



Applying Cognitive Science Principles to Promote Durable and Efficient Learning

—
Sean Kang, PhD
2 August 2019



Outline

1. Do tests only measure learning, or can they also promote learning?
Testing effect
 2. Should you review/practise the material you are trying to learn soon after you first encounter the material, or should you wait?
Spacing effect
 3. During practice, should items of the same type/topic be grouped together, or should they be mixed with items of other types/topics?
Interleaving
- General conclusions

Purpose of Tests / Quizzes

- Traditionally, an assessment tool
- But testing does not merely measure the contents of memory
- Taking a test can serve as a learning opportunity, enhancing memory retention to a greater extent than additional studying...

the testing effect

(also referred to as the benefit of *retrieval practice*)

First published study: Abbott (1909)

“A curious peculiarity of our memory is that things are impressed better by active than by passive repetition. I mean that in learning (by heart, for example), when we almost know the piece, it pays better to wait and recollect by an effort from within, than to look at the book again. If we recover the words in the former way, we shall probably know them the next time round; if in the latter way, we shall very likely need the book once more.”

(William James, 1890, *Principles of Psychology*)

“If you read a piece of text through twenty times, you will not learn it by heart so easily as if you read it ten times while attempting to recite from time to time and consulting the text when your memory fails.”

(Sir Francis Bacon, 1620, *Novum organum*)

“Exercise in repeatedly recalling a thing strengthens the memory.”

(Aristotle, 4th century B.C., *De Memoria et Reminiscentia*)

The Testing Effect

- Journal of Educational Psychology, 1989:
The “Testing” Phenomenon: Not Gone but Nearly Forgotten

John A. Glover
Teachers College and Burris Laboratory School
Ball State University

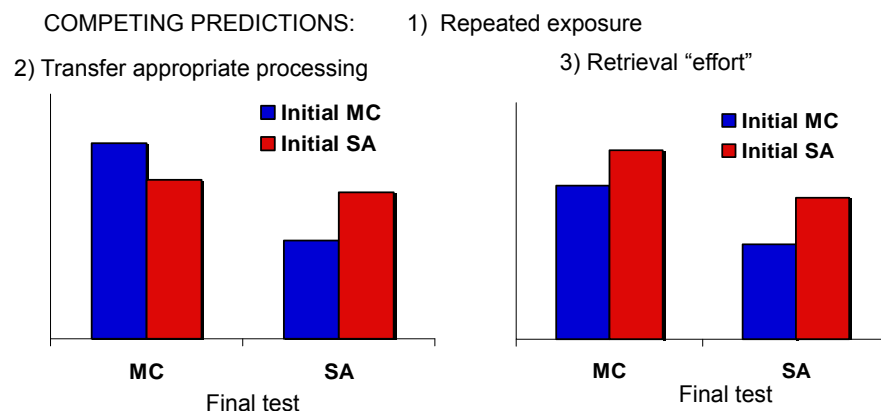
- Dempster, F. N. (1992). Using tests to promote learning: A **neglected classroom resource**. *Journal of Research & Development in Education*, 25, 213–217.
- Resurgence of interest in the testing effect in recent years

Testing effect: How does it work?

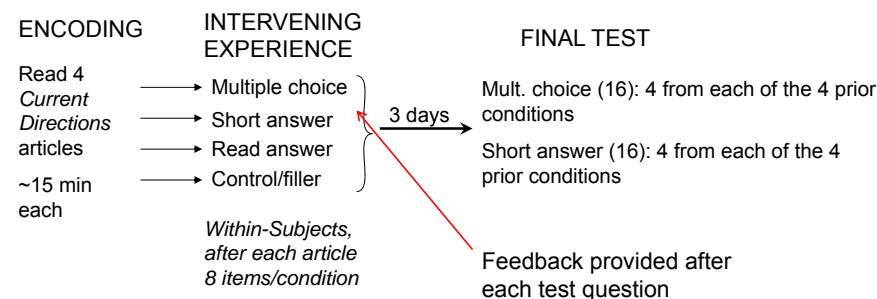
1. Additional (focused) presentation of material
2. Operations/processes engaged by an initial test are also engaged during the final test, resulting in positive transfer to same type of tests (i.e., practice effect)
3. Retrieval itself is a potent memory modifier, with increasing retrieval demand/effort enhancing later retention

Does test format matter?

