# Facilitating Conceptual Learning through Analogy and Explanation

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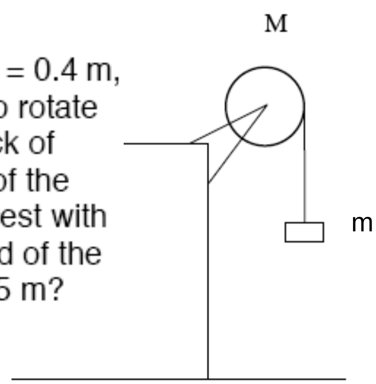
LearnLab
Pittsburgh Science of Learning Center

# Problem

- How can we facilitate students' deep learning and understanding of new concepts?
  - Clues from expertise research (Ericsson & Smith, 1991)

A disk of mass, M = 2 kg, and radius, R = 0.4 m, has string wound around it and is free to rotate about an axle through its center. A block of mass, m = 1 kg, is attached to the end of the string and the system is released from rest with no slack in the string. What is the speed of the block after it has fallen a distance, d=1.5 m?




Perceive deep structure

Forward-working strategies

Transfer to new contexts

Key component: understanding of the relations between principles and problem features

# Problem

- Novices use prior examples to solve new problems
  - Statistics (e.g., Catrambone, 1998; Ross, 1987, 1989)
  - Physics (e.g., Bassok & Holyoak, 1989; VanLehn, 1998)
  - Helps with near transfer problems but not far
- Students use examples even when they have access to the principle (e.g., LeFevre & Dixon, 1986; Ross & Kilbane, 1997)
- They lack a deep conceptual understanding for the relations between principles and examples

*How can we facilitate learning of these conceptual relations?*

# Today's Talk

- Multiple pathways to conceptual knowledge
  - Part 1. Explanation
    - Using explanations to learn the conceptual relations between principles and examples
  - Part 2. Analogy
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# Explanation

- Explanation can facilitate learning and transfer
  - Self-explanation (see Chi, 2000 for a review)
    - Generating inferences from text and prior knowledge
    - Helps to repair mental models
  - Explanation helps identify sub-goals (e.g.,Catrambone, 1996)

- Current Work: We use explanation to facilitate deeper understanding of a concept, linking examples to principles

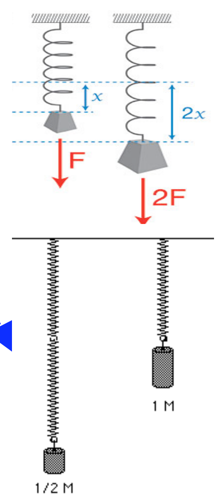
# Empirical Study (in collaboration w/ B. Ross)

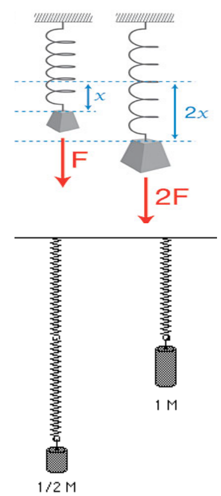
- How does the content of explanation affect learning and transfer?
  - Using a principle to explain examples (specialize)
  - Using examples to explain a principle (generalize)

Hooke's Law

*Use the principle to help explain an example*

**Specialize**




*Use the examples to help explain the principle*

**Generalize**

Hooke's Law

# Hypotheses

- Using a principle to explain examples (specializing)
  - Facilitates a specific understanding
  - Supports the construction of a mental model
  - Should facilitate performance on similar problems

- Using examples to explain a principle (generalizing)
  - Facilitates abstract understanding
  - Supports schema construction
  - Should facilitate wide application to different problems

# Design Details

- Domain: math probability concepts (e.g., Ross, 1987)
  - Permutations and combinations
- Participants - 40 UIUC students
- Training phase
  - Specialization task: read a principle and worked example, then explained the solution to a second example
  - Generalization task: read 2 worked examples, then explained the principle
- Test phase
  - Solved 10 probability word problems (5 of each concept)
    - 4 - same content; 6 - different content

# Learning Materials

## Permutations principle

Imagine there is a set of ***n*** different objects and someone chooses some number of these objects, say ***r***, and puts them in a specific order. How many different orderings of ***r*** objects can be taken from the ***n*** total objects?

To figure this out you need to know the number of *permutations*, or different orders, that are possible.

To find the total number of permutations that are possible you need to keep two things in mind. First, you must figure out which set of objects is being chosen from. The number of objects in this set is represented by the variable ***n***.

Etc ….. Formula: $P = n(n-1)(n-2)\ldots(n-r+1)$

# Learning Materials

**Worked-out example**

"It is the first day of class at Grant Elementary School and Mr. Smith wants his students to have partners for a science project. There are 5 new students and 7 returning students. He wants the 3 new students who need extra help to be paired with returning students. These new students choose their partners one at a time, with the first arrival choosing first. In how many different ways could these new students choose their class partner?"

This is a permutation problem.

To solve this problem, you need to answer the following questions:

The returning students are the objects being chosen. How many returning students are available for the new students to choose from? 7. This is the number ***n***.

Etc….. Formula: $P = n(n-1)(n-2)\ldots(n-r+1)$

# Test Materials

## Similar content

"It is the first day of class at Grant Elementary School and Ms. Tobey wants her students to have partners for a math project. There are 6 new students and 8 returning students. She wants the 4 new students who need extra help to be paired with returning students. These new students choose their partners one at a time, with the first arrival choosing first. In how many different ways could these new students choose their class partner?"

