Analogical Problem Solving in the Teaching of Psychology

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“I know that you want to challenge us to improve, but there are ways to do that, your way just pissed me off. Woodring [College of Education] is in this building, maybe you should talk to them! ... This is the worst class that I have ever had!! I repeat, Woodring is in this building, GO TALK TO THEM!”

- comment on a course evaluation for the first author, PSY 482 W07
A double-standard?

• Research
  – I had extensive training
  – I am familiar with “best practices” in research methods
  – I at least try to justify theoretical claims with solid empirical evidence and appropriate statistical analysis

• Teaching
  – I had almost no training
  – Until recently I had no clue what “best practices” are in education
  – I have largely relied on personal experience, anecdotes and observations, suggestions from students and colleagues, and trial and error
A model for improving my teaching

• Identify a question relating to my teaching
  – Example: What is the best way to achieve conceptual understanding of this topic?
• Look at the literature to identify research that is relevant to this question
• Use what I learn from the literature to formulate a hypothesis
  – Example: The best way to achieve conceptual understanding of this topic is to complete a hands-on lab and write a brief lab report
• Implement changes in the classroom based on this hypothesis
• Collect data on the effects of those changes
• Use those data to draw some conclusions
The Question

• First author teaches a large lecture course PSY 210 “Cognition”
• Exams test both knowledge of concepts and ability to solve problems involving concepts
• Students often report difficulty with abstract, difficult-to-visualize topics like categorical perception, auditory word recognition, and connectionist networks
• This difficulty prevents students from successfully solving problems that have a fairly simple logical structure
• How can I help students learn how to solve these problems?
What is an analogy?

• For purposes of this talk:
  – Two concepts, theories, situations, problems, etc.
  – One is familiar (the source or base)
  – One is novel (the target)
  – A mapping process whereby knowledge of the source is used to draw inferences about the target
## Two Literatures on Analogies

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<th>Instructional Analogies</th>
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<td>Goal is improving conceptual understanding</td>
<td>Goal is to determine a solution to a problem</td>
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<td>Focus is on acquiring knowledge</td>
<td>Focus is on applying knowledge</td>
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<td>Analogy between source and target usually explicitly identified by instructor</td>
<td>Analogy between source and target must often be discovered</td>
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<td>Most studies conducted in a classroom context</td>
<td>Most studies conducted in the lab</td>
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<td>Analogy involves subject matter of the class</td>
<td>Analogy usually involves an insight problem or brain-teaser</td>
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<td>Consideration of factors such as gender, student ability, prior knowledge, and motivation</td>
<td>Consideration of factors such as the relationship between source and target and whether a hint is provided</td>
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Example of an instructional analogy: Water and heat
(Adapted from Gentner, 1989)

• Source: Flow of water
Example of an instructional analogy: Water and heat

- Target: Flow of heat

![Diagram of heat transfer](image_url)
Example of an instructional analogy: Water and heat

• Knowledge of source:
  – Water moves from an area of higher pressure through the pipe to an area of lower pressure until the pressure is equalized

• Mapping:
  – Water -> heat
  – Pipe -> metal bar
  – Pressure -> temperature

• Inference:
  – Heat moves from an area of higher temperature through the metal bar to an area of lower temperature until the temperature is equalized
Example of an instructional analogy: Water and heat

- Target: Flow of heat
Example of analogical problem solving

• Source problem:

A grandfather has $30, and he wants to divide up this money between his four grandchildren: Veronica (12 years old), Wilbur (9 years old), Rita (6 years old) and Frank (3 years old). However, he decides that the older children should get more than the younger children; specifically, if the oldest child gets a certain amount, the next oldest should get half as much, the next oldest should get half as much as that, and so on. How much money will Frank get?
Example of analogical problem solving