Initial test type -- Short Answer (SA), Multiple Choice (MC), Read Fact
Final (criterial) test -- SA, MC
(Corrective feedback given after each initial test question)



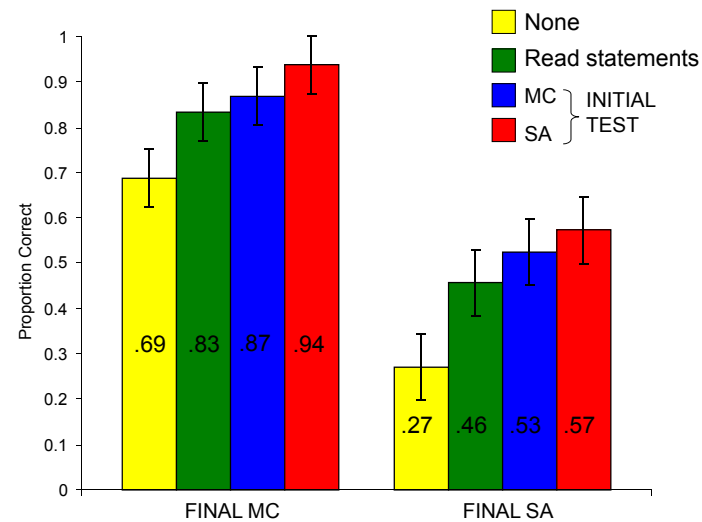
Procedure



N=48

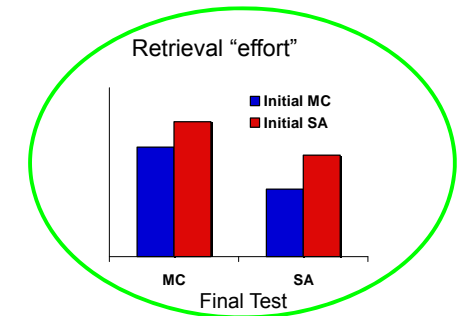
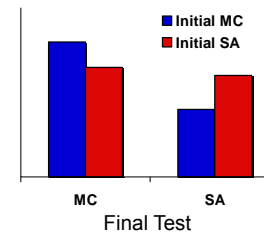
(Kang, McDermott, & Roediger, 2007)

Testing enhanced later memory, and the enhancement was greater when the initial test format was short answer

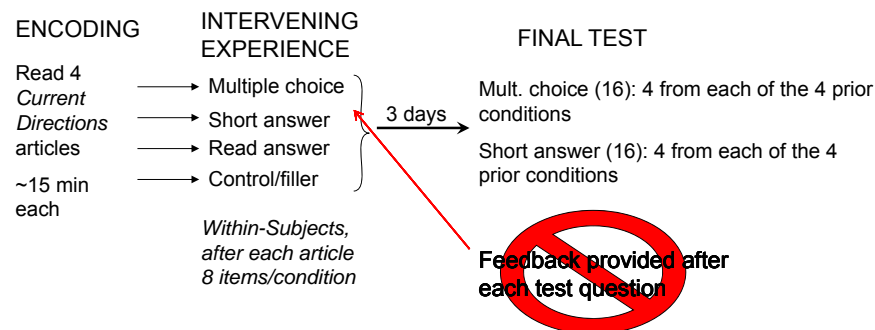


COMPETING PREDICTIONS:

Transfer appropriate processing



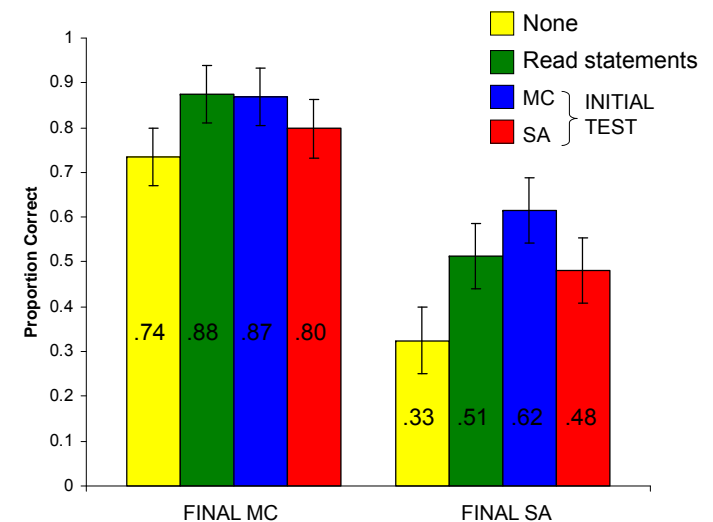
Does feedback matter?