**Same objects: Students choosing class partners**

# Test Materials

## Different content

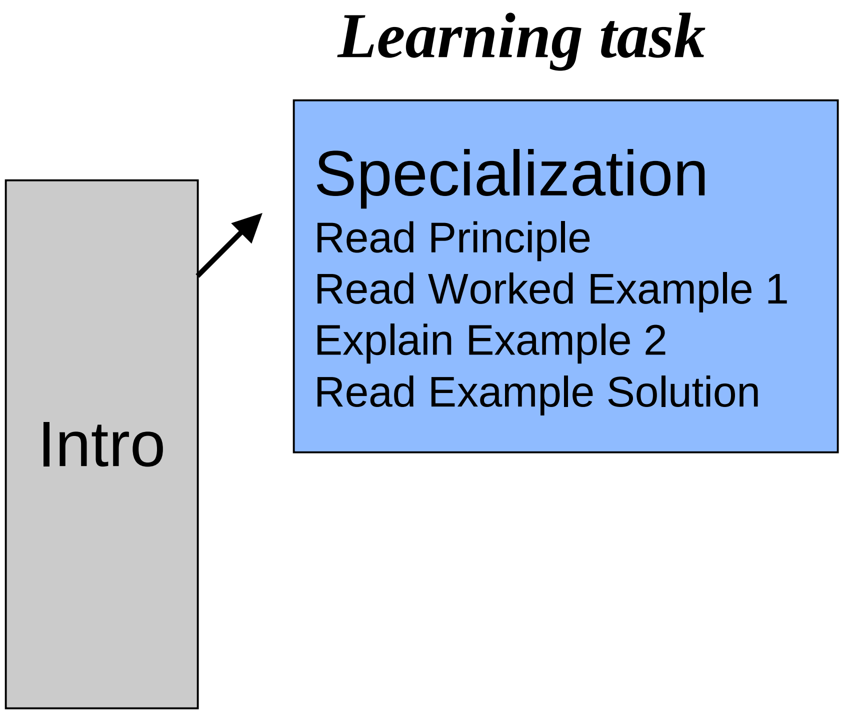
“A large corporation bought 10 cars for their regional office. First choices went to the 6 best sales associates. A clerk has the serial numbers of the 10 cars and has to keep track of who has what car. In how many different ways could these top sales people choose their cars?”

**Different objects: sales people choosing cars**

# Design Summary

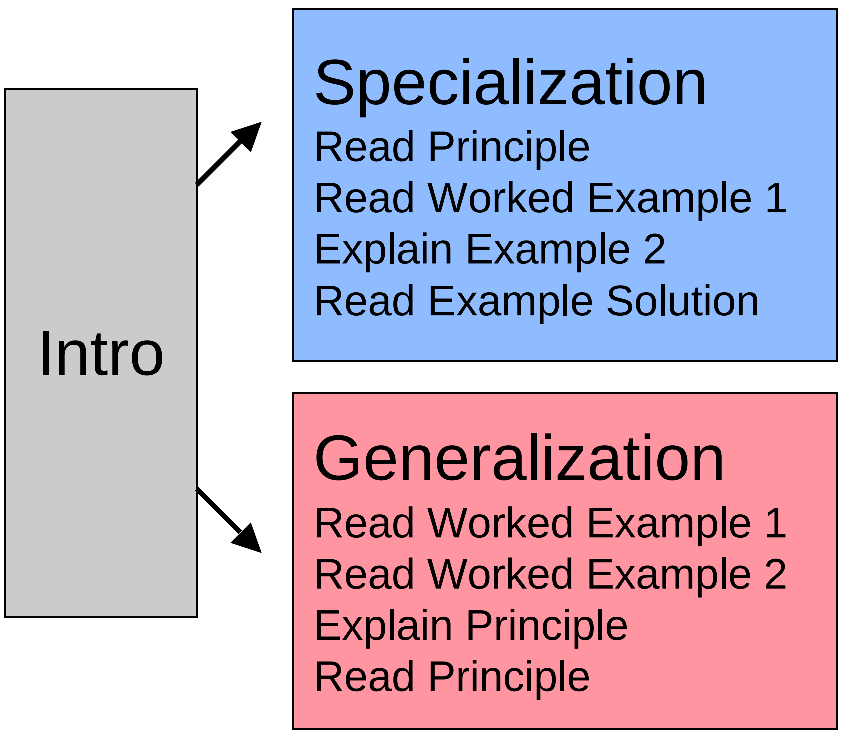
Intro

# Design Summary



# Design Summary

***Learning task***



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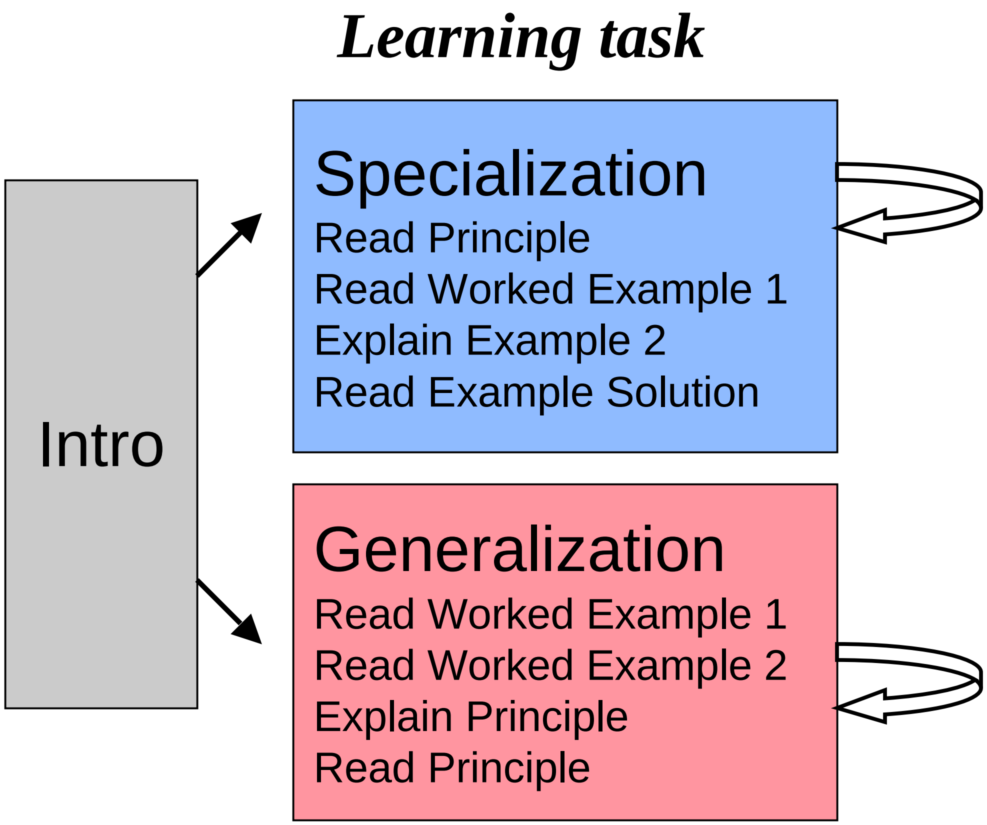

