Two students are studying for an exam. Student A studies the two days leading up to the exam. Student B starts studying two weeks before the exam, studying a little bit everyday. Both students spend the same total about of hours.

Two assignments ask students to learn the list of cranial nerves using a mnemonic device. Assignment A includes a commonly used mnemonic device provided by the instructor to assist students in their learning. Assignment B asks students to create their own mnemonic device to assist their learning. After two weeks, all students are asked to list the cranial nerves in order.

In two different classes, a 275-word prose passage about a specific topic is presented. In Class A, students first study the passage for seven minutes, and then are asked to write down from memory as much of the material from the passage as they can. In Class B, students first study the passage for seven minutes, and then are asked to study the passage again for another seven minutes. After one week, all students are asked to recall as much of the passage as they can remember.

Two art history professors present 6 paintings by each of 12 artists (72 paintings total). Professor A presents all six paintings by a single artist consecutively (i.e., grouped), and then moves on to the next artist’s six paintings, and so on, until all paintings have been presented. Professor B presents the various artists’ paintings in an intermingled fashion (i.e., mixed), such that a single painting by a particular artist would be followed by a different artist.
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)

The Testing Effect

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

   John A. Glover
   Teachers College and Burns Laboratory School
   New State University


   • 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)

COMPETING PREDICTIONS:  
1) Repeated exposure
2) Transfer appropriate processing
3) Retrieval "effort"

---

"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*)

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"Exercise in repeatedly recalling a thing strengthens the memory."

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

ENCODING
- Read 4 Current Directions articles
- ~15 min each

INTERVERNING EXPERIENCE
- Multiple choice
- Short answer
- Read answer
- Control/filler

Within-Subjects, after each article 8 items/condition

FINAL TEST
- Mult. choice (16): 4 from each of the 4 prior conditions
- Short answer (16): 4 from each of the 4 prior conditions

Feedback provided after each test question

N=48

(Kang, McDermott, & Roediger, 2007)

**Study 1: Does test format matter?**

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

Does feedback matter?

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

- Taking a test can be a potent learning event, often yielding better long-term retention than additional studying.

- Testing benefits learning of a diverse range of materials, both verbal and nonverbal.

- Repeated retrieval practice augments the benefit.

- The size of the testing effect is modulated by test format & feedback
  - Tests requiring effortful retrieval are more effective at enhancing retention, implicating retrieval as a causal mechanism
  - To maximize the benefit of testing, feedback should be provided when initial test performance is low
Summary
• Other (indirect) benefits of testing:
  – Helps identify gaps in knowledge
  – Improves metacognitive monitoring
  – Provides feedback to instructors
  – Encourages students to study

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

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:

<table>
<thead>
<tr>
<th>Initial Study</th>
<th>Review of the same material</th>
<th>Final Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 week</td>
<td>Inter-Study Interval (ISI)</td>
<td>4 weeks</td>
</tr>
<tr>
<td>1 week</td>
<td>Retention Interval (RI)</td>
<td></td>
</tr>
<tr>
<td>1 week</td>
<td></td>
<td>Final Test</td>
</tr>
</tbody>
</table>

![Graph showing Final Recall Performance](image)

(Kang, Pashler, & Rohrer, unpublished data)

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. 

OpenStax Tutor

- Experiment in Fall 2012 on upper-level engineering class (signals and systems) at Rice University
- Weekly homework assignments were manipulated (within-subjects):
  - Standard practice (same as in previous semesters—i.e., once material was covered in class and on the corresponding homework assignment, not revisited until the exam)
  - OpenStax Tutor
    - Spaced retrieval practice (practice problems for a given topic appeared on two subsequent homework assignments—e.g., problems pertaining to Week 1 material were given on homework assignments #1, #2, and #3)
    - Feedback (feedback provided immediately after assignment deadline; students required to view feedback to receive credit for the assignment)
- Performance on exams (closed-book):
  - OpenStax Tutor (60% / 76%) > Standard Practice (53% / 69%)

Applications of Testing & Spacing in Tutoring Software

- Supermemo
  - [www.supermemo.com](http://www.supermemo.com)
- Spaced Ed
  - [www.spaceded.com](http://www.spaceded.com)
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

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**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).

