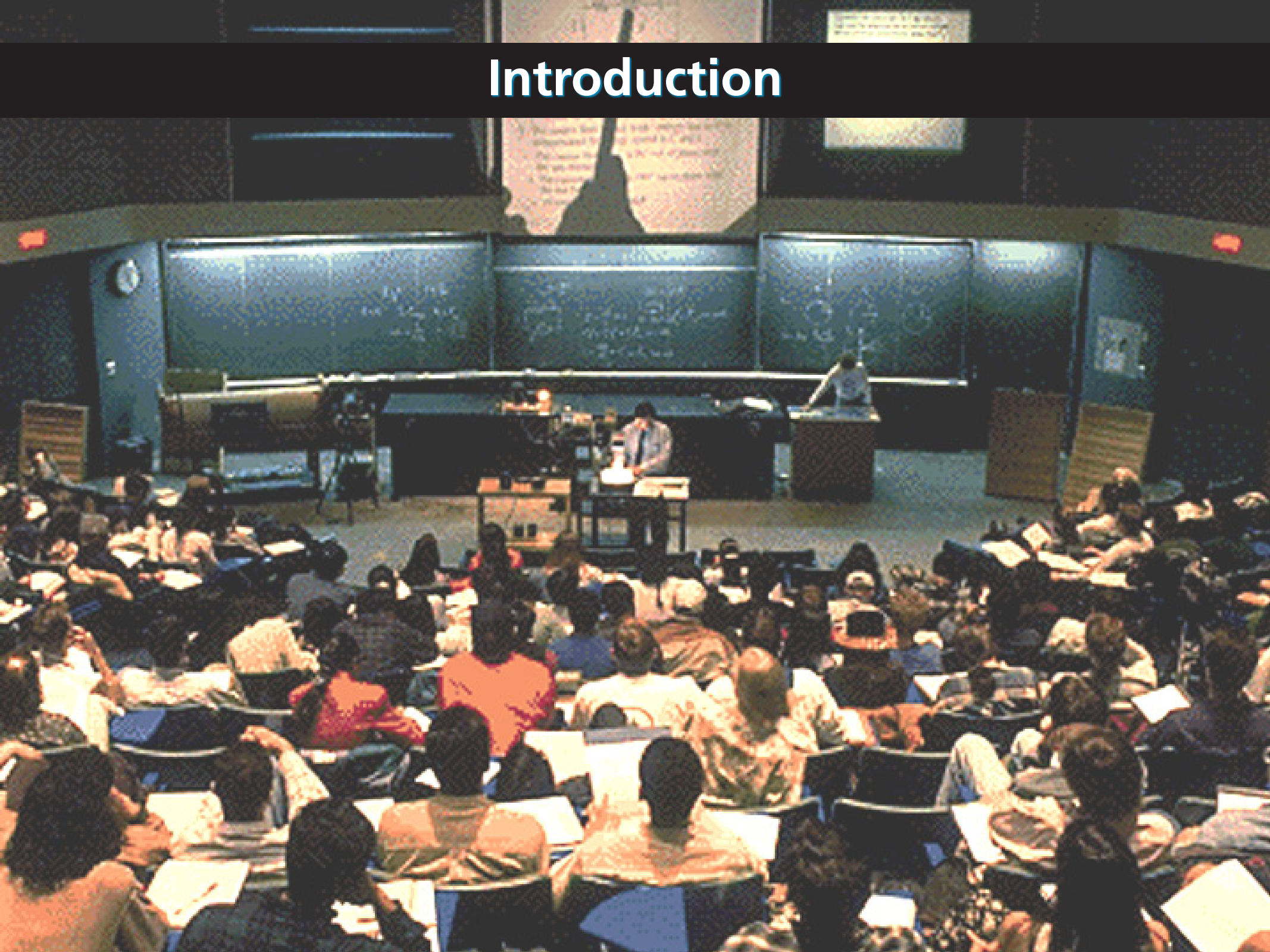
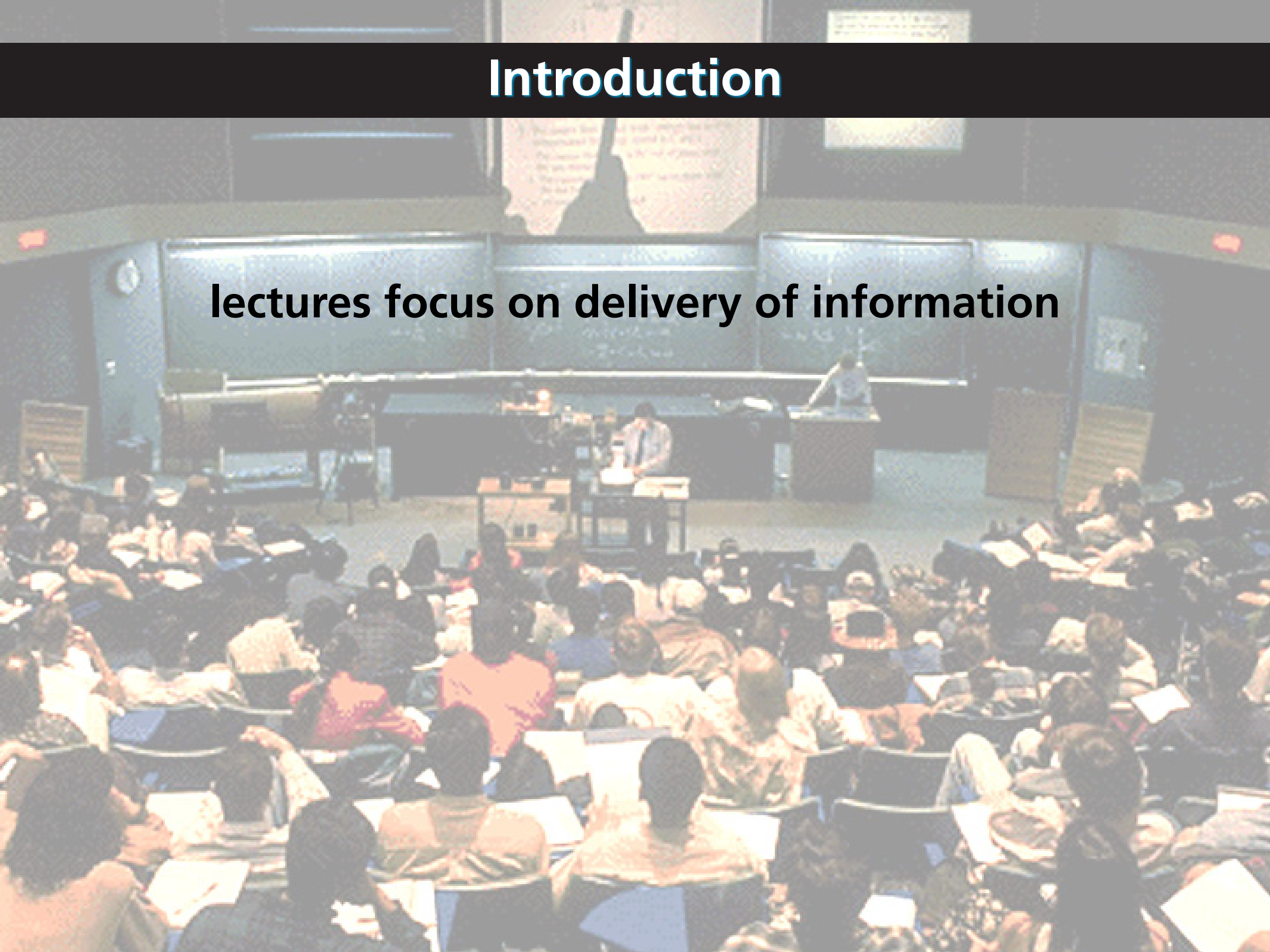
Peer Instruction: Why? And how?

KTH Royal Institute of Technology visit
Harvard University
Cambridge, MA, February 9, 2011

Introduction

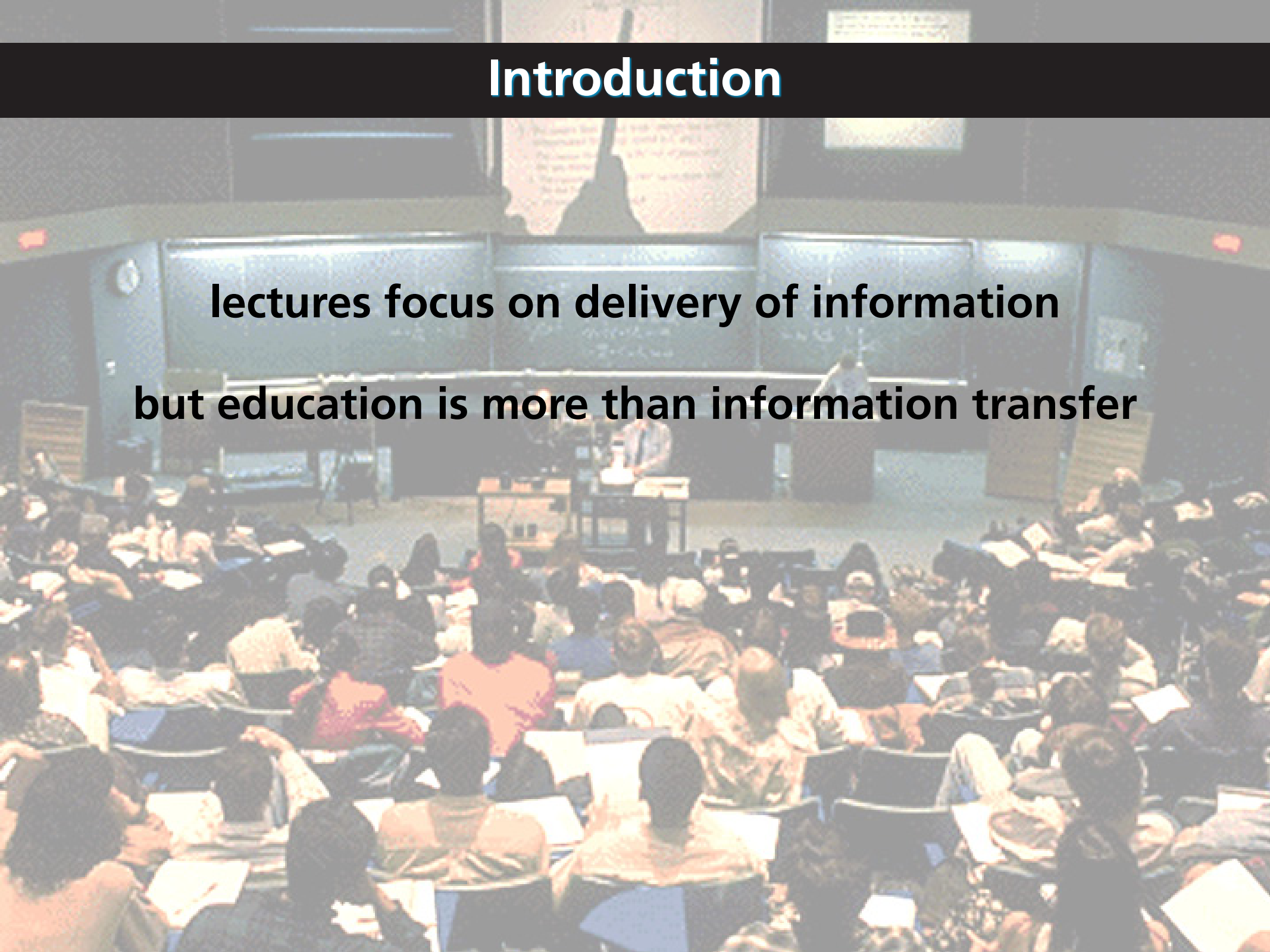


Introduction



lectures focus on delivery of information

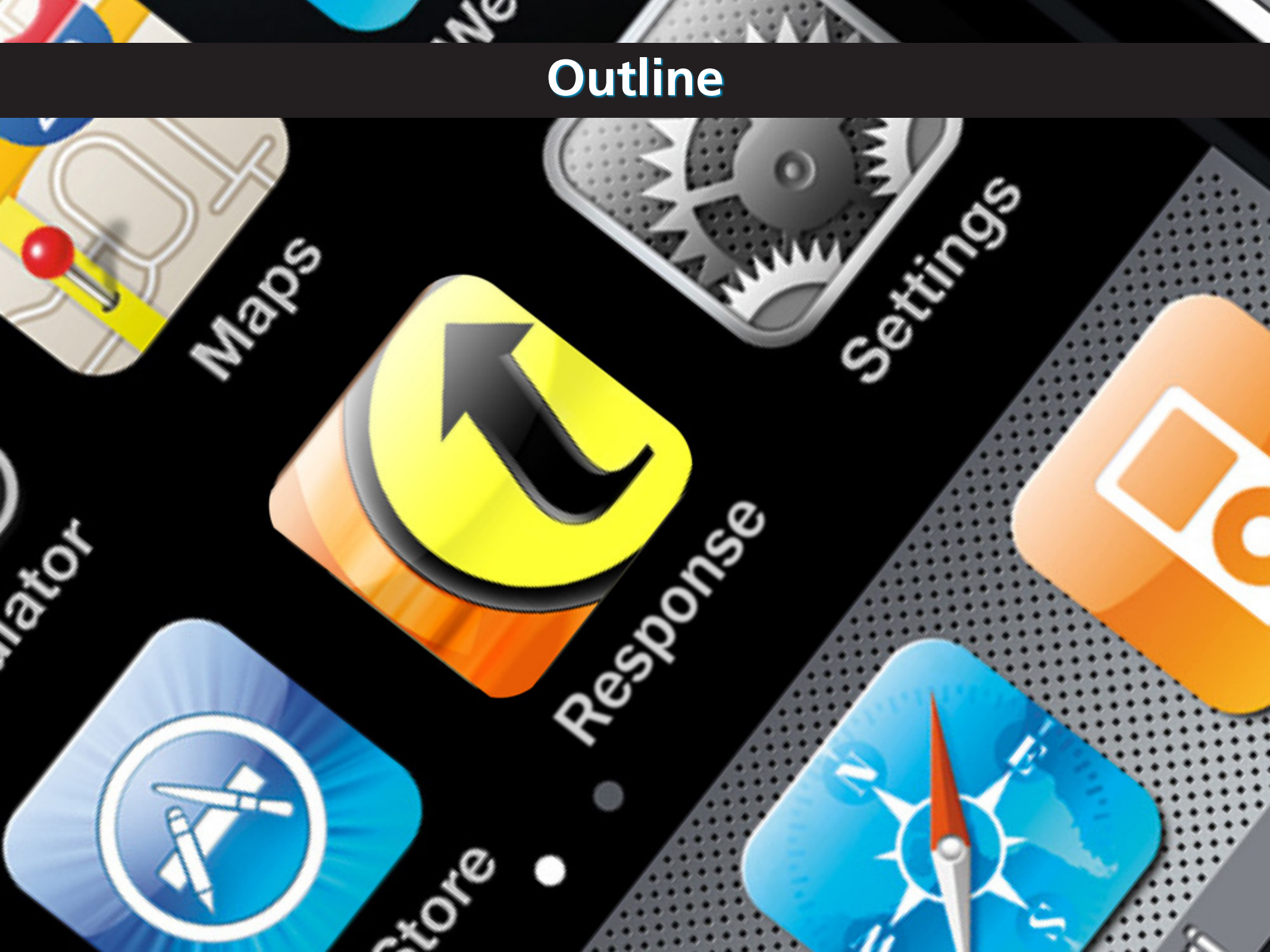
Introduction



lectures focus on delivery of information

but education is more than information transfer

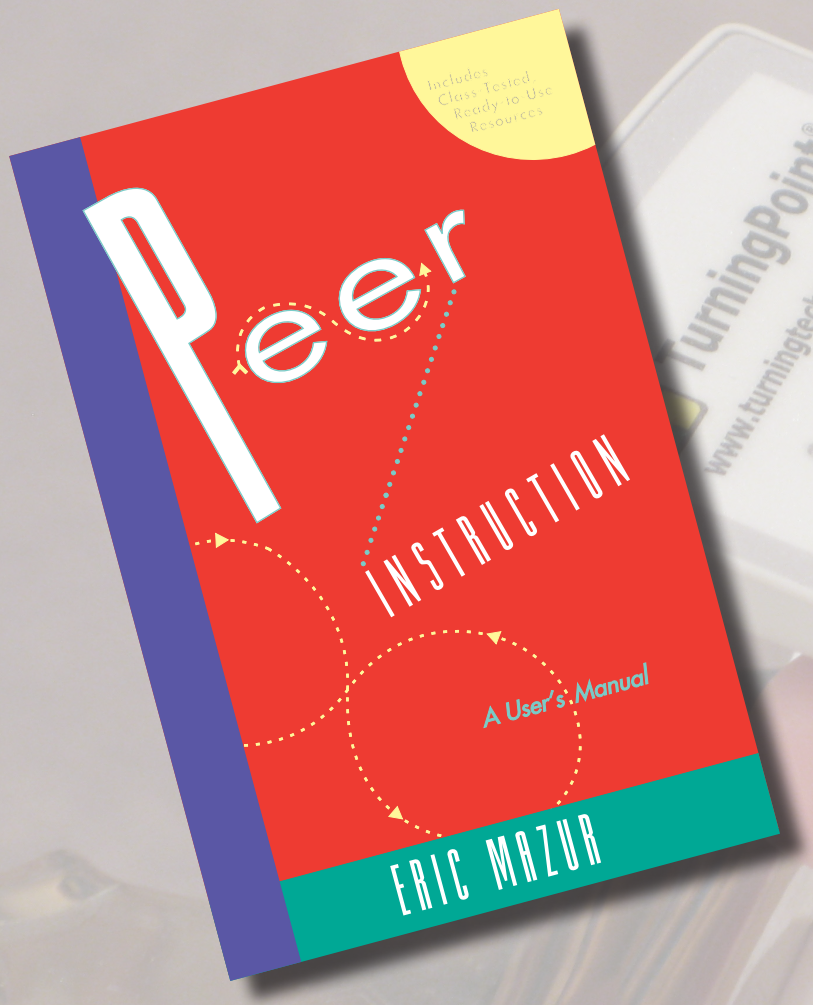
Outline



Outline

- Peer Instruction
- Let's try it!
- Results

Peer Instruction



move information transfer

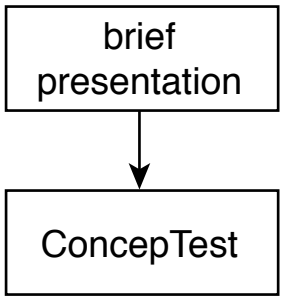
out of classroom

- assign reading
- teach by questioning

Peer Instruction

brief
presentation

Peer Instruction



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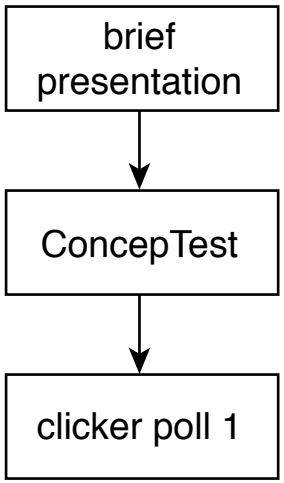

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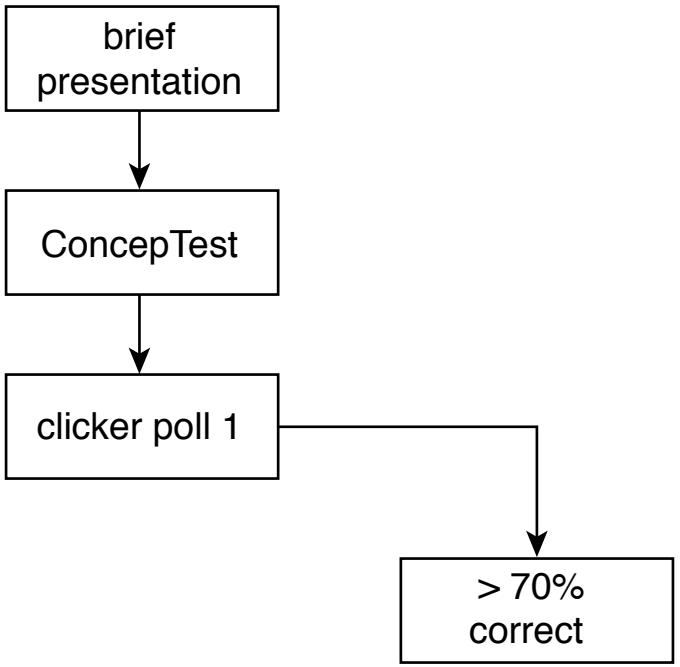

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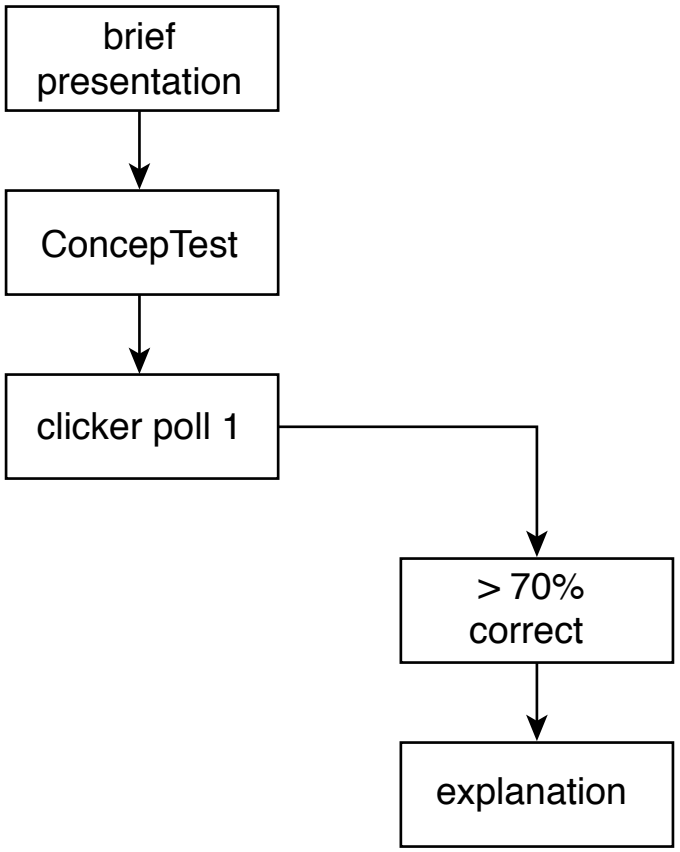

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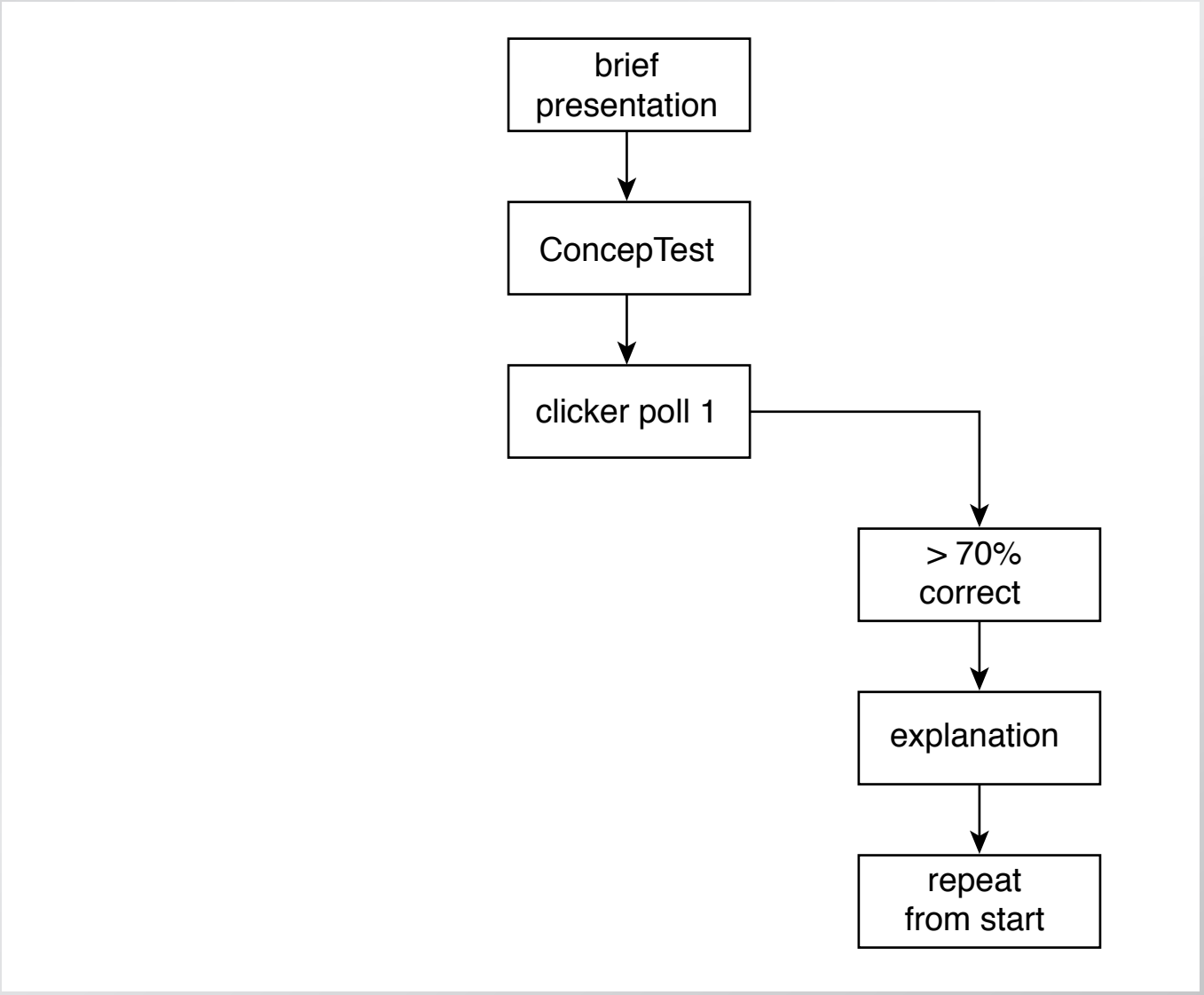

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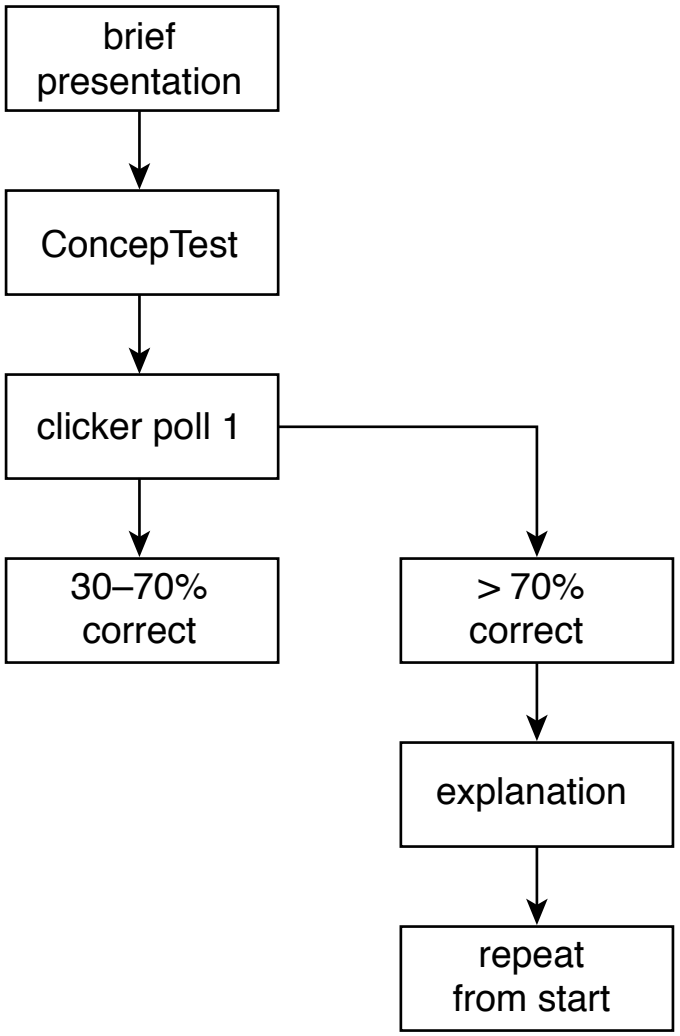

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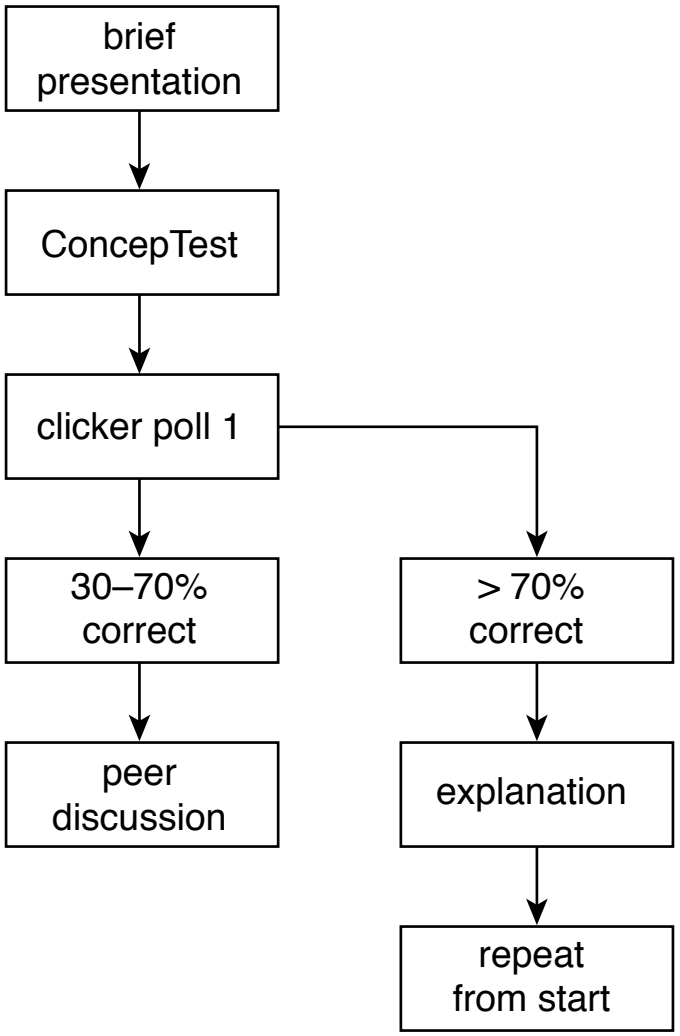

