Making it Stick: Incorporating Cognitive Science Research into Textbooks

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Textbook & Academic Authors Association

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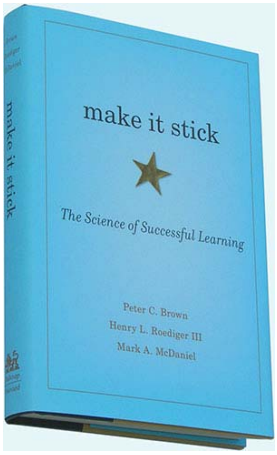
What do we know about learning?



The Science of Learning

"An empirical approach to understanding how people learn"
- Benassi, Overson, and Hakala, 2014

"Scientific study of how people learn"
- Mayer, 2011

Brown, P., Roediger, H., McDaniel, M. (2014). Make it stick: the science of successful learning, Belknap Press, Cambridge MA, p. 155-157.

How do students study?

- 84% of students re-read their notes or textbook
- 55% ranked this as their #1 strategy!

Karpicke, J.D., Butler, A.C., & Roediger, H.L., III. (2009). Metacognitive strategies in student learning: Do students practice retrieval when they study on their own? *Memory, 17,* 471-479.

Other evidence

Familiarity ≠ Content Mastery

Testing

Testing

Testing

Who are our readers?

- Low-structure builders (Example learners)
- High-structure builders (Rule learners)

Who are we as authors?

- Low-structure Builders (Example Learners)
- High-structure Builders (Rule Learners)
  - Don't get caught in the expert blind spot!

How can we help our readers?

- **Build a Structure**
- **Generate Understanding**
- **Offer Opportunities for Retrieval Practice**
- **Mix, Don't Block**

Building Structure

What works better than just re-reading?

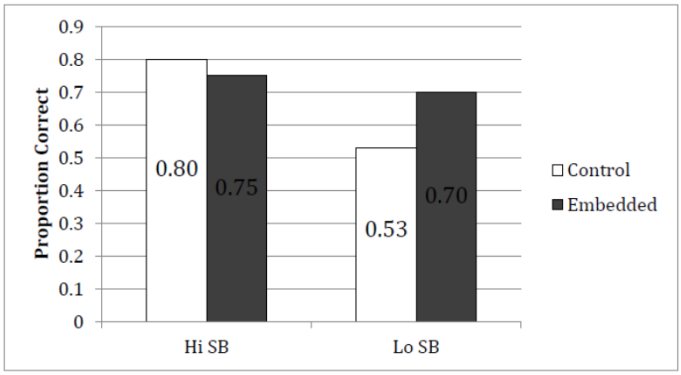


Figure 4. Final test performance as a function of condition and level of structure building ability. Adapted from Callender & McDaniel (2007).

From Nguyen and McDaniel *in* Benassi, V.A., Overson, C.E., & Hakala, C.M. (2014). *Applying Science of Learning in Education: Infusing psychological science into the curriculum*. Retrieved from the Society for the Teaching of Psychology website: http://teachpsych.org/ebooks/asle2014/index.php, p.112.

How can we build structure?

What do I need to know for the exam? How can I tell what is important?

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Building Structure

Identifying Core Chemistry Skills

CORE CHEMISTRY SKILL
Using the Heat Equation

Heat Equation

When we know the specific heat of a substance, we can calculate the heat lost or gained by measuring the mass of the substance and the initial and final temperatures. We can substitute these measurements into the specific heat equation that is rearranged to solve for heat, which we call the **heat equation**.

CORE CHEMISTRY SKILL
Converting between Temperature Scales

To convert from degrees Fahrenheit to degrees Celsius, the temperature equation is rearranged to solve for t_C. First, we subtract 32 from both sides since we must apply the same operation to both sides of the equation.

$$t_F - 32 = 1.8(t_C) + 32 - 32$$
$$t_F - 32 = 1.8(t_C)$$

CORE CHEMISTRY SKILL
Classifying Matter

3.1 Classification of Matter

LEARNING GOAL Classify examples of matter as pure substances or mixtures.

Matter is anything that has mass and occupies space. Matter is everywhere around us: the orange juice we had for breakfast, the water we put in the coffee maker, the plastic bag we put our sandwich in, our toothbrush and toothpaste, the oxygen we inhale, and the carbon dioxide we exhale. To a scientist, all of this material is matter. The different types of matter are classified by their composition.

