

# ALGEBRA & TRIGONOMETRY

Enhanced with Graphing Utilities

Seventh Edition



SULLIVAN • SULLIVAN

Available in MyMathLab<sup>®</sup> for Your Precalculus Course



## Achieve Your Potential

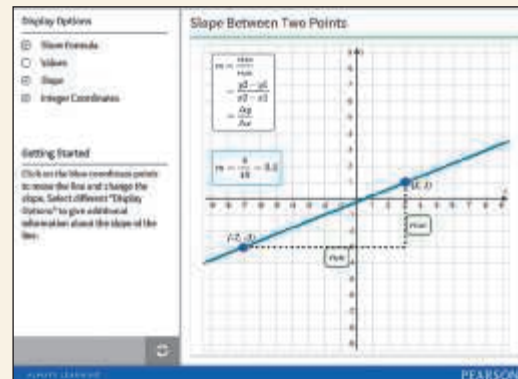
Success in math can make a difference in your life. MyMathLab is a learning experience with resources to help you achieve your potential in this course and beyond. MyMathLab will help you learn the new skills required, and also help you learn the concepts and make connections for future courses and careers.

## Visualization and Conceptual Understanding

These MyMathLab resources will help you think visually and connect the concepts.

### NEW! Guided Visualizations

These engaging interactive figures bring mathematical concepts to life, helping students visualize the concepts through directed explorations and purposeful manipulation. *Guided Visualizations* are assignable in MyMathLab and encourage active learning, critical thinking, and conceptual learning.



**EXAMPLE** Finding Vertical Asymptotes

Find the vertical asymptotes, if any, of the graph of each rational function.

$$R(x) = \frac{5x^2}{3+x}$$

$$R(x) = \frac{x^2 - 3x - 4}{x^2 + x + 1} = \frac{(x-4)(x+1)}{x^2 + x + 1}$$

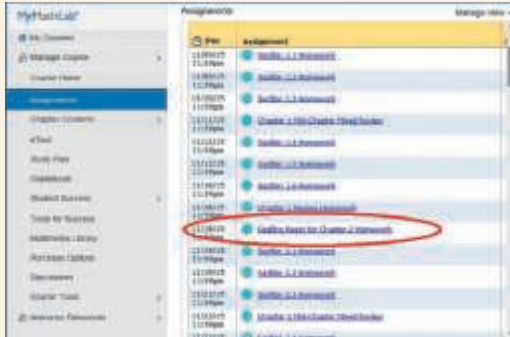
$$x^2 + x + 1 = 0$$

### Video Assessment Exercises

Video assessment is tied to key Author in Action videos to check students' conceptual understanding of important math concepts. Students watch a video and work corresponding assessment questions.

## Preparedness and Study Skills

MyMathLab® gives access to many learning resources that refresh knowledge of topics previously learned. *Getting Ready* material, *Retain Your Knowledge Exercises*, and *Note-Taking Guides* are some of the tools available.

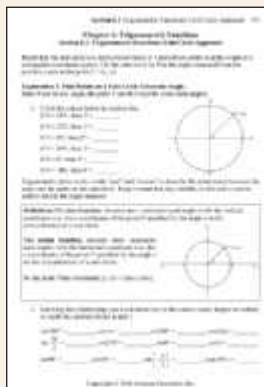
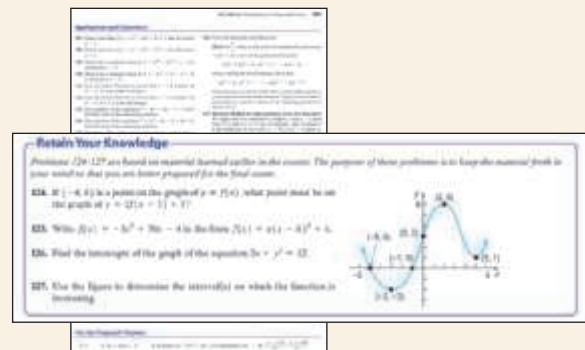


### Getting Ready

Students refresh prerequisite topics through skill review quizzes and personalized homework integrated in MyMathLab. With *Getting Ready* content in MyMathLab students get just the help they need to be prepared to learn the new material.

### Retain Your Knowledge Exercises

New! *Retain Your Knowledge Exercises* support ongoing review at the course level and help students maintain essential skills.



### Guided Lecture Notes

Get help focusing on important concepts with the use of this structured organized note-taking tool. The *Guided Lecture Notes* are available in MyMathLab for download or as a printed student supplement.