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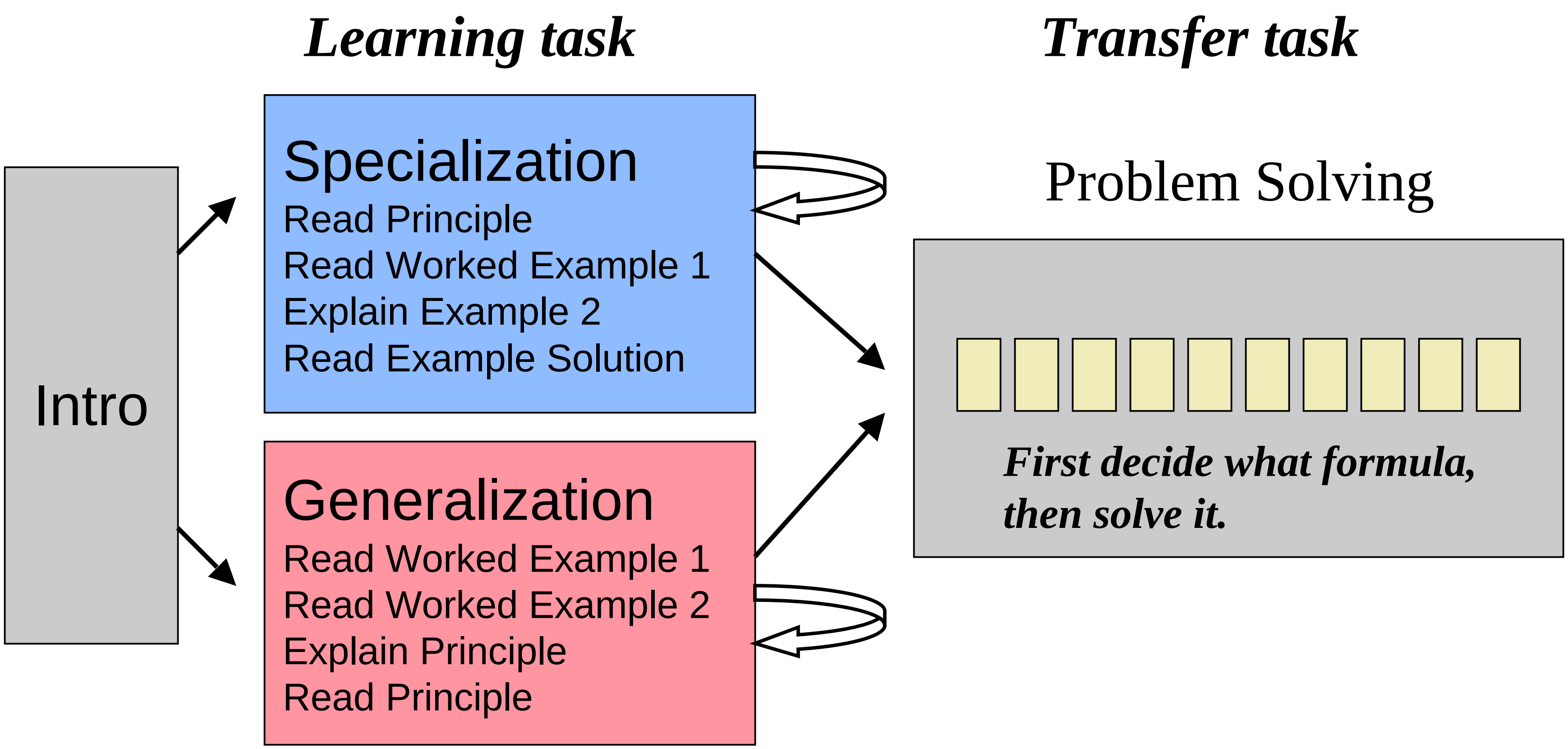
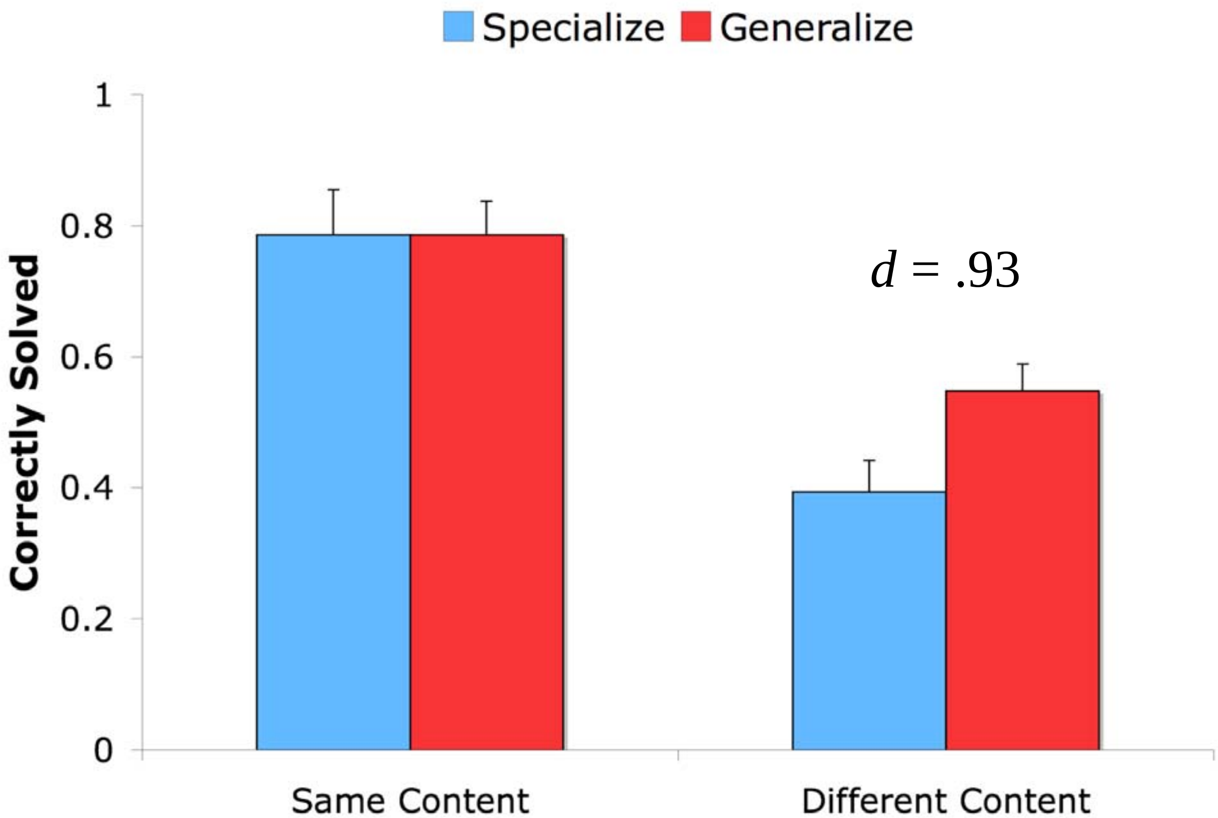