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Building Structure

Reviewing Core Chemistry Skills at End of Chapter

CORE CHEMISTRY SKILLS

The chapter section containing each Core Chemistry Skill is shown in parentheses at the end of each heading.

Counting Significant Figures (2.2)

The significant figures (SFs) are all the *measured* numbers including the last, estimated digit:

- All nonzero digits
- Zeros between nonzero digits
- Zeros within a decimal number
- All digits in a coefficient of a number written in scientific notation

An *exact* number is obtained from counting or a definition and has no effect on the number of significant figures in the final answer.

Example: State the number of significant figures in each of the following:

a. 0.003 045 mm
b. 15 000 m
c. 45.067 kg
d. 5.30×10^3 g
e. 2 cans of soda

Answer: a. four SFs; b. two SFs; c. five SFs; d. three SFs; e. exact

Writing Conversion Factors from Equalities (2.5)

- A conversion factor allows you to change from one unit to another.
- Two conversion factors can be written for any equality in the metric, U.S., or metric–U.S. systems of measurement.
- Two conversion factors can be written for a relationship stated within a problem.

Example: Write two conversion factors for the equality:
1 L = 1000 mL.

Answer: $\frac{1000\ \text{mL}}{1\ \text{L}}$ and $\frac{1\ \text{L}}{1000\ \text{mL}}$

Using Conversion Factors (2.6)

In problem solving, conversion factors are used to cancel the given unit and to provide the needed unit for the answer.

- State the given and needed quantities.
- Write a plan to convert the given unit to the needed unit.

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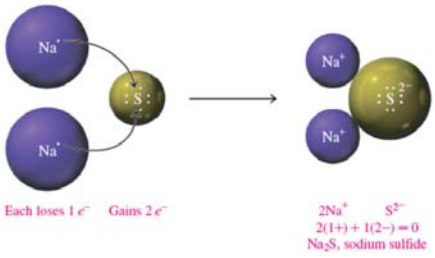
Building Structure

Embedding Questions

from the ionic charges of the positive and negative ions. Suppose we wish to write the formula for the ionic compound containing Na^+ and S^{2-} ions. To balance the ionic charge of the S^{2-} ion, we will need to place two Na^+ ions in the formula. This gives the formula Na_2S, which has an overall charge of zero. In the formula of an ionic compound, the cation is written first followed by the anion. Appropriate subscripts are used to show the number of



ENGAGE

How are the charges of ions used to write an ionic formula?

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Building Structure

Embedding Questions

6.1 Inquiry Question

How do we classify carbohydrates?

6.1 Classes of Carbohydrates

A carbohydrate is a simple or complex sugar composed of carbon, hydrogen, and oxygen. The simplest carbohydrates are **monosaccharides** (*mono* is Greek for "one," *sakkharis* is Greek for "sugar"). These often sweet-tasting sugars cannot be broken down into smaller carbohydrates. The common carbohydrate glucose, $C_6H_{12}O_6$, is a monosaccharide. Monosaccharides contain the elements carbon, hydrogen, and oxygen, and they have the general formula $C_n(H_2O)_n$, where n is a whole number 3 or higher.

Disaccharides consist of two monosaccharide units joined together. A disaccharide can be split into two monosaccharide units. Ordinary table sugar, sucrose, $C_{12}H_{22}O_{11}$, is a disaccharide that can be broken up through hydrolysis into the two monosaccharides glucose and fructose.

Oligosaccharides are carbohydrates containing three to nine monosaccharide units. The blood-typing groups known as ABO are oligosaccharides.

When 10 or more monosaccharide units are joined together, the large molecules that result are termed **polysaccharides** (*poly* is Greek for "many"). In polysaccharides, the sugar units can be connected in one continuous chain, or the chain can be branched. Starch, a polysaccharide in plants, contains large chains of glucose that can be broken down to produce energy.