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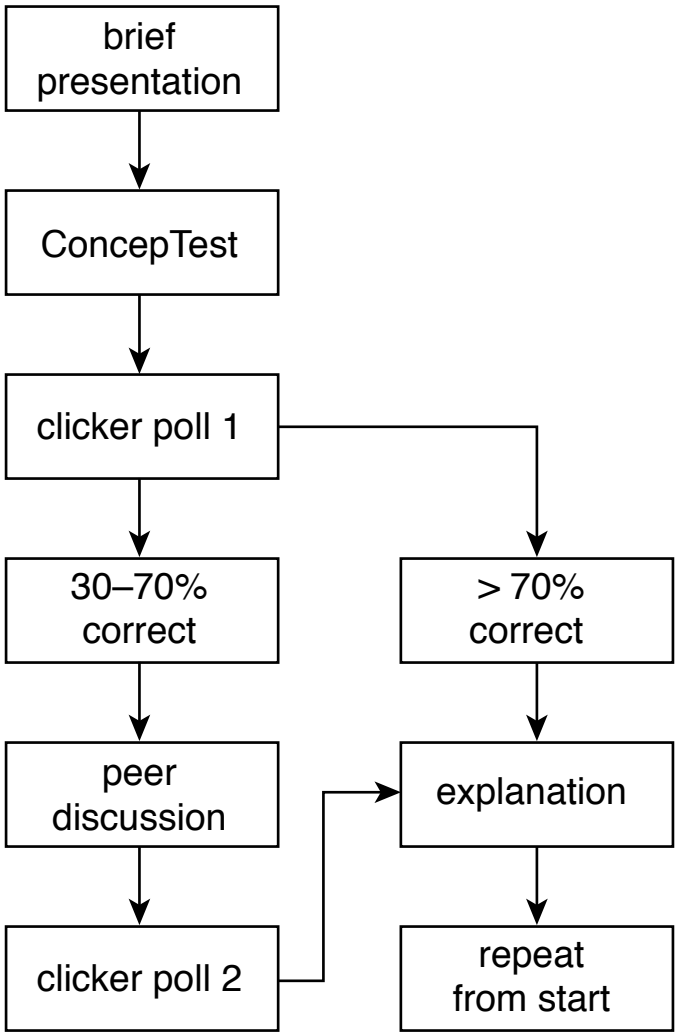

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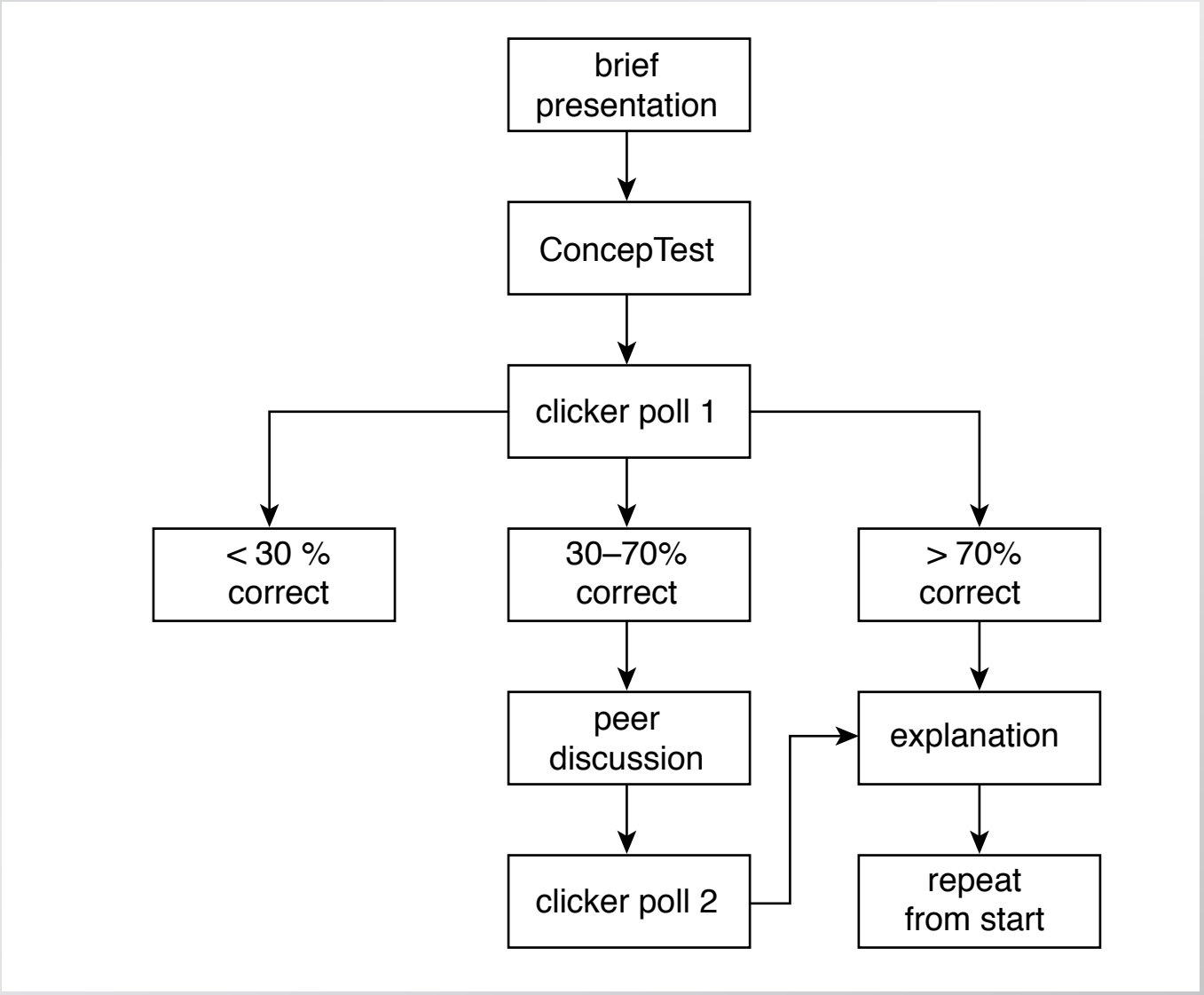

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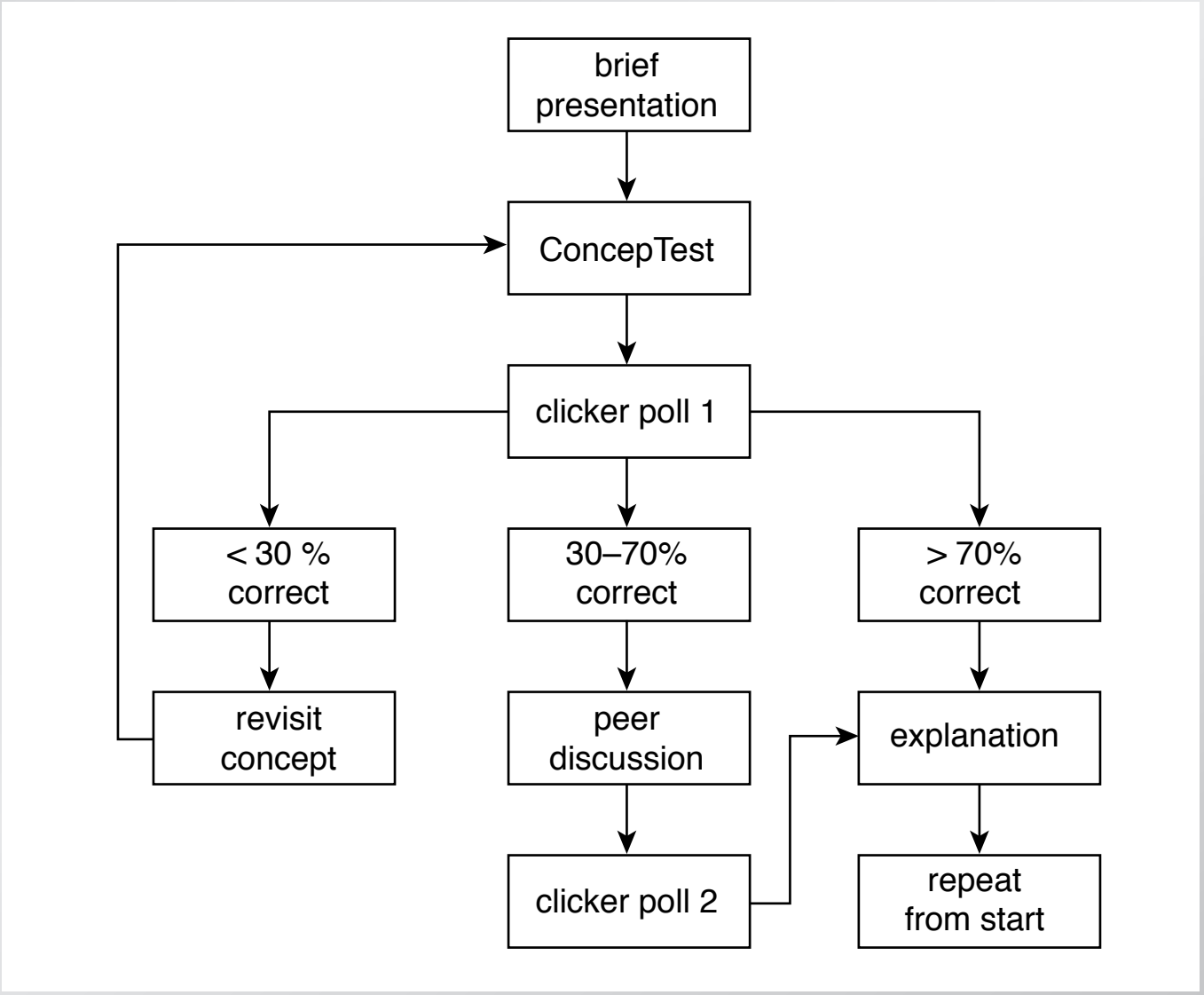

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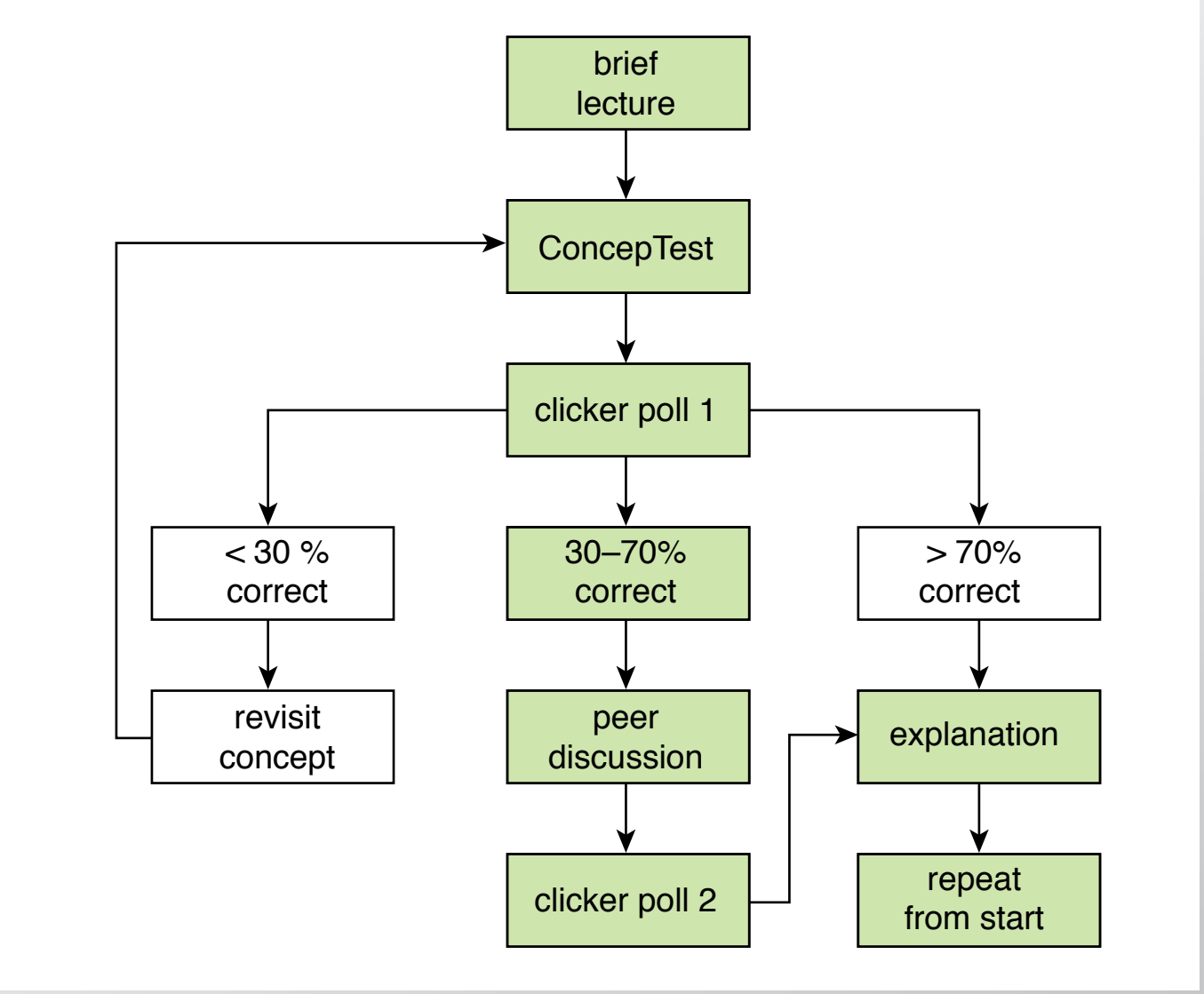

Outline

- Peer Instruction
- Let's try it!
- Results

Get your clickers ready!

- no ON/OFF button
- only last “click” counts
- display shows recorded answer

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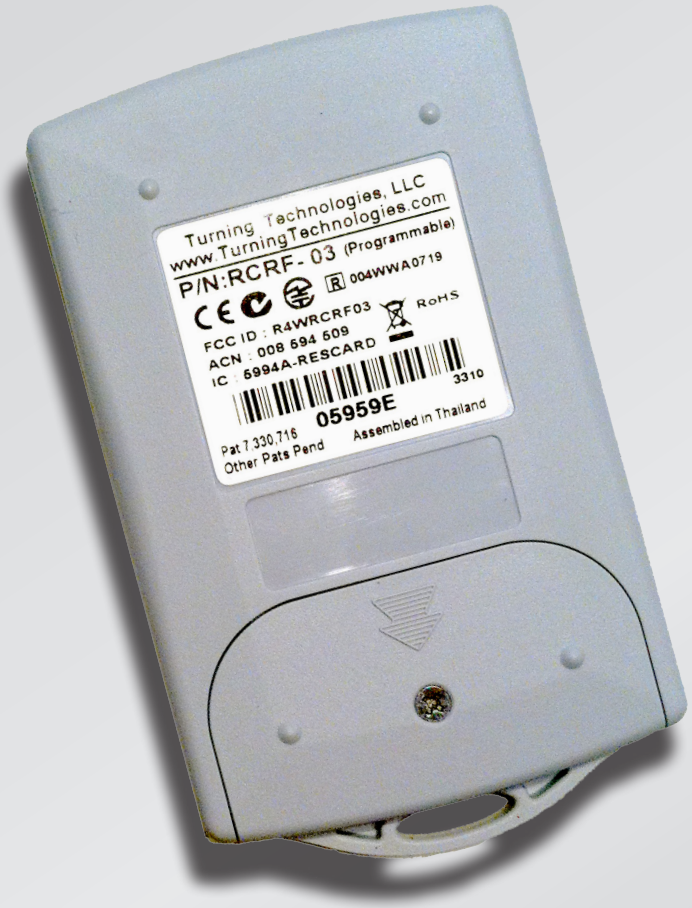
Get your clickers ready!



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Get your clickers ready!

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Let's try it!

When metals heat up, they expand because all atoms get farther away from each other.

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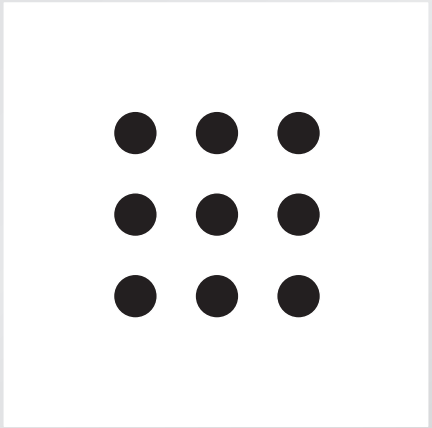

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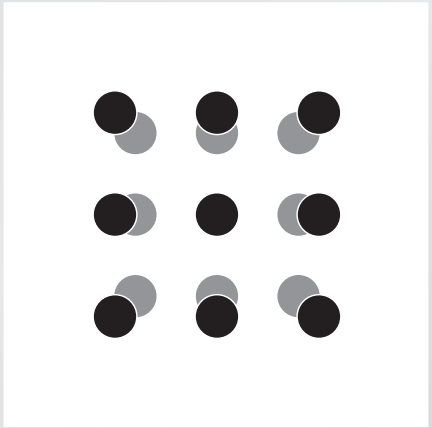
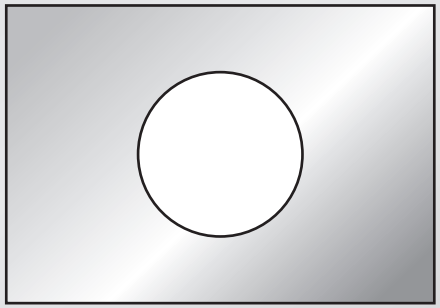


Let's try it!

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



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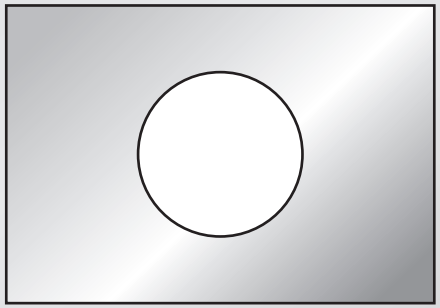


When the plate is uniformly heated, the diameter of the hole

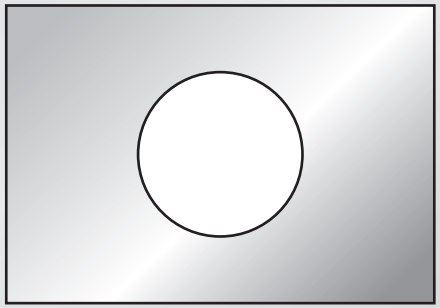
1. increases.
2. stays the same.
3. decreases.

Let's try it!

It's easy to fire up the audience!

Let's try it!

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



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

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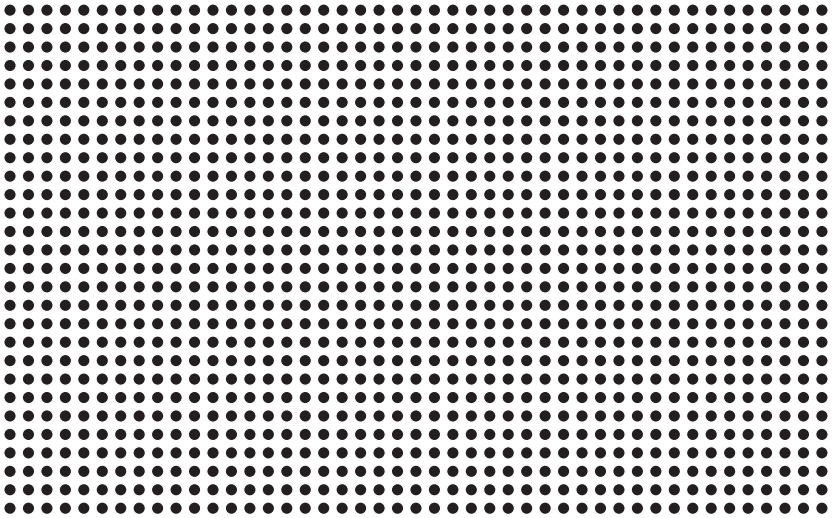
Let's try it!

remember: all atoms must get farther away from each other!



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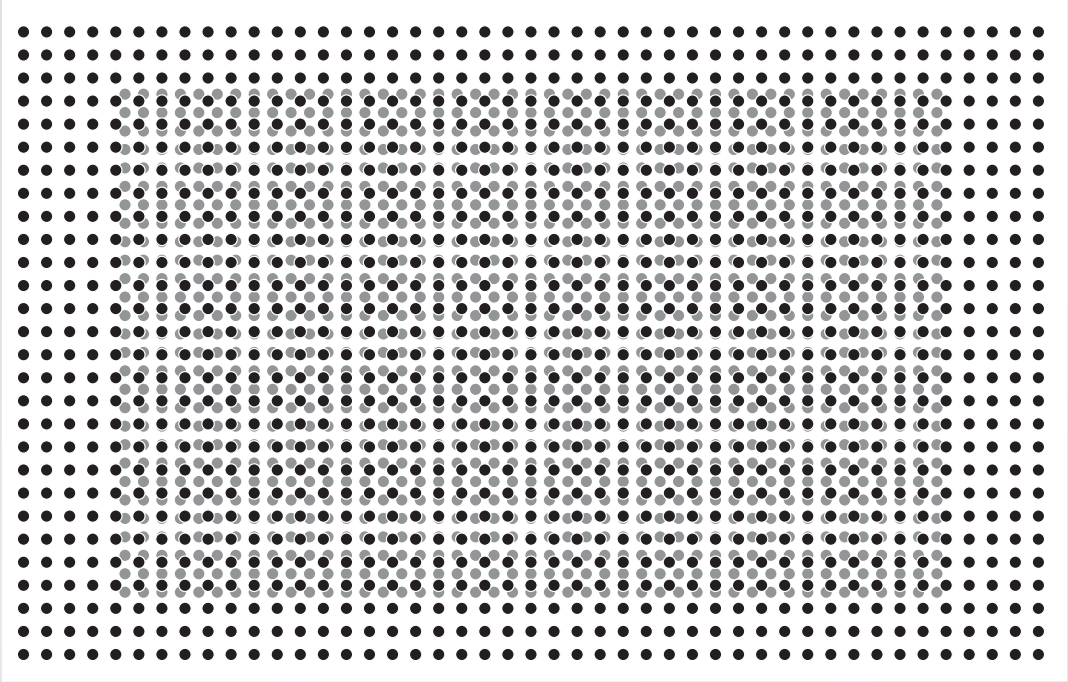
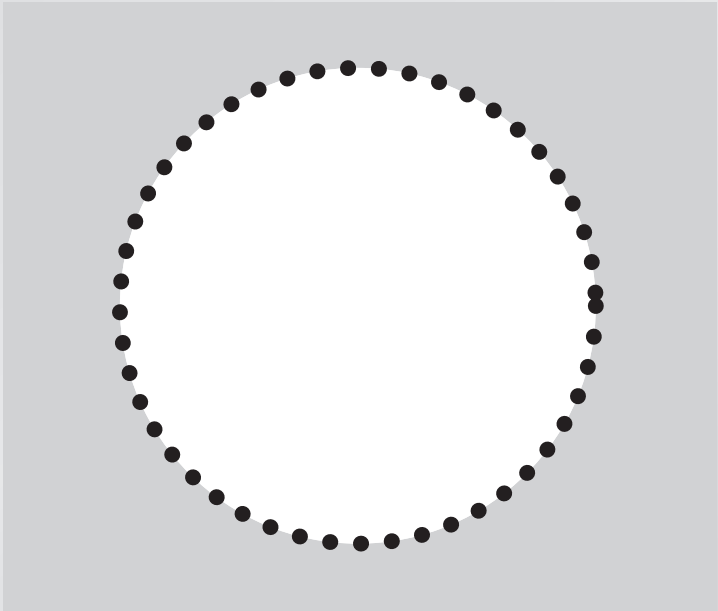


Let's try it!

consider the atoms at the rim of the hole



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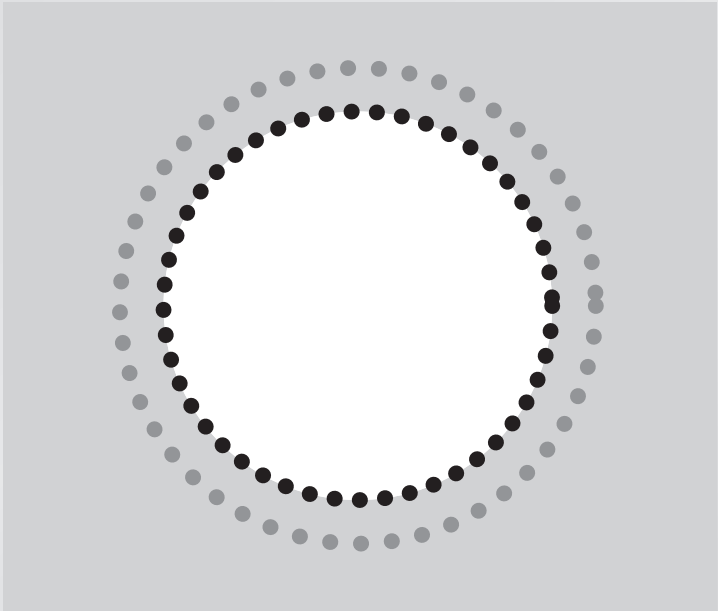

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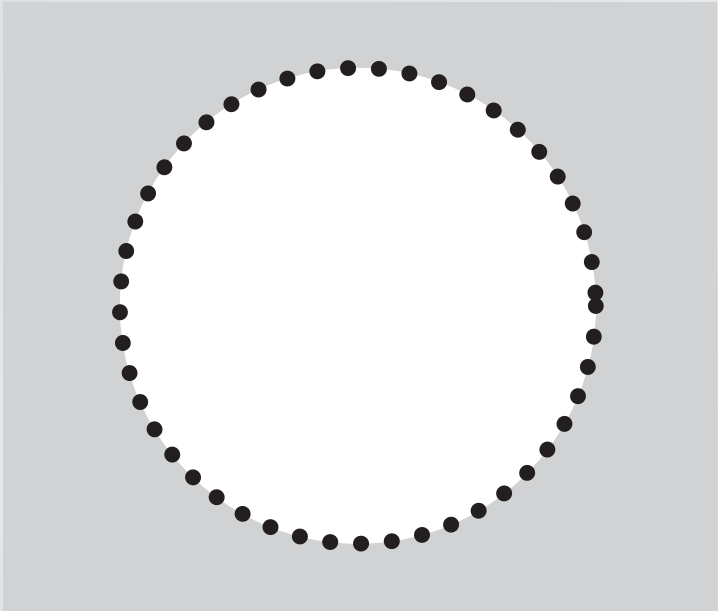

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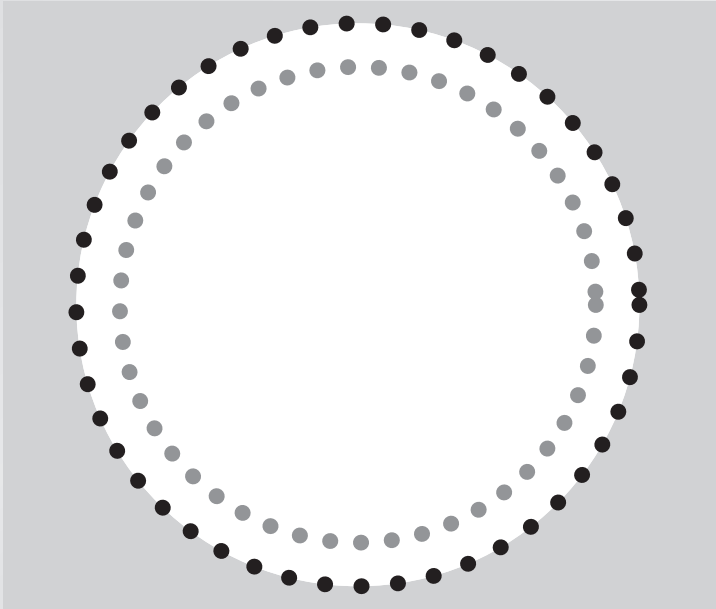


Let's try it!

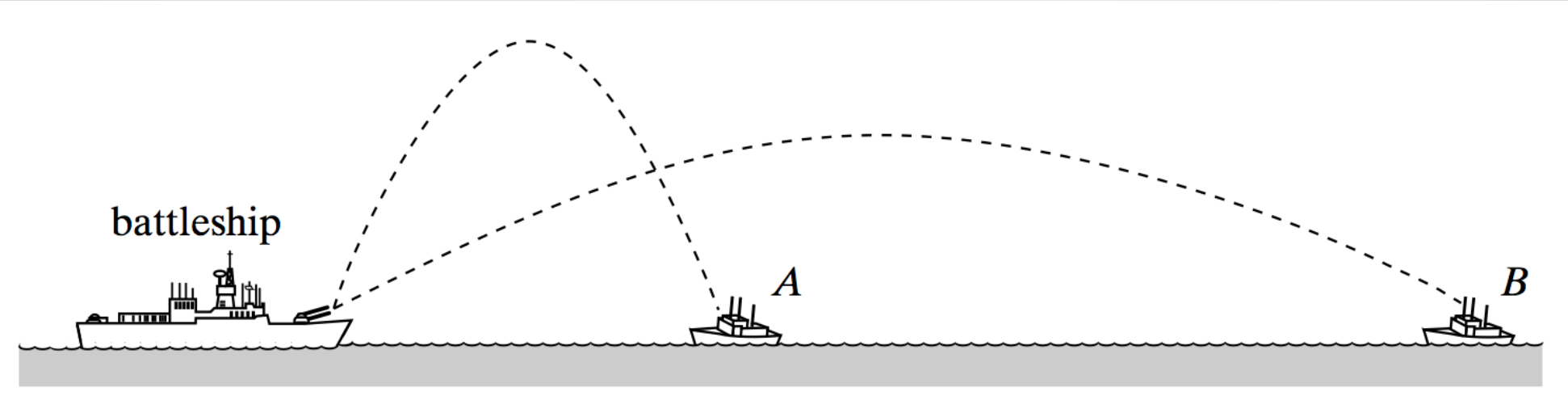
projectile trajectories:

time up = time down

horizontal/vertical motion decoupled

Let's try it!

A battleship simultaneously fires two shells at enemy ships. If the shells follow the parabolic trajectories shown below, which ship gets hit first?