# Predictions

- Accuracy predictions
  - Same Content: Specialize > Generalize
  - Different Content: Specialize < Generalize

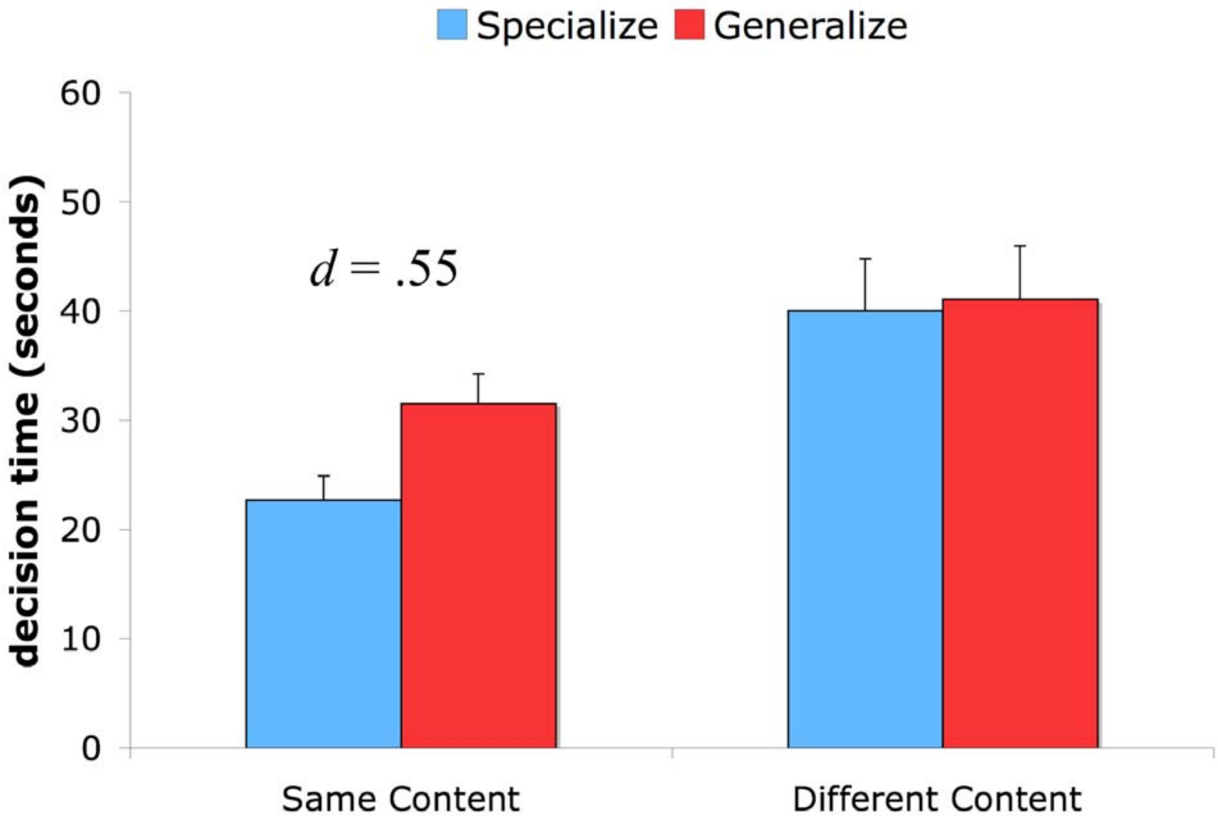
- Decision time predictions
  - Same content: Specialize < Generalize
  - Different content: Specialize ≥ Generalize

# Accuracy



Specialize
Generalize
Correctly Solved
1
0.8
0.6
0.4
0.2
0
d = .93
Same Content
Different Content

# Decision Time



# Summary of Explanation Study

- Explanations facilitate learning
  - But the ***type of explanation*** is critical to how the knowledge is understood and to where it transfers
- Using principles to explain examples
  - Facilitates specific understanding
    (high accuracy on similar problems)
  - Fast access to the concept
- Using examples to explain principles
  - Facilitates an abstract understanding
  - Improves accuracy performance on different problems

# Today's Talk

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# Analogical Learning

- Analogies can facilitate learning and problem solving (Gentner, Holyoak, & Kokinov, 2001)
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**Example 1** **Example 2**