N=48

(Kang, McDermott, & Roediger, 2007)

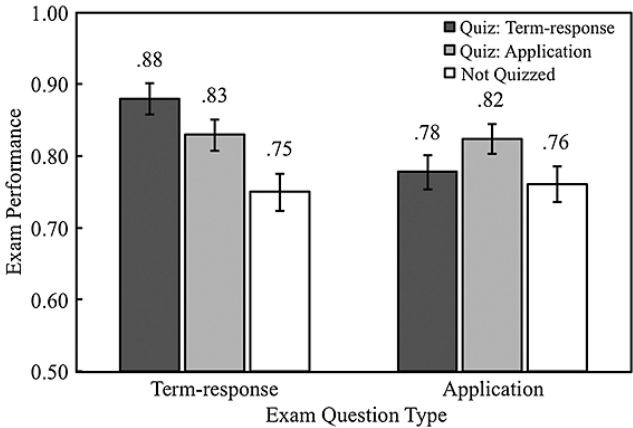
Corrective feedback important, especially when initial test performance is not high



Quizzing in Middle-School Science: Successful Transfer Performance on Classroom Exams

MARK A. MCDANIEL*, RUTHANN C. THOMAS, POOJA K. AGARWAL, KATHLEEN B. MCDERMOTT and HENRY L. ROEDIGER

Washington University in St. Louis, St. Louis, MO, USA



Term response

What is the struggle between organisms to survive in a habitat with limited resources?

What is the term for when two or more organisms vie for limited environmental resources?

- A. Parasitism
- B. Limited factors
- C. Predation
- D. Competition

Application

Both foxes and raccoons on Long Island eat pheasant, which in recent years, has been in decline. The foxes and raccoons' situation is an example of what ecological process?

A group of 500 pandas are living in a reserve. Recent dry weather has reduced the bamboo populations, which the pandas rely on. The pandas are in what type of relationship?

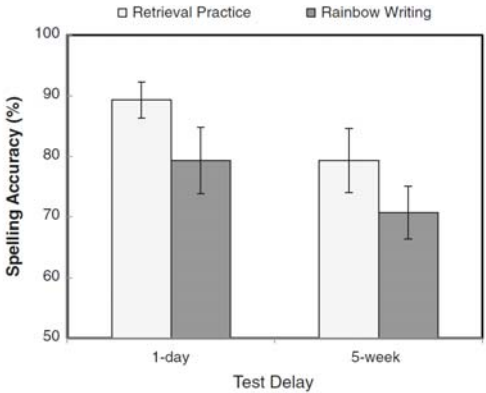
- A. Parasitism
- B. Competition
- C. Limiting factors
- D. Predation



INTERVENTION STUDY

Beyond the Rainbow: Retrieval Practice Leads to Better Spelling than does Rainbow Writing

Angela C. Jones¹ • Liane Wardlow² • Steven C. Pan³ • Cristina Zepeda³ • Gail D. Heyman³ • John Dunlosky⁴ • Timothy C. Rickard³



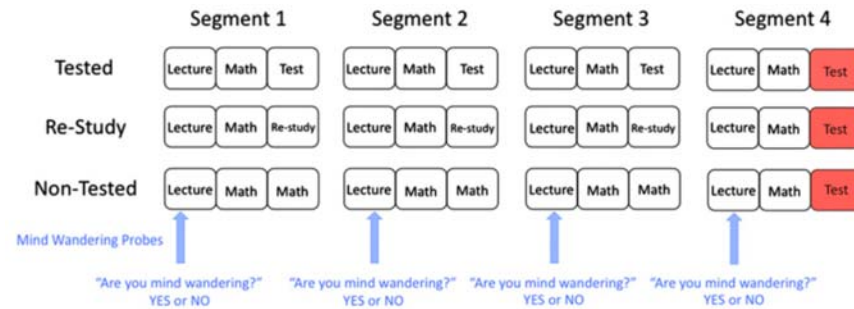
Spelling accuracy for students in experiment 1. Error bars are standard error

Interpolated memory tests reduce mind wandering and improve learning of online lectures

Karl K. Szpunar¹, Novall Y. Khan, and Daniel L. Schacter

Department of Psychology, Harvard University, Cambridge, MA 02138

Edited by Sean Kang, Dartmouth College, Hanover, NH, and accepted by the Editorial Board February 18, 2013 (received for review December 13

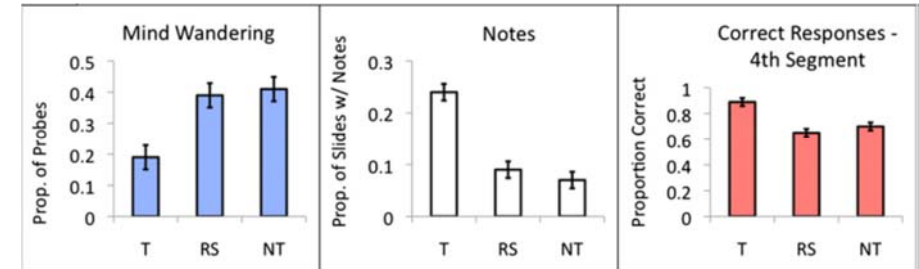


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- Other (indirect) benefits of testing:
 - Helps identify gaps in knowledge
 - Improves metacognitive monitoring
 - Provides feedback to instructors
 - Encourages students to study