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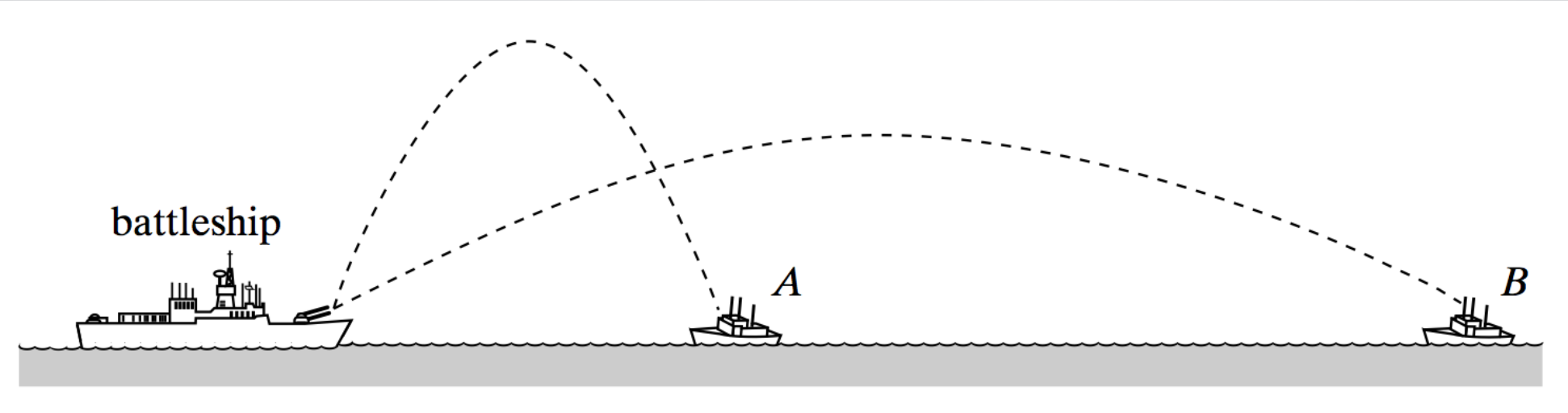


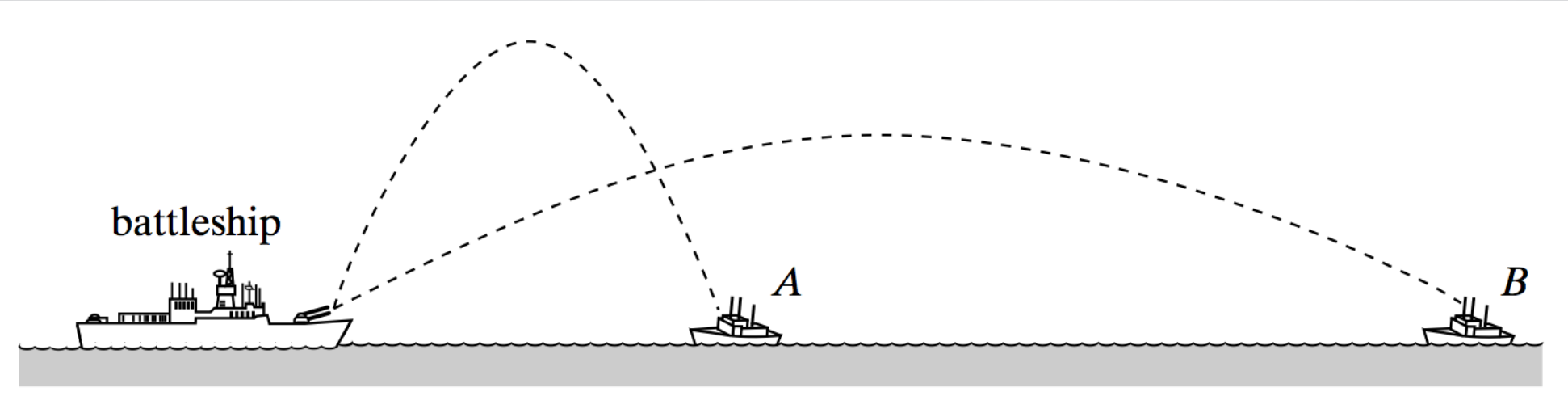
1. A
2. both at (nearly) the same time
3. B
4. need more information

Let's try it!

You all got worked up again!

Let's try it!

A battleship simultaneously fires two shells at enemy ships. If the shells follow the parabolic trajectories shown below, which ship gets hit first?



1. A
2. both at (nearly) the same time
3. B ✔
4. need more information

Let's try it!

time projectile spends in air:

$$2t_{\mathrm{h}}$$

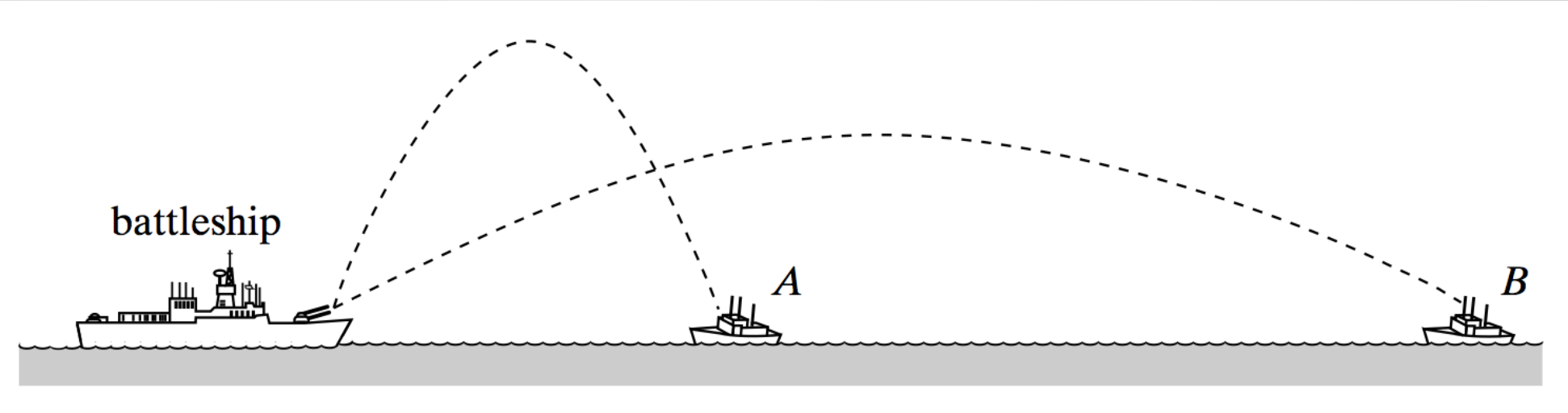
(twice time to fall from maximum height)

Let's try it!

time projectile spends in air:

$$2t_{\mathrm{h}}$$

(twice time to fall from maximum height)

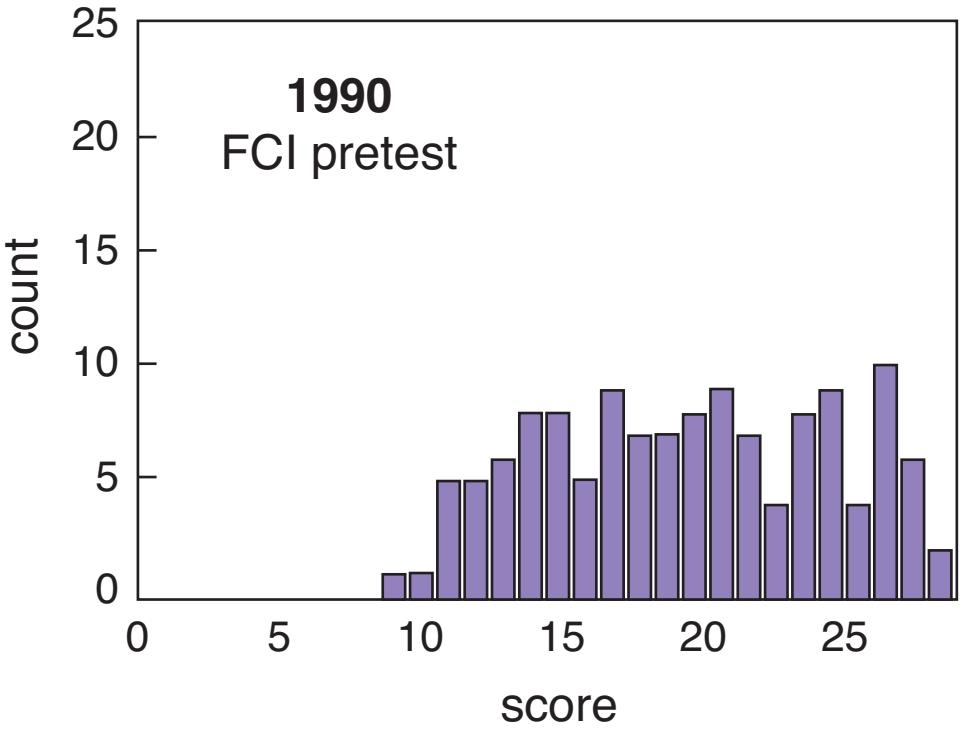


Outline

- Peer Instruction
- Let's try it!
- **Results**

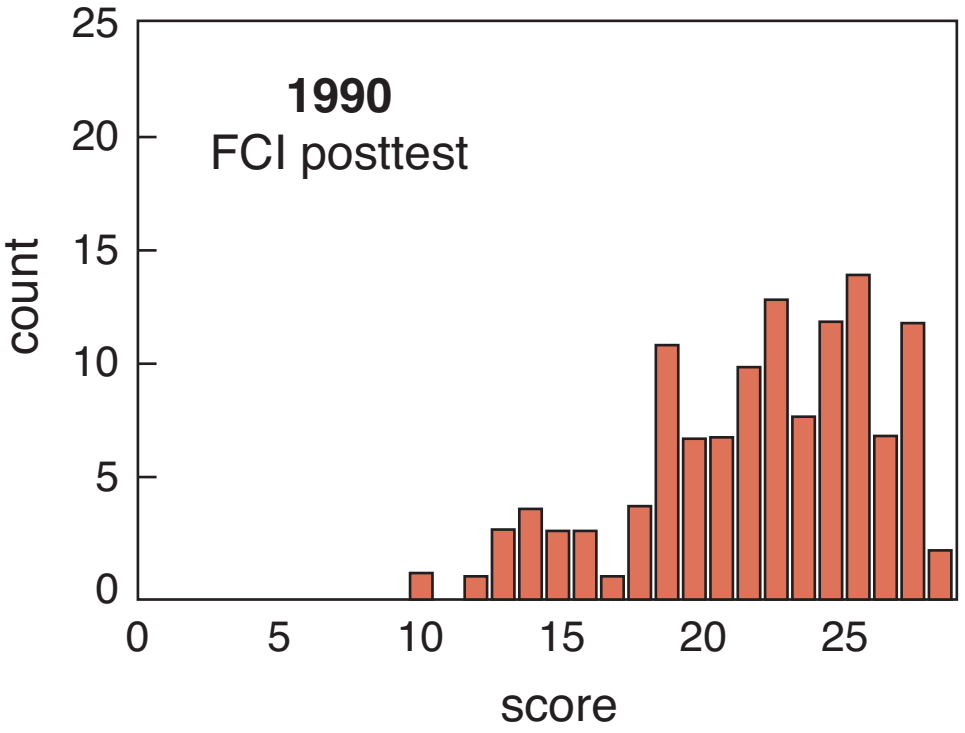
Results

traditional instruction



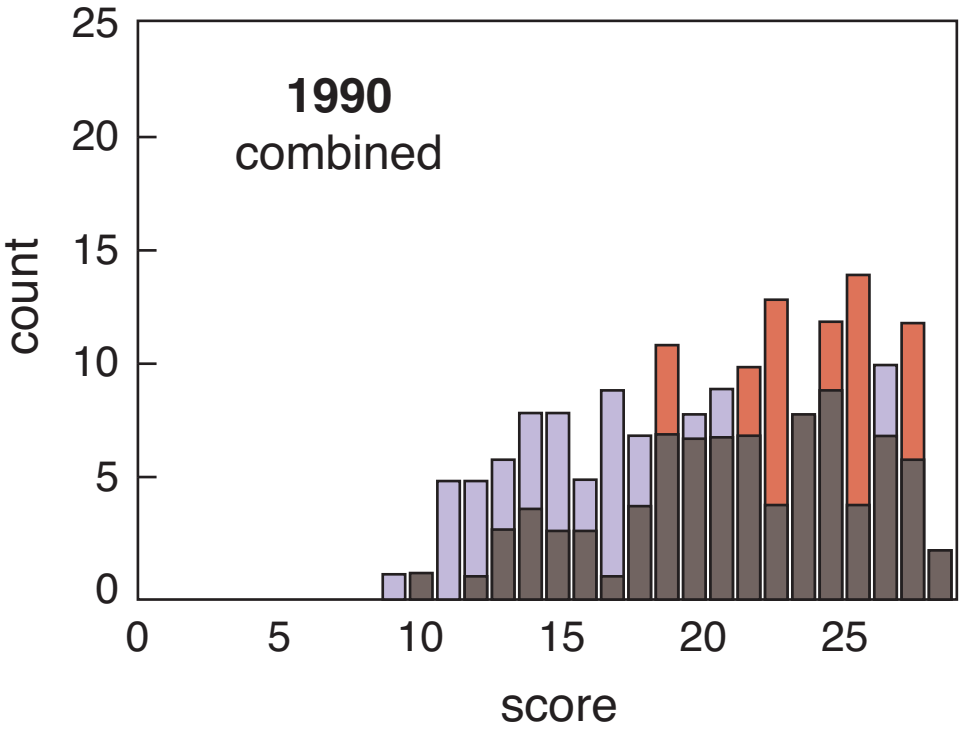
Results

traditional instruction



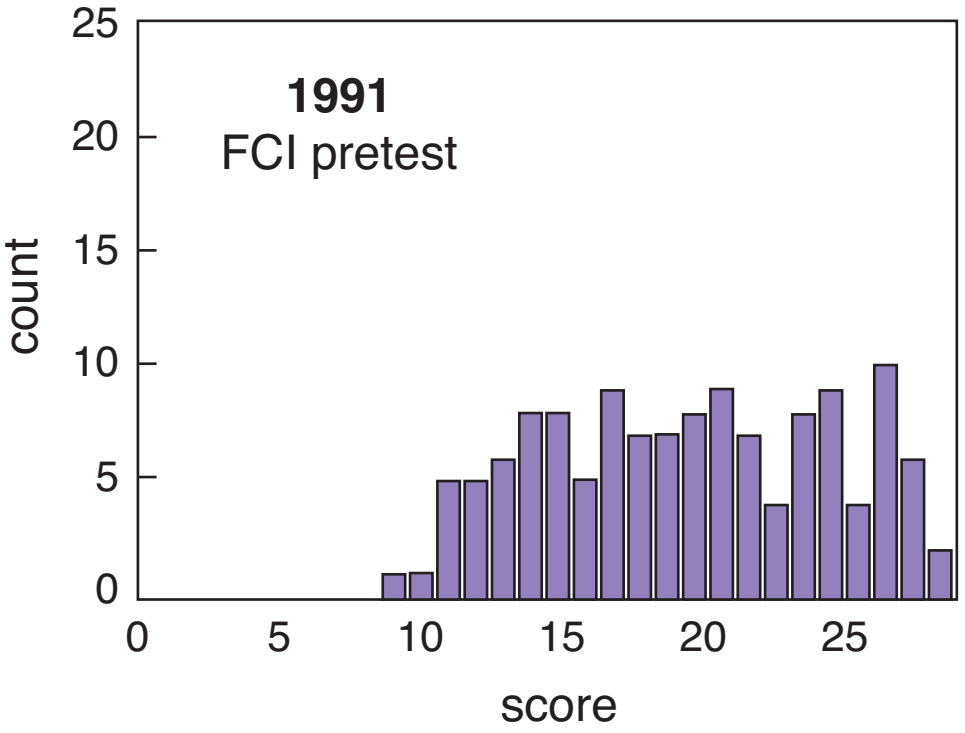
Results

traditional instruction



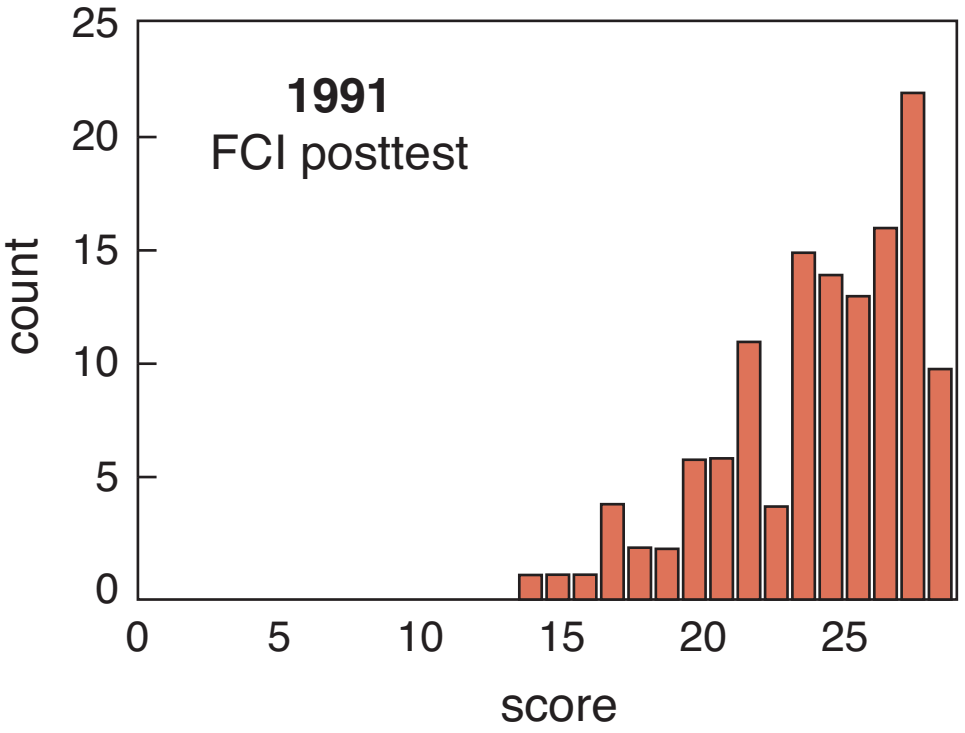
Results

first year of implementing PI



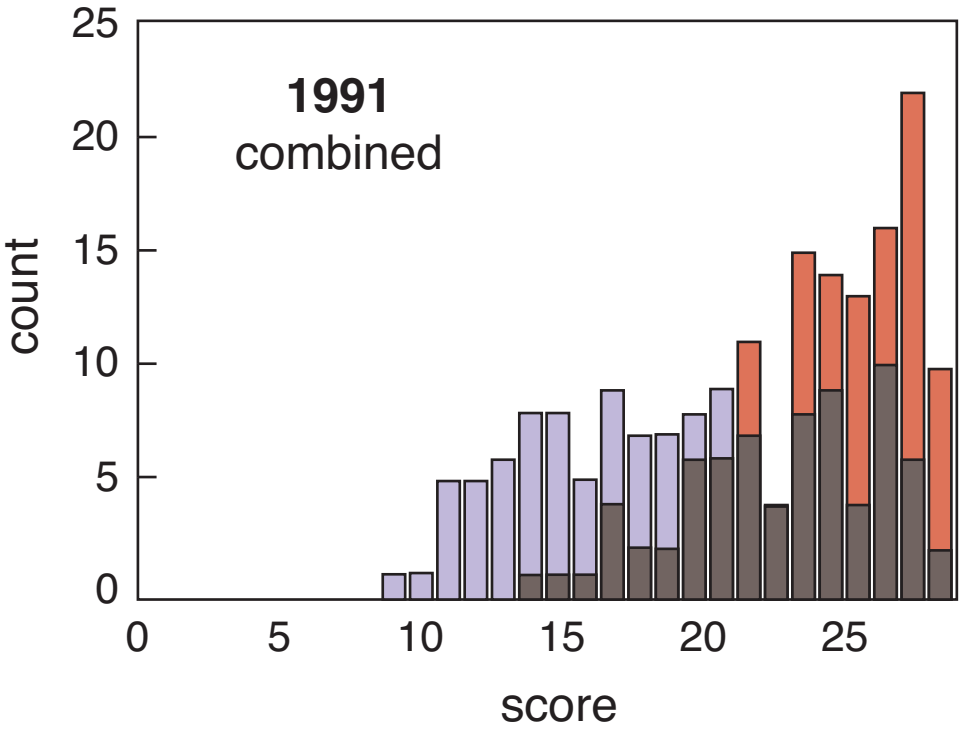
Results

first year of implementing PI



Results

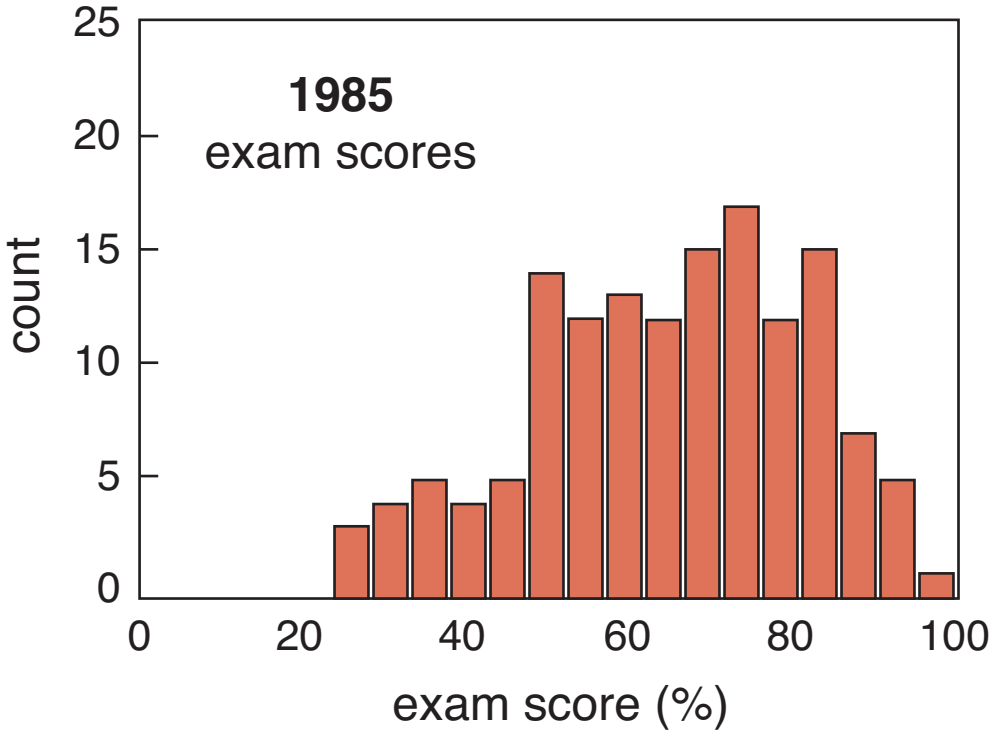
first year of implementing PI



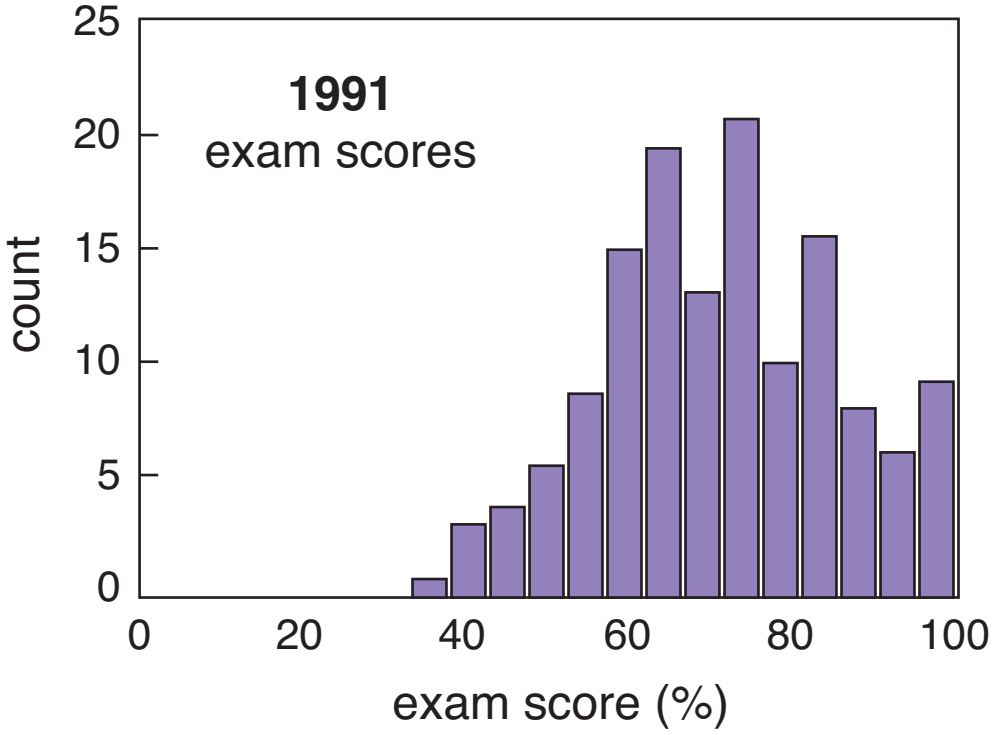
Results

what about problem solving?

Results

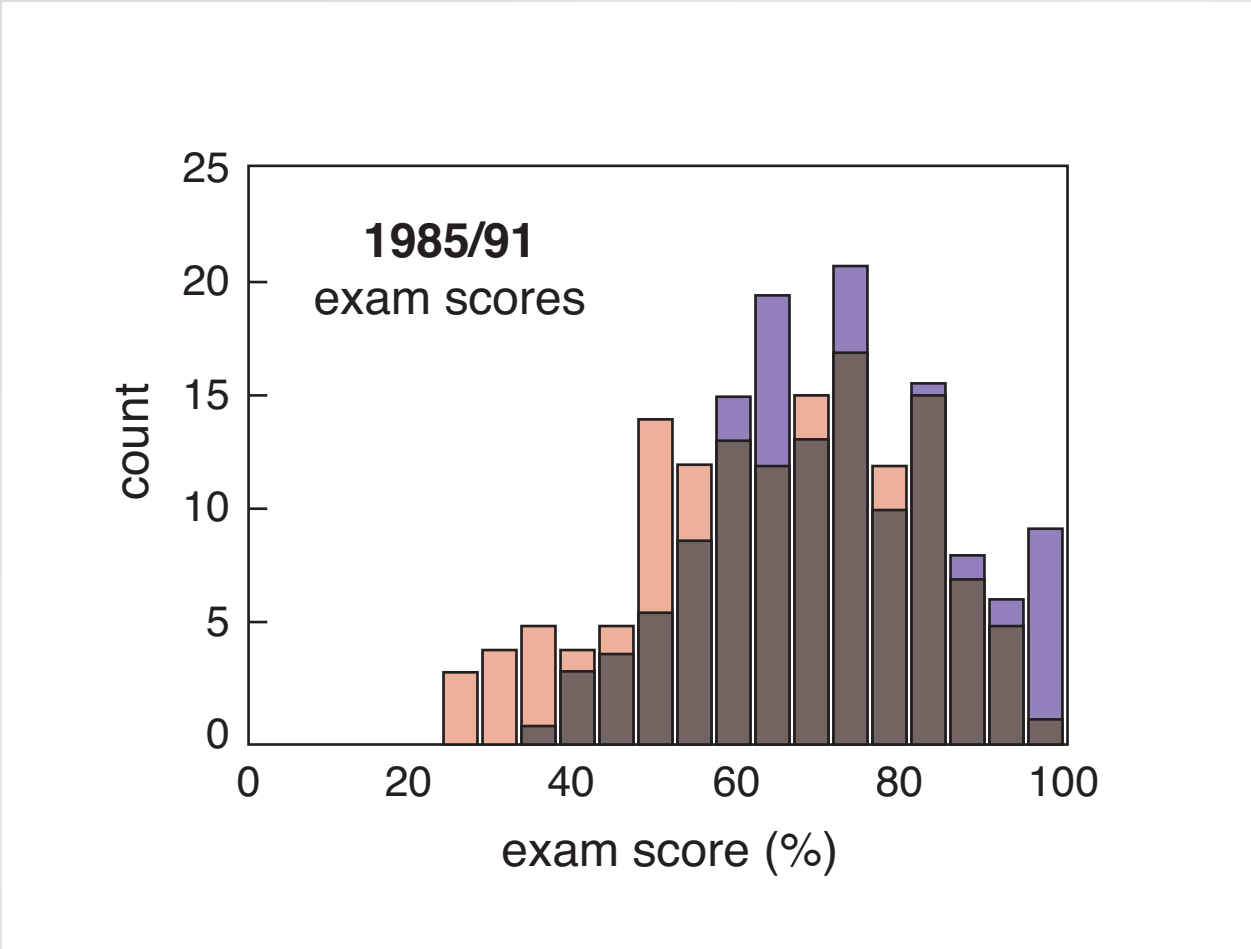

1985
exam scores
count
25
20
15
10
5
0
0
20
40
60
80
100
exam score (%)

Results


1991
exam scores
count
25
20
15
10
5
0
0
20
40
60
80
100
exam score (%)

Results

better understanding leads to better problem solving



Conclusion

Research Funding:

Pew Charitable Trust, Pearson/Prentice Hall, Davis Foundation, Engineering Information Foundation, Derek Bok Center for Teaching and Learning, National Science Foundation

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more information on clickers:

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Follow me!  **eric_mazur**

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KTH Royal Institute of Technology visit
Harvard University
Cambridge, MA, February 9, 2011

How do we learn?

Think of something you are really good at — something that you know you do well.

How do we learn?

Think of something you are really good at — something that you know you do well.

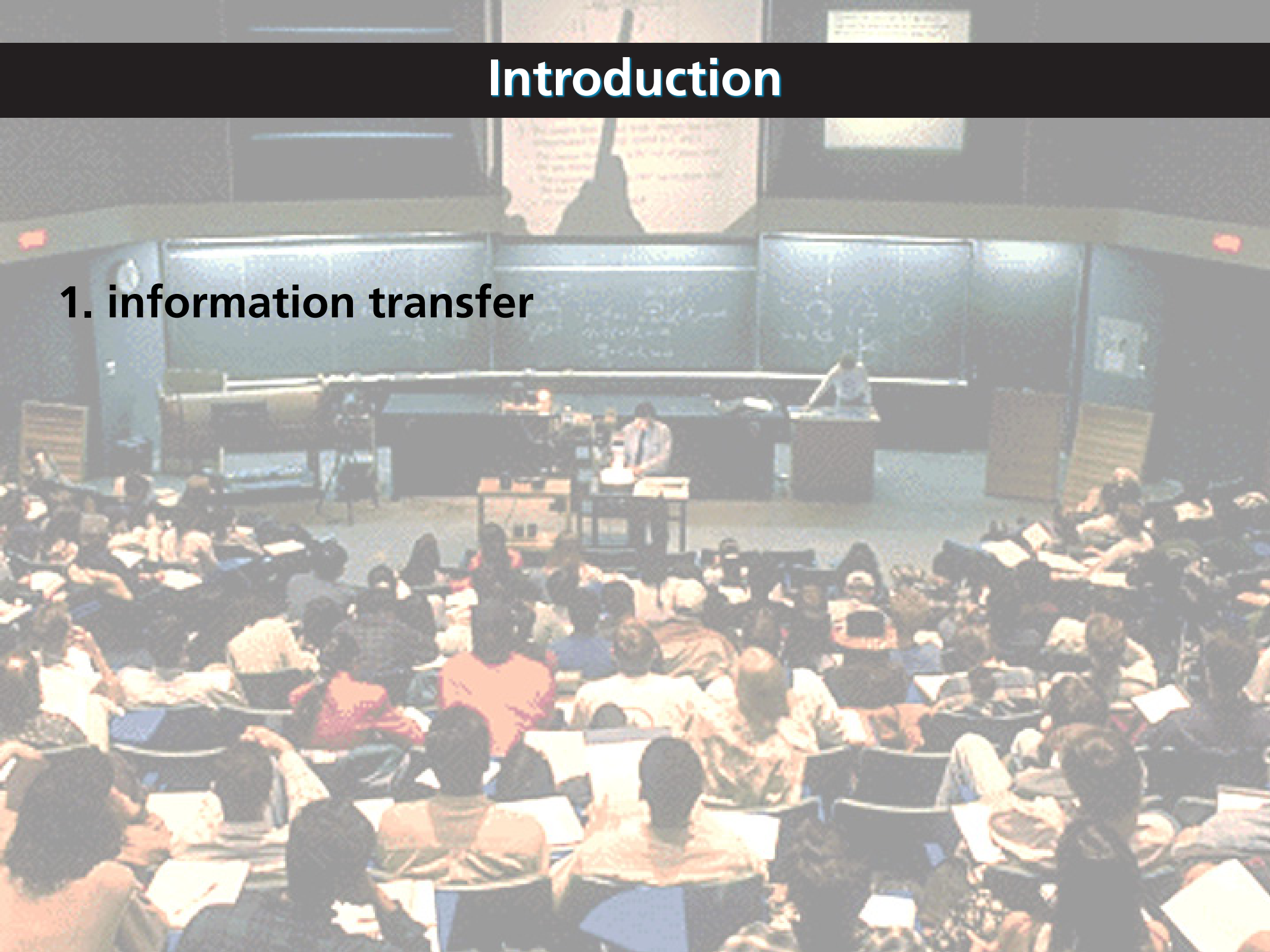
***How* did you become good at this?**

How do we learn?