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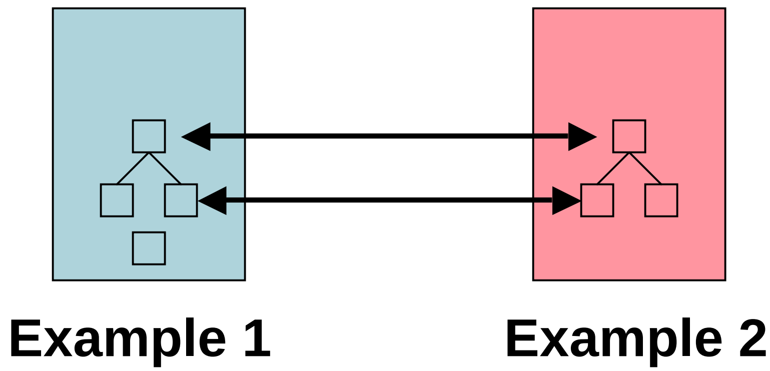

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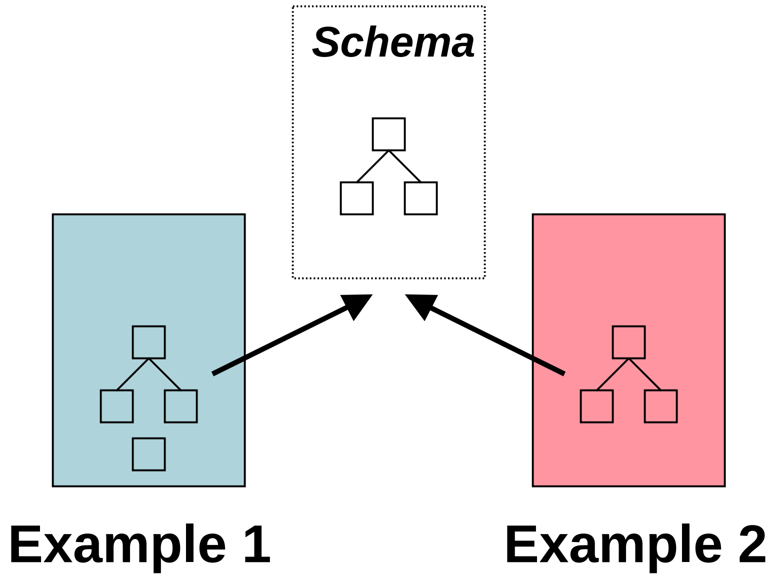

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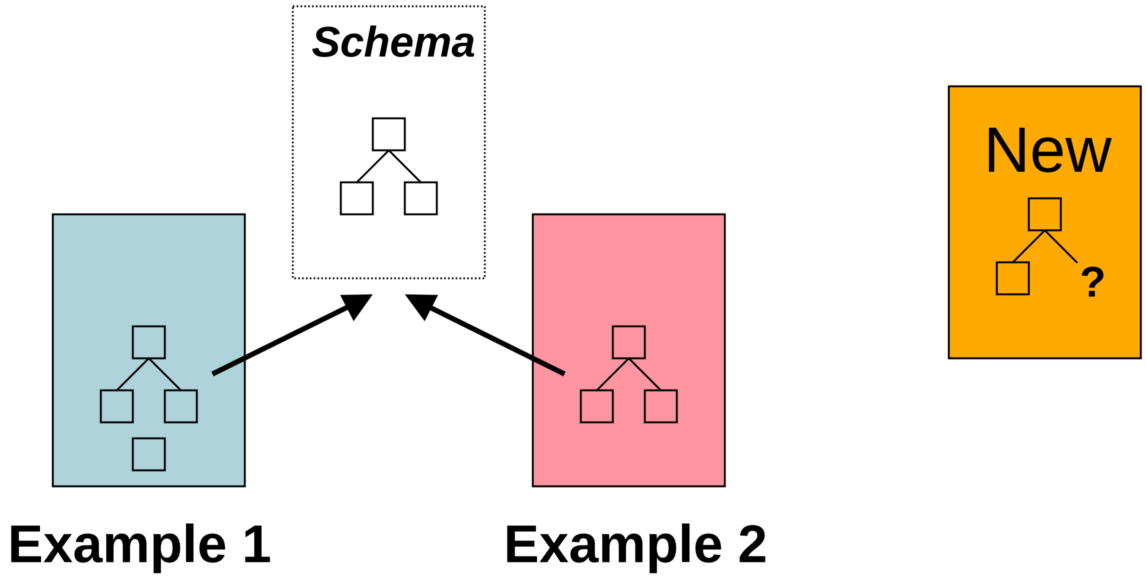

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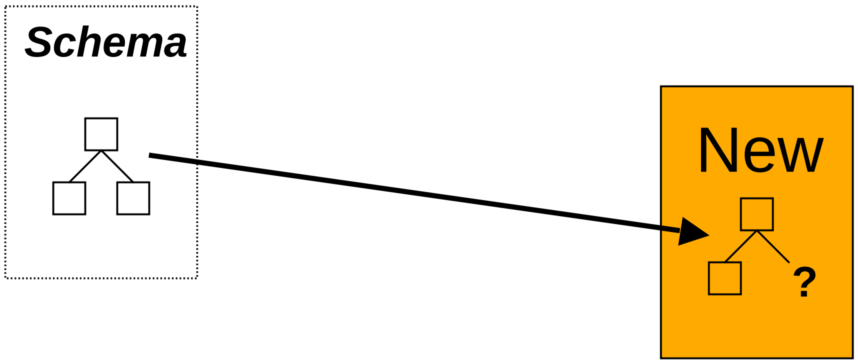

# Schema Acquisition

- Factors shown to improve schema acquisition:
  - Increasing the number of examples
    (e.g., Gick & Holyoak, 1983)
  - Increasing the variability of examples
    (e.g., Chen, 1999; Paas & Merrienboer, 1994)
  - Instructions that focus the learner on structural commonalities
    (e.g., Cummins, 1992; Gentner, Lowenstein, & Thompson, 2003)
  - Using examples that minimize cognitive load
    (e.g., Ward & Sweller, 1990)

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    (e.g., Ward & Sweller, 1990)

How does the type of problem comparison affect learning and transfer?