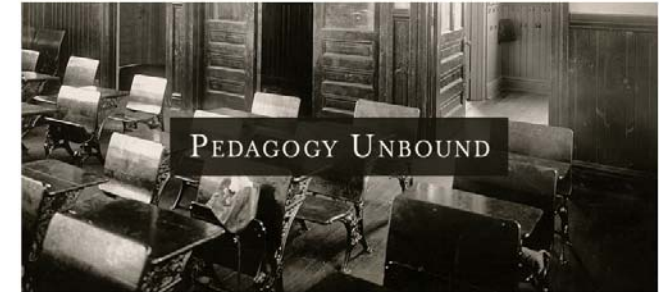
Students Should Be Tested More, Not Less

By Jessica Lahey



Bebeto Matthews/AP Images

We Should Give Students More Tests. Seriously.



February 5, 2014

I can't believe I'm typing these words, but I'm here today to convince you to give your students more tests.

Outline

1. Do tests only measure learning, or can they also promote learning? *Testing effect*
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 3. During practice, should items of the same type/topic be grouped together, or should they be mixed with items of other types/topics? *Interleaving*
- General conclusions

The Spacing Effect

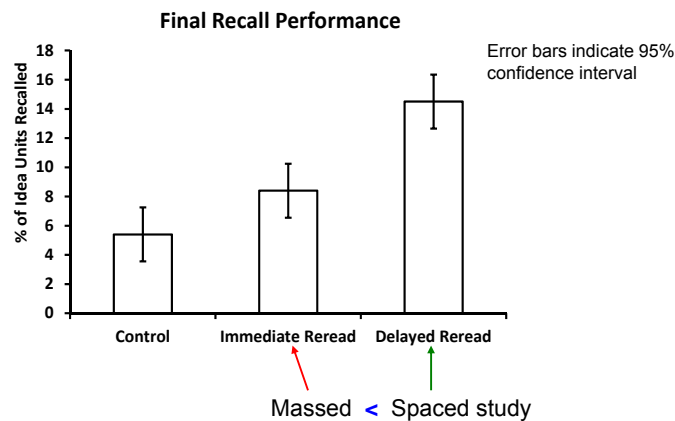
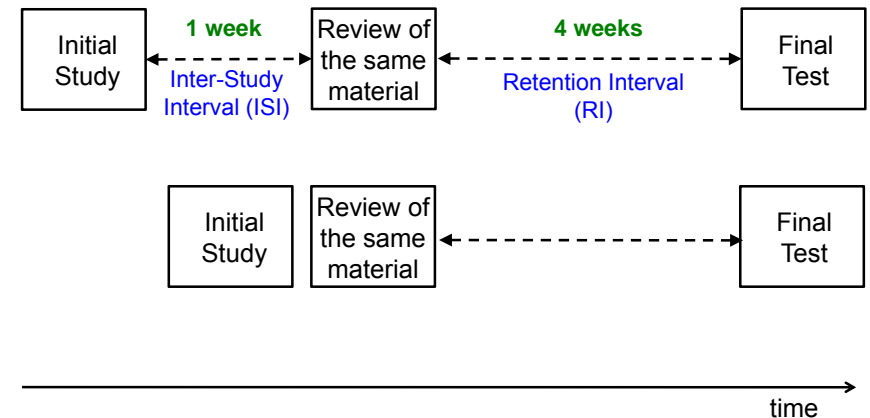
- Reviews are more effective when distributed or spaced out, rather than massed (with total time equated)
- One of the most robust phenomena; observed with diverse range of materials / types of learning
- Ebbinghaus (1885):
“...with any considerable number of repetitions a suitable distribution of them over a space of time is decidedly more advantageous than the massing of them at a single time.”

“...You now see why ‘cramming’ must be so poor a mode of study. Cramming seeks to stamp things in by intense application immediately before the ordeal. But a thing thus learned can form but few associations. On the other hand, the same thing recurring on different days, in different contexts, read, recited on, referred to again and again, related to other things and reviewed, gets well wrought into the mental structure. This is the reason why you should enforce on your pupils habits of continuous application.”