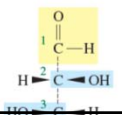
Building Structure

Provide Learning Outcomes and Practice

CHAPTER 6

CHAPTER REVIEW

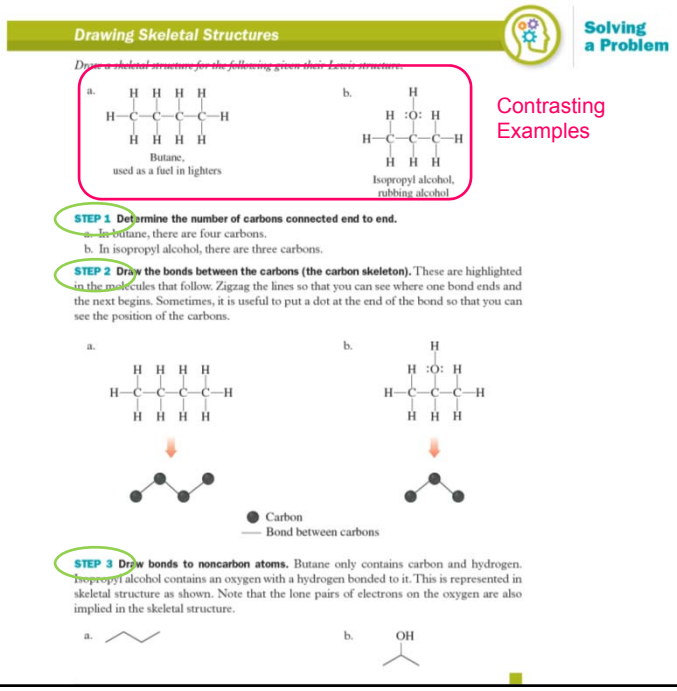
The study guide will help you check your understanding of the main concepts in Chapter 6. You should be able to answer problems for each learning outcome in this list. To check your mastery, try the problems listed after each.

STUDY GUIDE	SUMMARY
6.1 Classes of Carbohydrates **Classify carbohydrates.** • Classify carbohydrates as mono-, di-, oligo-, or polysaccharides. (Try 6.1, 6.47) • Distinguish soluble and insoluble fiber. (Try 6.3, 6.49)	**Inquiry Question** *How do we classify carbohydrates?* Carbohydrates are classified as monosaccharides (simple sugars), disaccharides (two monosaccharide units), oligosaccharides (three to nine monosaccharide units), and polysaccharides (many monosaccharide units). The simplest carbohydrates are the monosaccharides with a molecular formula of $C_n(H_2O)_n$ where $n = 3$–6. Edible carbohydrates that cannot be broken down by the body's enzymes are classified as either soluble or insoluble fibers based on their ability to mix with water.
6.2 Functional Groups in Monosaccharides **Locate organic functional groups in monosaccharides.** • Distinguish primary, secondary, and tertiary alcohols. (Try 6.5, 6.53) • Recognize and draw the functional groups alcohol, aldehyde, and ketone. (Try 6.7, 6.51)	**Inquiry Question** *What functional groups are present in monosaccharides?*  Monosaccharides contain several alcohol (hydroxyl) groups, and either an aldehyde or a ketone functional group. Alcohols can be primary, secondary, or tertiary depending on the number of carbons attached to the alcohol carbon. Aldehydes and ketones are carbonyl-containing functional groups

Building structure

Use contrasting examples

- **Use contrasting examples** with critical attributes
  - Look for differences, not similarities
- Similar examples are hard to learn together
  - Latitude and longitude
  - Simile and metaphor
  - Meiosis and mitosis
- Point out the differences first
- Discuss them one at a time



Drawing Skeletal Structures — **Solving a Problem**

Contrasting Examples

a. Butane, used as a fuel in lighters

b. Isopropyl alcohol, rubbing alcohol

STEP 1 **Determine the number of carbons connected end to end.**
a. In butane, there are four carbons.
b. In isopropyl alcohol, there are three carbons.

STEP 2 **Draw the bonds between the carbons (the carbon skeleton).** These are highlighted in the molecules that follow. Zigzag the lines so that you can see where one bond ends and the next begins. Sometimes, it is useful to put a dot at the end of the bond so that you can see the position of the carbons.

Carbon
Bond between carbons

STEP 3 **Draw bonds to noncarbon atoms.** Butane only contains carbon and hydrogen. Isopropyl alcohol contains an oxygen with a hydrogen bonded to it. This is represented in skeletal structure as shown. Note that the lone pairs of electrons on the oxygen are also implied in the skeletal structure.

Building Structure

Provide review information

CHAPTER READINESS*

KEY MATH SKILLS

- Using Positive and Negative Numbers in Calculations (1.4)
- Solving Equations (1.4)
- Interpreting Graphs (1.4)
- Converting between Standard Numbers and Scientific Notation (1.5)
- Rounding Off (2.3)

CORE CHEMISTRY SKILLS

- Counting Significant Figures (2.2)
- Using Significant Figures in Calculations (2.3)
- Writing Conversion Factors from Equalities (2.5)
- Using Conversion Factors (2.6)

*These Key Math Skills and Core Chemistry Skills from previous chapters are listed here for your review as you proceed to the new material in this chapter.