# Prepare for Class “Read the Book”

Feature	Description	Benefit	Page(s)
<b>Every Chapter Opener begins with ...</b>			
<b>Chapter-Opening Topic &amp; Project</b>	Each chapter begins with a discussion of a topic of current interest and ends with a related project.	In the concluding project, you will apply what you have learned to solve a problem related to the topic.	407, 511
 <b>Internet-Based Projects</b>	These projects allow for the integration of spreadsheet technology that you will need to be a productive member of the workforce.	The projects give you an opportunity to collaborate and use mathematics to deal with issues of current interest.	407, 511
<b>Every Section begins with ...</b>			
<b>Learning Objectives</b> 	Each section begins with a list of objectives. Individual objectives also appear in the text where they are covered.	These objectives focus your studying by emphasizing what's most important and where to find it.	428
<b>Sections contain ...</b>			
<b>PREPARING FOR THIS SECTION</b>	Most sections begin with a list of key concepts to review, with page numbers.	Ever forget what you've learned? This feature highlights previously learned material to be used in this section. Review it, and you'll always be prepared to move forward.	428
<b>Now Work the 'Are You Prepared?' Problems</b>	These problems assess whether you have the prerequisite knowledge for the upcoming section.	Not sure you need the Preparing for This Section review? Work the 'Are You Prepared?' problems. If you get one wrong, you'll know exactly what you need to review and where to review it!	428, 439
 <b>Now Work PROBLEMS</b>	These follow most examples and direct you to a related exercise.	We learn best by doing. You'll solidify your understanding of examples if you try a similar problem right away, to be sure you understand what you've just read.	437
<b>WARNING</b>	Warnings are provided in the text.	These point out common mistakes and help you avoid them.	462
<b>Explorations and Seeing the Concept</b>	These graphing utility activities foreshadow a concept or reinforce a concept just presented.	You will obtain a deeper and more intuitive understanding of theorems and definitions.	377, 434
 <b>In Words</b>	This feature provides alternative descriptions of select definitions and theorems.	Does math ever look foreign to you? This feature translates math into plain English.	430
 <b>Calculus</b>	This symbol appears next to information essential for the study of calculus.	Pay attention—if you spend extra time now, you'll do better later!	236, 238, 373
<b>SHOWCASE EXAMPLES</b>	These examples provide “how to” instruction by offering a guided, step-by-step approach to solving a problem.	With each step presented on the left and the mathematics displayed on the right, you can immediately see how each step is employed.	342–343
 <b>Model It! Examples and Problems</b>	These examples and problems require you to build a mathematical model from either a verbal description or data. The homework Model It! problems are marked by purple problem numbers.	It is rare for a problem to come in the form “Solve the following equation.” Rather, the equation must be developed based on an explanation of the problem. These problems require you to develop models that will enable you to describe the problem mathematically and suggest a solution to the problem.	453, 482

## Practice “Work the Problems”

Feature	Description	Benefit	Page(s)
<b>‘Are You Prepared?’ Problems</b>	These problems assess your retention of the prerequisite material. Answers are given at the end of the section exercises. This feature is related to the Preparing for This Section feature.	Do you always remember what you’ve learned? Working these problems is the best way to find out. If you get one wrong, you’ll know exactly what you need to review and where to review it!	428, 439
<b>Concepts and Vocabulary</b>	These short-answer questions, mainly fill-in-the-blank, multiple-choice, and true/false items, assess your understanding of key definitions and concepts in the current section.	It is difficult to learn math without knowing the language of mathematics. These problems test your understanding of the formulas and vocabulary.	440
<b>Skill Building</b>	Correlated with section examples, these problems provide straightforward practice.	It’s important to dig in and develop your skills. These problems give you ample opportunity to do so.	440–442
<b>Mixed Practice</b>	These problems offer comprehensive assessment of the skills learned in the section by asking problems related to more than one concept or objective. These problems may also require you to utilize skills learned in previous sections.	Learning mathematics is a building process. Many concepts build on each other and are related. These problems help you see how mathematics builds on itself and how the concepts are linked together.	442
<b>Applications and Extensions</b>	These problems allow you to apply your skills to real-world problems. They also enable you to extend concepts learned in the section.	You will see that the material learned within the section has many uses in everyday life.	442–444
<b>Explaining Concepts: Discussion and Writing</b>	“Discussion and Writing” problems are colored red. They support class discussion, verbalization of mathematical ideas, and writing and research projects.	To verbalize an idea, or to describe it clearly in writing, shows real understanding. These problems nurture that understanding. Many are challenging, but you’ll get out what you put in.	445
<b>NEW! Retain Your Knowledge</b>	These problems allow you to practice content learned earlier in the course.	Remembering how to solve all the different kinds of problems that you encounter throughout the course is difficult. This practice helps you remember previously learned skills.	445
<b>Now Work PROBLEMS</b>	Many examples refer you to a related homework problem. These related problems are marked by a pencil and orange numbers.	If you get stuck while working problems, look for the closest Now Work problem, and refer to the related example to see if it helps.	429, 437, 438, 441
<b>Review Exercises</b>	Every chapter concludes with a comprehensive list of exercises to practice. Use the list of objectives to determine what objective and examples correspond to each problem.	Work these problems to ensure that you understand all the skills and concepts employed in the chapter. Think of it as a comprehensive review of the chapter. All answers to Chapter Review problems appear in the back of the text.	506–509