- William James, 1899, *Talks to Teachers on Psychology: And to Students on Some of Life's Ideals*

The Spacing Effect

Basic structure of an experiment examining the effect of spacing:



(Kang, Pashler, & Rohrer, unpublished data)

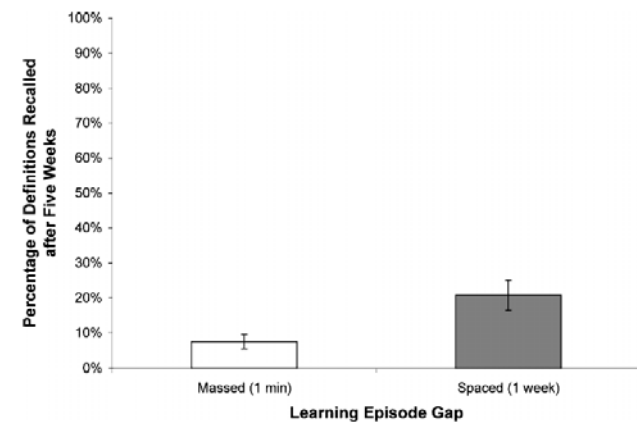
Applied Cognitive Psychology, Appl. Cognit. Psychol. **25**: 763–767 (2011)
Published online 22 September 2010 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/acp.1747

Spacing Effects in Real-World Classroom Vocabulary Learning

HAILEY S. SOBEL¹, NICHOLAS J. CEPEDA^{2*} and IRINA V. KAPLER²

¹School/Applied Child Psychology, McGill University, Montreal, Quebec, Canada

²Department of Psychology, York University, Toronto, Ontario, Canada



The Spacing Effect

A Case Study in the Failure to Apply the Results of Psychological Research

Frank N. Dempster *University of Nevada, Las Vegas*

“The spacing effect would seem to have considerable potential for improving classroom learning, yet there is no evidence of widespread application...

Even experienced educators, when judging the instructional effectiveness of text passages, tend to rate prose in which the repetition of a given unit of information is massed as better than those in which it is spaced...

In short, the spacing effect is neither intuitively obvious, nor well known among educators.”

Applications of Testing & Spacing in Tutoring Software

WIRED MAGAZINE: 16.05

Want to Remember Everything You'll Ever Learn?
Surrender to This Algorithm

By Gary Wolf 04.21.08

- Supermemo

www.supermemo.com

- Spaced Ed

www.spaceded.com



Piotr Wozniak
(creator of
Supermemo)

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- General conclusions

PSYCHOLOGICAL SCIENCE

Learning Concepts and Categories

Is Spacing the “Enemy of Induction”?

Nate Kornell and Robert A. Bjork

University of California, Los Angeles



A Six paintings by one of the artists



Massed condition

B One painting by each of the six different artists



Spaced condition

Kornell & Bjork (2008)

- Paintings were presented either in *massed* or *spaced* condition (artist's name accompanied each painting).
- After training, subjects were tested on the ability to correctly categorise 48 new paintings (painted by the same 12 artists).

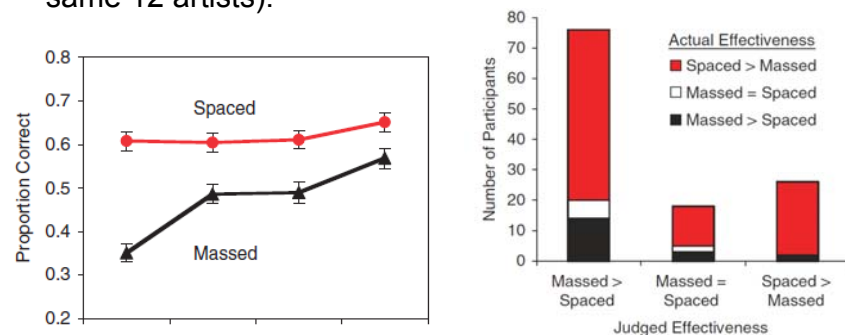
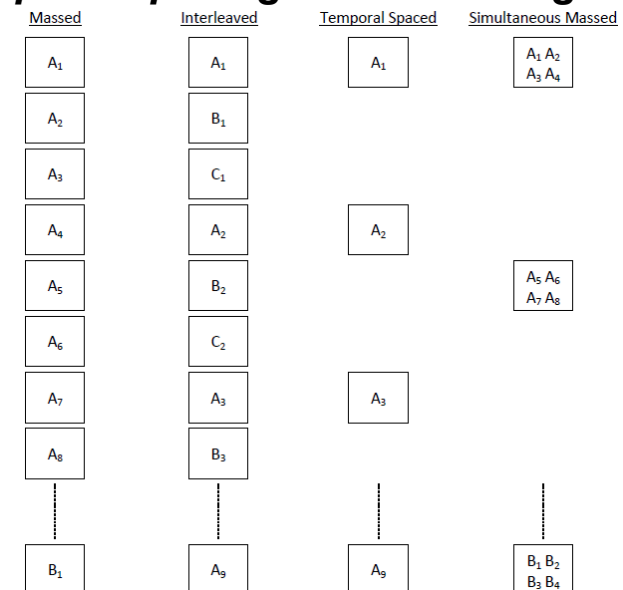


Fig. 3. Number of participants (out of 120) who judged massing as more effective than, equally effective as, or less effective than spacing in Experiment 1a. For each judgment, the number of participants is divided according to their actual performance in the spaced condition relative to the massed condition.