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Generate Understanding

Color Blocks Identify Factors

SAMPLE PROBLEM 2.11 Problem Solving Using Two Conversion Factors

Synthroid is used as a replacement or supplemental therapy for diminished thyroid function. A doctor's order prescribes a dosage of 0.150 mg of Synthroid. If tablets in stock contain 75 mcg of Synthroid, how many tablets are required to provide the prescribed medication?

SOLUTION

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need
	0.150 mg of Synthroid	number of tablets

STEP 2 Write a plan to convert the given unit to the needed unit.

milligrams → (Metric factor) → micrograms → (Clinical factor) → number of tablets

STEP 3 State the equalities and conversion factors.

$$1\text{ mg} = 1000\text{ mcg} \qquad 1\text{ tablet} = 75\text{ mcg of Synthroid}$$

$$\frac{1\text{ mg}}{1000\text{ mcg}} \text{ and } \frac{1000\text{ mcg}}{1\text{ mg}} \qquad \frac{1\text{ tablet}}{75\text{ mcg Synthroid}} \text{ and } \frac{75\text{ mcg Synthroid}}{1\text{ tablet}}$$

STEP 4 Set up the problem to cancel units and calculate the answer. The problem can be set up using the metric factor to cancel milligrams, and then the clinical factor to obtain the number of tablets as the final unit.

$$0.150\ \cancel{\text{mg Synthroid}} \times \frac{1000\ \cancel{\text{mcg}}}{1\ \cancel{\text{mg}}} \times \frac{1\text{ tablet}}{75\ \cancel{\text{mcg Synthroid}}} = 2\text{ tablets}$$

(Exact; Exact; Three SFs; Exact; Two SFs)

56

Retrieval-practice

53%

39%

28%

What is better, re-reading or retrieval-practice?

S = Study
T = Test

Cramming actually works short term!

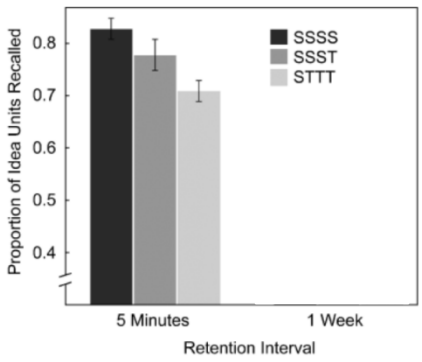

Fig. 2. Mean proportion of idea units recalled on the final test after a 5-min or 1-week retention interval as a function of learning condition (SSSS, SSST, or STTT) in Experiment 2. The labels for the learning conditions indicate the order of study (S) and test (T) periods. Error bars represent standard errors of the means.

Retrieval-practice works for retention

Roediger, H.L., & Karpicke, J.D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Science, 17,* 249-255.

Opportunities for Retrieval Practice
Suggested Practice Problems

CHAPTER 6

CHAPTER REVIEW

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STUDY GUIDE

6.1 Classes of Carbohydrates

Classify carbohydrates.

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Locate organic functional groups in monosaccharides.

- Distinguish primary, secondary, and tertiary alcohols. (Try 6.5, 6.53)
- Recognize and draw the functional groups alcohol, aldehyde, and ketone. (Try 6.7, 6.51)

SUMMARY

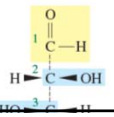
Inquiry Question

How do we classify carbohydrates?

Carbohydrates are classified as monosaccharides (simple sugars), disaccharides (two monosaccharide units), oligosaccharides (three to nine monosaccharide units), and polysaccharides (many monosaccharide units). The simplest carbohydrates are the monosaccharides with a molecular formula of $C_n(H_2O)_n$ where $n = 3–6$. Edible carbohydrates that cannot be broken down by the body's enzymes are classified as either soluble or insoluble fibers based on their ability to mix with water.

Inquiry Question

What functional groups are present in monosaccharides?