# Review “Study for Quizzes and Tests”

Feature	Description	Benefit	Page(s)
<b>The Chapter Review at the end of each chapter contains ...</b>			
<b>Things to Know</b>	A detailed list of important theorems, formulas, and definitions from the chapter.	Review these and you'll know the most important material in the chapter!	504–505
<b>You Should Be Able to ...</b>	A complete list of objectives by section and, for each, examples that illustrate the objective, and practice exercises that test your understanding of the objective.	Do the recommended exercises and you'll have mastered the key material. If you get something wrong, go back and work through the example listed, and try again.	505–506
<b>Review Exercises</b>	These provide comprehensive review and practice of key skills, matched to the Learning Objectives for each section.	Practice makes perfect. These problems combine exercises from all sections, giving you a comprehensive review in one place.	506–509
<b>Chapter Test</b>	About 15–20 problems that can be taken as a Chapter Test. Be sure to take the Chapter Test under test conditions—no notes!	Be prepared. Take the sample practice test under test conditions. This will get you ready for your instructor's test. If you get a problem wrong, you can watch the Chapter Test Prep Video.	509
<b>Cumulative Review</b>	These problem sets appear at the end of each chapter, beginning with Chapter 2. They combine problems from previous chapters, providing an ongoing cumulative review. When you use them in conjunction with the Retain Your Knowledge problems, you will be ready for the final exam.	These problem sets are really important. Completing them will ensure that you are not forgetting anything as you go. This will go a long way toward keeping you primed for the final exam.	510
<b>Chapter Projects</b>	The Chapter Projects apply to what you've learned in the chapter. Additional projects are available on the Instructor's Resource Center (IRC).	The Chapter Projects give you an opportunity to apply what you've learned in the chapter to the opening topic. If your instructor allows, these make excellent opportunities to work in a group, which is often the best way of learning math.	511
 <b>Internet-Based Projects</b>	In selected chapters, a Web-based project is given.	These projects give you an opportunity to collaborate and use mathematics to deal with issues of current interest by using the Internet to research and collect data.	511

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# ALGEBRA & TRIGONOMETRY

**Enhanced with Graphing Utilities**

Seventh Edition

**Michael Sullivan**

Chicago State University

**Michael Sullivan III**

Joliet Junior College

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Acquisitions Editor: *Dawn Murrin*  
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Production Coordination,  
Composition, Illustrations: *Cenveo® Publisher Services*  
Associate Director of Design,  
USHE EMSS/HSC/EDU: *Andrea Nix*  
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Colleen (O'Hara) and Bill	Kaleigh, Billy, Timmy

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# Three Distinct Series

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Students have different goals, learning styles, and levels of preparation. Instructors have different teaching philosophies, styles, and techniques. Rather than write one series to fit all, the Sullivans have written three distinct series. All share the same goal—to develop a high level of mathematical understanding and an appreciation for the way mathematics can describe the world around us. The manner of reaching that goal, however, differs from series to series.

## Enhanced with Graphing Utilities Series, Seventh Edition

This series provides a thorough integration of graphing utilities into topics, allowing students to explore mathematical concepts and encounter ideas usually studied in later courses. Using technology, the approach to solving certain problems differs from the Contemporary or Concepts through Functions Series, while the emphasis on understanding concepts and building strong skills does not: *College Algebra, Algebra & Trigonometry, Precalculus*.

## Contemporary Series, Tenth Edition

The Contemporary Series is the most traditional in approach, yet modern in its treatment of precalculus mathematics. Graphing utility coverage is optional and can be included or excluded at the discretion of the instructor: *College Algebra, Algebra & Trigonometry, Trigonometry: A Unit Circle Approach, Precalculus*.

## Concepts through Functions Series, Third Edition

This series differs from the others, utilizing a functions approach that serves as the organizing principle tying concepts together. Functions are introduced early in various formats. This approach supports the Rule of Four, which states that functions are represented symbolically, numerically, graphically, and verbally. Each chapter introduces a new type of function and then develops all concepts pertaining to that particular function. The solutions of equations and inequalities, instead of being developed as stand-alone topics, are developed in the context of the underlying functions. Graphing utility coverage is optional and can be included or excluded at the discretion of the instructor: *College Algebra; Precalculus, with a Unit Circle Approach to Trigonometry; Precalculus, with a Right Triangle Approach to Trigonometry*.

# The Enhanced with Graphing Utilities Series

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## College Algebra

This text provides an approach to college algebra that completely integrates graphing technology without sacrificing mathematical analysis and conceptualization. The text has three chapters of review material preceding the chapters on functions. After completing this text, a student will be prepared for trigonometry, finite mathematics, and business calculus.

## Algebra & Trigonometry

This text contains all the material in *College Algebra*, but it also develops the trigonometric functions using a right triangle approach and shows how that approach is related to the unit circle approach. Graphing techniques are emphasized, including a thorough discussion of polar coordinates, parametric equations, and conics using polar coordinates. Graphing calculator usage is integrated throughout. After completing this text, a student will be prepared for finite mathematics, business calculus, and engineering calculus.