# Empirical Study (in collaboration w/ B. Ross)

- We investigated the effect of two types of problem comparisons on learning probability principles
  - Near-miss vs. surface-different

Near-miss: same content and principle but with one critical surface change that highlights some aspect of the principle structure

Surface-different: have *different* contents but the same principle

# Worked-out Example

The knights of Nottingham County were to have a jousting tournament. To test who was the best jouster, the 8 knights participating in the joust had to use one of the Prince's 11 horses. The knights randomly chose a horse, but the choosing went by the weight of the knight in armor (heaviest choosing first). What is the probability that the heaviest knight got the biggest horse, the second heaviest knight got the second biggest horse, and the third heaviest knight got the third biggest horse?

The horses are the objects being chosen. How many horses are available for the knights to choose from? _____. This is the number n.

etc…….

**Knights choosing horses**

# Near-miss

The Nottingham County was known throughout the kingdom for conducting the most unusual jousting tournament. Every year the wizard cast a spell on the Prince's 29 horses so that they could talk. Then, the **horses chose from the 24 knights** who would have the honor of riding them in the tournament. Each horse randomly chose a knight, but the choosing went by the size of the horse (biggest choosing first). What is the probability that the heaviest knight got the biggest horse, the second heaviest knight got the second biggest horse, and the third heaviest knight got the third biggest horse, and the fourth heaviest knight got the fourth biggest horse?

**Same content but now horses choosing knights**

# Surface-different

The Puppy Pound Palace was having an open house to help find homes for their 29 new puppies.  The 24 children who came were very excited about getting friendly puppies.  Unfortunately, the children continually fought over who would get which puppy.  To be fair to all, the curator decided to let the **puppies choose their new masters**.  Each child's name was scratched into a puppy treat and put in a dogfood bowl.  Each puppy went and fetched one of the puppy treats to choose a child.  The choosing went by age with the youngest puppy choosing first.  What is the probability that the youngest child got the youngest puppy, the second youngest child got the second youngest puppy, and the third youngest child got the third youngest puppy, and the fourth youngest child got the fourth youngest puppy?

**Different content, puppies choosing children**

# Hypotheses

- Near-miss comparisons focus the learner on how the variables are instantiated
  - This learning will help on tests of principle use (understanding the relations between objects and variables)
- Surface-different comparisons focus the learner on multiple contents for a given principle (underlying structure)
  - This learning will help accessing the principle (associating the principle with different contexts)

# Design Details

- Participants - 29 UIUC students
- Domain - 4 elementary probability concepts
- Design - within subjects, learning condition
- Learning phase
  - Read a worked example and then solved either a near-miss or surface-different problem
- Test phase
  - Use: solve problem with equation given
  - Access: multiple choice, choose correct formula

# Test - Use

The Mahomet Marathon attracts 44 entrants, but on the day of the race, only 31 runners are present, exactly the same 31 as the year before. If each year the runners are randomly given a number from 1 to 31 to wear, what is the probability that the first 8 runners each wear the same number they did the year before?

$$\frac{1}{(n)\,(n-1)\,(n-2)\,\ldots\,(n-r+1)}$$

# Test - Access

North High School has 16 teachers that are willing to help with ticket sales for the 12 athletic teams. Each team randomly chooses a teacher to help with their sales, with the basketball team choosing first and the soccer team choosing second. What is the probability that the algebra teacher sells tickets for the basketball team and the geometry teacher sells tickets for the soccer team?

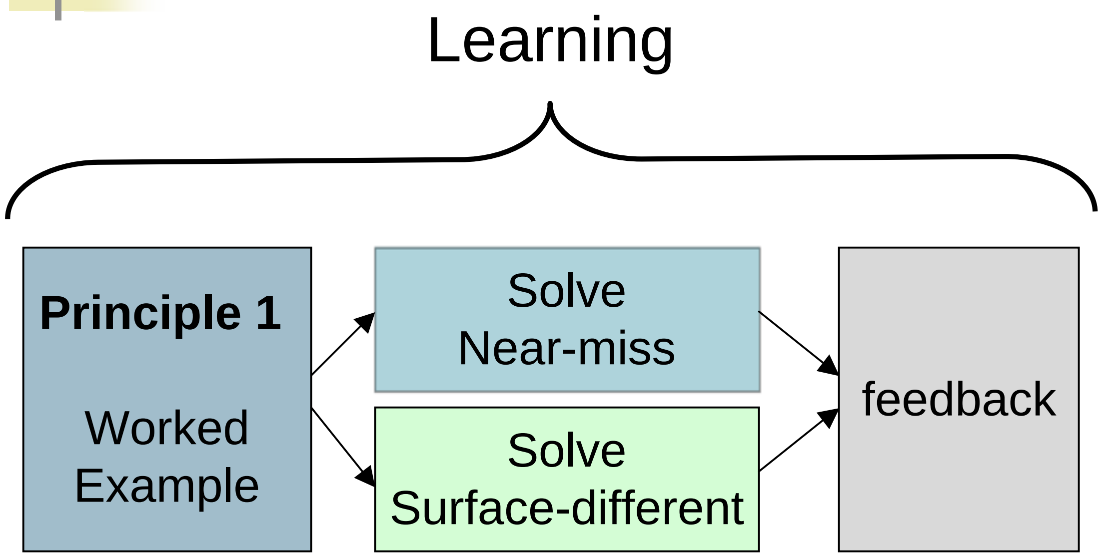
a. $$\frac{1}{(n)\,(n-1)\,(n-2)\ldots(n-r+1)}$$

b. $$\frac{1}{j!\,/\,[h!\,(j-h)!]}$$

c. $$q^{(k-1)}\,p$$

d. $$1-(1-c)^{t}$$

# Design Summary




4 principles total (2 with near-miss and 2 with surface-different)