Monosaccharides contain several alcohol (hydroxyl) groups, and either an aldehyde or a ketone functional group. Alcohols can be primary, secondary, or tertiary depending on the number of carbons attached to the alcohol carbon. Aldehydes and ketones are carbonyl-containing functional groups

Opportunities for Retrieval Practice
Self-Test Practice Problems

SELF-TEST
Problems 1.21 and 1.22

STUDY CHECK 1.4

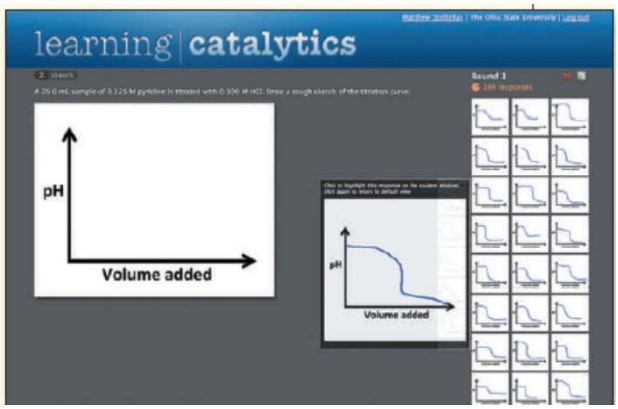
A bullet seized from the suspect's ammunition has a composition of lead 11.6 g, tin 0.5 g, and antimony 0.4 g.

a. What is the percentage of each metal in the bullet? Express your answers to the ones place.
b. Could the bullet removed from the suspect's ammunition be considered as evidence that the suspect was at the crime scene mentioned in Sample Problem 1.4?

ANSWER

a. The bullet from the suspect's ammunition is lead 93%, tin 4%, and antimony 3%.
b. The composition of this bullet does not match the bullet from the crime scene and cannot be used as evidence.

Opportunities for Retrieval Practice
During Class – Clicker Questions



Student Responses

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Opportunities for Retrieval Practice
After Class – Video Practice

Practicing the Concepts
Predicting Solubility of Molecules in Water

Blue play button icons in margins of text
- ask students to practice the concepts through watching a short video
- use QR on text cover

Green play button icons
margins throughout text
introduce key topics before/after class
walk through problem solving
in web and mobile formats in etexts
at App Store
or use QR on text cover

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Opportunities for Retrieval Practice

After Class – Online Homework

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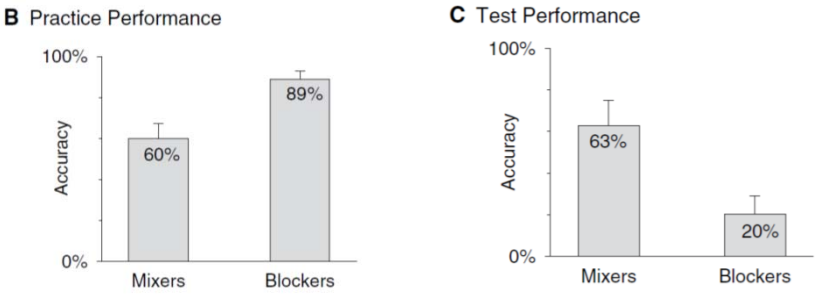
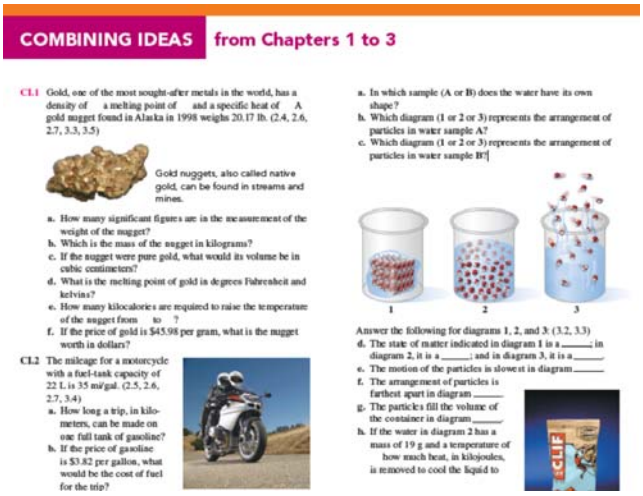
Mix, don't Block



- Blocking facilitates processing of similarities, mixing facilitates processing of differences.

Rohrer, D., & Taylor, K. (2007). The shuffling of mathematics problems improves learning, *Instructional Science, 35(6),* 481-498.