## Precalculus

This text contains one review chapter before covering the traditional precalculus topics of functions and their graphs, polynomial and rational functions, and exponential and logarithmic functions. The trigonometric functions are introduced using a unit circle approach and show how it is related to the right triangle approach. Graphing techniques are emphasized, including a thorough discussion of polar coordinates, parametric equations, and conics using polar coordinates. Graphing calculator usage is integrated throughout. The final chapter provides an introduction to calculus, with a discussion of the limit, the derivative, and the integral of a function. After completing this text, a student will be prepared for finite mathematics, business calculus, and engineering calculus.

# Preface to the Instructor

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As professors at an urban university and a community college, Michael Sullivan and Michael Sullivan III are aware of the varied needs of Algebra and Trigonometry students. Such students range from those who have little mathematical background and are fearful of mathematics courses, to those with a strong mathematical education and a high level of motivation. For some of your students, this will be their last course in mathematics, whereas others will further their mathematical education. We have written this text with both groups in mind.

As a teacher, and as an author of precalculus, engineering calculus, finite mathematics, and business calculus texts, Michael Sullivan understands what students must know if they are to be focused and successful in upper-level math courses. However, as a father of four, he also understands the realities of college life. As an author of a developmental mathematics series, Michael's son and co-author, Michael Sullivan III, understands the trepidations and skills that students bring to the Algebra and Trigonometry course. As the father of a current college student, Michael III realizes that today's college students demand a variety of media to support their education. This text addresses that demand by providing technology and video support that enhances understanding without sacrificing math skills. Together, both authors have taken great pains to ensure that the text offers solid, student-friendly examples and problems, as well as a clear and seamless writing style.

A tremendous benefit of authoring a successful series is the broad-based feedback we receive from teachers and students. We are sincerely grateful for their support. Virtually every change in this edition is the result of their thoughtful comments and suggestions. We are confident that, building on the success of the first six editions and incorporating many of these suggestions, we have made *Algebra & Trigonometry Enhanced with Graphing Utilities*, 7th Edition, an even better tool for learning and teaching. We continue to encourage you to share with us your experiences teaching from this text.

## Features in the Seventh Edition

A descriptive list of the many special features of *Algebra & Trigonometry* can be found in the front of this text.

This list places the features in their proper context, as building blocks of an overall learning system that has been carefully crafted over the years to help students get the most out of the time they put into studying. Please take the time to review this and to discuss it with your students at the beginning of your course. When students utilize these features, they are more successful in the course.

## New to the Seventh Edition

- **Retain Your Knowledge** This new category of problems in the exercise set is based on the article “To Retain

New Learning, Do the Math” published in the *Educational Review*. In this article, Kevin Washburn suggests that “the more students are required to recall new content or skills, the better their memory will be.” It is frustrating when students cannot recall skills learned earlier in the course. To alleviate this recall problem, we have created “Retain Your Knowledge” problems. These are problems considered to be “final exam material” that students can use to maintain their skills. All the answers to these problems appear in the back of the text, and all are programmed in MyMathLab.

- **Guided Lecture Notes** Ideal for online, emporium/redesign courses, inverted classrooms, or traditional lecture classrooms. These lecture notes help students take thorough, organized, and understandable notes as they watch the Author in Action videos. They ask students to complete definitions, procedures, and examples based on the content of the videos and text. In addition, experience suggests that students learn by doing and understanding the why/how of the concept or property. Therefore, many sections have an exploration activity to motivate student learning. These explorations introduce the topic and/or connect it to either a real-world application or a previous section. For example, when the vertical-line test is discussed in Section 3.2, after the theorem statement, the notes ask the students to explain why the vertical-line test works by using the definition of a function. This challenge helps students process the information at a higher level of understanding.
- **Illustrations** Many of the figures now have captions to help connect the illustrations to the explanations in the body of the text.
- **TI Screen Shots** In this edition we have replaced all the screen shots from the sixth edition with screen shots using TI-84 Plus C. These updated screen shots help students visualize concepts clearly and help make stronger connections among equations, data, and graphs in full color.
- **Exercise Sets** All the exercises in the text have been reviewed and analyzed for this edition, some have been removed, and new ones have been added. All time-sensitive problems have been updated to the most recent information available. The problem sets remain classified according to purpose.

The “*Are You Prepared?*” problems have been improved to better serve their purpose as a just-in-time review of concepts that the student will need to apply in the upcoming section.

The *Concepts and Vocabulary* problems have been expanded and now include multiple-choice exercises. Together with the fill-in-the-blank and true/false problems, these exercises have been written to serve as reading quizzes.



**Skill Building** problems develop the student's computational skills with a large selection of exercises that are directly related to the objectives of the section. **Mixed Practice** problems offer a comprehensive assessment of skills that relate to more than one objective. Often these require skills learned earlier in the course.

**Applications and Extensions** problems have been updated. Further, many new application-type exercises have been added, especially ones involving information and data drawn from sources the student will recognize, to improve relevance and timeliness.

The **Explaining Concepts: Discussion and Writing** exercises have been improved and expanded to provide more opportunity for classroom discussion and group projects.

New to this edition, **Retain Your Knowledge** exercises consist of a collection of four problems in each exercise set that are based on material learned earlier in the course. They serve to keep information that has already been learned “fresh” in the mind of the student. Answers to all these problems appear in the Student Edition.