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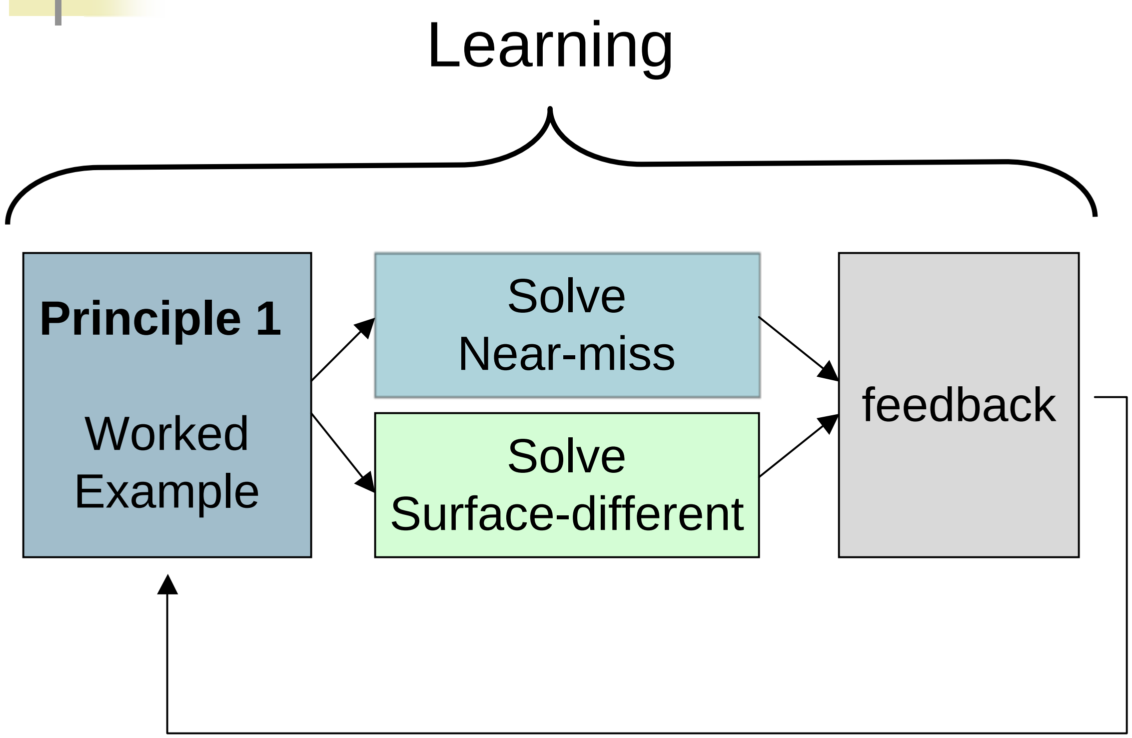


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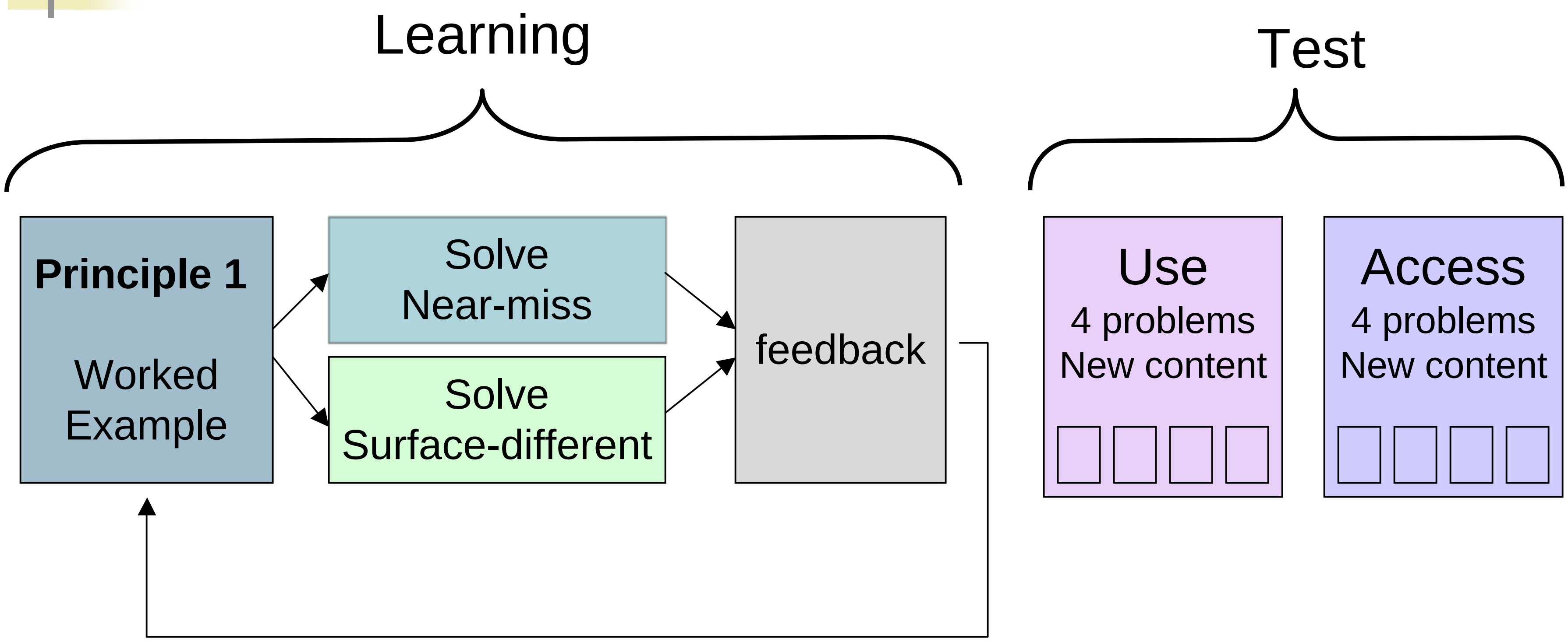



4 principles total (2 with near-miss and 2 with surface-different)