Mixing
Combining Ideas



COMBINING IDEAS from Chapters 1 to 3

CI.1 Gold, one of the most sought-after metals in the world, has a density of a melting point of and a specific heat of A gold nugget found in Alaska in 1998 weighs 20.17 lb. (2.4, 2.6, 2.7, 3.3, 3.5)

Gold nuggets, also called native gold, can be found in streams and mines.

a. How many significant figures are in the measurement of the weight of the nugget?
b. Which is the mass of the nugget in kilograms?
c. If the nugget were pure gold, what would its volume be in cubic centimeters?
d. What is the melting point of gold in degrees Fahrenheit and kelvins?
e. How many kilocalories are required to raise the temperature of the nugget from to ?
f. If the price of gold is $45.98 per gram, what is the nugget worth in dollars?

CI.2 The mileage for a motorcycle with a fuel-tank capacity of 22 L is 35 mi/gal. (2.5, 2.6, 2.7, 3.4)

a. How long a trip, in kilometers, can be made on one full tank of gasoline?
b. If the price of gasoline is $3.82 per gallon, what would be the cost of fuel for the trip?

a. In which sample (A or B) does the water have its own shape?
b. Which diagram (1 or 2 or 3) represents the arrangement of particles in water sample A?
c. Which diagram (1 or 2 or 3) represents the arrangement of particles in water sample B?

1 2 3

Answer the following for diagrams 1, 2, and 3: (3.2, 3.3)
d. The state of matter indicated in diagram 1 is a _____; in diagram 2, it is a _____; and in diagram 3, it is a _____.
e. The motion of the particles is slowest in diagram _____.
f. The arrangement of particles is farthest apart in diagram _____.
g. The particles fill the volume of the container in diagram _____.
h. If the water in diagram 2 has a mass of 19 g and a temperature of how much heat, in kilojoules, is removed to cool the liquid to

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Why Interleave vs. Block?

Interleave $a_1\, b_1\, c_1\, b_2\, c_2\, a_2\, c_3\, b_3\, a_3$

Block $a_1\, a_2\, a_3\, b_1\, b_2\, b_3\, c_1\, c_2\, c_3$

Interleaved practice requires the brain to bring the appropriate knowledge into working memory each time ABCBCACBA (9)
Block practice only requires this process the first time AAABBBCCC (3).

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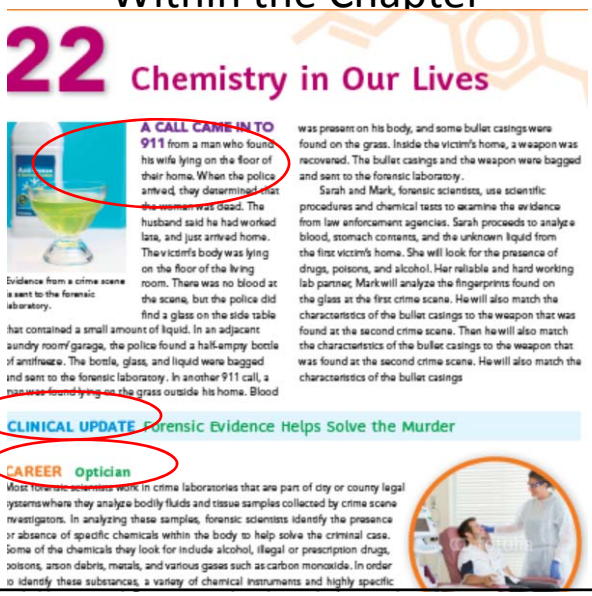
Interleaving
Within the Chapter

Clinical Themes Begin each Chapter



22 Chemistry in Our Lives

A CALL CAME IN TO 911 from a man who found his wife lying on the floor of their home. When the police arrived, they determined that the woman was dead. The husband said he had worked late, and just arrived home. The victim's body was lying on the floor of the living room. There was no blood at the scene, but the police did find a glass on the side table that contained a small amount of liquid. In an adjacent laundry room/garage, the police found a half-empty bottle of antifreeze. The bottle, glass, and liquid were bagged and sent to the forensic laboratory. In another 911 call, a man was found lying on the grass outside his home. Blood was present on his body, and some bullet casings were found on the grass. Inside the victim's home, a weapon was recovered. The bullet casings and the weapon were bagged and sent to the forensic laboratory.