The **Review Exercises** in the Chapter Review have been streamlined, but they remain tied to the clearly expressed objectives of the chapter. Answers to all these problems appear in the Student Edition.

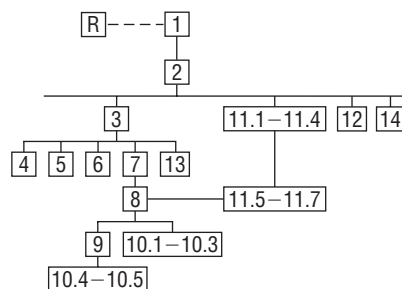
- **Annotated Instructor's Edition** As a guide, the author's suggestions for homework assignments are indicated by a blue underscore below the problem number. These problems are assignable in MyMathLab.

## Content Changes in the Seventh Edition

- **Section 3.1** The objective Find the Difference Quotient of a Function has been added.
- **Section 5.2** The objective Use Descartes' Rule of Signs has been included.
- **Section 5.2** The theorem Bounds on the Zeros of a Polynomial Function is now based on the traditional method of using synthetic division.
- **Section 5.5** Content has been added that discusses the role of multiplicity of the zeros of the denominator of a rational function as it relates to the graph near a vertical asymptote.

## Using the Seventh Edition Effectively with Your Syllabus

To meet the varied needs of diverse syllabi, this text contains more content than is likely to be covered in an *Algebra and Trigonometry* course. As the chart illustrates, this text has been organized with flexibility of use in mind. Within a given chapter, certain sections are optional (see the details that follow the accompanying figure) and can be omitted without loss of continuity.



### Chapter R Review

This chapter consists of review material. It may be used as the first part of the course or later as a just-in-time review when the content is required. Specific references to this chapter occur throughout the text to assist in the review process.

### Chapter 1 Equations and Inequalities

Primarily a review of intermediate algebra topics, this material is a prerequisite for later topics. The coverage of complex numbers and quadratic equations with a negative discriminant is optional and may be postponed or skipped entirely without loss of continuity.

### Chapter 2 Graphs

This chapter lays the foundation for functions. Section 2.4 is optional.

### Chapter 3 Functions and Their Graphs

This is perhaps the most important chapter. Section 3.6 is optional.

### Chapter 4 Linear and Quadratic Functions

Topic selection depends on your syllabus. Sections 4.2 and 4.4 may be omitted without loss of continuity.

### Chapter 5 Polynomial and Rational Functions

Topic selection depends on your syllabus.

### Chapter 6 Exponential and Logarithmic Functions

Sections 6.1–6.6 follow in sequence. Sections 6.7, 6.8, and 6.9 are optional.

### Chapter 7 Trigonometric Functions

Section 7.8 may be omitted in a brief course.

### Chapter 8 Analytic Trigonometry

Sections 8.2, 8.6, and 8.7 may be omitted in a brief course.

### Chapter 9 Applications of Trigonometric Functions

Sections 9.4 and 9.5 may be omitted in a brief course.

### Chapter 10 Polar Coordinates; Vectors

Sections 10.1–10.3 and Sections 10.4–10.5 are independent and may be covered separately.

**Chapter 11 Analytic Geometry**

Sections 11.1–11.4 follow in sequence. Sections 11.5, 11.6, and 11.7 are independent of each other, but each requires Sections 11.1–11.4.

**Chapter 12 Systems of Equations and Inequalities**

Sections 12.2–12.7 may be covered in any order, but each requires Section 12.1. Section 12.8 requires Section 12.7.

**Chapter 13 Sequences; Induction; The Binomial Theorem**

There are three independent parts: Sections 13.1–13.3, Section 13.4, and Section 13.5.

**Chapter 14 Counting and Probability**

The sections follow in sequence.