• Source solution:
  – Let $a$ be the amount that Frank receives. Then Rita will get $2a$, Wilbur will get $4a$, and Veronica will get $8a$. Thus, the total amount given out must be $a + 2a + 4a + 8a = 15a$. Since we also know that the total amount given out is $30$, then $15a = 30$, or $a = 2$. So, Frank will get $2$. 
Example of analogical problem solving

- Target problem:
  A student has 7 ½ hours in which to study for four finals. The finals are for Organic Chemistry (5 credits), Feminist Psychology (4 credits), Research Ethics (3 credits), and Bookbinding (2 credits). The student wants to spend more time studying for the classes that are worth more credits. Specifically, if a certain amount of time is spent for the class with the most credits, half as much time would be spent on the class with the next highest number of credits, half again as much time on the class with the next highest number of credits, and so on. How much time would be spent studying for the Bookbinding final?
Example of analogical problem solving

• Mapping:
  – Grandchild -> class (RECIPIENT)
  – Money received -> time spent studying (THING BEING DIVIDED UP)
  – Age - > number of credits (BASIS OF COMPARISON)
  – $30 -> 7 ½ hours (OVERALL TOTAL)
  – Amount of money Frank receives -> amount of time spent studying Bookbinding (SMALLEST AMOUNT)

• Target solution:
  – From the source problem, we know the following:
    OVERALL TOTAL = 15 x SMALLEST AMOUNT
  – Here the overall total is 7 ½ hours
  – Thus, the smallest amount must be ½ hour
  – ½ hour would be spent on Bookbinding
The Hypothesis

• We can help students learn the logical steps necessary to answer the exam question by presenting them with an analogous problem that is concrete / easy to visualize, and asking them to solve that problem

• Tell them that the same logical steps can be used to solve the more abstract problem
Choice of target question

• Question chosen to satisfy following criteria:
  – Underlying concept is abstract / hard to visualize
  – Question requires application of concept to solve a problem
  – Students exhibit difficulty with this question
• The question that was selected was drawn from a PSY 210 midterm given by the first author
• Question involved a phenomenon in speech perception called speaker normalization
• 61% of students answered the problem correctly on the exam (multiple choice, four answer choices)
Format of the question

1) The /s/ from the person with a high-pitched voice inserted into a word spoken with a low-pitched voice
   a) Hear /s/    b) Hear /ʃ/

2) The /ʃ/ from the person with a high-pitched voice inserted into a word spoken with a low-pitched voice
   a) Hear /s/    b) Hear /ʃ/

3) The /s/ from the person with a low-pitched voice inserted into a word spoken with a high-pitched voice
   a) Hear /s/    b) Hear /ʃ/

4) The /ʃ/ from the person with a low-pitched voice inserted into a word spoken with a high-pitched voice
   a) Hear /s/    b) Hear /ʃ/
Basic Paradigm

Reading Phase → Study Phase 1 → Study Phase 2 → Test Phase

4 minutes → 4 minutes → 4 minutes → 4 minutes
Baseline Condition

- Reading Phase
  - Filler Task
  - 4 minutes

- Study Phase 1
  - Filler Task
  - 4 minutes

- Study Phase 2
  - Filler Task
  - 4 minutes

- Test Phase
  - Answer Question
  - 4 minutes
Find the Changes

There are 7 differences between the two following pictures. Circle all the differences that you can find.
Study Phases: Baseline

Phase 1: Word Search

Word Search
Find and circle all the vegetables that are hidden in the grid. The words may be hidden in any direction.

GLARWHGANIPS
ZLKEPPTATOT
NBBDWOINOINO
HRMFONNHAPC
AMOUKESSLTE
SNCCEOIFPREL\LL
AMCUDHGLACE
ESOCAGLELAPR
POLREITRRUY
PUIIIBTPRAEAD
LALFAUBCBEBUC
NSQSCDUBRSIK
JHJERRUTABAGA

Phase 2: Sudoku

Sudoku
A sudoku puzzle is a grid of nine by nine squares or cells, that has been subdivided into nine subgrids or “regions” of three by three cells.