Sarah and Mark, forensic scientists, use scientific procedures and chemical tests to examine the evidence from law enforcement agencies. Sarah proceeds to analyze blood, stomach contents, and the unknown liquid from the first victim's home. She will look for the presence of drugs, poisons, and alcohol. Her reliable and hard working lab partner, Mark will analyze the fingerprints found on the glass at the first crime scene. He will also match the characteristics of the bullet casings to the weapon that was found at the second crime scene. Then he will also match the characteristics of the bullet casings to the weapon that was found at the second crime scene. He will also match the characteristics of the bullet casings

Evidence from a crime scene is sent to the forensic laboratory.

CLINICAL UPDATE Forensic Evidence Helps Solve the Murder

CAREER Optician

Most forensic scientists work in crime laboratories that are part of city or county legal systems where they analyze bodily fluids and tissue samples collected by crime scene investigators. In analyzing these samples, forensic scientists identify the presence or absence of specific chemicals within the body to help solve the criminal case. Some of the chemicals they look for include alcohol, illegal or prescription drugs, poisons, arson debris, metals, and various gases such as carbon monoxide. In order to identify these substances, a variety of chemical instruments and highly specific

Interleaving
Clinical Themes Within the Chapter

CLINICAL UPDATE

Forensic Evidence Solves the Murder

Using a variety of laboratory tests, Sarah finds ethylene glycol in the victim's blood. The quantitative tests indicate that the victim had ingested 125 g of ethylene glycol. Sarah determines that the liquid in a glass found at the crime scene was ethylene glycol that had been added to an alcoholic beverage. Ethylene glycol is a clear, sweet-tasting, thick liquid that is odorless and mixes with water. It is easy to obtain since it is used as antifreeze in automobiles and in brake fluid. Because the symptoms of ethylene glycol poisoning are similar to intoxication, the victim is often unaware of its presence.

If ingestion of ethylene glycol occurs, it can cause depression of the central nervous system, cardiovascular damage, and kidney failure. If discovered quickly, hemodialysis may be used to remove ethylene glycol from the blood. A toxic amount of ethylene glycol is 1.5 g of ethylene glycol/kg of body mass. Thus, 75 g could be fatal for a 50-kg (110 lb) person. Mark determines that fingerprints on the glass containing the ethylene glycol were those of the victim's husband. This evidence along with the container of antifreeze found in the home led to the arrest and conviction of the husband for poisoning his wife.

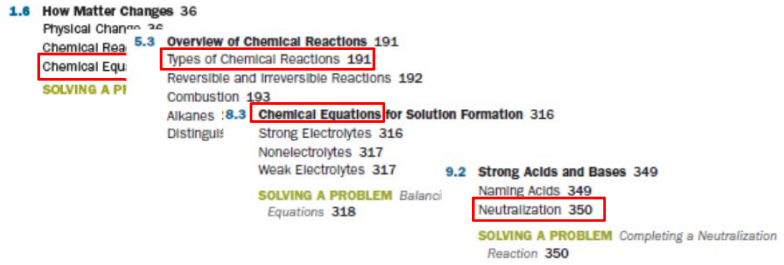
Clinical Applications

1.31 A container was found in the home of the victim that contained 120 g of ethylene glycol in 450 g of liquid. What was the percentage of ethylene glycol? Express your answer to the ones place.

1.32 If the toxic quantity is 1.5 g of ethylene glycol per 1000 g of body mass, what percentage of ethylene glycol is fatal?

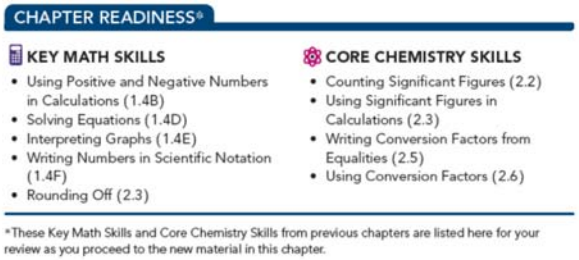
Interleaving
Throughout textbook

- Re-introduce topics during the semester



- Develop homework sets for your text that brings in material from previous chapters

Interleaving
Chapter Readiness
Skills Needed from Previous Chapters



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How can we help our readers?

- **Build a Structure**
- **Generate Understanding**
- **Offer Opportunities for Retrieval Practice**
- **Mix, Don't Block**

Successful Learning

This is beginning to making sense now.

I actually got a B+ on the last exam. Looks like I can do this.

75

Acknowledgements

Mark McDaniel, Ph.D.
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