I learned it:

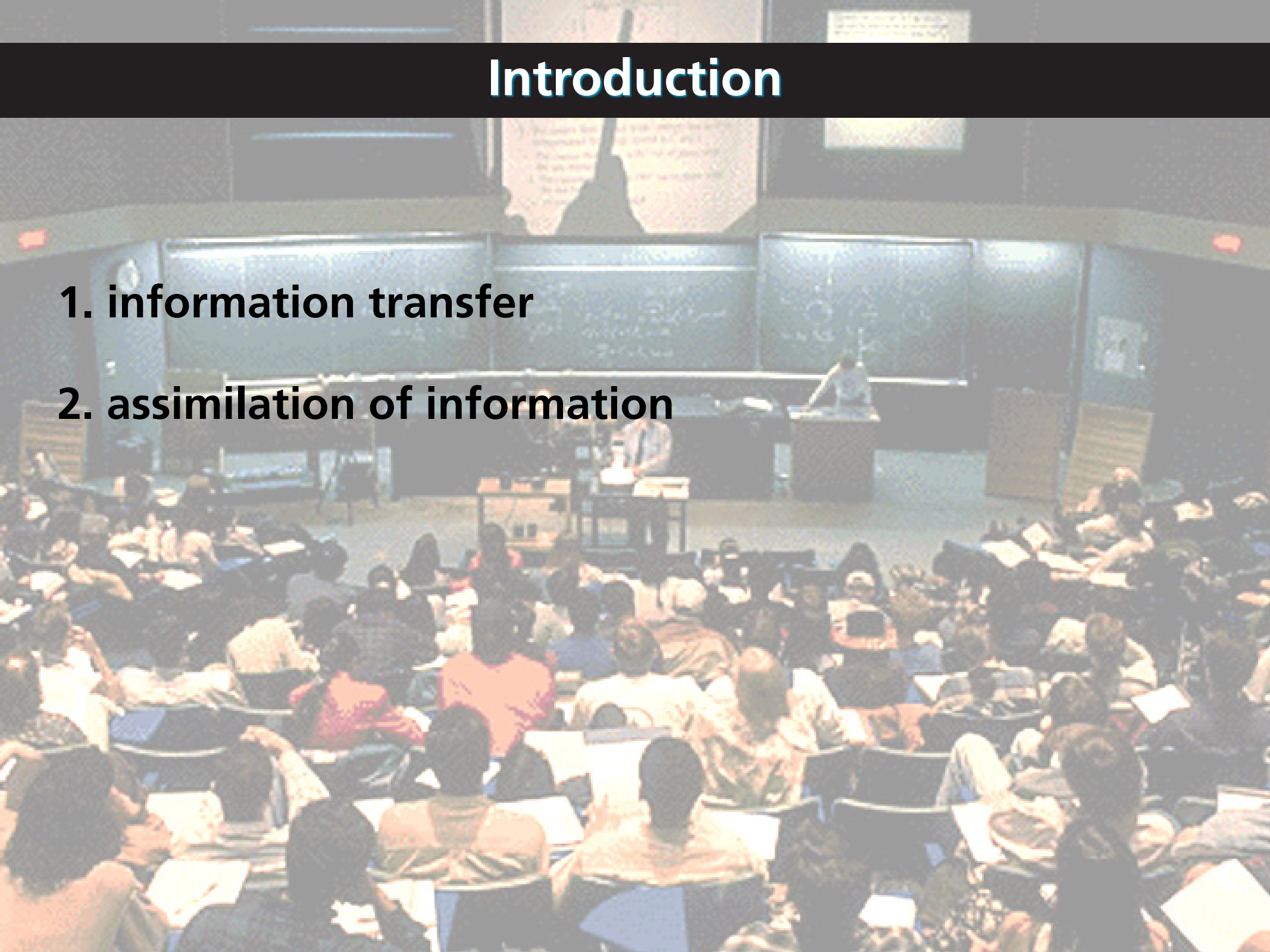
A. by practicing
B. in lectures
C. by doing it (trial and error)
D. other

Introduction



1. information transfer

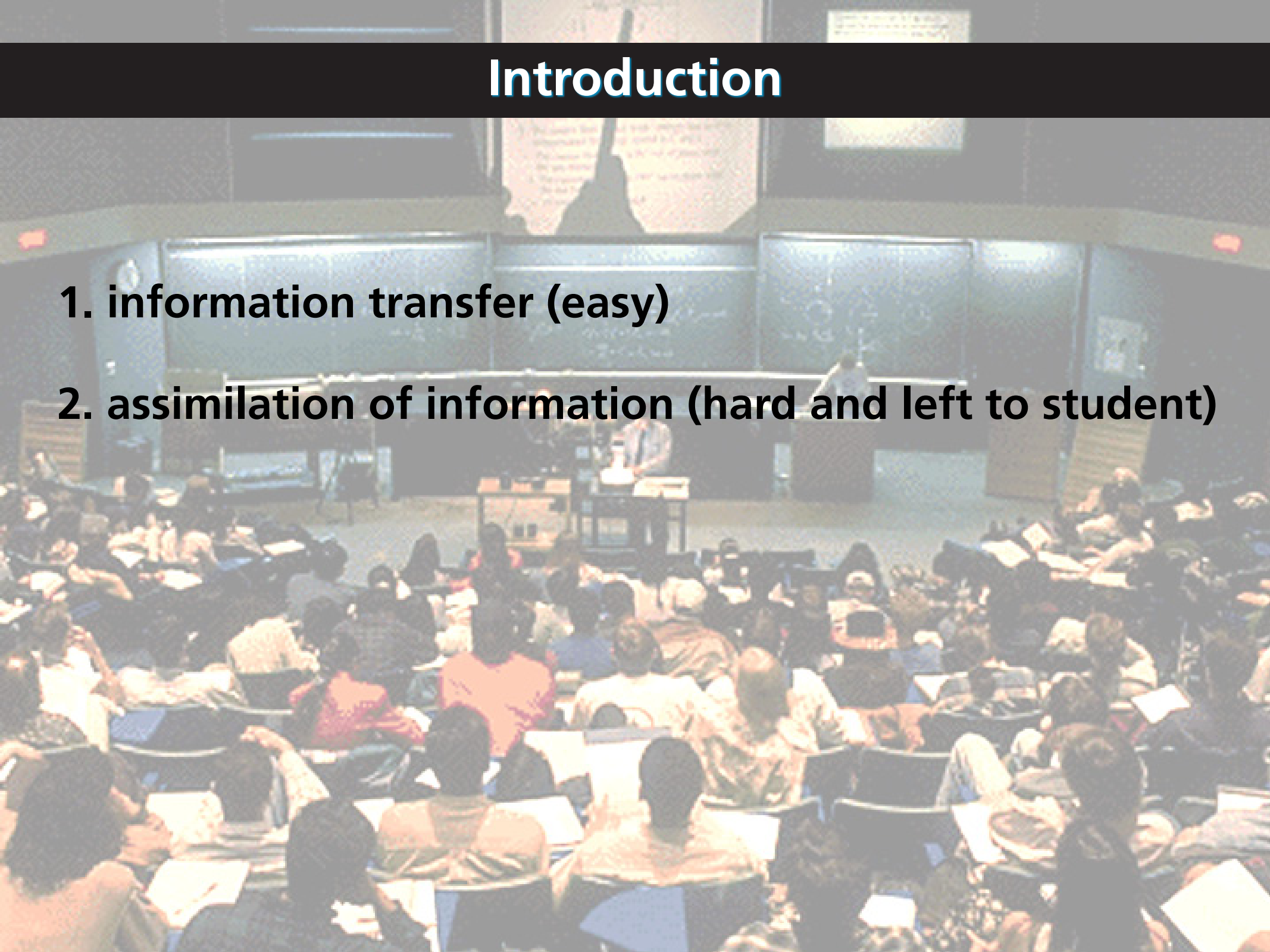
Introduction



1. information transfer

2. assimilation of information

Introduction



1. information transfer (easy)

2. assimilation of information (hard and left to student)

Introduction

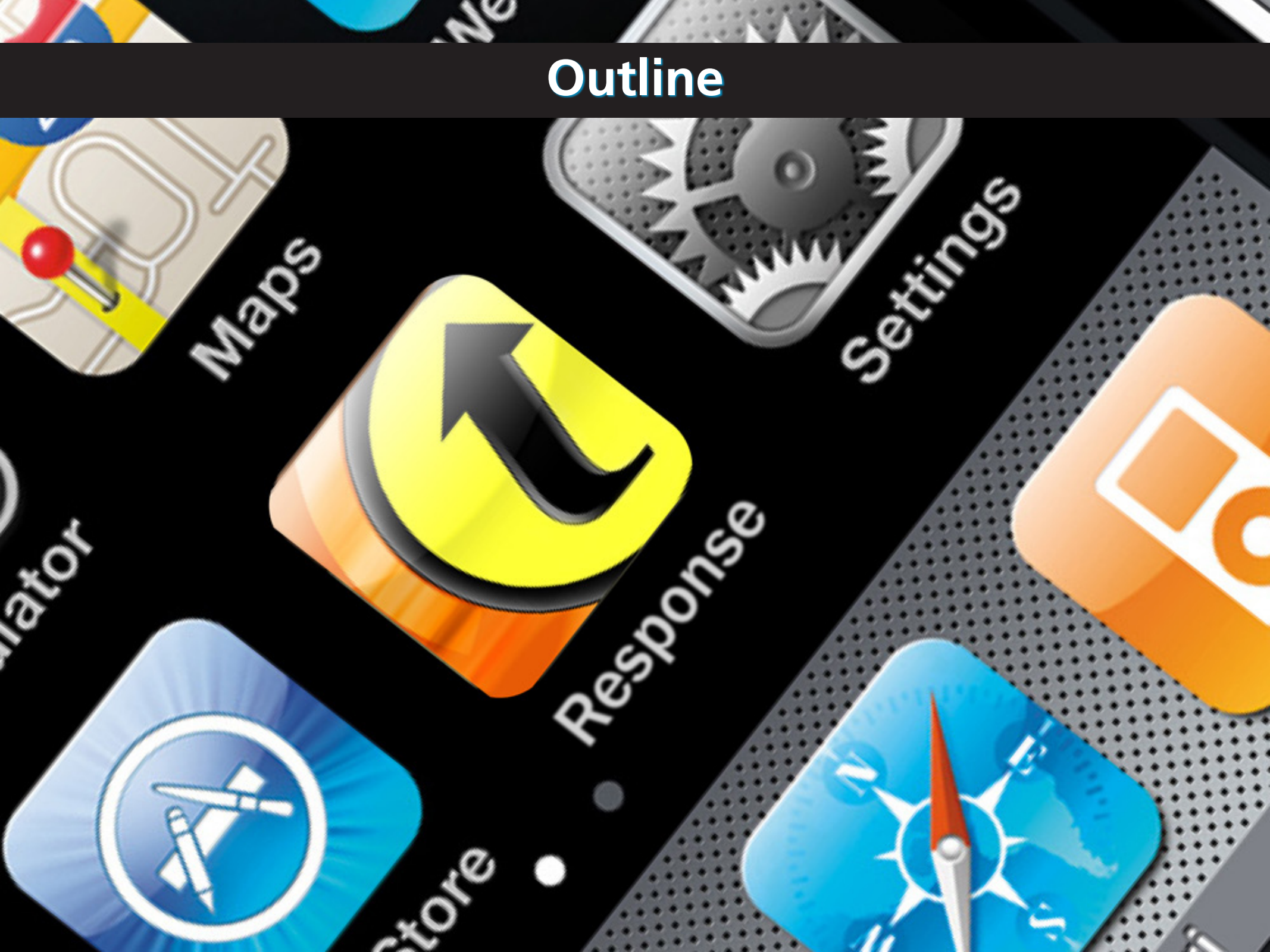
Solution: move information transfer out of classroom!

Introduction

Solution: move information transfer out of classroom!

(so we can help students assimilate the information in class)

Outline



Outline

- PI & JiTT overview
- Implementing PI & JiTT
- Discussion

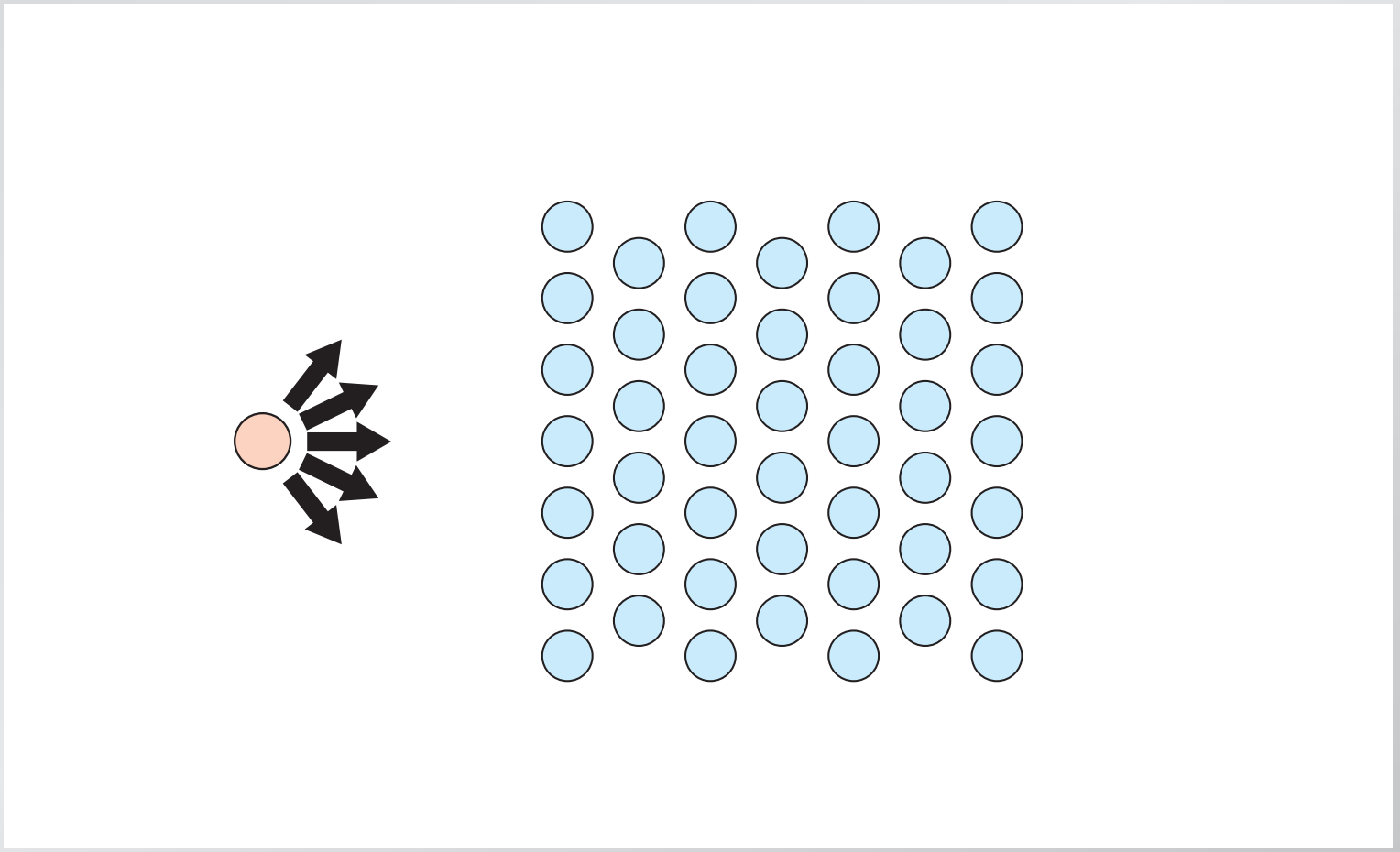
Implementing PI & JiTT

“I am very interested to learn more about the systematic use of peer instruction”

“Can peer instruction be organized in traditional courses? and how?”

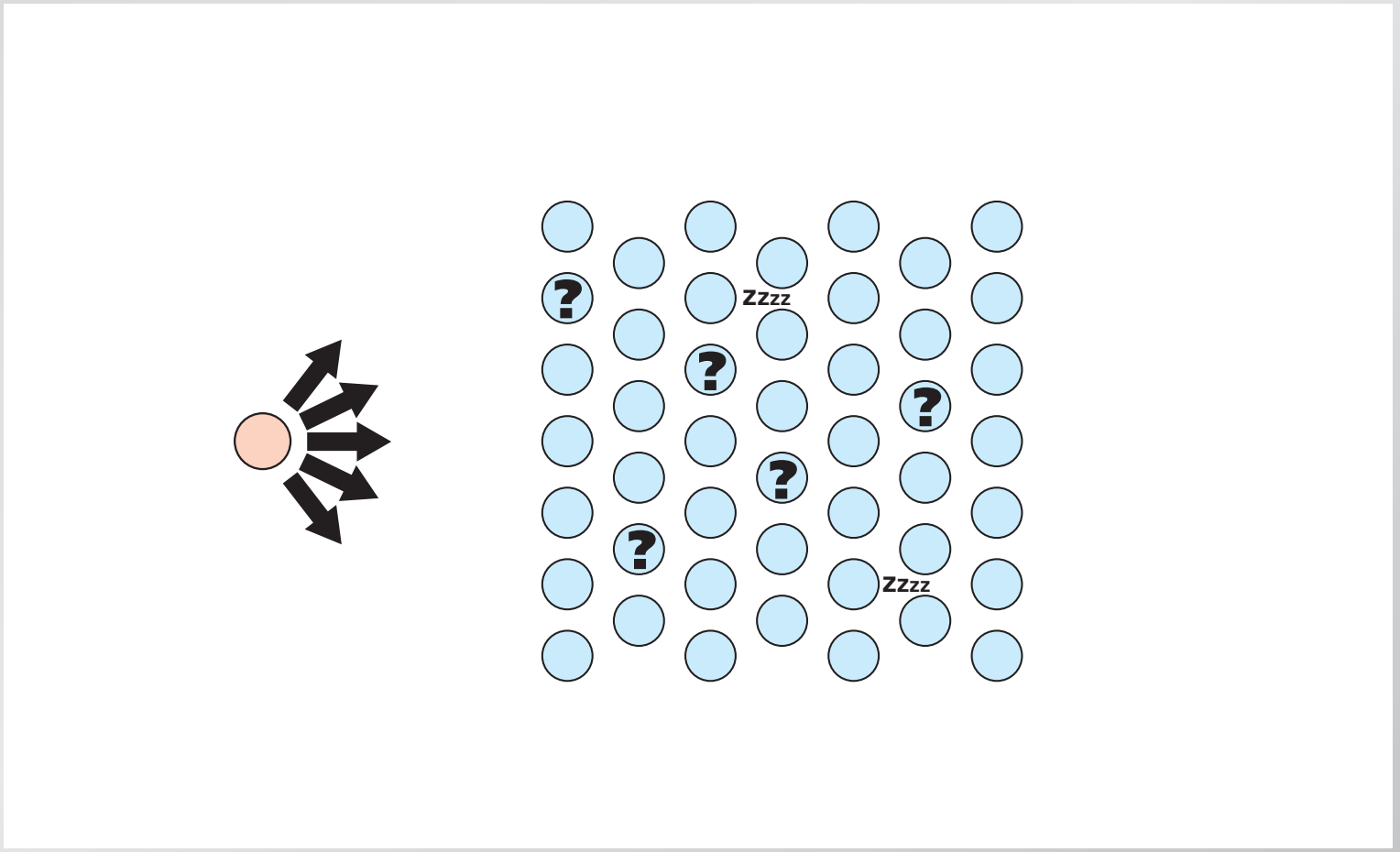
PI & JiTT Overview

traditional approach: one-way flow of information



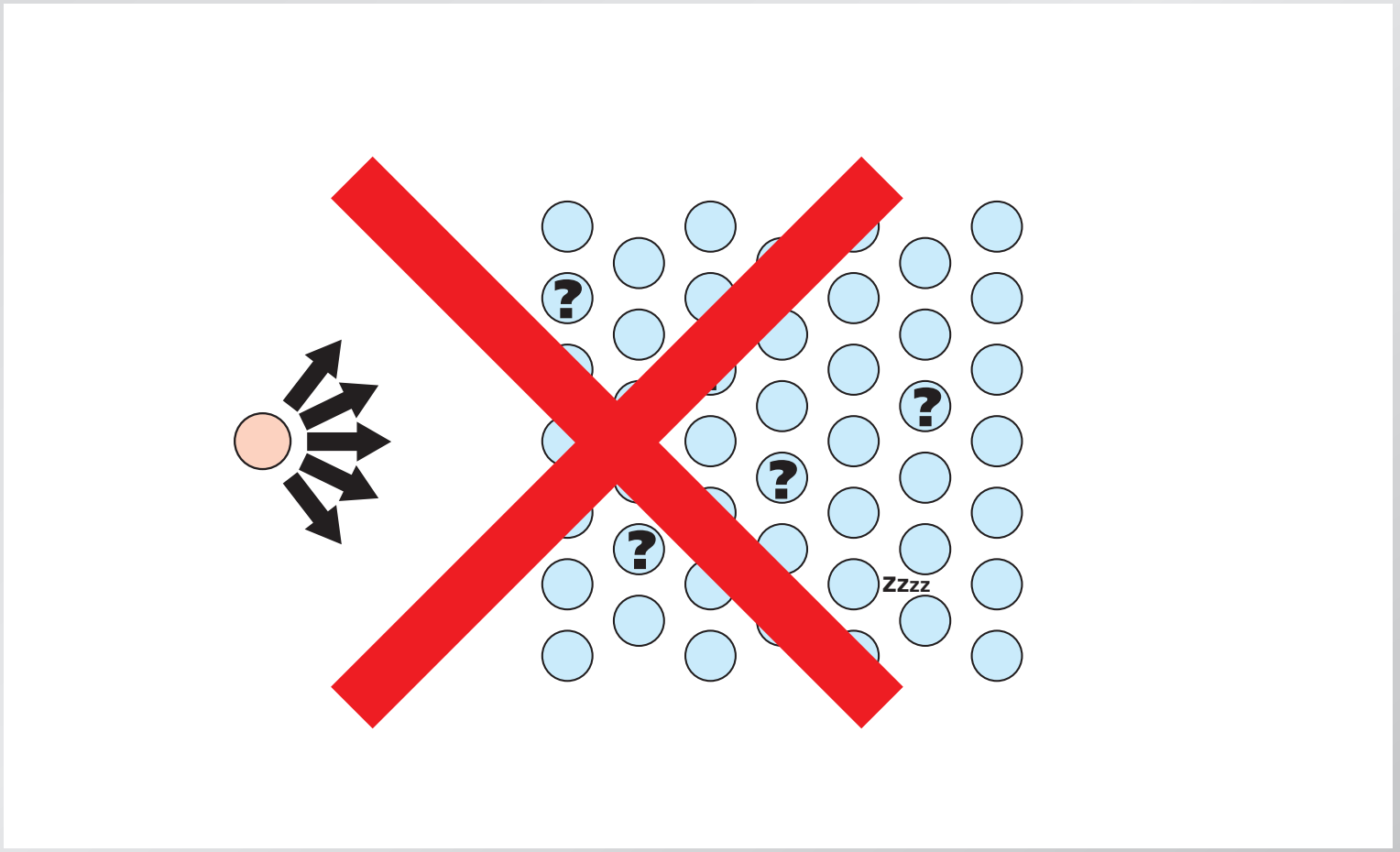
PI & JiTT Overview

traditional approach: one-way flow of information



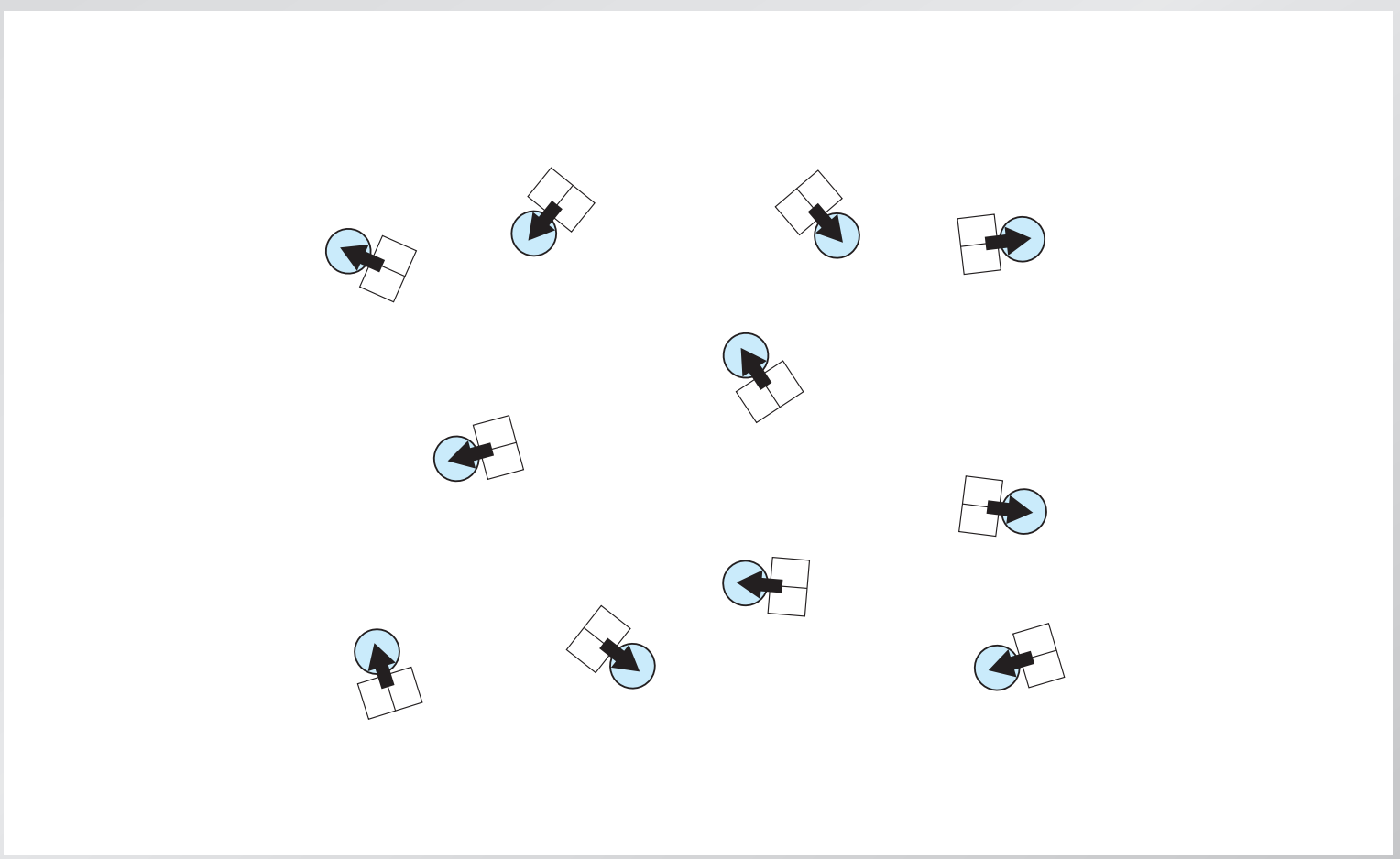
PI & JiTT Overview

no learning



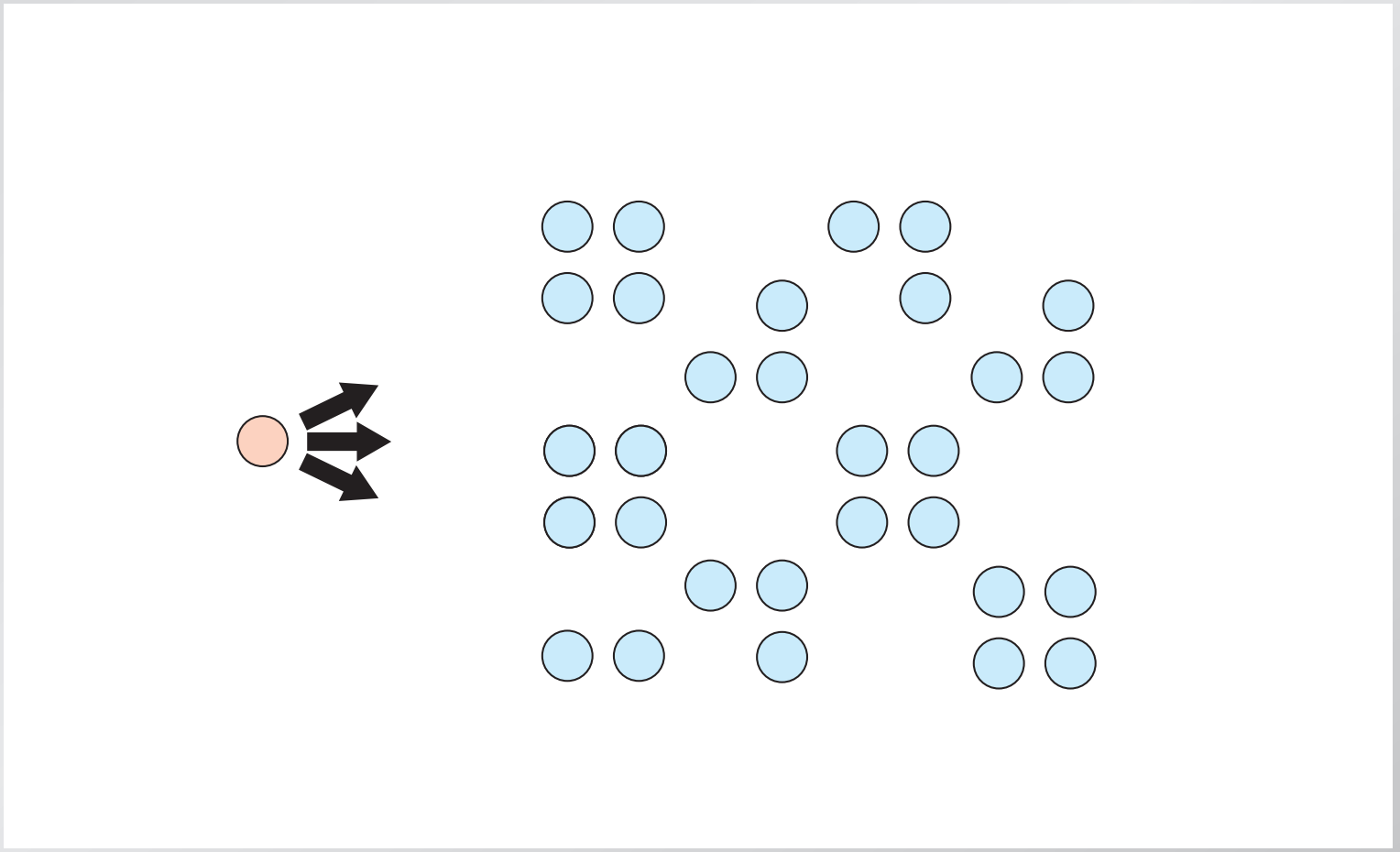
PI & JiTT Overview

instead: assign reading (JiTT)