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James Africh, College of DuPage	Annette Blackwelder, Florida State University	Jim Campbell, Lincoln Public Schools	Joanna DelMonaco, Middlesex Community College
Steve Agronsky, Cal Poly State University	Richelle Blair, Lakeland Community College	Roger Carlsen, Moraine Valley Community College	Vivian Dennis, Eastfield College
Gerardo Aladro, Florida International University	Linda Blanco, Joliet Junior College	Elena Catoiu, Joliet Junior College	Deborah Dillon, R. L. Turner High School
Grant Alexander, Joliet Junior College	Kevin Bodden, Lewis and Clark College	Mathews Chakkanakuzhi, Palomar College	Guesna Dohrman, Tallahassee Community College
Dave Anderson, South Suburban College	Jeffrey Boerner, University of Wisconsin-Stout	Tim Chappell, Penn Valley Community College	Cheryl Doolittle, Iowa State University
Richard Andrews, Florida A&M University	Barry Booten, Florida Atlantic University	John Collado, South Suburban College	Karen R. Dougan, University of Florida
Joby Milo Anthony, University of Central Florida	Rebecca Bonk, Joliet Junior College	Alicia Collins, Mesa Community College	Jerrett Dumouchel, Florida Community College at Jacksonville
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Carolyn Autray, University of West Georgia	Trudy Bratten, Grossmont College	Jim Cooper, Joliet Junior College	Don Edmondson, University of Texas-Austin
Agnes Azzolino, Middlesex County College	Martin Bredeck, Northern Virginia Community College (Annandale Campus)	Denise Corbett, East Carolina University	Erica Egizio, Lewis University
Taoufik Bahadi, University of Tampa	Tim Bremer, Broome Community College	Carlos C. Corona, San Antonio College	Laura Egner, Joliet Junior College
Wilson P. Banks, Illinois State University	Tim Britt, Jackson State Community College	Theodore C. Coskey, South Seattle Community College	Jason Eltrevoog, Joliet Junior College
Scott Barnett, Henry Ford Community College	Michael Brook, University of Delaware	Rebecca Connell, Troy University	Christopher Ennis, University of Minnesota
Sudeshna Basu, Howard University	Joanne Brunner, Joliet Junior College	Donna Costello, Plano Senior High School	Kathy Eppler, Salt Lake Community College
Dale R. Bedgood, East Texas State University	Warren Burch, Brevard Community College	Paul Crittenden, University of Nebraska at Lincoln	Ralph Esparza Jr., Richland College
Beth Beno, South Suburban College	Mary Butler, Lincoln Public Schools	John Davenport, East Texas State University	Garret J. Etgen, University of Houston
Carolyn Bernath, Tallahassee Community College	Melanie Butler, West Virginia University	Faye Dang, Joliet Junior College	Scott Fallstrom, Shoreline Community College
Rebecca Berthiaume, Edison State College	Jim Butterbach, Joliet Junior College	Antonio David, Del Mar College	Pete Falzone, Pensacola Junior College
William H. Beyer, University of Akron	William J. Cable, University of Wisconsin-Stevens Point	Stephanie Deacon, Liberty University	Arash Farahmand, Skyline College
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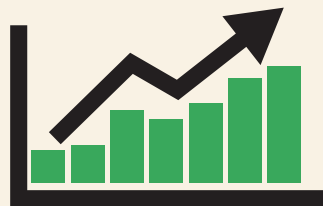
- Iris B. Fetta, Clemson University  
Mason Flake, student at Edison  
Community College  
Timothy W. Flood, Pittsburg State  
University  
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County Community College  
Merle Friel, Humboldt State  
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Richard A. Fritz, Moraine Valley  
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Loran W. Gierhart, University of  
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Palo Alto College  
Robert Gill, University of  
Minnesota Duluth  
Nina Girard, University of  
Pittsburgh at Johnstown  
Sudhir Kumar Goel, Valdosta State  
University  
Adrienne Goldstein, Miami Dade  
College, Kendall Campus  
Joan Goliday, Sante Fe  
Community College  
Lourdes Gonzalez, Miami Dade  
College, Kendall Campus  
Frederic Gooding, Goucher  
College  
Donald Goral, Northern Virginia  
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Sue Graupner, Lincoln Public  
Schools  
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Edward R. Hancock, DeVry  
Institute of Technology  
Julia Hassett, DeVry Institute,  
Dupage  
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University of South Dakota  
Michah Heibel, Lincoln Public  
Schools  
LaRae Helliwell, San Jose City  
College  
Celeste Hernandez, Richland  
College  
Gloria P. Hernandez, Louisiana  
State University at Eunice  
Brother Herron, Brother Rice  
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Robert Hoburg, Western  
Connecticut State University  
Lynda Hollingsworth, Northwest  
Missouri State University  
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University  
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Lee Hruby, Naperville North High  
School  
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University  
Kim Hughes, California State  
College-San Bernardino  
Stanislav, Jabuka, University of  
Nevada, Reno  
Ron Jamison, Brigham Young  
University  
Richard A. Jensen, Manatee  
Community College  
Glenn Johnson, Middlesex  
Community College  
Sandra G. Johnson, St. Cloud State  
University  
Tuesday Johnson, New Mexico  
State University  
Susitha Karunaratne, Purdue  
University North Central  
Moana H. Karsteter, Tallahassee  
Community College  
Donna Katula, Joliet Junior  
College  
Arthur Kaufman, College of  
Staten Island  
Thomas Kearns, North Kentucky  
University  
Jack Keating, Massasoit  
Community College  
Shelia Kellenbarger, Lincoln  
Public Schools  
Rachael Kenney, North Carolina  
State University  
John B. Klassen, North Idaho  
College  
Debra Kopco, Louisiana State  
University  
Lynne Kowski, Raritan Valley  
Community College  
Yelena Kravchuk, University of  
Alabama at Birmingham  
Ray S. Kuan, Skyline College  
Keith Kuchar, Manatee  
Community College  
Tor Kwembe, Chicago State  
University  
Linda J. Kyle, Tarrant County Jr.  
College  
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University  
Harriet Lamm, Coastal Bend  
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James Lapp, Fort Lewis College  
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College  
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University  
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Central Oklahoma  
Tom McCollow, DeVry Institute of  
Technology  
Marilyn McCollum, North  
Carolina State University  
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Will McGowan, Howard  
University  
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College  
Angela McNulty, Joliet Junior  
College  
Laurence Maher, North Texas  
State University  
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Community College  
Rebecca Mann, Apollo High  
School  
Lynn Marecek, Santa Ana College  
Sherry Martina, Naperville North  
High School  
Alec Matheson, Lamar University  
Nancy Matthews, University of  
Oklahoma  
James Maxwell, Oklahoma State  
University-Stillwater  
Marsha May, Midwestern State  
University  
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University  
Judy Meckley, Joliet Junior  
College  
David Meel, Bowling Green State  
University  
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University  
Samia Metwali, Erie Community  
College  
Rich Meyers, Joliet Junior College  
Matthew Michaelson, Glendale  
Community College  
Eldon Miller, University of  
Mississippi  
James Miller, West Virginia  
University  
Michael Miller, Iowa State  
University  
Kathleen Miranda, SUNY at Old  
Westbury  
Chris Mirbaha, The Community  
College of Baltimore County  
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Community College  
Thomas Monaghan, Naperville  
North High School  
Miguel Montanez, Miami Dade  
College, Wolfson Campus  
Maria Montoya, Our Lady of the  
Lake University  
Susan Moosai, Florida Atlantic  
University  
Craig Morse, Naperville North  
High School  
Samad Mortabit, Metropolitan  
State University  
Pat Mower, Washburn University  
Tammy Muhs, University of  
Central Florida  
A. Muhundan, Manatee  
Community College  
Jane Murphy, Middlesex  
Community College  
Richard Nadel, Florida  
International University  
Gabriel Nagy, Kansas State  
University  
Bill Naegele, South Suburban  
College  
Karla Neal, Louisiana State  
University  
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Community College  
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Community College  
Victoria Noddings, MiraCosta  
College  
Denise Nunley, Maricopa  
Community Colleges  
James Nymann, University of  
Texas-El Paso  
Mark Omodt, Anoka-Ramsey  
Community College  
Seth F. Oppenheimer, Mississippi  
State University  
Leticia Oropesa, University of  
Miami  
Linda Padilla, Joliet Junior College  
Sanja Pantic, University of Illinois  
at Chicago  
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University  
Kelly Pearson, Murray State  
University  
Dashmir Petrela, Florida Atlantic  
University  
Philip Pina, Florida Atlantic  
University  
Charlotte Pisors, Baylor University  
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Northern Iowa  
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University  
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University  
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Thomas Radin, San Joaquin Delta  
College  
Aibeng Serene Radulovic, Florida  
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Community College  
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College, Wolfson Campus  
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of Minnesota, MPLS  
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International University  
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Alan Saleski, Loyola University of  
Chicago  
Susan Sandmeyer, Jamestown  
Community College  
Brenda Santistevan, Salt Lake  
Community College  
Linda Schmidt, Greenville  
Technical College  
Ingrid Scott, Montgomery  
College