But is the spacing advantage due to *temporal spacing* or *interleaving*?



Paintings

Jan Blencowe



Paintings

Richard Lindenberg



Paintings

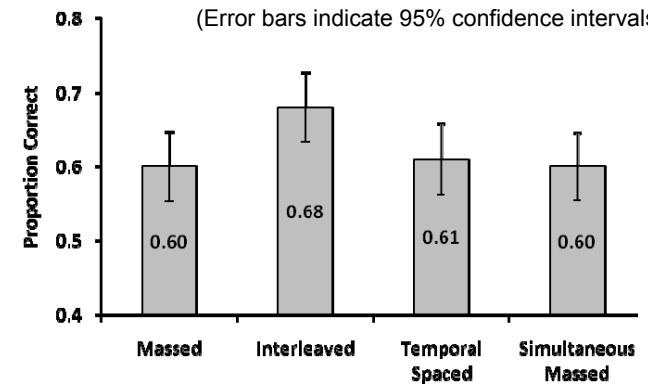
Rae O'Shea



But is the spacing advantage due to *temporal spacing* or *interleaving*?

Results ($N = 88$)

(Error bars indicate 95% confidence intervals)



- Benefit of spacing not due to temporal spacing *per se*, but rather the interleaving of exemplars from different categories.

(Kang & Pashler, 2012)

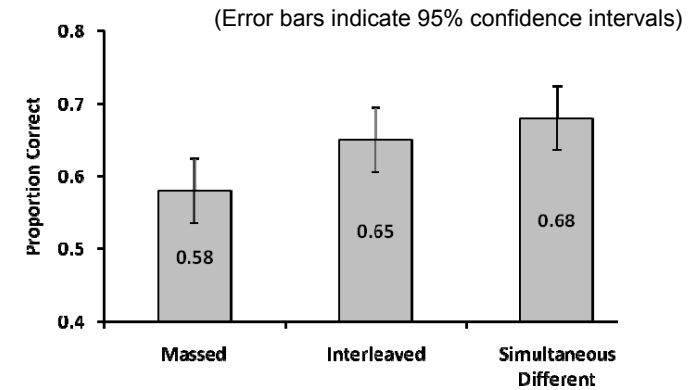
Why does interleaving facilitate inductive learning?

- If the benefit of interleaving is due to the highlighting of differences among categories, other manipulations that promote this should also enhance induction.
- Follow-up experiment:
 - Learning conditions (manipulated between-subjects):
 1. Massed
 2. Interleaved
 3. Simultaneous *Different* (i.e., 3 paintings, each by a different artist, presented at a time for 15s, followed by 3s blank screen)

(Kang & Pashler, 2012)

Results ($N = 90$)

(Kang & Pashler, 2012)



- Manipulations that facilitate discriminative contrast among categories enhance induction (at least for categories that have low across-category differences).
- Similar types of results found in learning bird and butterfly categories

Interleaving effects in motor skill

Perceptual and Motor Skills, 1994, 78, 835-841. © Perceptual and Motor Skills 1994

CONTEXTUAL INTERFERENCE EFFECTS WITH SKILLED BASEBALL PLAYERS^{1, 2}

KELLIE GREEN HALL, DEREK A. DOMINGUES, RICHARD CAVAZOS

California Polytechnic State University

College baseball players were given practice with hitting 3 types of pitches: fastballs, curveballs, and change-ups. Practice was either blocked or interleaved.