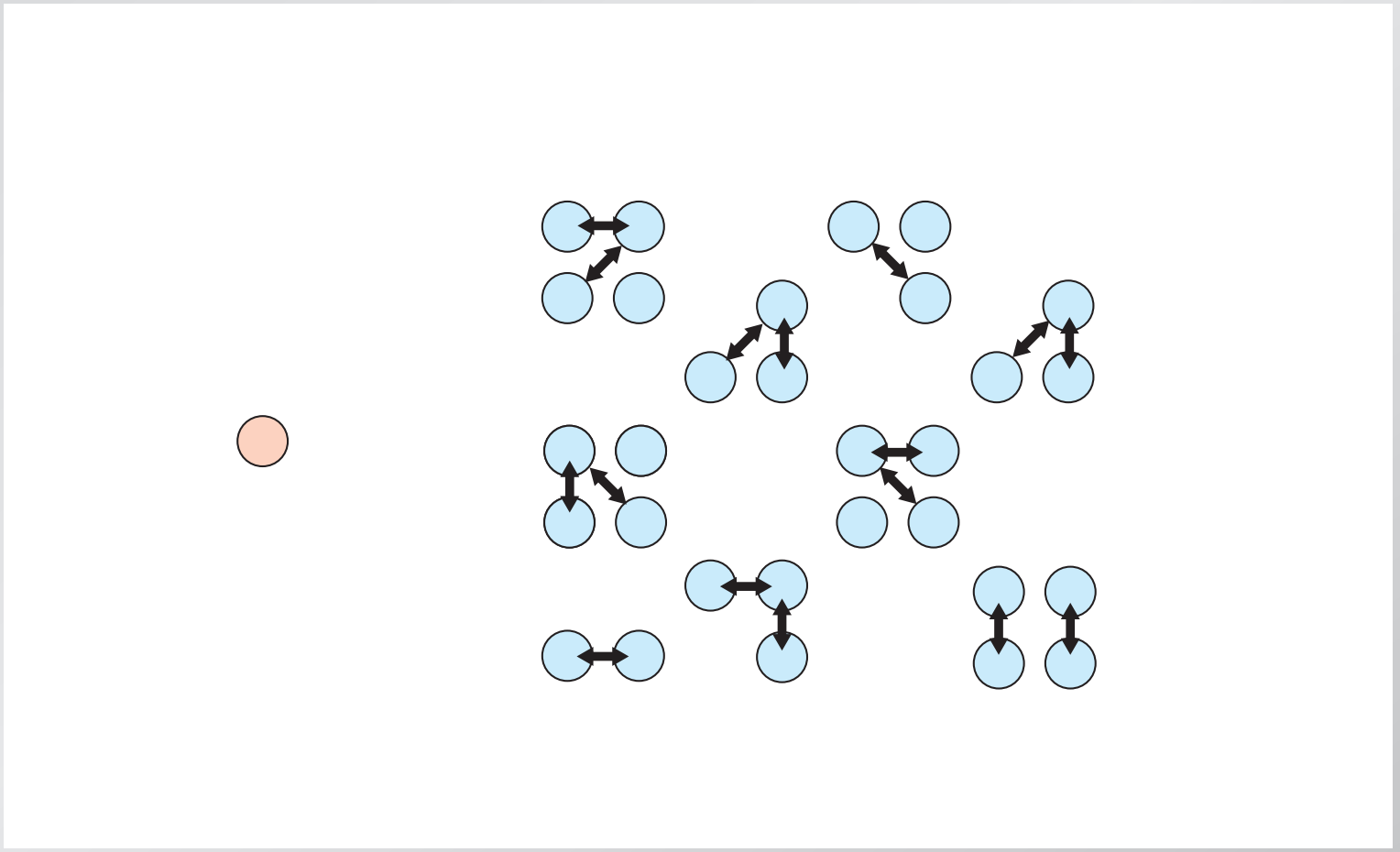
PI & JiTT Overview

lecture a little…



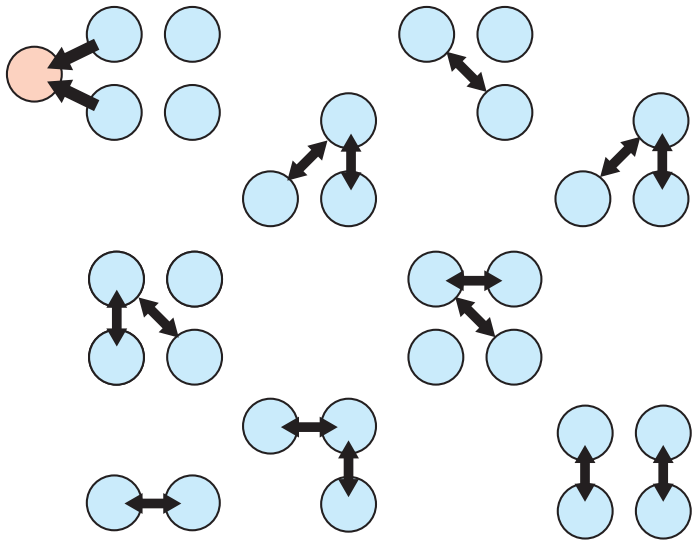
PI & JiTT Overview

…and have students discuss and learn (PI)



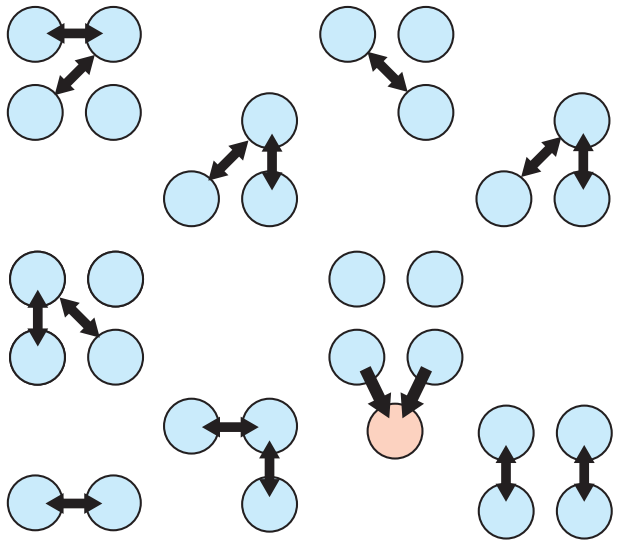
PI & JiTT Overview

information flows two ways



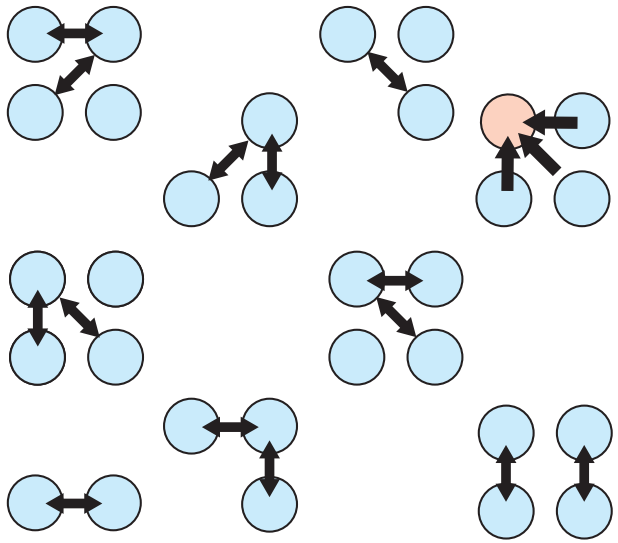
PI & JiTT Overview

information flows two ways



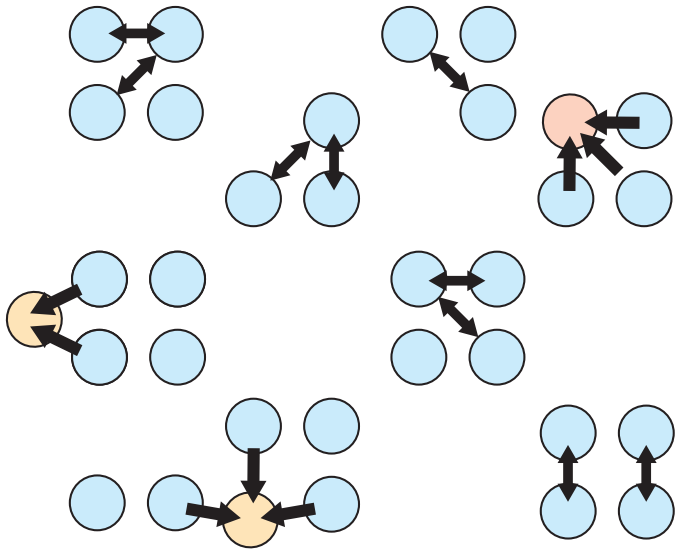
PI & JiTT Overview

information flows two ways



PI & JiTT Overview

(bring in your assistants too!)



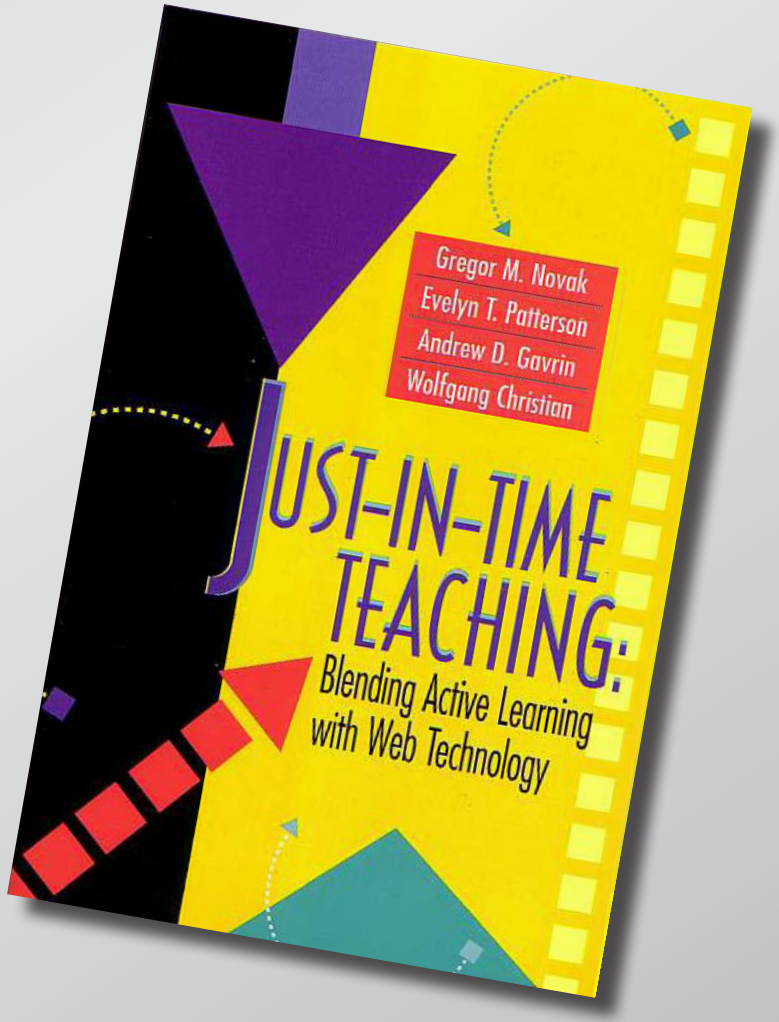
Implementing PI & JiTT

“[How do I] prepare learning materials in a way that allows students to self study and prepare beforehand to have efficient communication in the class?”

PI & JiTT Overview

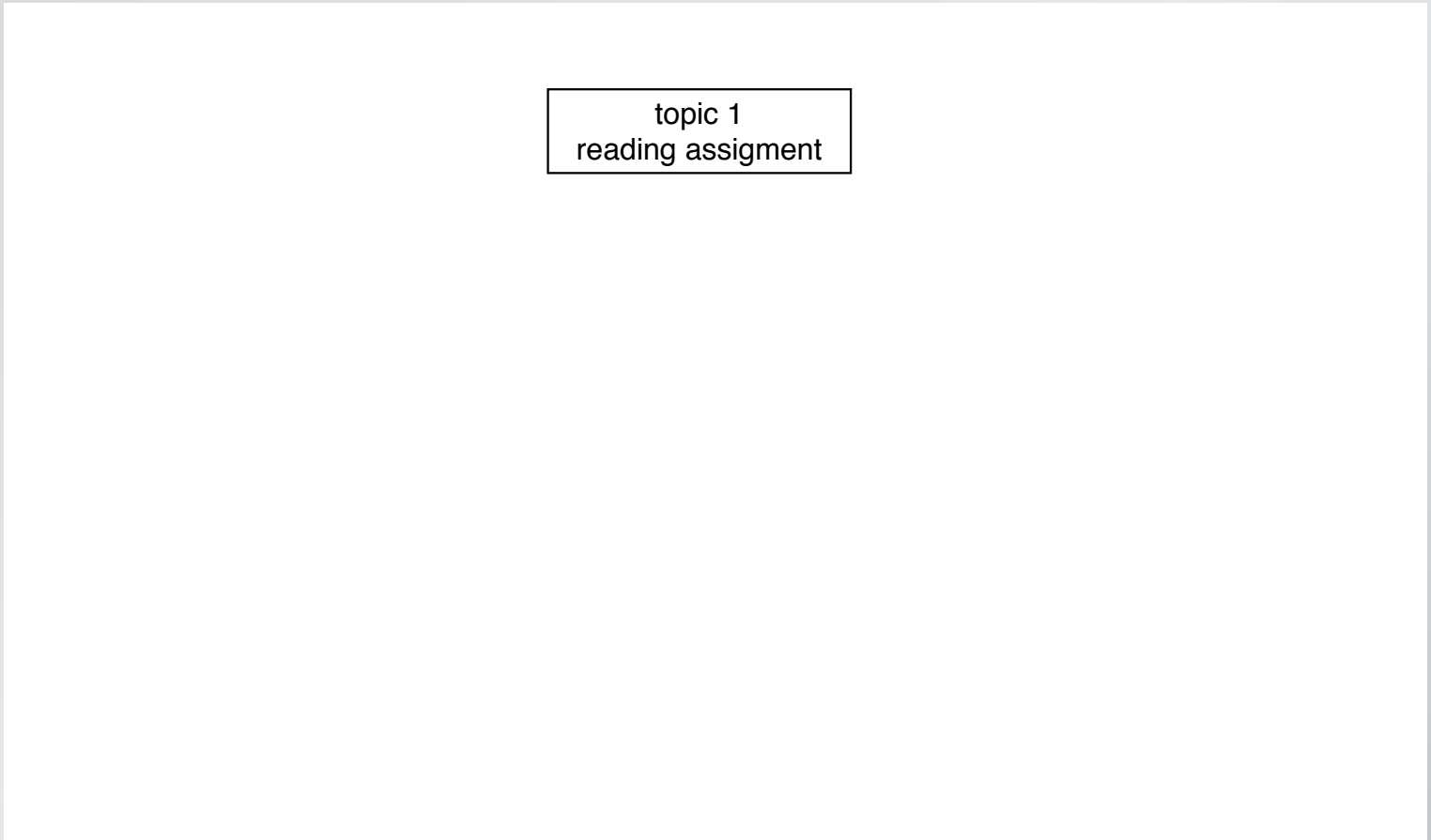
Just-in-time-Teaching (JiTT)

www.jitt.org



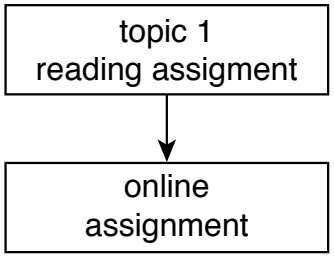
PI & JiTT Overview

JiTT workflow



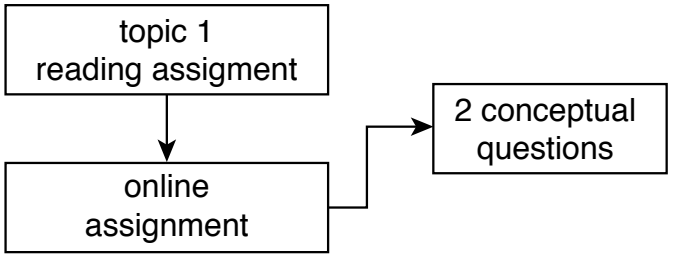
PI & JiTT Overview

JiTT workflow



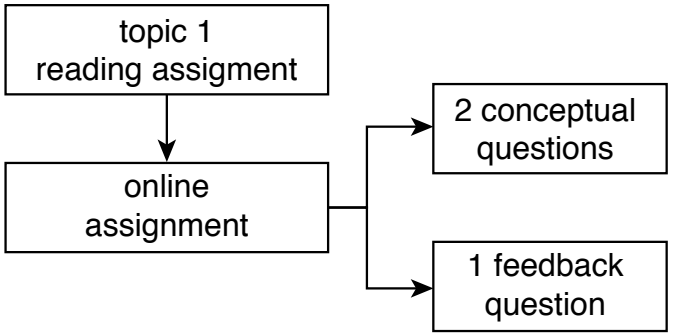
PI & JiTT Overview

JiTT workflow



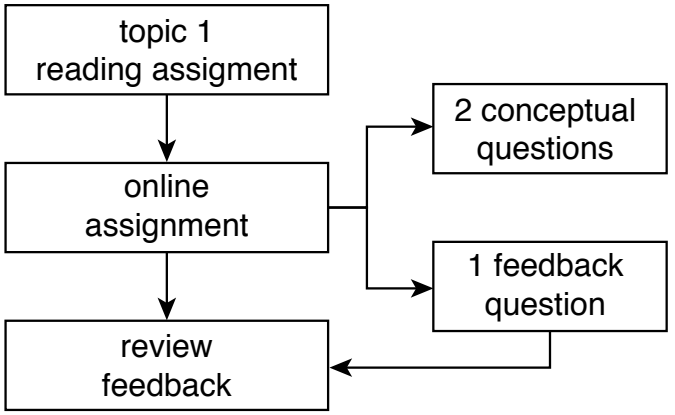
PI & JiTT Overview

JiTT workflow



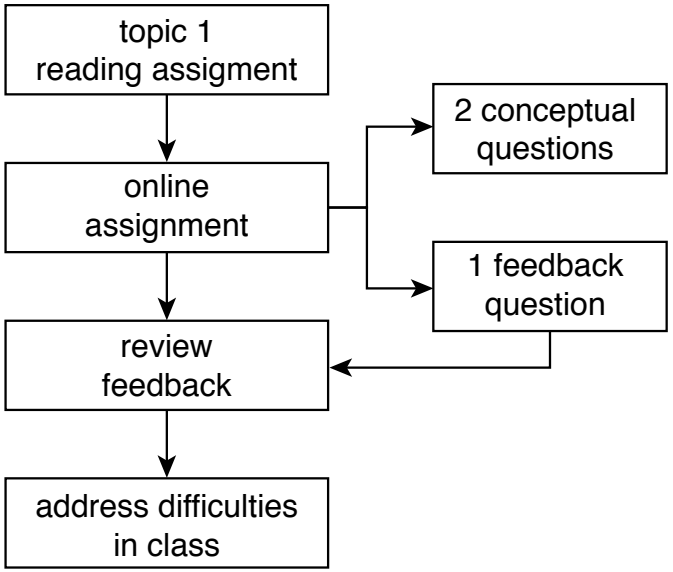
PI & JiTT Overview

JiTT workflow



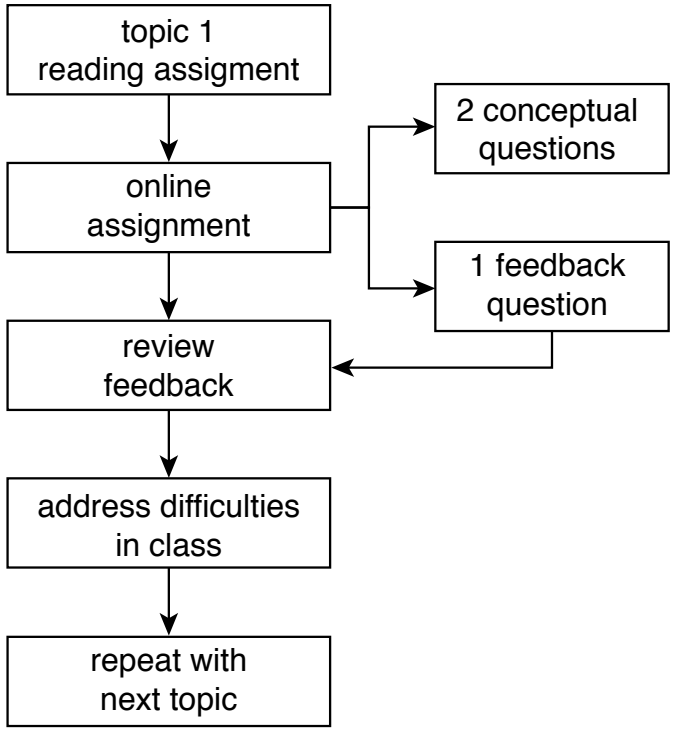
PI & JiTT Overview

JiTT workflow



PI & JiTT Overview

JiTT workflow



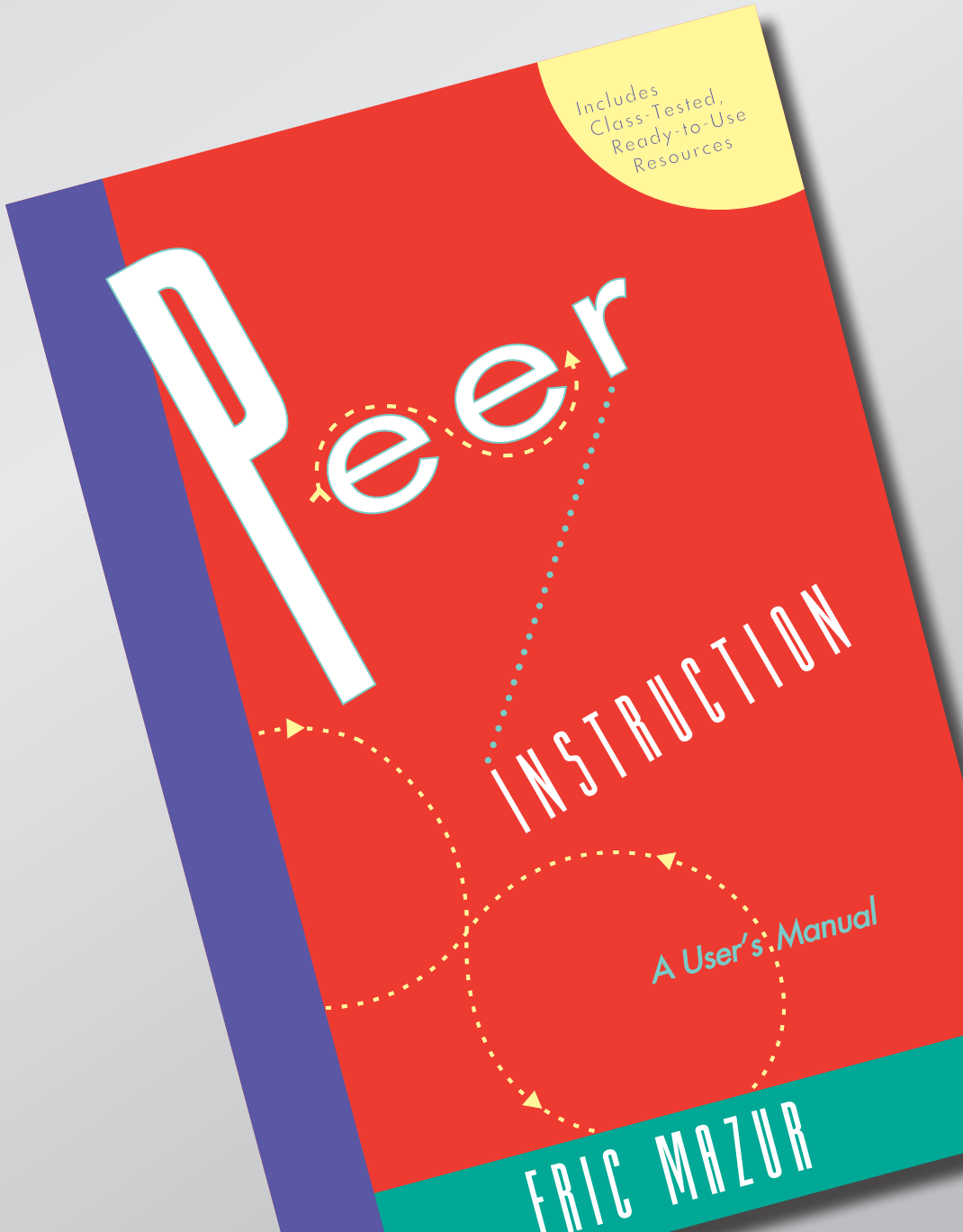
PI & JiTT Overview

JiTT:

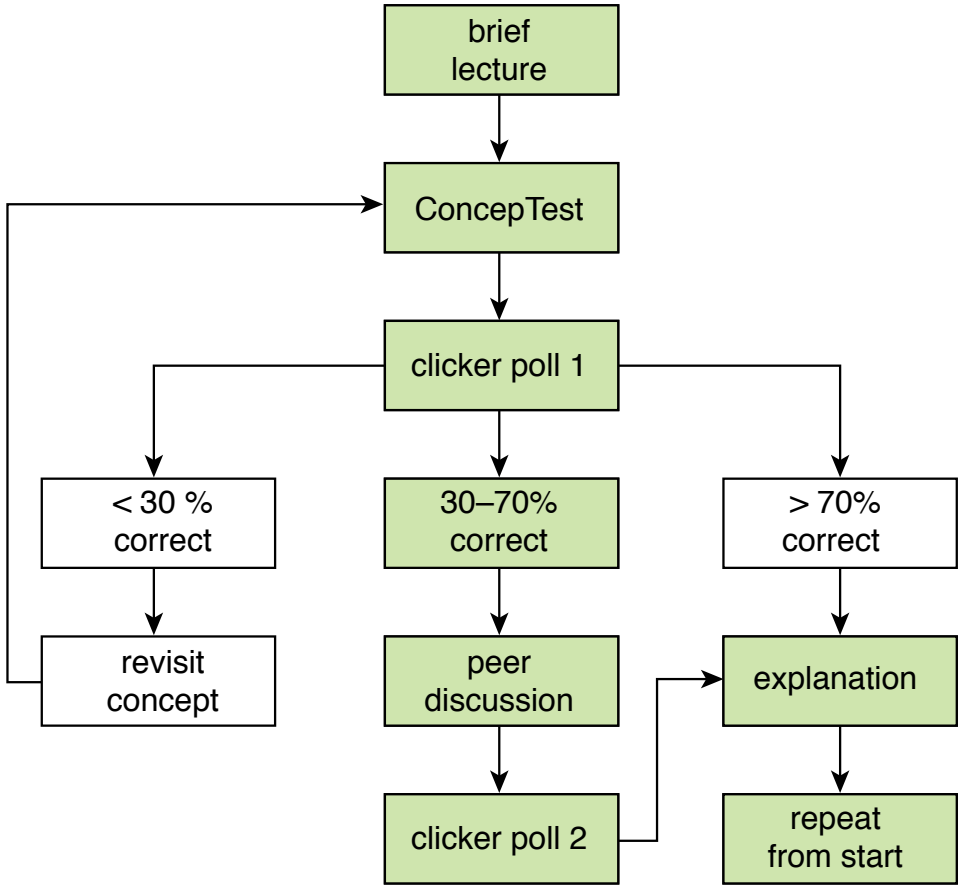
- prepares you for class
- prepares students for class
- helps you address student difficulties

PI & JiTT Overview

Peer Instruction (PI)



PI & JiTT Overview



PI & JiTT Overview

PI:

- **helps students overcome difficulties**
- **encourages deep learning**
- **provides depth, not “coverage”**
- **helps you become aware of misconceptions**

PI & JiTT Overview

Benefits:

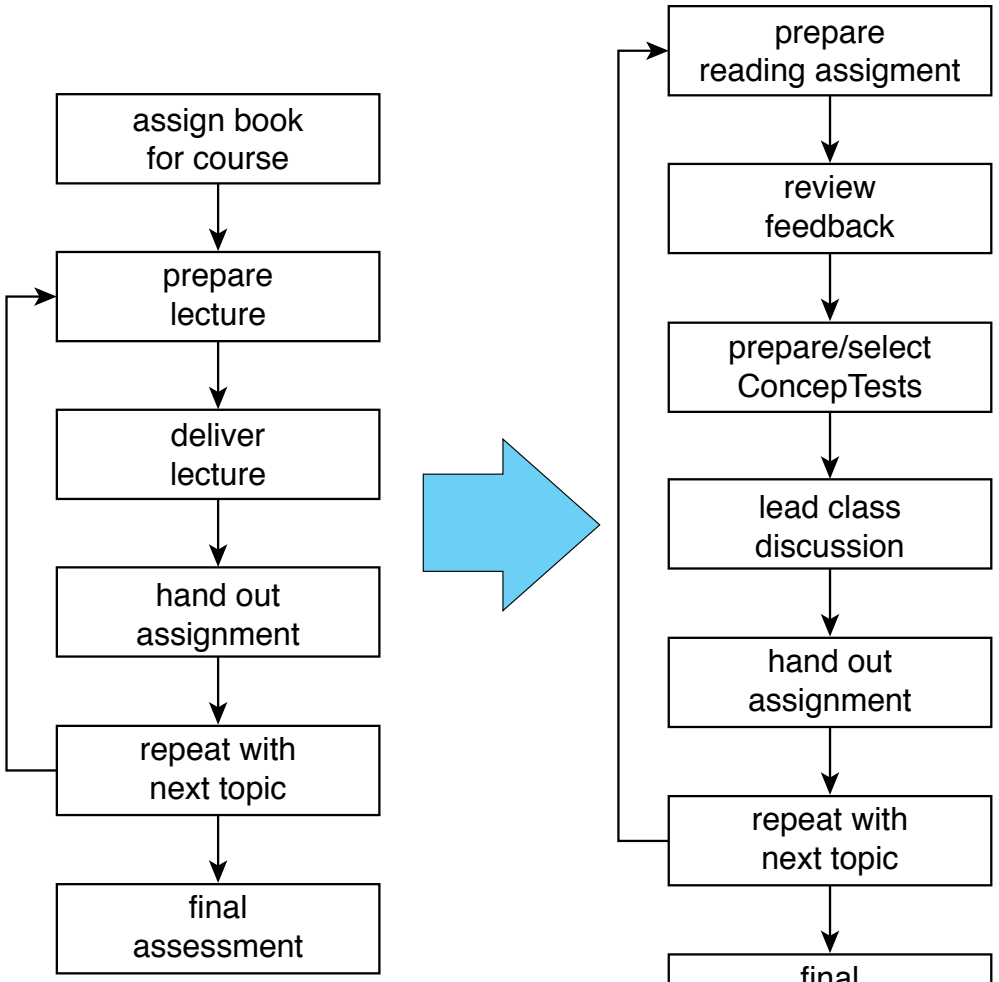
- helps develop conceptual models
- solidifies understanding
- provides feedback
- empowers students

Outline

- PI & JiTT Overview
- **Implementing PI & JiTT**
- Discussion

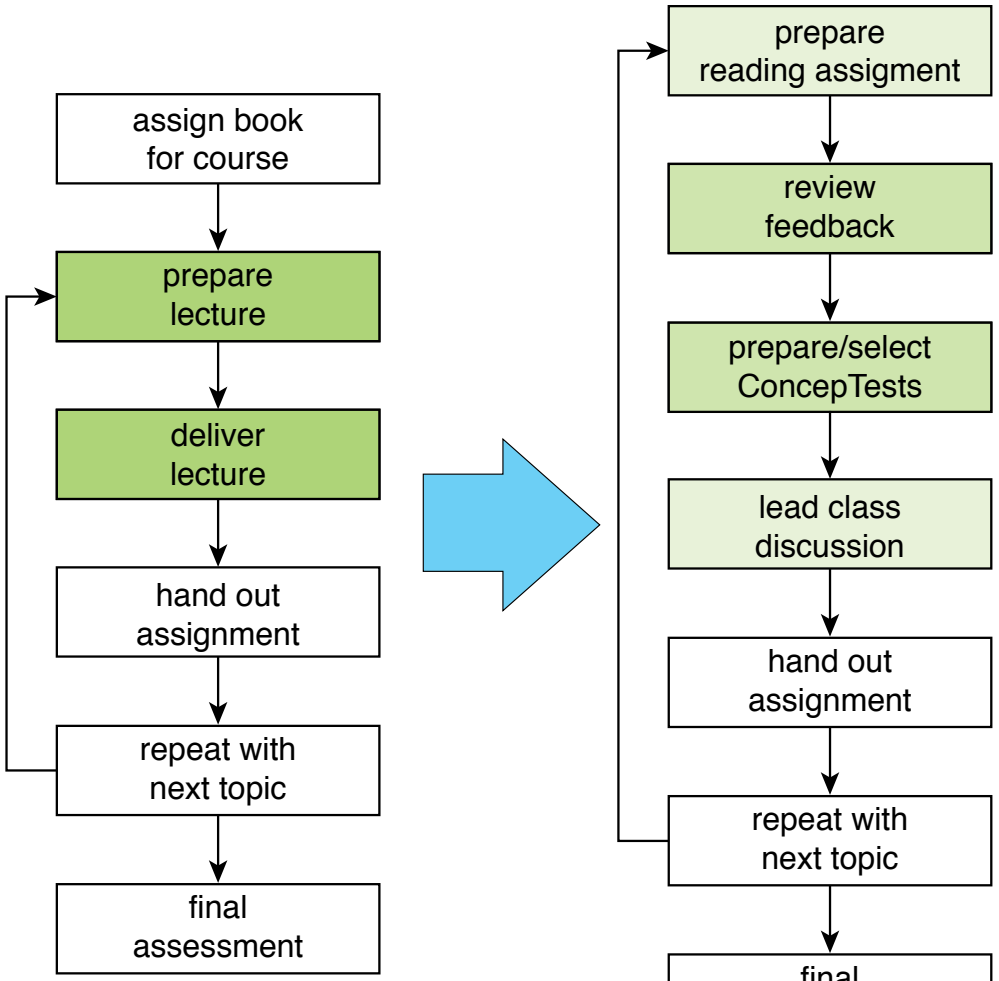
Implementing PI & JiTT

transitioning: where does the effort go?