A.K. Shamma, University of West Florida	Becky Stamper, Western Kentucky University	Florentina Tone, University of West Florida	Kathryn Wetzel, Amarillo College
Zachery Sharon, University of Texas at San Antonio	Judy Staver, Florida Community College-South	Suzanne Topp, Salt Lake Community College	Darlene Whitkenack, Northern Illinois University
Martin Sherry, Lower Columbia College	Robin Steinberg, Pima Community College	Marilyn Toscano, University of Wisconsin, Superior	Suzanne Williams, Central Piedmont Community College
Carmen Shershin, Florida International University	Neil Stephens, Hinsdale South High School	Marvel Townsend, University of Florida	Larissa Williamson, University of Florida
Tatрана Shubin, San Jose State University	Sonya Stephens, Florida A&M Univeristy	Jim Trudnowski, Carroll College	Christine Wilson, West Virginia University
Anita Sikes, Delgado Community College	Patrick Stevens, Joliet Junior College	Robert Tuskey, Joliet Junior College	Brad Wind, Florida International University
Timothy Sipka, Alma College	Mary Stinnett, Umpqua Community College	Mihaela Vajiac, Chapman University-Orange	Anna Wiodarczyk, Florida International University
Charlotte Smedberg, University of Tampa	John Sumner, University of Tampa	Julia Varbalow, Thomas Nelson Community College-Leesville	Mary Wolyniak, Broome Community College
Lori Smellegar, Manatee Community College	Matthew TenHuisen, University of North Carolina, Wilmington	Richard G. Vinson, University of South Alabama	Canton Woods, Auburn University
Gayle Smith, Loyola Blakefield	Christopher Terry, Augusta State University	Jorge Viola-Prioli, Florida Atlantic University	Tamara S. Worner, Wayne State College
Cindy Soderstrom, Salt Lake Community College	Diane Tesar, South Suburban College	Mary Voxman, University of Idaho	Terri Wright, New Hampshire Community Technical College, Manchester
Leslie Soltis, Mercyhurst College	Theresa Thompson, Tulsa Community College	Jennifer Walsh, Daytona Beach Community College	Aletheia Zambesi, University of West Florida
John Spellman, Southwest Texas State University	Tommy Thompson, Brookhaven College	Donna Wandke, Naperville North High School	George Zazi, Chicago State University
Karen Spike, University of North Carolina	Martha K. Tietze, Shawnee Mission Northwest High School	Timothy L. Warkentin, Cloud County Community College	Steve Zuro, Joliet Junior College
Rajalakshmi Sriram, Okaloosa-Walton Community College	Richard J. Tondra, Iowa State University	Melissa J. Watts, Virginia State University	
Katrina Staley, North Carolina Agricultural and Technical State University		Hayat Weiss, Middlesex Community College	