---

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

- **Massed**
  - $A_1$
  - $A_2$
  - $A_3$
  - $A_4$
  - $A_5$
  - $A_6$
  - $A_7$
  - $A_8$
  - $A_9$
  - $A_{10}$
  - $A_{11}$
  - $A_{12}$

- **Interleaved**
  - $B_1$
  - $B_2$
  - $B_3$
  - $B_4$
  - $B_5$
  - $B_6$
  - $B_7$
  - $B_8$
  - $B_9$
  - $B_{10}$

**Fig. 2.** Number of participants that of 129 who judged massed as more effective than equally effective, as less effective than spacing in the performance. For each judgement, the number of participants judged massed as equally effective than spaced performance in the spaced condition relative to the massed condition.
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

(Kang & Pashler, 2012)
Interleaving effects in motor skill

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

Interleaving effects in math learning

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

Choosing a strategy is hard because

1. 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

\[ x - 3x = -2 \]

2. Execute strategy

\[ -2x = -2 \]

\[ x = 1 \]

Choosing a strategy is hard because

2. Problems that look alike may require different strategies

Find the length of the line segment with endpoints (1, 1) and (5, 4).

A bird flies 48 mi east and then 14 mi north. How far is it from its starting point?

Pythagorean Theorem

\[ x^2 - 3x + 2 = 0 \]

Factor

\[ (x - 1)(x - 2) = 0 \]

\[ x = 1 \text{ or } 2 \]
Strategy choice bedevils students at higher levels, too.

Solve $x^2 - x = 1$

Solve $x^3 - x = 0$

Quadratic formula

Factor

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

Integration by parts

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

Substitution

50 kids divided into two groups.

Group 1 used method A.

Group 2 used method B.

Independent measures $t$ test

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 lessons)
- Every student worked the same problems – only their order varied.

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

Interleaved Practice: A Sample Assignment

**Small block**

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

1. What number is 25% of 52?

2. What percent of 72 is 18?

3. What percent of 140 is 77?

4. What number is 10% of 90?

**Interleaved practice**

One problem on each of 8 previous lessons

5. Graph the equation. $y = 3x + 1$

6. Find the area of a circle with radius $\pi$.

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. $\frac{1}{3} + \frac{1}{3}$

12. Simplify. $\frac{3}{7} - \frac{1}{7}$

Results

Test Score

Interleaved 72%

Blocked 38%

$d = 1.05$

Summary

- Spacing benefits category learning when exemplars are interleaved
  - Juxtaposition of two members from different categories helps learners appreciate which dimensions or features are most relevant to the task of discrimination
- Interleaving during practice enhances math problem solving
  - In order to solve a problem correctly, students need to learn to distinguish among different kinds of problems
  - Knowing how to execute a strategy is insufficient; one needs to first identify the features of a problem that indicate which concept or procedure is appropriate (blocked practice short-circuits this step)
**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

"Instructors and students alike are susceptible to assuming that conditions of instruction that enhance performance during instruction are the same conditions that enhance long-term learning. That assumption, however, is sometimes dramatically wrong: Manipulations that speed the rate of acquisition during instruction can fail to support long-term retention and transfer, whereas other manipulations that appear to introduce difficulties and slow the rate of acquisition can enhance post-instruction recall and transfer."

- Robert A. Bjork (2013) on desirable difficulties during training

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**Instructor and student knowledge of study strategies**

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Students’ self-reported study skills and beliefs are often inconsistent with empirically supported (ES) study strategies. However, little is known regarding instructors’ beliefs about study skills and if such beliefs differ from those of students. In the current study, we surveyed college students’ and instructors’ knowledge of study strategies and had both groups evaluate the efficacy of learning strategies described in six learning scenarios. Results from the survey indicated that instructors frequently reported engaging in methods of studying that were not optimal for learning. Instructors’ responses to the survey indicated that they endorsed a number of effective study skills but also held several beliefs inconsistent with research in learning and memory (e.g., learning styles). Further, results from the learning scenarios indicated that instructors were moderately more likely than students to endorse ES learning strategies. Collectively, these data suggest that instructors exhibited better knowledge of effective study skills than students, although the difference was small. We discuss several notable findings and argue for the improvement of both students’ and instructors’ study skill knowledge.