Implementing PI & JiTT

transitioning: where does the effort go?



Implementing PI & JiTT

“I very much like the approach,

but think its hard to formulate ConcepTests”

Implementing PI & JiTT

What constitutes a good problem?

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces.

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces.

How long do you have to wait before someone frees up a space?

Implementing PI & JiTT

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How long do you have to wait before someone frees up a space?

Requires:

Assumptions
Developing a model
Applying that model

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces. On average people shop for 2 hours.

How long do you have to wait before someone frees up a space?

Implementing PI & JiTT

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Implementing PI & JiTT

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Assuming people leave at regularly-spaced intervals, how long do you have to wait before someone frees up a space?

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces. On average people shop for 2 hours.

Assuming people leave at regularly-spaced intervals, how long do you have to wait before someone frees up a space?

Requires:

Applying a (new) model

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area, where people are known to shop, on average, for 2 hours. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces.

How long do you have to wait before someone frees up a space?

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area, where people are known to shop, on average, for 2 hours. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces.

How long do you have to wait before someone frees up a space?

$$t_{wait} = \frac{T_{shop}}{N_{spaces}}$$

Implementing PI & JiTT

On a Saturday afternoon, you pull into a parking lot with unmetered spaces near a shopping area, where people are known to shop, on average, for 2 hours. You circle around, but there are no empty spots. You decide to wait at one end of the lot, where you can see (and command) about 20 spaces.

How long do you have to wait before someone frees up a space?

Requires:

Using a calculator

$$t_{wait} = \frac{T_{shop}}{N_{spaces}}$$

Implementing PI & JiTT

A good reading assignment question…

- relates to the reading assignment
- cannot be copied from the text
- tests a concept in the book in a new context
- lets students demonstrate familiarity with text

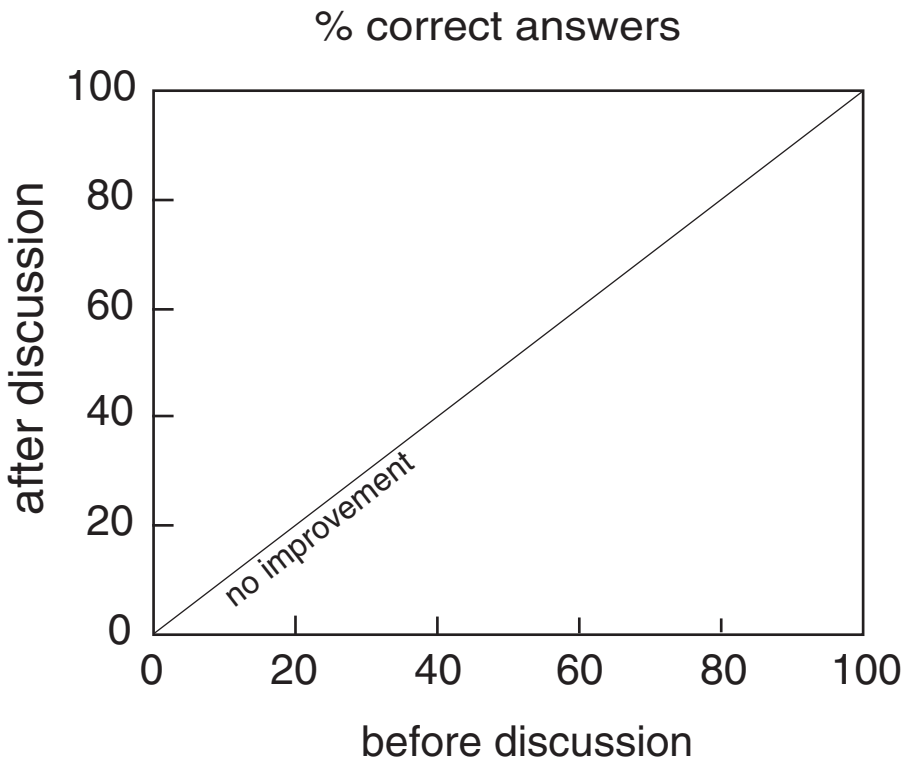
Implementing PI & JiTT

A good ConcepTest…

- helps develop mental models (or stimulate discussion)
- tests undestanding, not memorization
- is just challenging enough (30–70% rule)
- has appropriate distractors

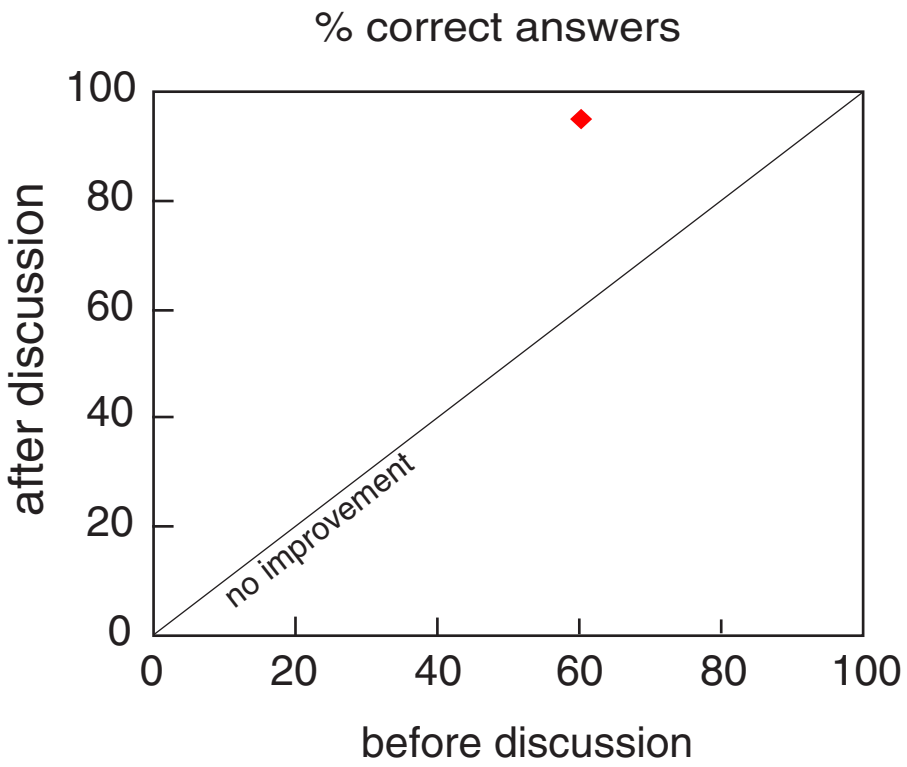
Implementing PI & JiTT

ConcepTest data



Implementing PI & JiTT

ConcepTest data



Implementing PI & JiTT

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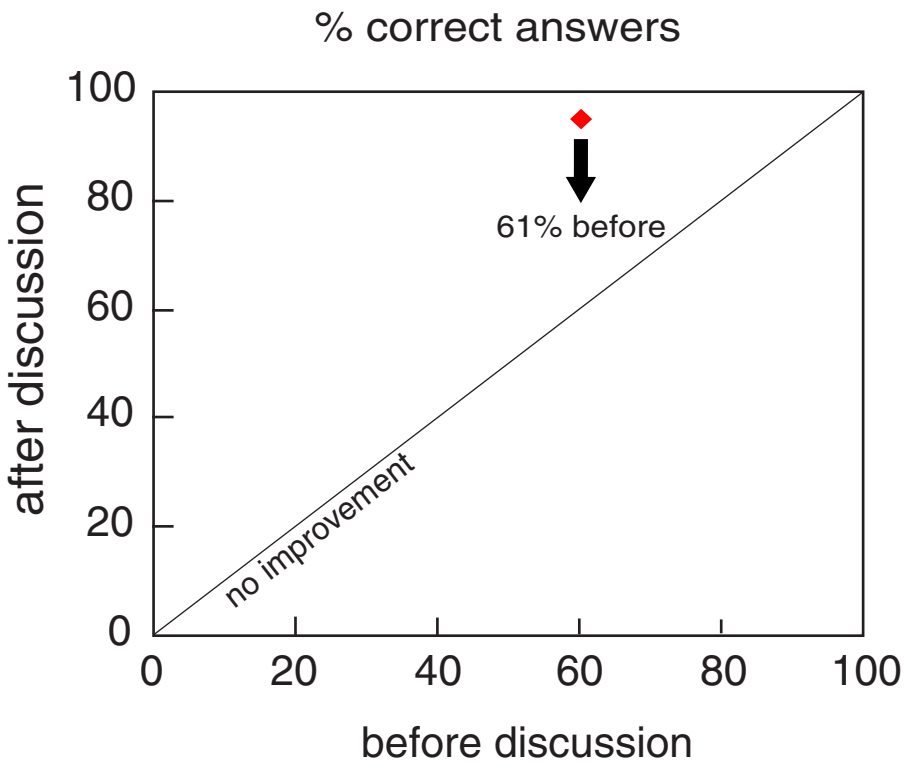

Implementing PI & JiTT

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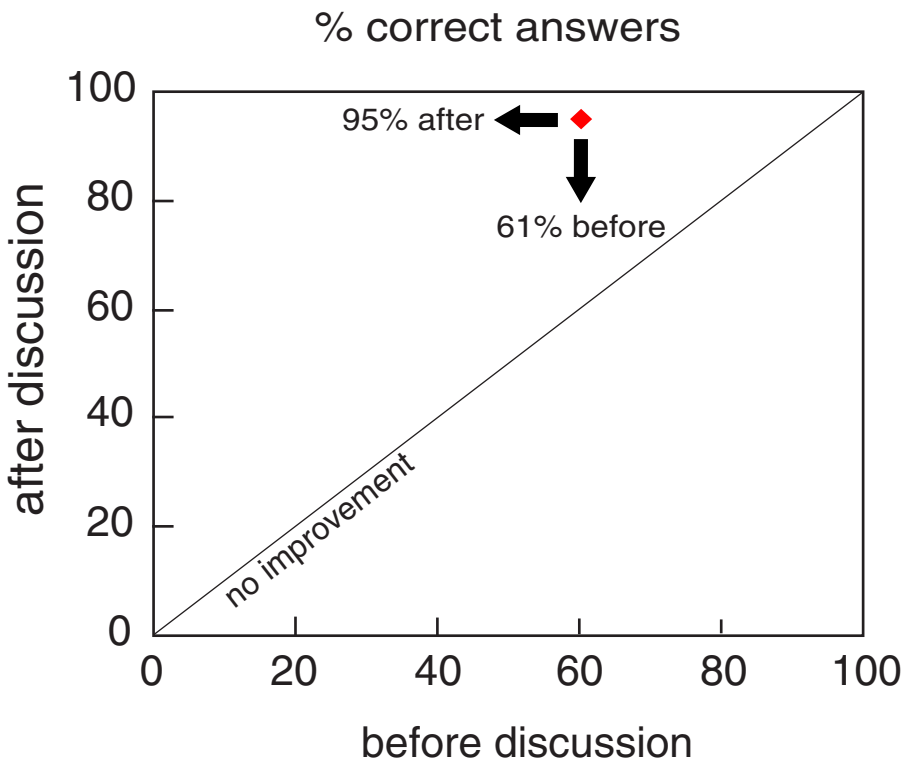

Implementing PI & JiTT

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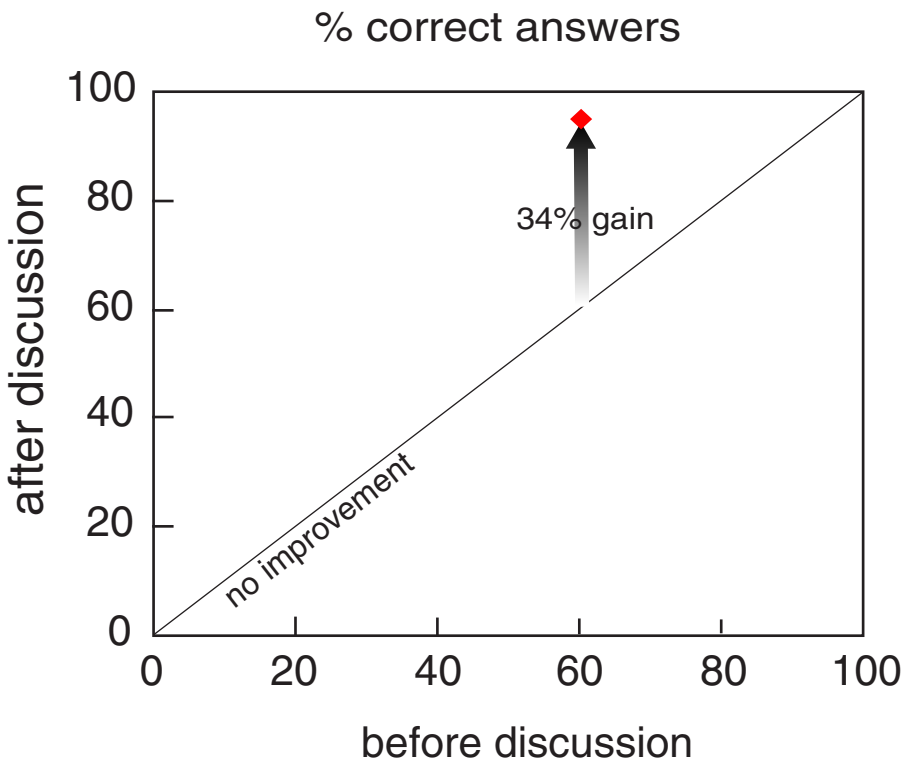

Implementing PI & JiTT

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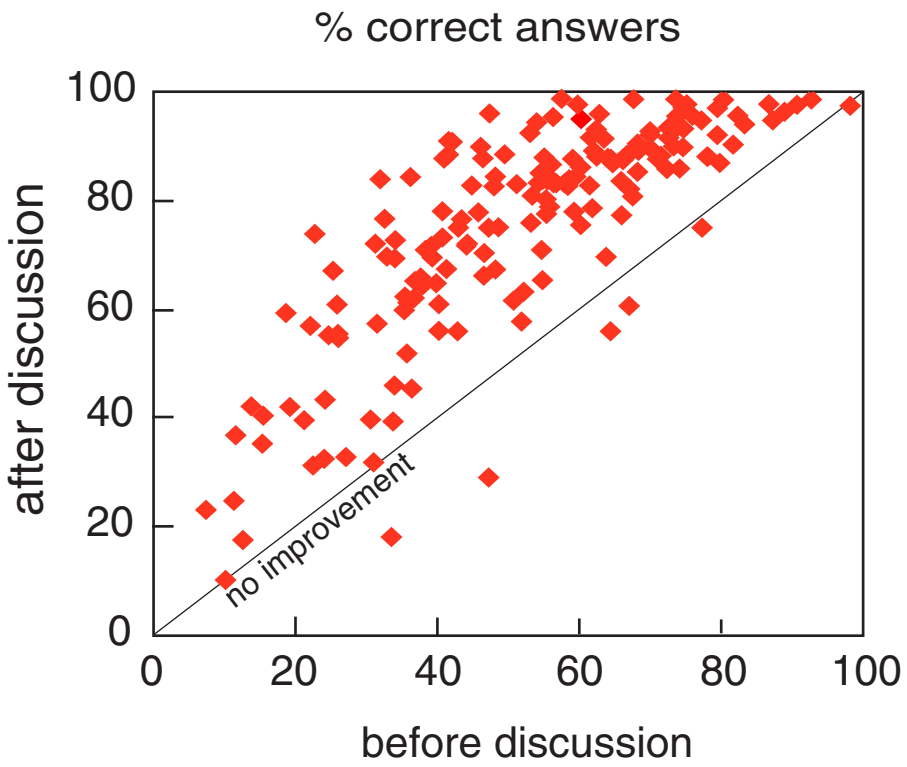

Implementing PI & JiTT

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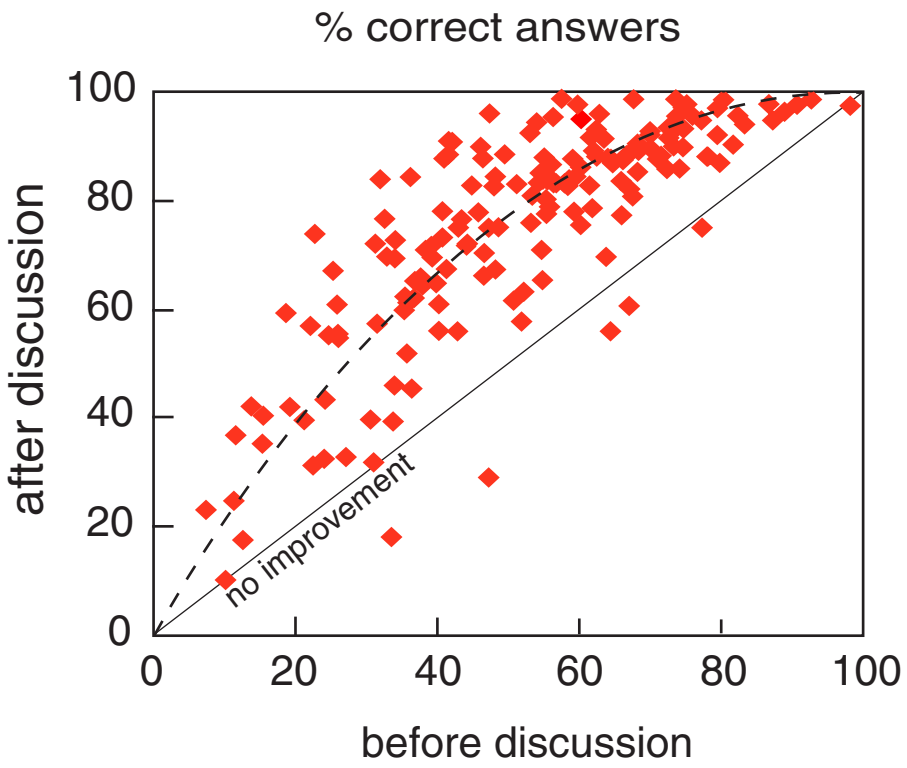
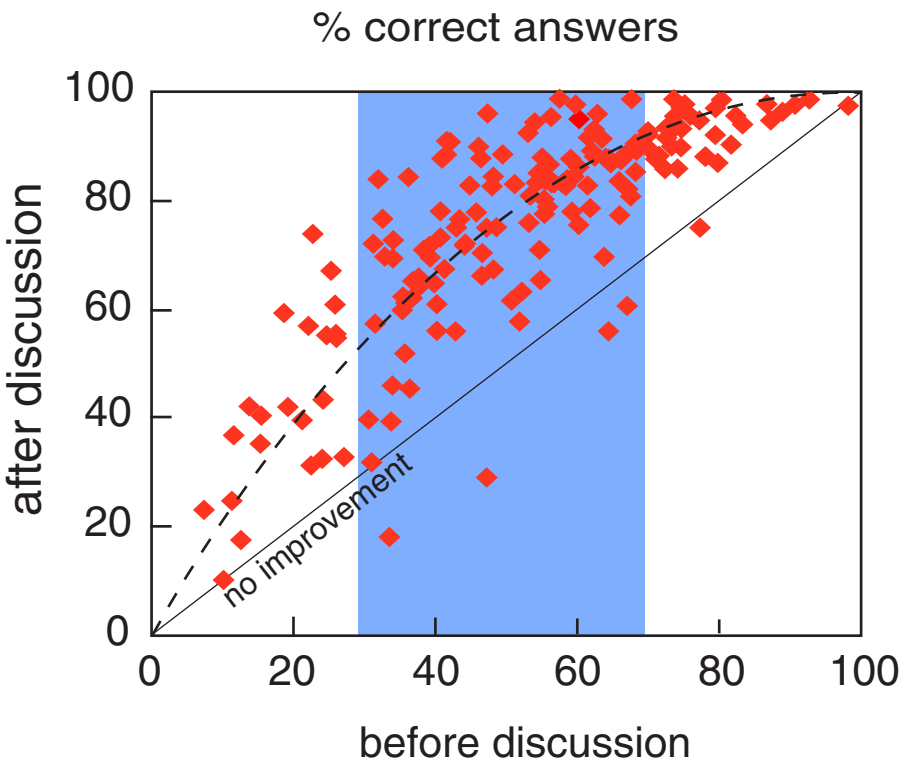
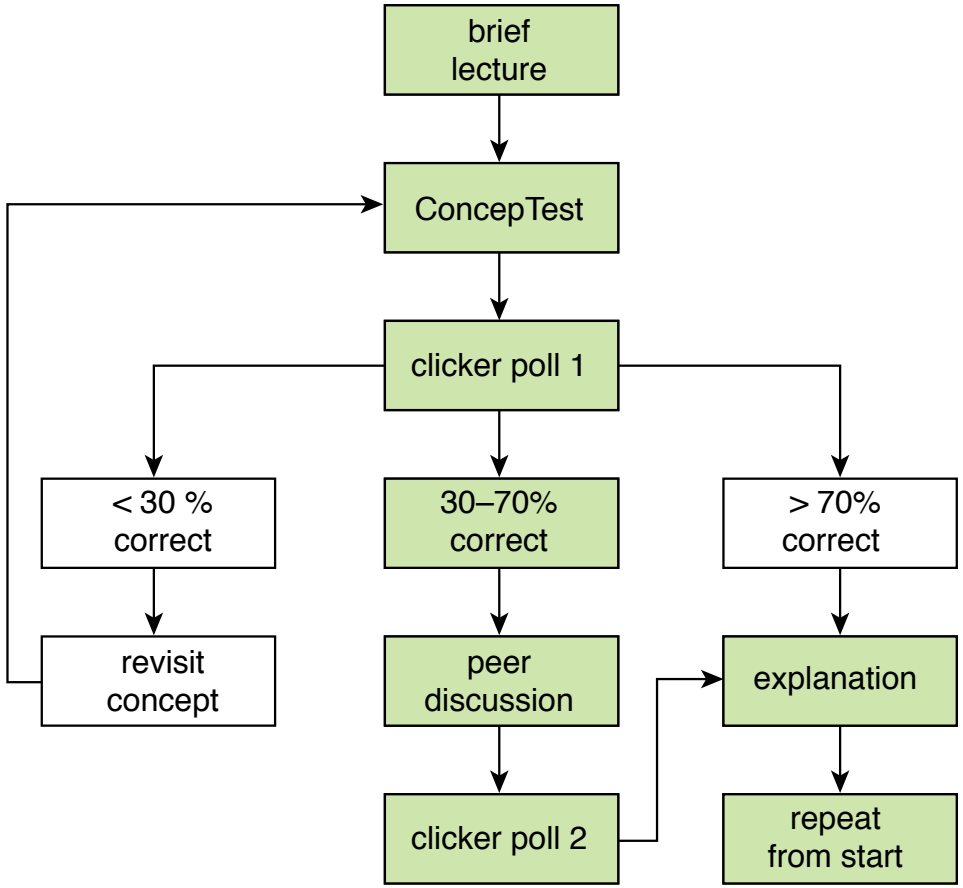


Implementing PI & JiTT

ConcepTest data



Implementing PI & JiTT



Implementing PI & JiTT

A good ConcepTest…

- needs not be multiple choice
- needs not have a correct answer

Outline

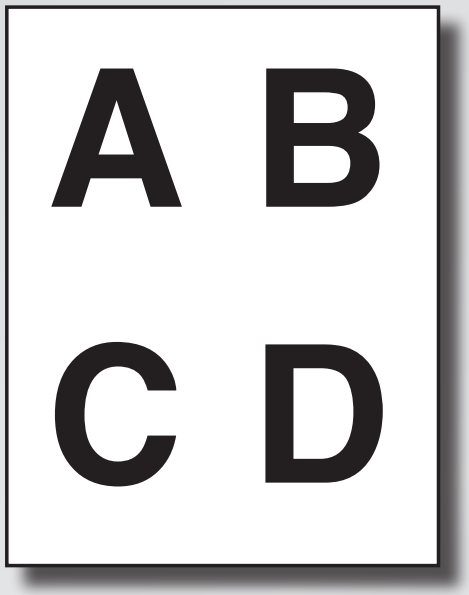
- PI & JiTT Overview
- Implementing PI & JiTT
- Discussion

Discussion

“Are clickers a required resource?”

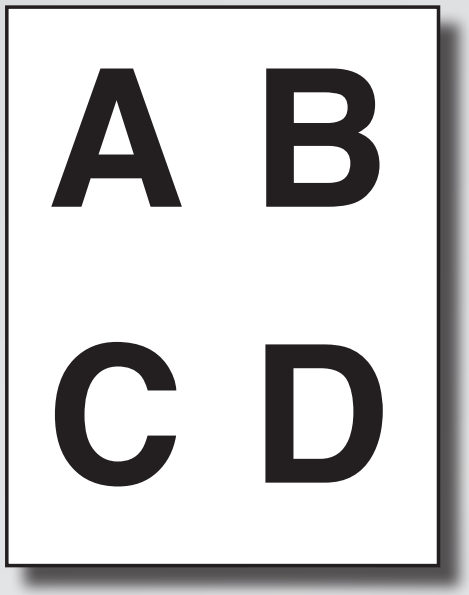
Discussion

Flashcards: simple and effective



Discussion

Flashcards: simple and effective



Meltzer and Mannivanan, South Eastern Louisiana University

Discussion

circumference of a circle:

$$2\pi R$$

Discussion

Imagine a rope that fits snugly along the equator.

Discussion

Imagine a rope that fits snugly along the equator.

Suppose the rope is cut and 1 m of rope is inserted between the cut ends. If the rope were to maintain a circular shape, how far off the surface of the Earth would it float?

1. the width of a few atoms
2. the width of a few hairs
3. the height of a curb
4. exactly 1 m
5. more than 1 m

Discussion

Imagine a rope that fits snugly along the equator.

Suppose the rope is cut and 1 m of rope is inserted between the cut ends. If the rope were to maintain a circular shape, how far off the surface of the Earth would it float?

1. the width of a few atoms
2. the width of a few hairs
3. **the height of a curb** ✔
4. exactly 1 m
5. more than 1 m

Discussion

circumference at equator:

$$2\pi R_{\mathrm{E}}$$

Discussion

circumference at equator:

$$2\pi R_{\mathrm{E}}$$

new circumference:

$$2\pi R_{\mathrm{E}} + 1\ \mathrm{m}$$

Discussion

circumference at equator:

$$2\pi R_{\mathrm{E}}$$

new circumference:

$$2\pi R_{\mathrm{E}} + 1\ \mathrm{m}$$

radius of circle with new circumference:

$$2\pi R = 2\pi R_{\mathrm{E}} + 1\ \mathrm{m}, \quad \textbf{and so} \quad R = R_{\mathrm{E}} + \frac{1\ \mathrm{m}}{2\pi}.$$

Discussion

You all got fired up!