The objective of sudoku is to enter a digit from 1 through 9 in each cell, in such a way that:
- Each horizontal row contains each digit exactly once
- Each vertical column contains each digit exactly once
- Each subgrid or region contains each digit exactly once

```
 5 3 1
 8 4 6
 9 7 2

 7 2 8
 1 9 6
 6 4 3

 4 9 2
 8 5 7
 2 1 3
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Test Phase

Speaker Normalization

Please read the following information, then try to answer the questions below. If you are unsure how to answer the questions, please just do the best you can. You will have 4 minutes to do this.

Linguists write the ‘s’ sound in ‘spat’ as /s/ and the ‘sh’ sound in ‘ship’ as /ʃ/. Linguists consider both /s/ and /ʃ/ to be single phonemes, even though /ʃ/ is usually written with two letters. The major difference between these two phonemes is their pitch; /s/ has a higher pitch than /ʃ/. Of course, the pitch of people's voices also varies. For example, women tend to have higher-pitched voices than men, which means they tend to say all their phonemes at a higher pitch. Thus, when we listen to someone speaking, we must carry out speaker normalization to adjust the phonetic boundary between /s/ and /ʃ/ based on the pitch of the person's voice, or we will mishear things.

Questions

Suppose we record someone with a low-pitched voice saying both ‘spat’ and ‘ship’. The pitch of the /s/ in ‘spat’ is about 3700 Hz and the pitch of the /ʃ/ in ‘ship’ is about 2700 Hz (Hz stands for Hertz and is a measure of pitch; larger numbers mean higher pitch). We then record someone with a high-pitched voice saying both ‘spat’ and ‘ship’. The pitch of the /s/ in ‘spat’ is about 8000 Hz and the pitch of the /ʃ/ in ‘ship’ is about 4000 Hz. We then use sound-editing software to take phonemes spoken by the person with a high-pitched voice and insert them into a word spoken by the person with a low-pitched voice, and vice versa. What would you expect to hear in each of the following cases (write in ‘s’ or ‘ʃ’ in the appropriate space):

1) The /s/ from the person with a high-pitched voice inserted into a word spoken with a low-pitched voice
   a) Hear /s/      b) Hear /ʃ/  

2) The /ʃ/ from the person with a high-pitched voice inserted into a word spoken with a low-pitched voice
   a) Hear /ʃ/      b) Hear /s/  

3) The /s/ from the person with a low-pitched voice inserted into a word spoken with a high-pitched voice
   a) Hear /s/      b) Hear /ʃ/  

4) The /ʃ/ from the person with a low-pitched voice inserted into a word spoken with a high-pitched voice
   a) Hear /ʃ/      b) Hear /s/
Results

Percentage of Correct Answers

Baseline

35.48
No Study Condition

Reading Phase
Read Background

4 minutes

Study Phase 1
Filler Task

4 minutes

Study Phase 2
Filler Task

4 minutes

Test Phase
Answer Question

4 minutes
Reading Phase

Speaker Normalization

Please read the following information about speaker normalization. You will have 4 minutes for this part of the experiment.

In writing, words are made up of letters. For example, the word 'cat' is made up of the three letters C, A, and T. In speaking, words are made up of units called phonemes. Linguists use a special alphabet called the international Phonetic Alphabet (IPA) which has a symbol for each phoneme. Linguists use slashes to indicate when they are using IPA symbols rather than ordinary English letters. For example, the word 'cat' is made up of the phonemes /kæt/, and /t/.

English has about 40 phonemes, but our alphabet only has 26 letters. Thus, we often use letters for a single phoneme. For example, in the word 'food', the two O's correspond to the single phoneme /u/. In addition, the same letters are often pronounced differently in different words. For example, the vowel in the word 'tough' is the phoneme /ʌ/, while the vowel in the word 'cough' is the phoneme /aʊ/.

There is a lot of variability in the way a particular phoneme is pronounced. Different speakers may pronounce a phoneme differently, and even the same speaker may pronounce a phoneme differently on different occasions. Thus, a phoneme is not so much a single sound, but rather a bunch of similar sounds. In many cases, there are two phonemes that are similar to each other, like the vowel /æ/ in 'bat' and the vowel /ɑ/ in 'bat.' If you hear a sound approximately halfway between those vowels, you have to decide which vowel it is. The point where you switch over from one vowel to the other vowel is called the phonetic boundary. The idea of a phonetic boundary is illustrated by Figure 1.