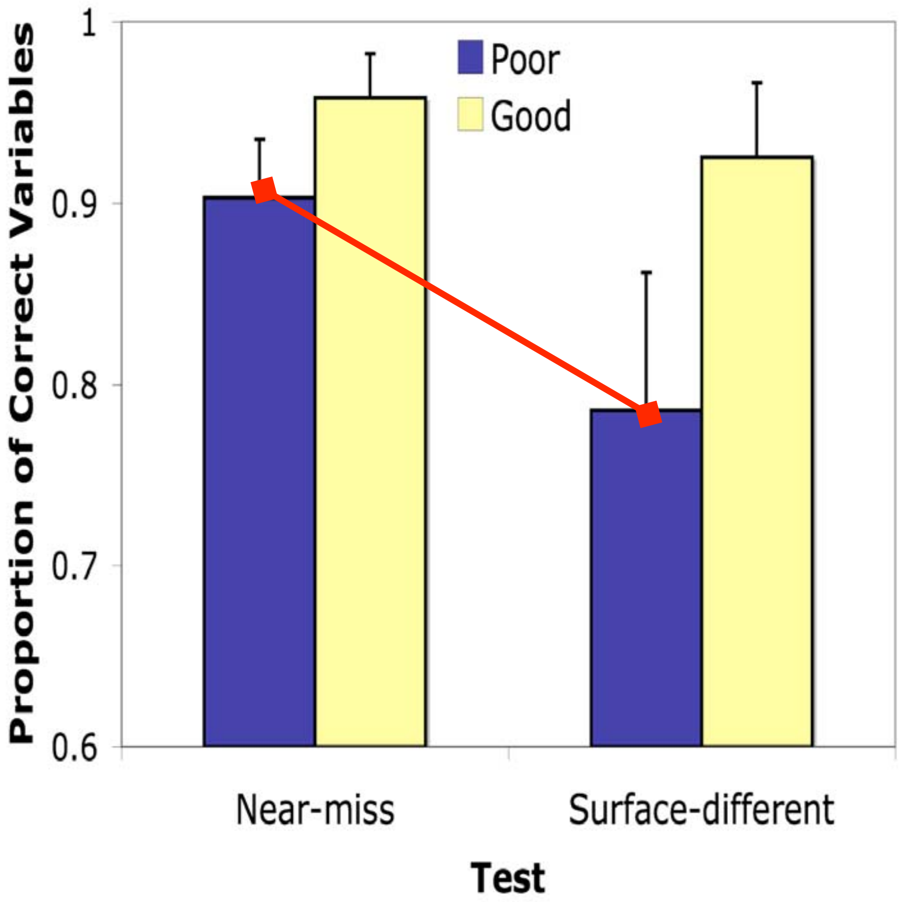
# Predictions

- Near-miss comparisons should facilitate principle use
  (using those principles in new contexts)

- Surface-different comparisons should facilitate principle access
  (telling which principle is relevant in new contexts)

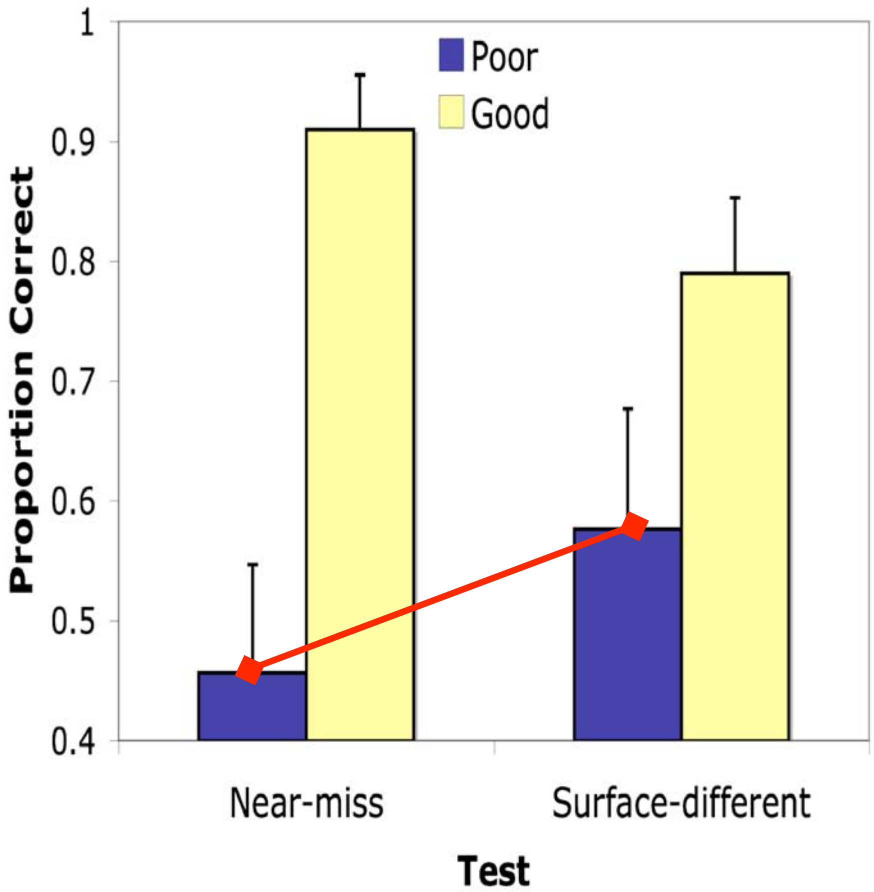
- Such effects may be more likely for in students who rely more on the *surface contents for learning*
  - Median split on learning performance
  - Poor learners versus good learners

# Results - Use



Proportion of Correct Variables
1
0.9
0.8
0.7
0.6
Poor
Good
Near-miss
Surface-different
Test

# Results - Access



# Summary of Analogy Study

- Poor learners showed the expected pattern
  - Use: near-miss > surface-different
  - Access: near-miss < surface-different
- Near-miss helps students understand how the structure of the problem relate to the variables in the formula
- Surface-different helps students learn how to tell which principle is relevant
- Different comparisons may be helpful for teaching (poor learners) different aspects of the principle knowledge

# Conclusions

- Multiple paths to facilitate conceptual learning
- Generating explanations
  - Type of explanation is critical to what is learned and where that knowledge transfers
- Making analogies
  - Different kinds of comparisons help students learn different aspects of the principle
- These processes have large impacts in the psychologist's laboratory and are now being tested in classroom environments
  - Current Project: Bridging principles and examples in Physics
    - *Pittsburgh Science of Learning Center*

# Acknowledgements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WHERE DISCOVERIES BEGIN

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# Questions?