Discussion

You all got fired up!

(WITHOUT CLICKERS!)

Discussion

It’s not the technology, but the pedagogy!

Discussion

“How do I respond when students ask me to lecture?”

Discussion

Written on Wednesday Feb 16, two weeks into the course:

> Subject: concerns
>
> Professor Mazur,
>
> Here are a few concerns. I speak for many of my classmates.
>
> 1) You are giving us WAY to much work. After spending multiple hours on the problem set, and not being able to figure out many of the questions, I now see that we have an additional 6 or 7 pages or homework in the workbook. I just spent 4 hours on the lab, and I am not confident on almost half of the questions. This is more work than I have had all semester in all of my other classes combined.
>
> 2) If you are going to give us this much work, I would suggest re-structuring the lectures. I find the readings very difficult to understand. I am not a bad student (I got a solid A in physics 1a), but it is very difficult to internalize the readings. You should spend most of the lecture going over, point by point, the readings in their entirety. While the PRS clickers are fun, they do not help me understand the complex material.
>
> I am extremely flustered by the incredibly large amount of work, and my inability to understand it, and I am strongly considering dropping the course.

Discussion

Written on Monday May 23, just after the final exam:

> Subject: Thanks!
>
> Professor Mazur,
>
> First of all I want to thank you for a great semester. You are an excellent professor, and it is clear that you truly care about each and every student.
>
> The exam went well today. I'm not sure to what extent you will curve the final grades (if at all), but it looks like I may be right around the cutoff point between an A and an A-. I studied as hard as I could and I'm keeping my fingers crossed about the A, but no matter what happens with my grade you should know that you are one of the best professors that I have ever had at Harvard.
>
> Thanks again!

Discussion

“Are there specific challenges when applying this technique to the social sciences?”

“[How to formulate questions in courses] where the learning trains analysis and argument, but where single solutions are rare?

Consider this

Professors A and B teach the same mechanics class at the same college during different semesters. Professor A uses the traditional approach to teaching and lectures. Professor B uses Peer Instruction and students respond to the questions using clickers. Each class is evaluated using the traditional end-of-semester questionnaire and using the FCI to measure students' comprehension of mechanics. Both professors are middle-aged and male. The results are as follows.

A: student evaluation: 1.5/5.0; $\langle g \rangle = 0.42$

B: student evaluation: 3.7/5.0; $\langle g \rangle = 0.57$

Consider this

Professor	A	B
pedagogy	traditional	PI with clickers
student evaluation	1.5/5.0	3.7/5.0
FCI <g>	0.42	0.57

What might account for the large difference in evaluation?

I. professor personality
II. technology
III. pedagogy

1. I only
2. II only
3. III only
4. II and III
5. I, II, and III
6. other combination

Consider this

a couple of points worth noting:

Consider this

a couple of points worth noting:

1. you got engaged

Consider this

a couple of points worth noting:

1. you got engaged
2. no “correct” answer

Consider this

a couple of points worth noting:

1. you got engaged
2. no “correct” answer
3. you got engaged

Consider this

a couple of points worth noting:

1. you got engaged
2. no “correct” answer
3. you got engaged
4. you don’t need a correct answer!

Discussion

“What about coverage?”

Discussion

	“lectures”	PI
coverage	complete	partial

Discussion

	“lectures”	PI
coverage	complete	partial
material learned	little	substantial

Discussion

	"lectures"	PI
coverage	complete	partial
material learned	little	substantial

what does coverage mean if little is retained?

Discussion

Keep those good question coming!

Discussion

Your next assignment:

work on ConcepTest development

http://bit.ly/KTHday2

Research Funding:

Pew Charitable Trust, Pearson/Prentice Hall, Davis Foundation, Engineering Information Foundation, Derek Bok Center for Teaching and Learning, National Science Foundation

for more information and a copy of this presentation:

http://mazur.harvard.edu

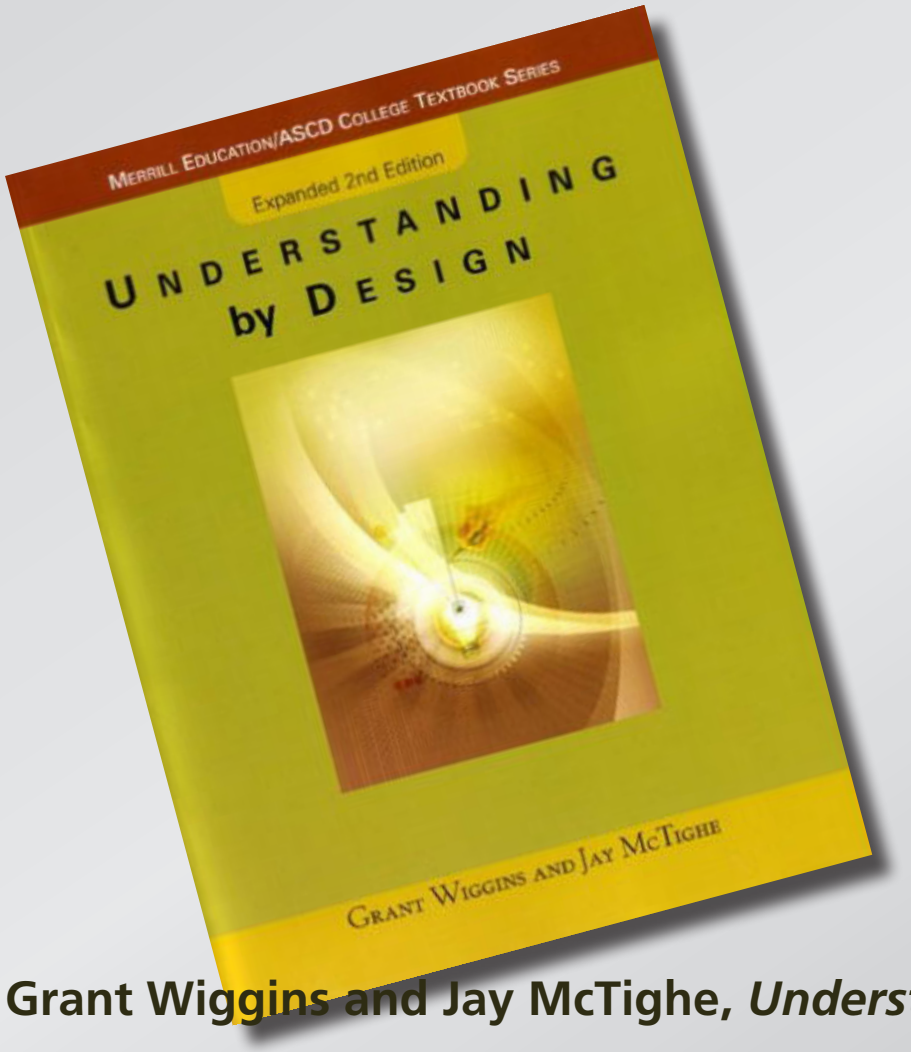
Follow me!  **eric_mazur**

Looking ahead

Improve course by setting learning goals

Course design

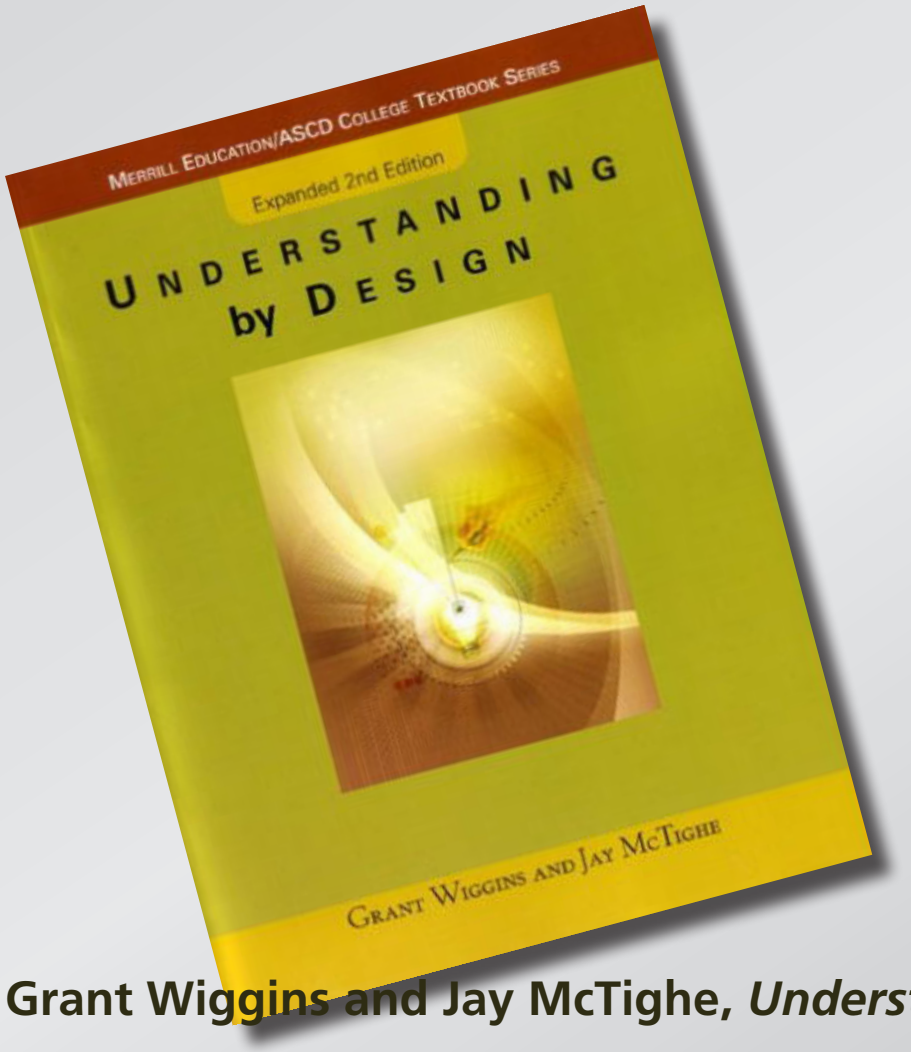
Setting learning goals



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

Course design

Setting learning goals

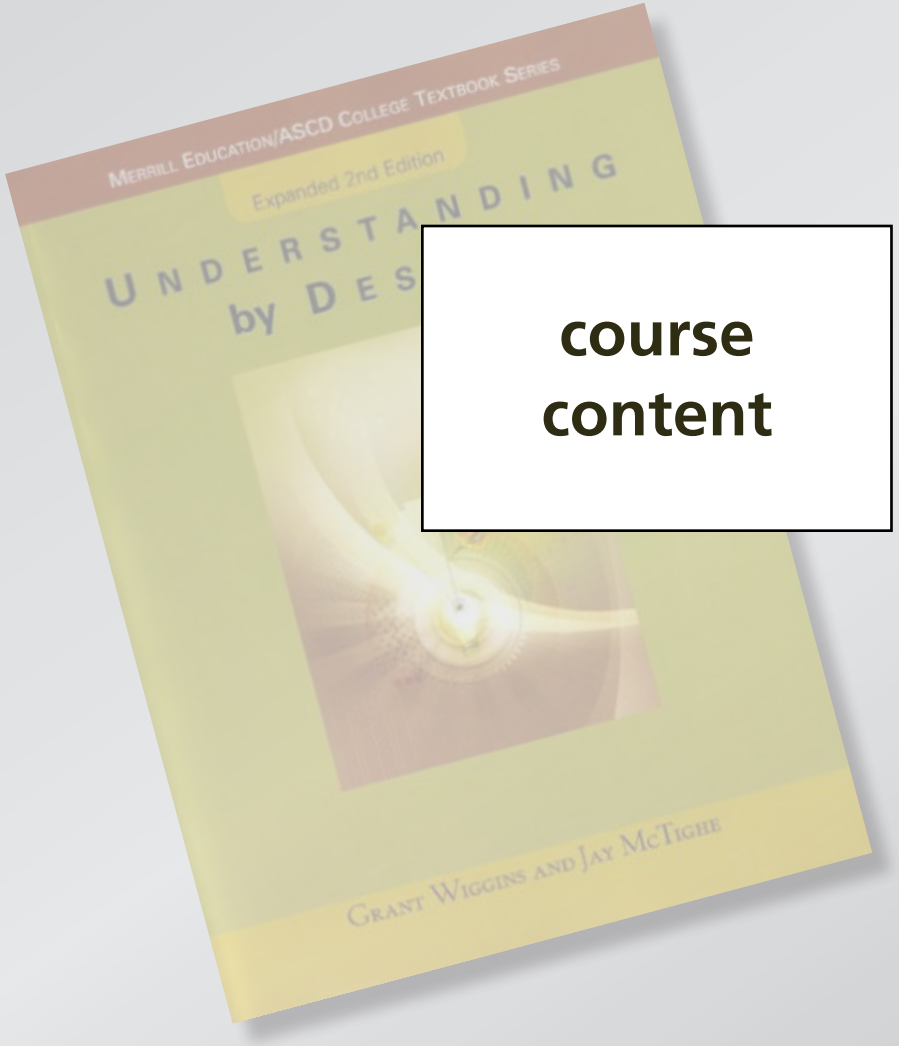


- approach, not content
- focus on understanding
- backward design

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

Course design

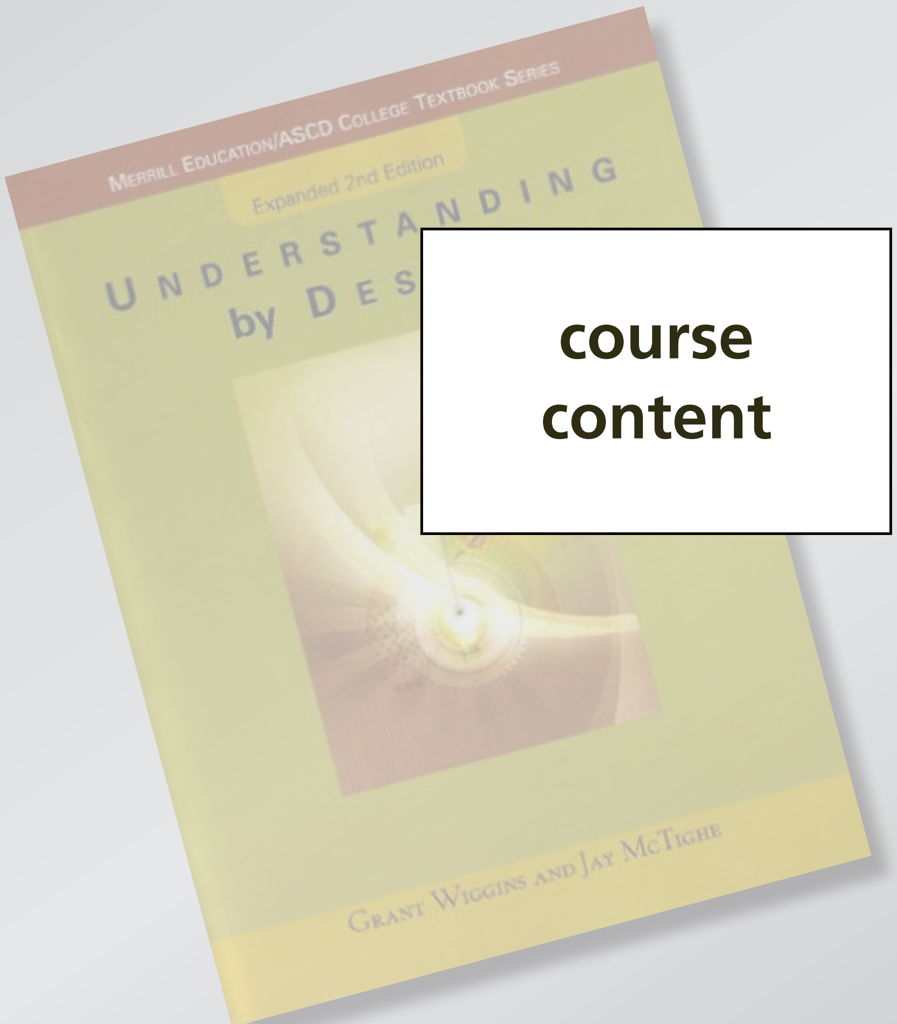
Traditional approach to course planning



course content

Course design

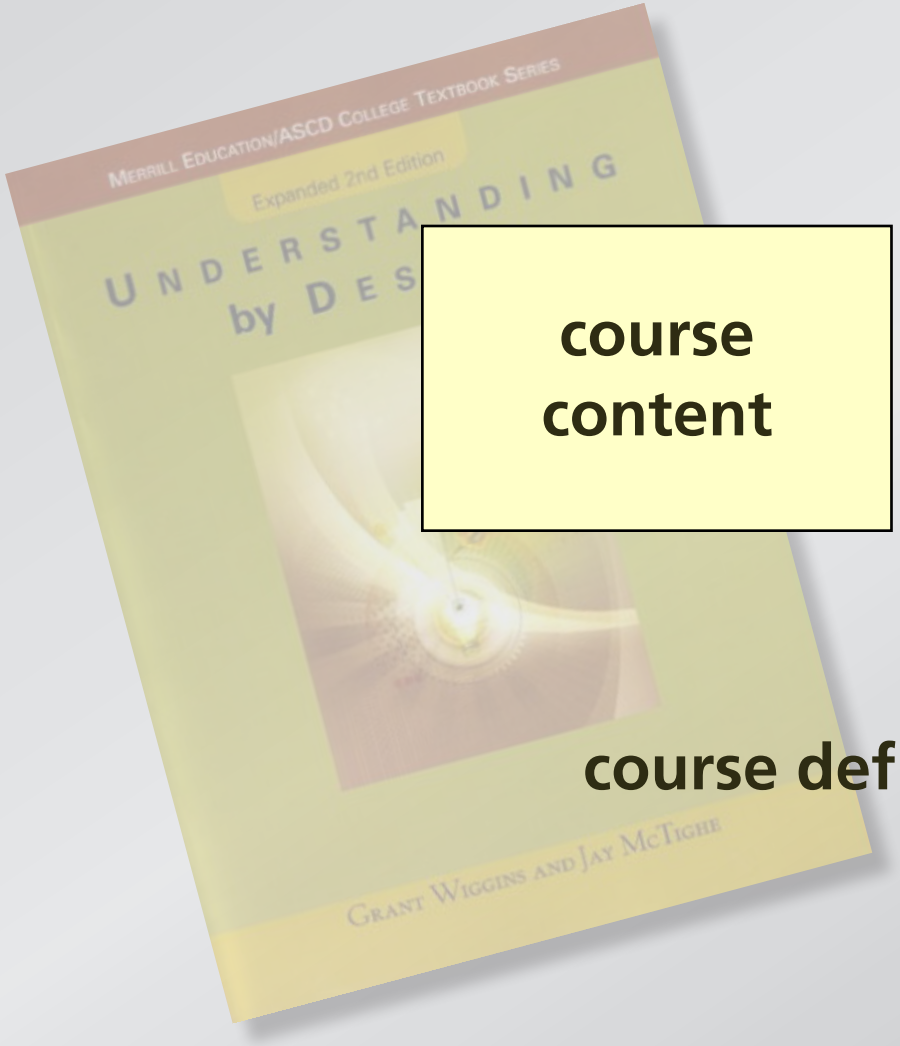
Traditional approach to course planning



course content → assessment

Course design

Traditional approach to course planning



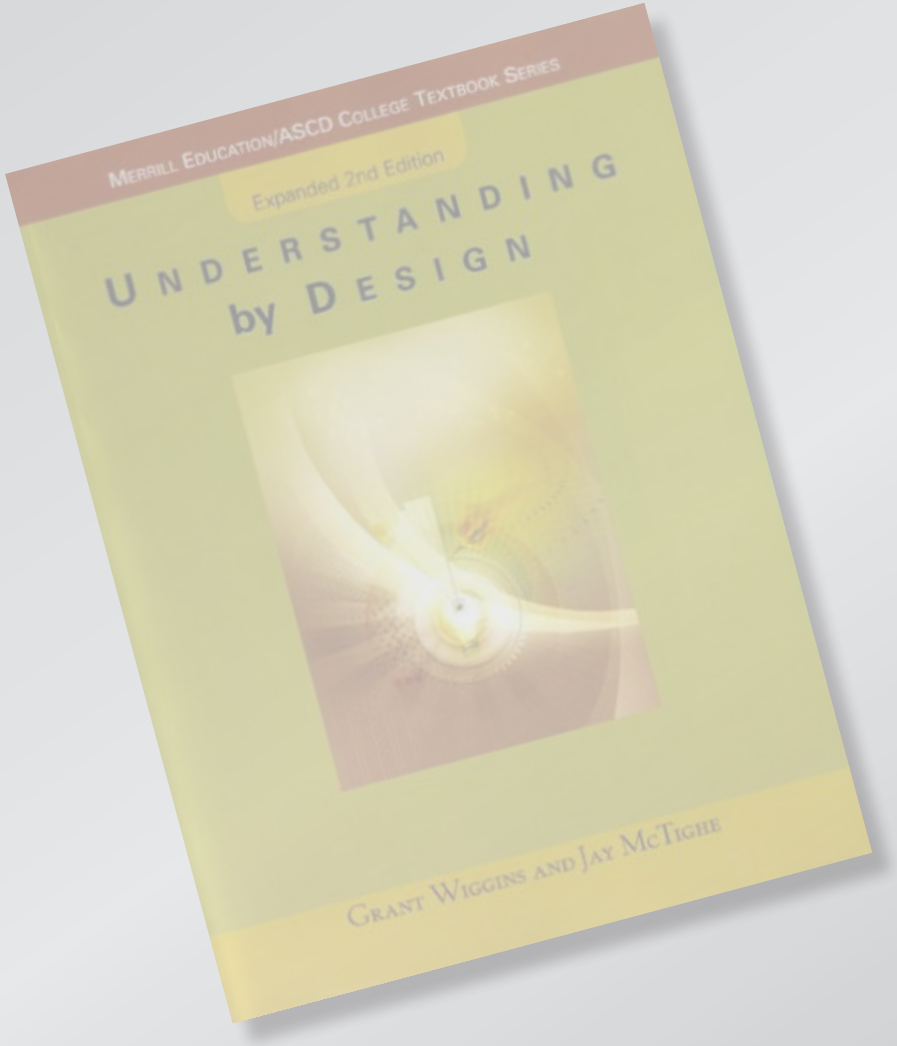
course content

assessment

course defined by content

Course design

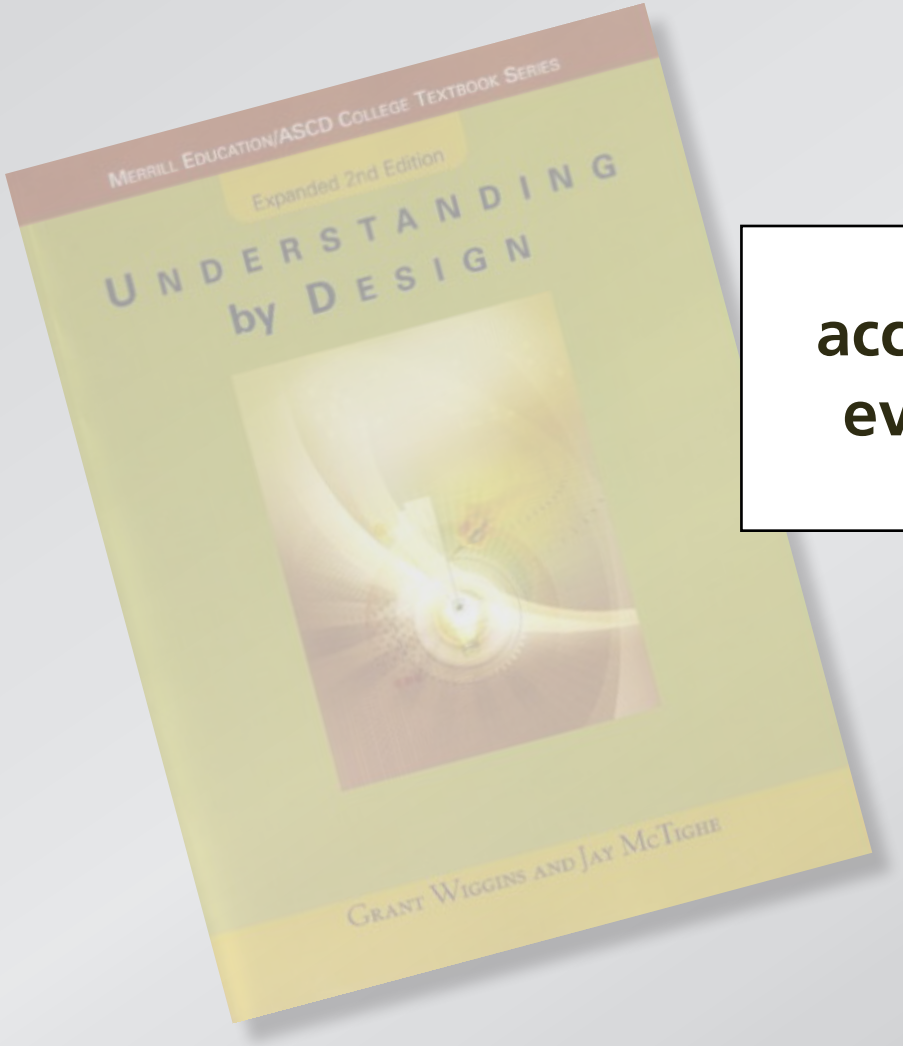
Backward design



desired outcomes

Course design

Backward design

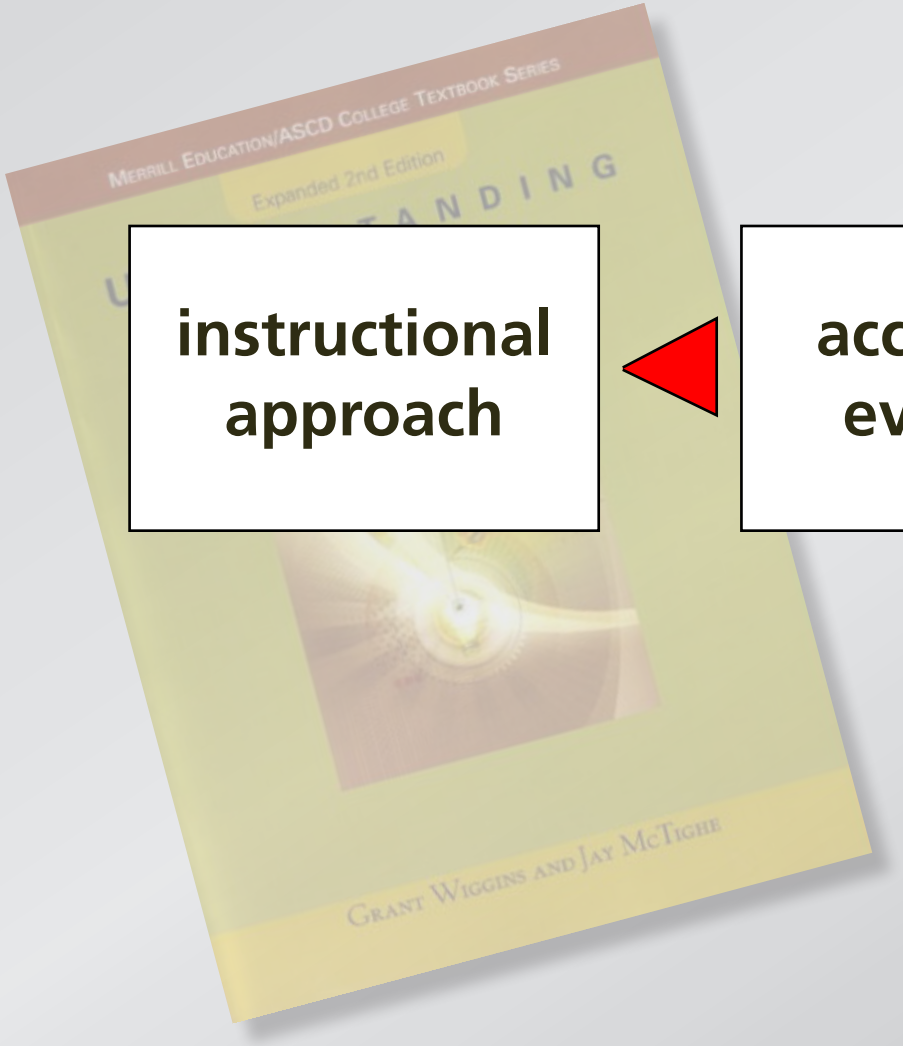


acceptable evidence

desired outcomes

Course design

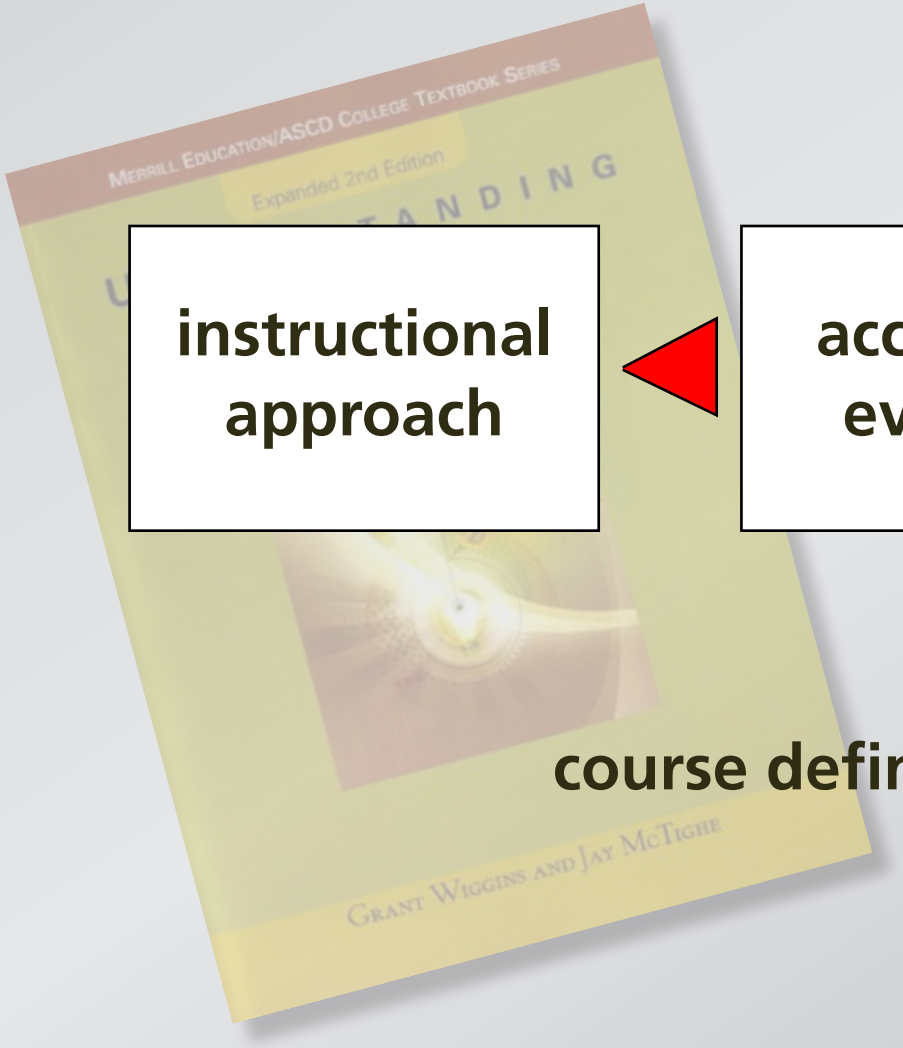
Backward design



instructional approach ◀ **acceptable evidence** ◀ **desired outcomes**

Course design

Backward design



desired outcomes ◀ **acceptable evidence** ◀ **instructional approach**

course defined by outcomes

Consider this

Professor	A	B
pedagogy	traditional	PI with clickers
student evaluation	1.5/5.0	3.7/5.0
FCI <g>	0.42	0.57

What might account for the large difference in evaluation?