Figure 1

The phonetic boundary is not a set location, but depends on properties of the speaker's voice like how high or low it is, or how quickly they are speaking. Thus, in order to understand what people are saying, we have to adjust the phonetic boundary to be appropriate for the particular person we are listening to. This process is referred to as speaker normalization. Figure 2 shows a case where the phonetic boundary has been adjusted, so that sounds which were heard as the vowel /æ/ before are now heard as the vowel /ɑ:/ instead.

Figure 2

Speaker normalization is a very complex process, but we are so good at it that we are usually unaware that we are even doing it. However, we sometimes can become aware of it when the process takes longer than usual. For example, if you watch a movie where the characters have a strong British accent, you may not understand what they are saying at first, but after a few minutes you are able to adjust, and their speech may seem to become clearer.
Traditional Study Condition

- Reading Phase: Read Background (4 minutes)
- Study Phase 1: Underline (4 minutes)
- Study Phase 2: Summarize (4 minutes)
- Test Phase: Answer Question (4 minutes)
Study Phases: Traditional

Phase 1: Underlining

Underlining
Please look back over the material on speaker normalization that you were given before, and underline what you think are the most important concepts. If you're not sure you understand the material, please just do the best you can. You will have 4 minutes to complete this portion of the experiment.

Phase 2: Summarizing

Summarizing
Using the space below, please write a brief summary (3-4 sentences) describing what speaker normalization is in your own words. If you aren't sure you fully understand the material, just describe it as best you can. You will have 4 minutes to complete this portion of the experiment.
Results

The graph shows the percentage of correct answers across different conditions: Baseline, No study, and Traditional study. The percentage of correct answers is as follows:
- Baseline: 35.5
- No study: 37.5
- Traditional study: 59.3

The graph includes a note: $p = 0.035$, one-tailed.
Analogy Study Condition

Reading Phase
Read Background
4 minutes

Study Phase 1
Analogy Problem
4 minutes

Study Phase 2
Analogy Problem
4 minutes

Test Phase
Answer Question
4 minutes
Study Phases: Analogy

Phase 1: Analogy Problem

Businesses in the Land of Moomphlah

Please read the following information, then try to answer the questions below. If you are unsure how to answer the questions, please do the best you can. Remember how you figured out the answers, because although this problem is not about speaker normalization, you can use the same logic to solve the problem about speaker normalization at the end. You will have 4 minutes to complete this portion of the experiment.

In the land of Moomphlah, there are two major business associations, the National Association of Corporations (NAC) and the United Business Association (UBA). Broadmoor Industries and National Distributors are two members of the NAC. Broadmoor Industries has 100 employees, and within the NAC it is considered a rather small business. National Distributors has 300 employees, and within the NAC it is considered a rather large business. Lazy River Furniture and Main Street Lumber are members of the UBA. Lazy River Furniture has 20 employees, and within the UBA it is considered a rather small business. Main Street Lumber has 50 employees, and within the UBA it is considered a rather large business.

Questions
Please circle the appropriate answer for each question below.

1) If Lazy River Furniture were to join the NAC, it would most likely be considered ...
   a) a small business
   b) a large business

2) If Main Street Lumber were to join the NAC, it would most likely be considered ...
   a) a small business
   b) a large business

3) If Broadmoor Industries were to join the UBA, it would most likely be considered ...
   a) a small business