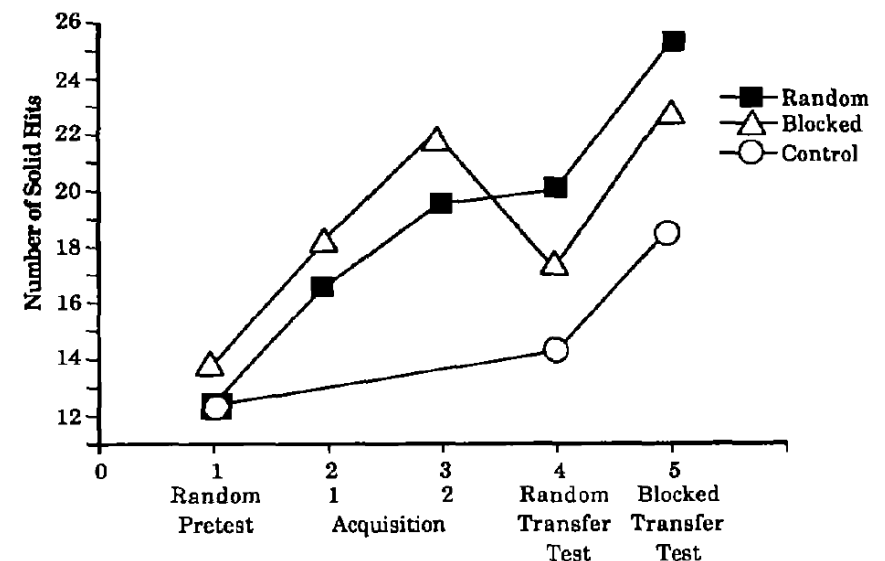


FIG. 1. Mean number of solid hits (per 45 pitches) for each condition

(Hall et al., 1994)

Interleaving effects in math learning

- To successfully solve a math problem, students must choose the correct strategy...

Doug Rohrer



Univ of
South Florida

Choosing a strategy is hard because

- Students usually must infer the strategy

Solve for x

$$x - 3x + 2 = 0$$

1. Choose strategy

Rearrange terms so that
 x is alone on one side

2. Execute strategy

$$x - 3x + 2 = 0$$

$$x - 3x = -2$$

$$-2x = -2$$

$$x = 1$$

Choosing a strategy is hard because

- Problems that look alike may require different strategies

Solve for x

$$x - 3x + 2 = 0$$

1. Choose strategy

Rearrange terms so that
 x is alone on one side

2. Execute strategy

$$x - 3x + 2 = 0$$

$$x - 3x = -2$$

$$-2x = -2$$

$$x = 1$$

Solve for x

$$x^2 - 3x + 2 = 0$$

Factor

$$x^2 - 3x + 2 = 0$$

$$(x - 1)(x - 2) = 0$$

$$x = 1 \text{ or } 2$$

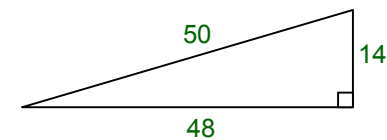
Choosing a strategy is hard because

- Problems that don't look alike may require the same strategy

A bird flies 48 mi east and then 14 mi north.

How far is it from its starting point?

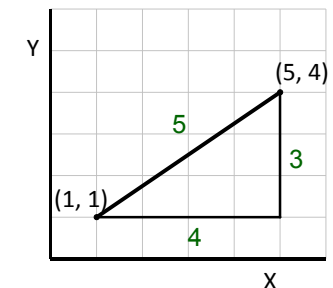
Pythagorean Theorem



Find the length of the line segment

with endpoints $(1, 1)$ and $(5, 4)$.

Pythagorean Theorem



Strategy choice bedevils students at higher levels, too.

Solve $x^2 - x = 1$

quadratic formula

$\int e(x+1)^e dx$

substitution

50 kids divided into two groups.

Group 1 used method A.

Group 2 used method B.

independent measures t test

Solve $x^3 - x = 0$

factor

$\int x(e+1)^x dx$

integration by parts

50 kids divided into two groups.

Group 1 used method A, then method B.

Group 2 used method B, then method A.

repeated measures t test

Interleaving effects in actual classrooms

- Study done in 7th-grade math classes at Liberty Middle School in Tampa, FL (Rohrer, Dedrick, & Burgess, 2014)
- Homework assignments manipulated (within-subjects):
 - Blocked practice (12 problems in the assignment following the lesson, all on the same topic)
 - Interleaved practice (4 problems in the assignment following the lesson, on that topic; 8 problems on that topic distributed across future assignments)
- Every student worked on the same problems – only their order varied.

Interleaved Practice: A Sample Assignment

small block

4 problems on the current lesson (i.e., same strategy)

interleaved practice

One problem on each of 8 previous lessons

1. What number is 25% of 52?
2. What percent of 72 is 18?
3. What percent of 140 is 7?
4. What number is 10% of 90?
5. Graph the equation. $y = 3x + 1$
6. Find the area of a circle with radius π .
7. Solve for x . $9(1+x) = 5(x+9)$
8. Find the slope of a horizontal line.
9. Simplify. $(-5)^3$
10. Simplify. $3(4+2) - 7$
11. Simplify. $2\frac{1}{5} \div 3\frac{1}{3}$
12. Simplify. $\frac{3}{7} - \frac{1}{5}$

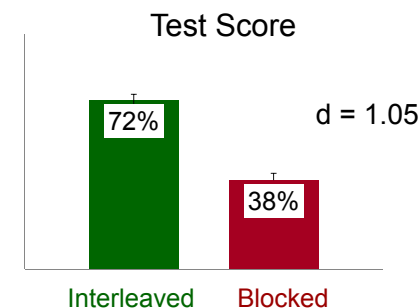
In brief, interleaved practice assignments had the following critical features:

1. Problems of different kinds were interleaved within the same assignment
2. Problems of the same kind were spaced across different assignments

Timeline



Results



Cognitive Science Meets Pre-Algebra

By BENEDICT CAREY

TAMPA, Fla. — The math students at Liberty Middle School were not happy.