I. professor personality
II. technology
III. pedagogy

1. I only
2. II only
3. III only
4. II and III
5. I, II, and III
6. other combination

Consider this

a couple of points worth noting:

Consider this

a couple of points worth noting:

1. you got engaged

Consider this

a couple of points worth noting:

1. you got engaged
2. no “correct” answer

Consider this

a couple of points worth noting:

1. you got engaged
2. no “correct” answer
3. you got engaged

Consider this

a couple of points worth noting:

1. you got engaged
2. no “correct” answer
3. you got engaged
4. you don’t need a correct answer!

Setting the stage

To set stage for successful implementation, I need to…

Setting the stage

To set stage for successful implementation, I need to…

(actions to take *before* course begins)

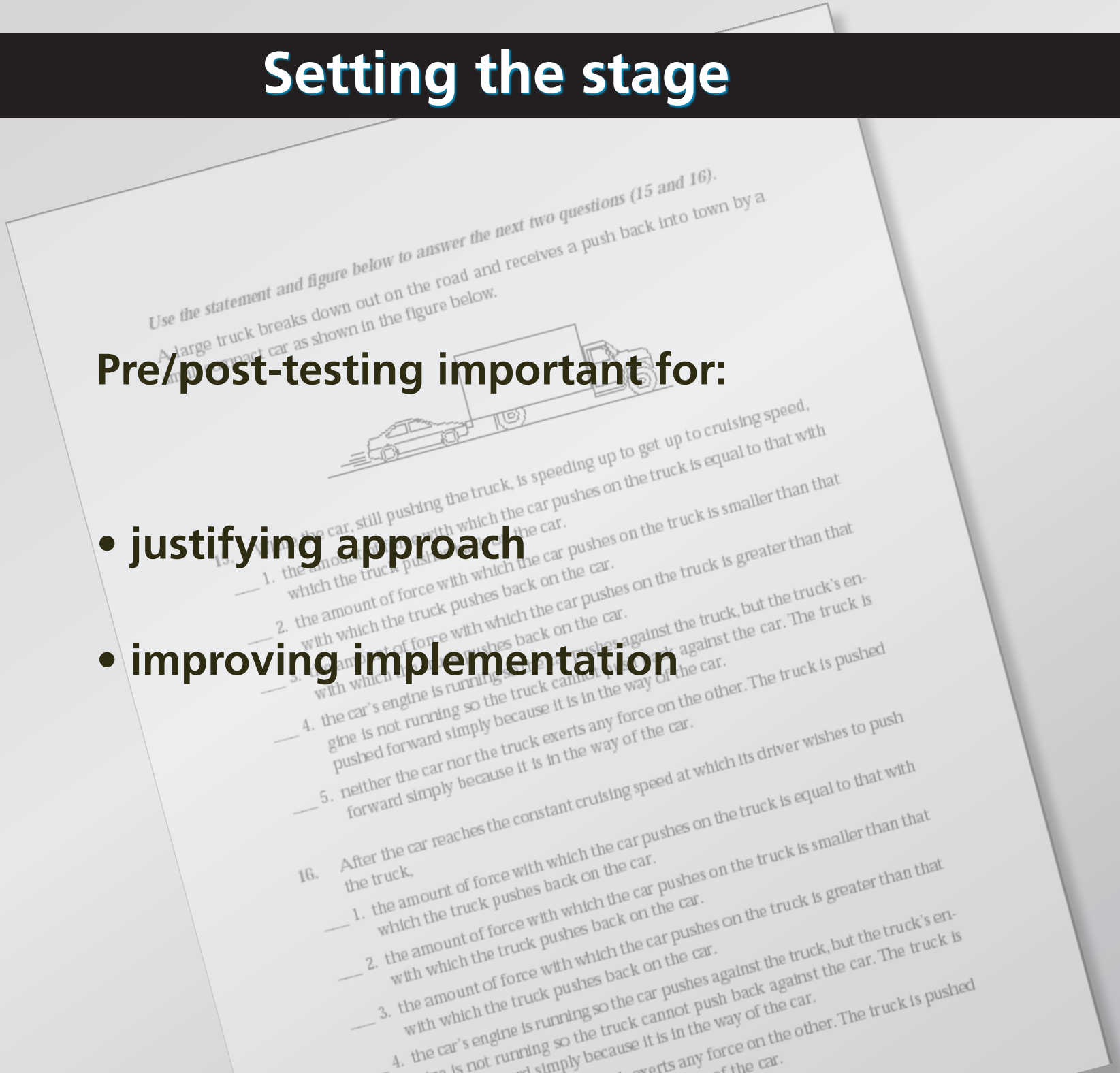
Setting the stage

- convince yourself (and your colleagues)
- set learning goals
- select approaches
- identify resources

Setting the stage

Pre/post-testing important for:

- justifying approach
- improving implementation



Setting the stage

Evaluate assessment by comparing

student performance on various kinds of problems

Setting the stage

How to move information transfer out of classroom?

Setting the stage

Imagine a rope that fits snugly along the equator.

Setting the stage

Imagine a rope that fits snugly along the equator.

Suppose the rope is cut and 1 m of rope is inserted between the cut ends. If the rope were to maintain a circular shape, how far off the surface of the Earth would it float?

1. the width of a few atoms
2. the width of a few hairs
3. the height of a curb
4. exactly 1 m
5. more than 1 m

Setting the stage

circumference at equator:

$$2\pi R_{\mathrm{E}}$$

Setting the stage

circumference at equator:

$$2\pi R_{\mathrm{E}}$$

new circumference:

$$2\pi R_{\mathrm{E}} + 1\ \mathrm{m}$$

Setting the stage

circumference at equator:

$$2\pi R_{\mathrm{E}}$$

new circumference:

$$2\pi R_{\mathrm{E}} + 1\ \mathrm{m}$$

radius of circle with new circumference:

$$2\pi R = 2\pi R_{\mathrm{E}} + 1\ \mathrm{m}, \quad \textbf{and so} \quad R = R_{\mathrm{E}} + \frac{1\ \mathrm{m}}{2\pi}.$$

Setting the stage

You all got fired up!

Setting the stage

You all got fired up!

(WITHOUT CLICKERS!)

Setting the stage

It's not the technology, but the pedagogy!

(but clickers do offer advantages)

Making it happen

To make it happen, I need to…

Making it happen

To make it happen, I need to…

(actions to take during course)

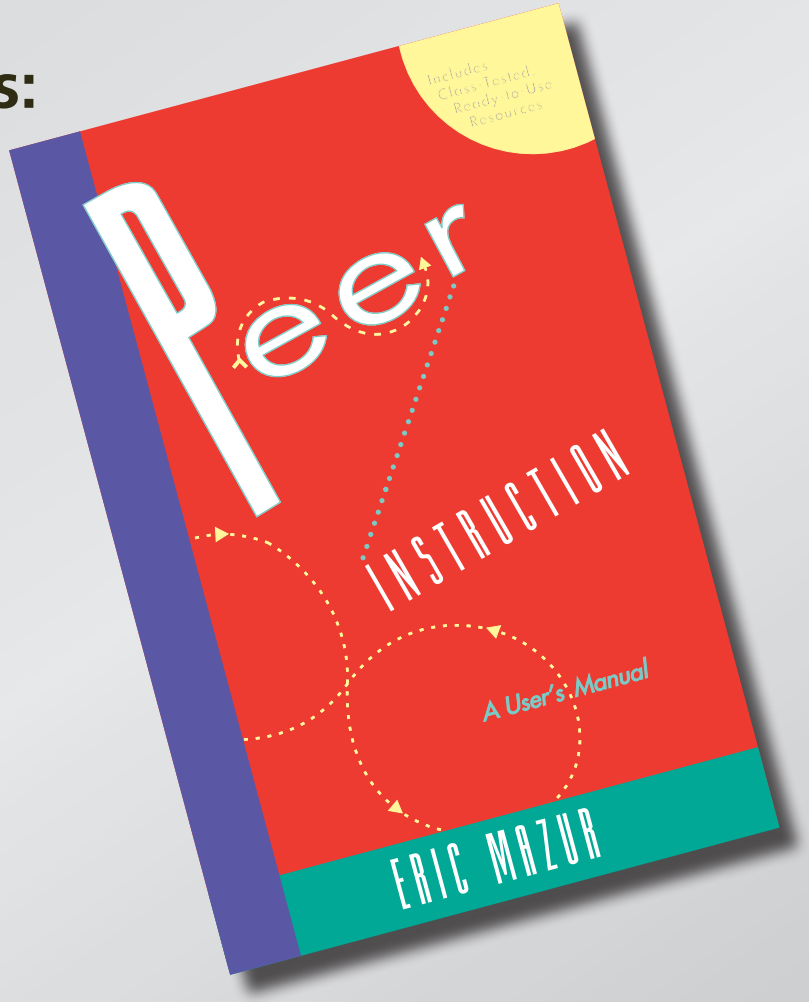
Making it happen

- find or develop good questions
- know how to manage time

Making it happen

Books with ConcepTests:

- **Physics (Prentice Hall)**



Making it happen

Books with ConcepTests:

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Making it happen

Books with ConcepTests:

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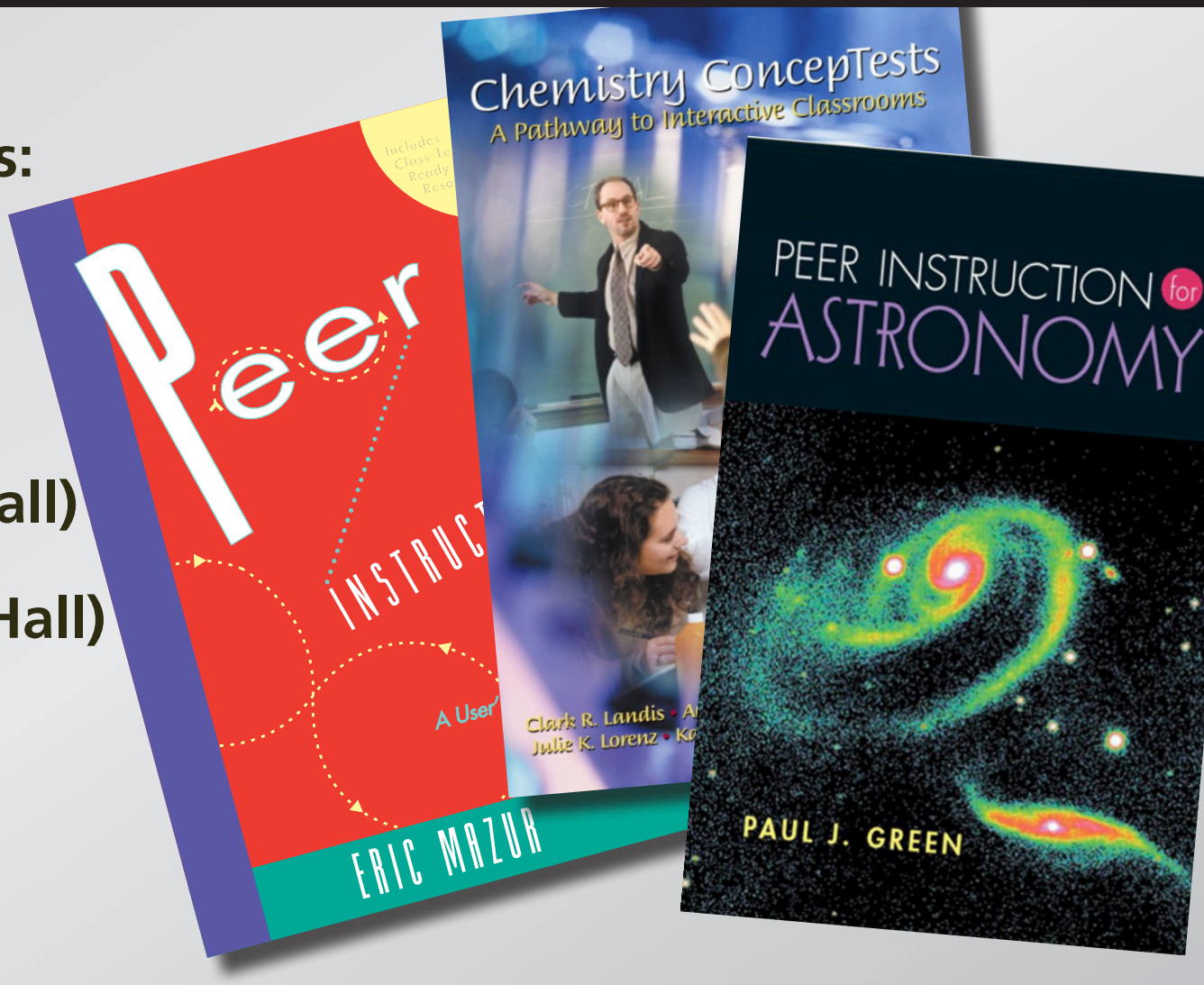
- **Astronomy (Prentice Hall)**



Making it happen

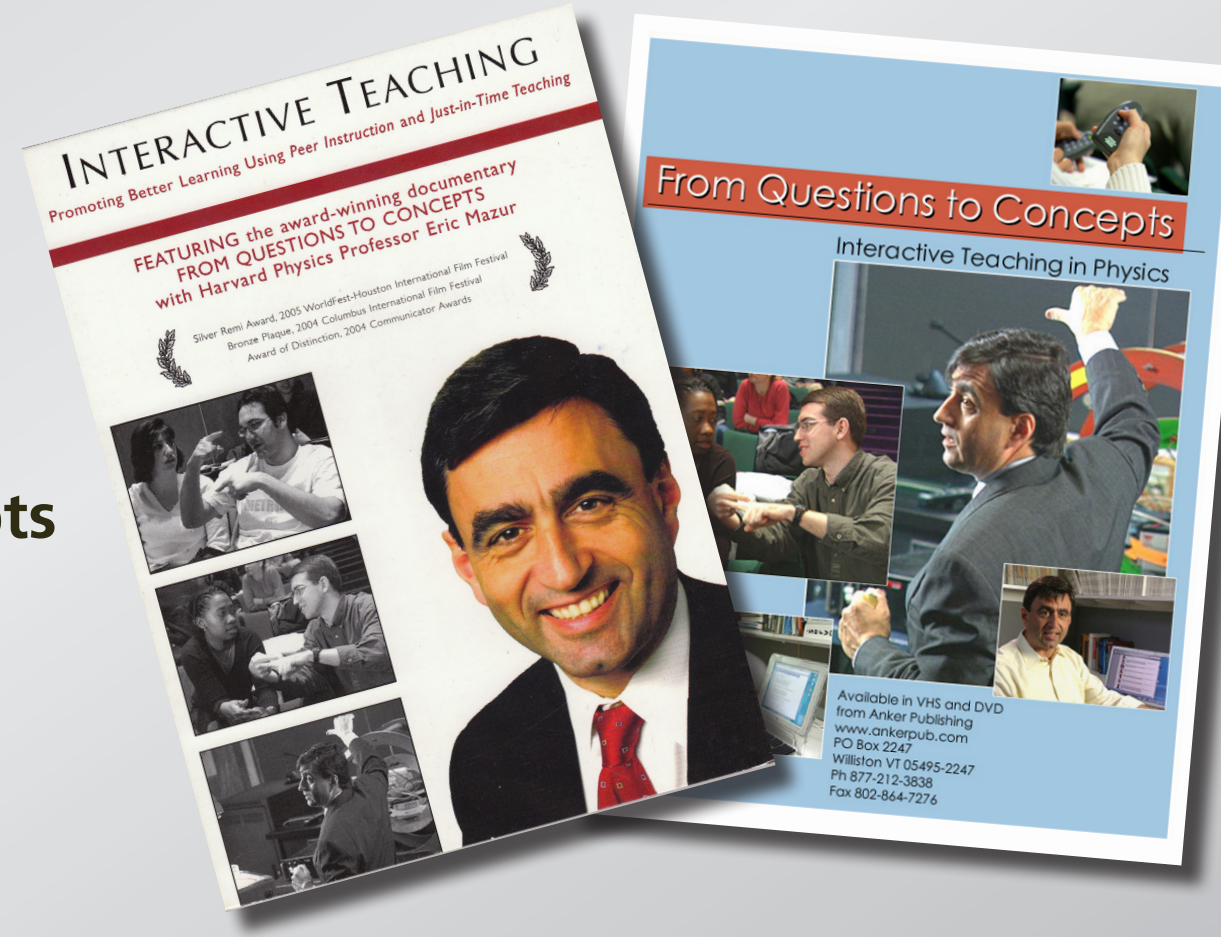
Books with ConcepTests:

- Physics (Prentice Hall)
- Chemistry (Prentice Hall)
- Astronomy (Prentice Hall)
- Calculus (Wiley)

Making it happen

Videos:

- **Interactive Teaching DVD**
- **From questions to concepts**



Making it happen

Types of questions

- survey
- discussion
- model testing
- select from list

Setting the stage

It's not the technology, but the pedagogy!

(but clickers do offer advantages)

Making it happen

Which of the following airlines tries to save fuel by suggesting that its passengers use the bathroom before boarding?

1. Delta Airlines
2. Lufthansa
3. All Nippon Airways
4. British Midland Airways
5. Air France
6. JAL
7. Aboriginal Air Services
8. Aeroflot
9. Are you kidding me? None of the above.

Making it happen

Which of the following airlines tries to save fuel by suggesting that its passengers use the bathroom before boarding?

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Making it happen

hole in plate/circumference

Professor A/B

airline

model

discussion

fact

Making it happen

hole in plate/circumference

Professor A/B

airline

model

discussion

fact

fact-recall not engaging

Making it happen

Good conceptual questions (ConcepTests):

- are based on common student difficulties
- focus on single concept
- require more than “plug and chug”
- are clear and concise
- are of manageable difficulty

Making it happen

must adjust level to audience

Outline

- Setting the stage
- Making it happen
- Overcoming barriers

Overcoming barriers

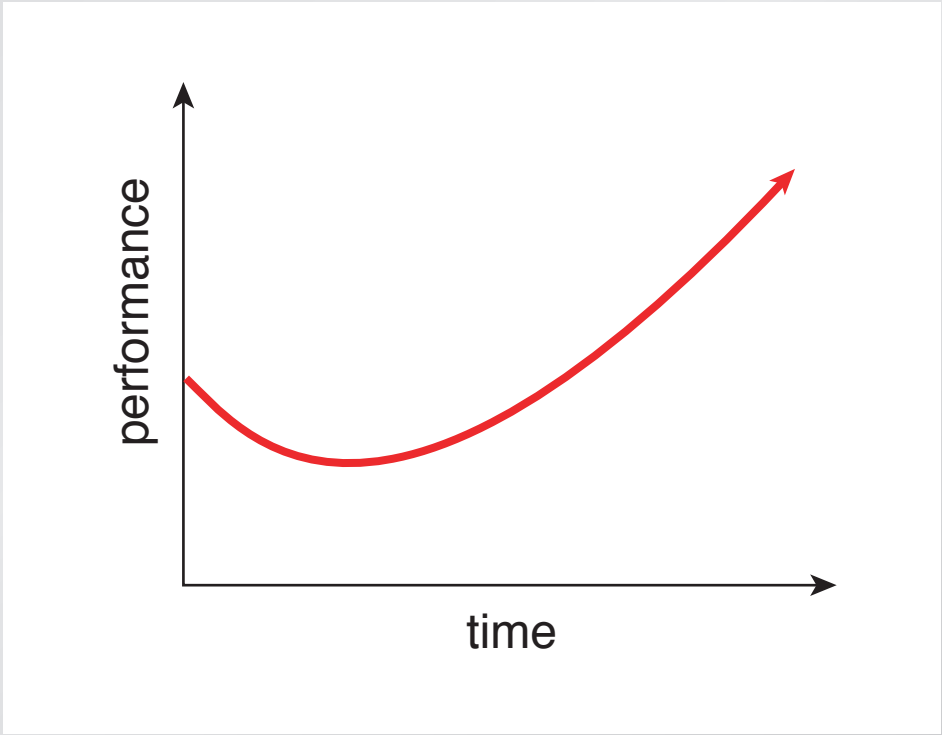
What are some potential barriers?

Overcoming barriers

- skepticism
- growing pains
- negative feedback
- limited circle of influence

Overcoming barriers

After changing, things might get *worse* before they get better!



Overcoming barriers

Better understanding leads to *more* — not fewer — questions!

(must recognize confusion as step towards understanding)

Overcoming barriers

Things to do:

- take/analyze data
- motivate students
- be prepared for initial adjustments

Overcoming barriers

Why is change so hard?

Overcoming barriers

	“lectures”	PI	considered
coverage	complete	partial	requirement
preclass reading	none	cover everything	
confusion	little none	substantial	
evaluations	known	unknown	

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Overcoming barriers

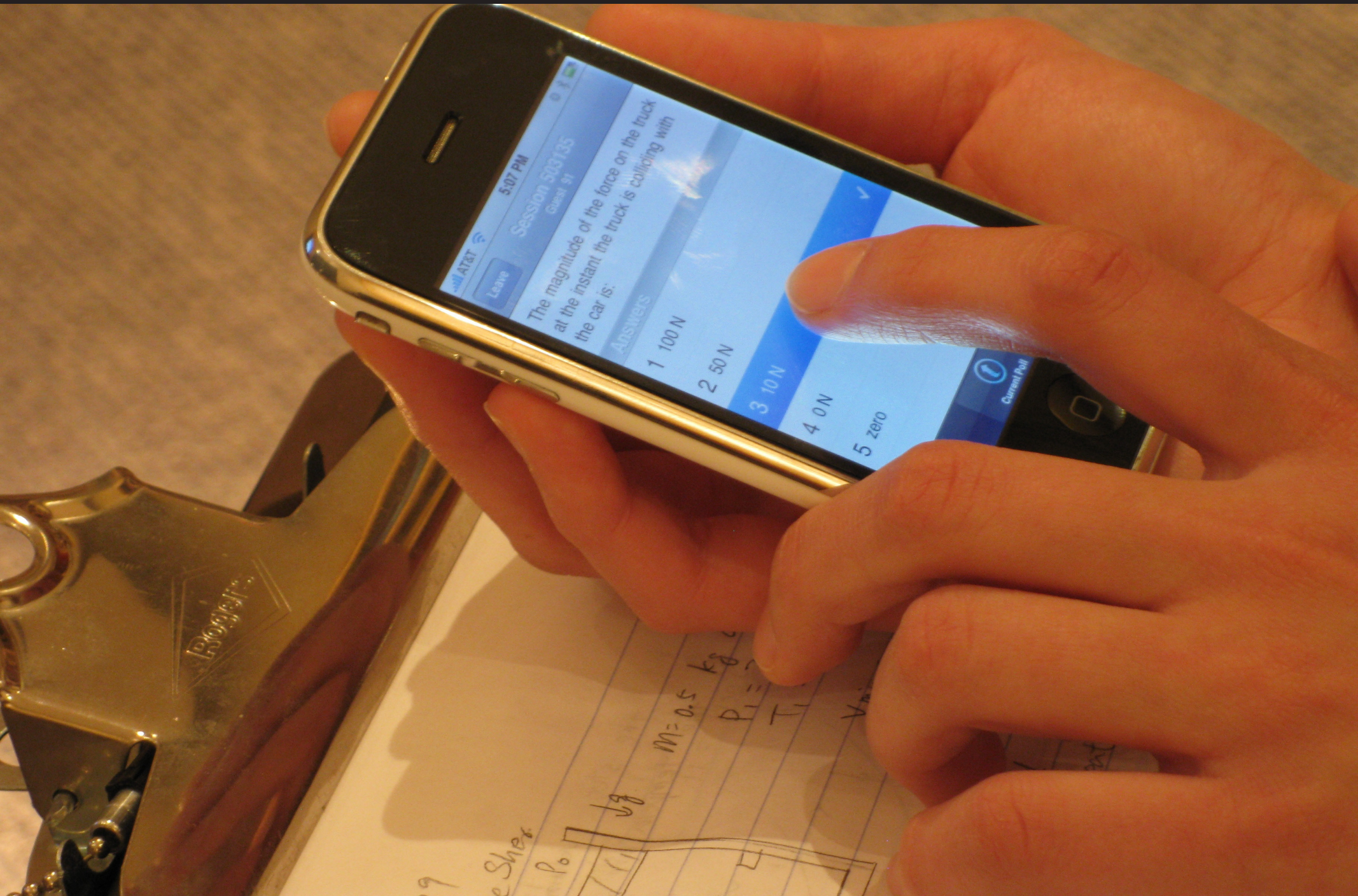
But PI leads to better learning and retention

Overcoming barriers

But PI leads to better learning and retention

(neither of which is traditionally measured)

Summary


AT&T
5:07 PM
Session 5051755
Guest 51
Leave
The magnitude of the force on the truck at the instant the truck is colliding with the car is:
Answers
1 100 N
2 50 N
3 10 N
4 0 N
5 zero
Current Poll

Summary

PI easy to implement (and improves learning gains)

Conclusion

PI easy to implement (and improves learning gains)

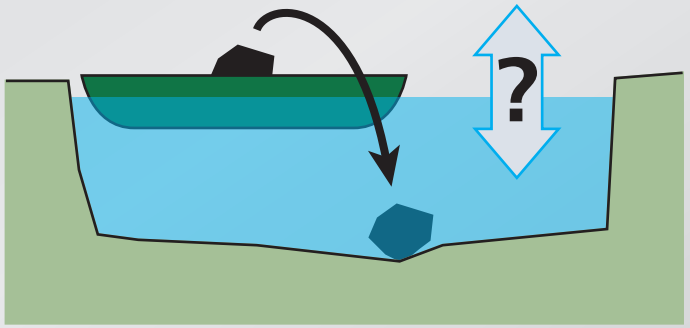
technology facilitates active engagement (but not required)

Conclusion

not just a polling tool, but an *engagement* tool!

Let's try it!

A boat carrying a large boulder is floating on a small pond. The boulder is thrown overboard and sinks to the bottom of the pond.



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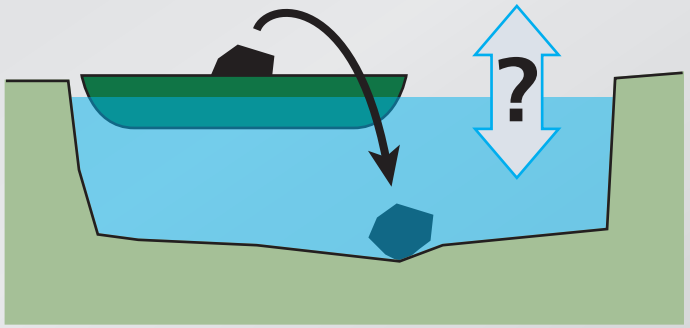


After the boulder sinks to the bottom of the pond, the level of the water in the pond is

1. higher than
2. the same as
3. lower than

it was when the boulder was in the boat.

Let's try it!

We all make mistakes!

Let's try it!

When we hold a page of printed text in front of a mirror, the text on the image in the mirror runs from right to left:

The New York Times

Let's try it!

When we hold a page of printed text in front of a mirror, the text on the image in the mirror runs from right to left:

The New York Times

Why is it that right and left are interchanged and not top and bottom? Because:

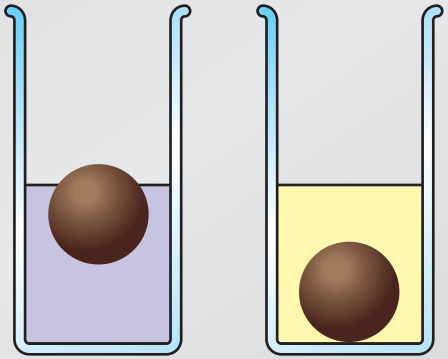
1. the mirror is oriented vertically.
2. we have two eyes in the horizontal plane.
3. the Earth's gravitation is directed downward.
4. a habit we have when looking at images in a mirror.
5. It only *appears* to run from left to right.

Let's try it!

It's "simple" only if you know the answer

Let's try it!

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



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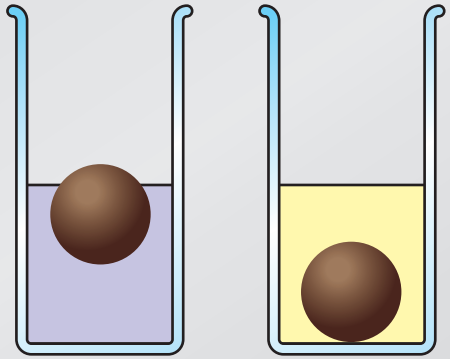
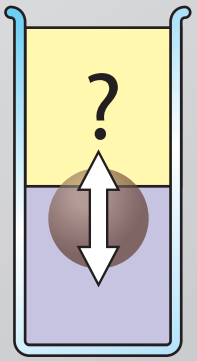


If we slowly pour the oil on top of the water so it completely covers the object, the object

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



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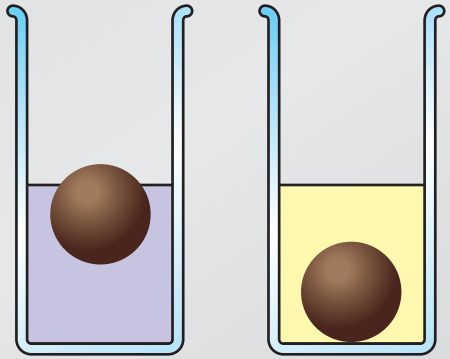

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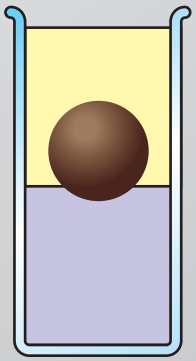

Let's try it!

It's easy to make simple demonstrations fascinating!

Let's try it!

The specific heat at constant volume for a monatomic crystal approaches zero at low temperature even though the specific heat for a monatomic gas remains $\frac{3}{2}k$ per atom. Why is this so?

Let's try it!

The specific heat at constant volume for a monatomic crystal approaches zero at low temperature even though the specific heat for a monatomic gas remains $\frac{3}{2}k$ per atom. Why is this so?

1. **Potential energy doesn't play a role for the monatomic gas, but it does for the crystal.**

2. **The particles are indistinguishable in the gas, but not in the crystal.**

3. **The energy difference between allowed states for the crystal is much larger than it is for the atoms.**

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