   b) a large business

4) If National Distributors were to join the UBA, it would most likely be considered ...
   a) a small business
   b) a large business

Phase 2: Analogy Problem

The Land of Short People and the Land of Tall People

Please read the following information, then try to answer the questions below. If you are unsure how to answer the questions, please do the best you can. Remember how you figured out the answers, because although this problem is not about speaker normalization, you can use the same logic to solve the problem about speaker normalization at the end. You will have 4 minutes to complete this portion of the experiment.

Agnes (5 ft. 9 in.) and Belinda (5 ft. 1 in.) live in the land of short people. In the land of short people, Agnes is considered rather short and Belinda is considered rather tall. Carmen (5 ft. 2 in.) and Deanna (5 ft. 6 in.) live in the land of tall people. In the land of tall people, Carmen is considered rather short and Deanna is considered rather tall.

Questions
Please circle the appropriate answer for each question below.

1) If Agnes moves to the land of tall people, will she be considered tall or short?
   TALL SHORT

2) If Belinda moves to the land of tall people, will she be considered tall or short?
   TALL SHORT

3) If Carmen moves to the land of short people, will she be considered tall or short?
   TALL SHORT

4) If Deanna moves to the land of short people, will she be considered tall or short?
   TALL SHORT
Results

- Baseline: 35.5%
- No study: 37.5%
- Traditional study: 59.3%
- Analogy study: 46.2%

$p > .1$
Format of the question (revised)

1) The /s/ from the person with a high-pitched voice inserted into a word spoken with a low-pitched voice
   a) Hear /s/                b) Hear /ʃ/               Try 1: _____  Try 2: _____  Try 3: _____

2) The /ʃ/ from the person with a high-pitched voice inserted into a word spoken with a low-pitched voice
   a) Hear /s/                b) Hear /ʃ/               Try 1: _____  Try 2: _____  Try 3: _____

3) The /s/ from the person with a low-pitched voice inserted into a word spoken with a high-pitched voice
   a) Hear /s/                b) Hear /ʃ/               Try 1: _____  Try 2: _____  Try 3: _____

4) The /ʃ/ from the person with a low-pitched voice inserted into a word spoken with a high-pitched voice
   a) Hear /s/                b) Hear /ʃ/               Try 1: _____  Try 2: _____  Try 3: _____
Results

![Bar chart showing percentage of correct answers for different study methods.](chart.png)

- Baseline: 35.5%
- No study: 37.5%
- Traditional study: 59.3%
- Analogy study: 46.2%
- Traditional w/incentive: 40.7%
- Analogy w/incentive: 59.3%

**p > .1**
Results

$p = .035$, one-tailed
Types of Errors

- Speaker normalization is a symmetrical process
- Incorrect responses classified as symmetrical or non-symmetrical
Types of Errors

Baseline/No Study: 29.4%
Traditional (combined): 41.7%
Analogy (combined): 56%

Percent Symmetrical Errors
Conclusions (Narrow)

• An analogy-based study procedure can be as effective as a traditional study method
• Results thus far suggests that external incentives may improve performance with the analogy-based method but hinder performance with traditional studying
• These findings need to be replicated in an actual classroom setting (IRB willing!)
Conclusions (Broad)

• It is possible to approach teaching in the same way we approach research

• Benefits:
  – Evidence-based practice
  – Reading the education literature
  – Greater reflection and self-awareness as instructor

• Costs:
  – Not realistic to apply this approach to everything you try in the classroom
  – Don’t do this unless you’re prepared to change how you teach
Thank you!
Instructional Analogies

- Analogies appear to be most commonly used in physics and chemistry (Curtis & Reigeluth, 1984)
- Analogies can be used to aid elaboration, i.e., constructing relations between known information and new information (Glynn, 2008)
- Analogies can promote “conceptual change”, i.e., getting us to think about a concept in a new way (Duit, 1991)
Thiele & Treagust (1994)

• Observed 10th grade chemistry teachers explaining abstract concepts
• Conducted an interpretative (qualitative) analysis
• Conclusions:
  – Teachers used analogies when they judged that students did not understand a concept
  – Use of analogies was not preplanned
  – Analogies were based on the teacher’s own knowledge or experience
Spier-Dance et al. (2005)

• Compared effectiveness of teacher-generated vs. student-generated analogies for understanding a particular concept in undergraduate chemistry classes

• Students in the student-generated analogy condition did better on a corresponding question on the final exam

• Suggested that some functions of analogies can be to make material more meaningful, and at least for student-generated analogies, to increase motivation
Bassok & Holyoak (1989)

- 9th grade students were trained on how to solve a particular type of math problem either in the context of algebra (“arithmetic progression”) or physics (“constant acceleration”)

- They were then tested on analogous problems from the domain they were trained on, or the other domain
Bassok & Holyoak (1989)

• Sample algebra problem:
  – 1. A boy was given an allowance of 50 cents a week beginning on his sixth birthday. On each birthday following this, the weekly allowance was increased 25 cents. What is the weekly allowance for the year beginning on his 15th birthday?
• Sample physics problem:
  – 1. An express train traveling at 30 meters per second (30 m/s) at the beginning of the 3rd second of its travel, uniformly accelerates increasing in speed 5 m/s each successive second. What is its final speed at the end of the 9th second?
Transfer of training method as a function of training and test domains

Percent applying trained method

Training domain

Algebra test
Physics test
Needham & Begg (1991)

- Participants read a training story, and were asked either to try to remember it for a recall test, or try to solve the problem.
- They were then either asked to recall the training story, or solve a target problem that was analogous to the problem in the training story.
Needham & Begg (1991)

• Training story:
  – A certain casino has three boxes of poker chips. One box is labeled “$5” and contains $5 poker chips. The second box is labeled “$10” and contains $10 poker chips. The third box is labeled “$5 and $10” and contains both $5 and $10 poker chips. One evening a prankster switched all the labels. He told the casino operator that although each label was wrong, he did not alter the contents of any of the boxes. The casino operator realized that by choosing just one chip from one of the boxes without looking inside, he could correctly label all three boxes.
Needham & Begg (1991)

• Target problem:
  – A grocer ordered a box of apples, a box of oranges, and a box of apples and oranges from his distributor. A week later, the grocer received three boxes of fruit from the distributor. The boxes were labeled “oranges,” “apples and oranges,” and “apples.” The distributor’s representative warned the grocer that although the order had been filled correctly, each label on the boxes was wrong. The grocer realized that he could label each box correctly by selecting one fruit from just one box without looking inside. From which mislabeled box should the grocer select a fruit? Explain.
Needham & Begg (1991)

Percent recalled/solved

Problem training
Memory training

Problem test
Recall test
An example: Activation and word recognition

• Key concepts:
  – Activation (activation increases)
  – Decay (activation decreases)
  – Level of activation
  – Threshold
An example: Activation and word recognition

• Analog: A leaky bucket
An example: Activation and word recognition

• How is the word ‘CAT’ recognized?
  – When we encounter the word, the faucet turns on and the level of water starts to increase (activation)
  – When the water reaches the top of the bucket, the word is recognized (threshold)
  – After the word is recognized, the faucet is turned off and the water level begins to decrease as it leaks out of the bottom of the bucket (decay)
Using an analogy to solve problems

- Question: How can the bucket analogy explain repetition priming, i.e., faster responding to a word that was recently encountered?
Using an analogy to solve problems

**Recently recognized:** Bucket still mostly full

**Long time since last recognized:** Bucket mostly empty

**Conclusion:** Will take longer to recognize DOG than CAT