The seventh graders' homework was harder and more time-consuming at first, and many of the problems seemed stale. They were old, from weeks or months ago — *proportions, again?* — and solving them interrupted the flow of the students' current work.

"They were having to remember, and to work on, stuff they'd learned previously — plus the new material," their teacher, Jen DeMik, said of last semester's assignments. "They had to focus on several things instead of just one."

Or as 13-year-old Giulia Falabella, one of her students at the time, put it, "It took some getting used to, that's for sure."

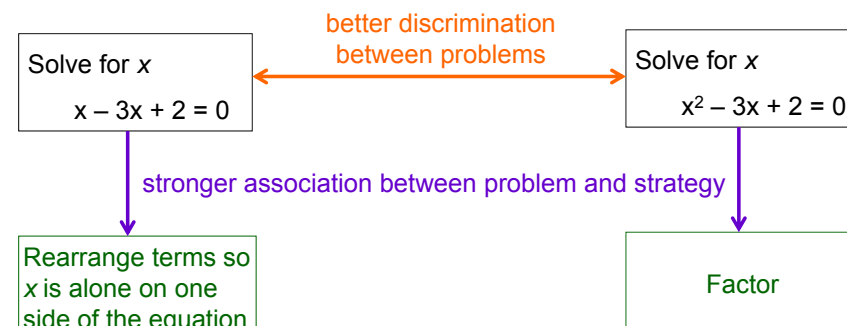
But as little as Giulia and her classmates may have liked it, the curriculum was part of an unusual educational experiment — one of an increasing number using tools of cognitive psychology, which focuses on the mental dynamics behind thinking, remembering and problem solving.

The technique under study in Tampa, called interleaving, has become an especially hot area of interest among researchers. It mixes distinct but related problems or ideas — long division, say, and multiplying fractions — in daily homework assignments.

Most textbooks and schools do the opposite, concentrating or "blocking" lessons to drive home skills by having students practice one at a time, over and over. This is the equivalent of shooting 100 free throws in a row for basketball practice, or running through just the A minor scale for an hour's music lesson.

How exactly does interleaving improve strategy choice?

Two possible mechanisms



- Practical implications
 - Think of your class/textbook assignments/exercises -- is practice usually blocked or interleaved?

Sample Assignments from Middle School Math Workbooks

11-3 NAME _____ DATE _____ PERIOD _____

Homework Practice

The Pythagorean Theorem

Find the missing measure of each triangle. Round to the nearest tenth if necessary.

-
-
-
-
-
-
- $a = 3.3$ in., $b = 5.6$ in.
- $b = 2.9$ mm, $c = 4.4$ mm
- $a = 21$ yd, $c = 29$ yd
- $a = 2\frac{1}{5}$ ft, $b = 4\frac{2}{5}$ ft
- $b = 7\frac{1}{4}$ in., $c = 7\frac{3}{4}$ in.
- $a = 6\frac{1}{2}$ yd, $b = 10$ yd
- SOCCER** Find the width of the soccer goal. Round to the nearest tenth.

The Pythagorean Theorem

Directions: Find the length of the missing side in the following examples. Round answers to the nearest tenth, if necessary.

-
-
-
-
-
-
-
-
-

What is the length of the hypotenuse, c , of the following right angle triangles?

- $a = 3$; $b = 4$; $c = ?$
- $a = 6$; $b = 8$; $c = ?$

12. A ladder is leaning against the side of a 10m house. If the base of the ladder is 3m away from the house, how tall is the ladder?

General Conclusions

- Taking a test can be a potent learning event, often yielding better long-term retention than additional studying.
 - Tests that involve effortful retrieval (coupled with corrective feedback) tend to be more effective
- If you are going to review to-be-learned material, you should wait a while between each exposure (i.e., space out the review opportunities)
- Testing + Spacing = Spaced Retrieval Practice
- Interleaving of items from different categories improves inductive learning by facilitating discrimination of easily confusable categories

Questions / Feedback?

sean.kang@unimelb.edu.au