*Michael Sullivan*  
Chicago State University

*Michael Sullivan III*  
Joliet Junior College

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Additional resources can be downloaded from [www.mymathlab.com](http://www.mymathlab.com) or [www.pearsonhighered.com](http://www.pearsonhighered.com) or hardcopy resources can be ordered from your sales representative.

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Includes all answers to the exercises sets. Shorter answers are on the page beside the exercises, and longer answers are in the back of the text. Sample homework assignments are indicated by a blue underline within each end-of-section exercise set and may be assigned in MyMathLab.

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Additional projects that give students an opportunity to apply what they learned in the chapter.

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Author in Action videos are actual classroom lectures with fully worked-out examples presented by Michael Sullivan III. All video is assignable in MyMathLab.

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### Student Solutions Manual

Provides detailed worked-out solutions to odd-numbered exercises.

### Guided Lecture Notes

These lecture notes assist students in taking thorough, organized, and understandable notes while watching Author in Action videos. Students actively participate in learning the how/why of important concepts through explorations and activities. The Guided Lecture Notes are available as pdfs and customizable Word files in MyMathLab. They can also be packaged with the text and MyMathLab access code.

### Algebra Review

Four Chapters of Intermediate Algebra review. Perfect for a slower-paced course or for individual review.

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# To the Student

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As you begin, you may feel anxious about the number of theorems, definitions, procedures, and equations you encounter. You may wonder if you can learn it all in time. Don't worry, your concerns are normal. This text was written with you in mind. If you attend class, work hard, and read and study effectively, you will build the knowledge and skills you need to be successful. Here's how you can use the text to your benefit.

## Read Carefully

When you get busy, it's easy to skip reading and go right to the problems. Don't! The text provides a large number of examples and clear explanations to help you break down the mathematics into easy-to-understand steps. Reading will provide you with a clearer understanding, beyond simple memorization. Read before class (not after) so you can ask questions about anything you didn't understand. You'll be amazed at how much more you'll get out of class when you do this.

## Use the Features

We use many different methods in the classroom to communicate. Those methods, when incorporated into the text, are called "features." The features serve many purposes, from supplying a timely review of material you learned before (just when you need it), to providing organized review sessions to help you prepare for quizzes and tests. Take advantage of the features and you will master the material.

To make this easier, we've provided a brief guide to getting the most from this book. Refer to the "Prepare for Class," "Practice," and "Review" guidelines on pages i–iii. Spend fifteen minutes reviewing the guide and familiarizing yourself with the features by flipping to the page numbers provided. Then, as you read, use them. This is the best way to make the most of your text.

Please do not hesitate to contact us, through Pearson Education, with any questions, comments, or suggestions about ways to improve this text. We look forward to hearing from you, and good luck with all of your studies.

*Best Wishes!*

*Michael Sullivan*

*Michael Sullivan III*

# R Review



## A Look Ahead ...

Chapter R, as the title states, contains review material. Your instructor may choose to cover all or part of it as a regular chapter at the beginning of your course or later as a just-in-time review when the content is required. Regardless, when information in this chapter is needed, a specific reference to this chapter will be made so you can review.

## Outline

- R.1** Real Numbers
- R.2** Algebra Essentials
- R.3** Geometry Essentials
- R.4** Polynomials
- R.5** Factoring Polynomials
- R.6** Synthetic Division
- R.7** Rational Expressions
- R.8**  $n$ th Roots; Rational Exponents

**PREPARING FOR THIS TEXT** Before getting started, read “To the Student” at the front of this text.

- OBJECTIVES**
- 1 Work with Sets (p. 2)
  - 2 Classify Numbers (p. 4)
  - 3 Evaluate Numerical Expressions (p. 8)
  - 4 Work with Properties of Real Numbers (p. 10)

## 1 Work with Sets

A **set** is a well-defined collection of distinct objects. The objects of a set are called its **elements**. By **well-defined**, we mean that there is a rule that enables us to determine whether a given object is an element of the set. If a set has no elements, it is called the **empty set**, or **null set**, and is denoted by the symbol  $\emptyset$ .

For example, the set of **digits** consists of the collection of numbers 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. If we use the symbol  $D$  to denote the set of digits, then we can write

$$D = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$$

In this notation, the braces  $\{ \}$  are used to enclose the objects, or **elements**, in the set. This method of denoting a set is called the **roster method**. A second way to denote a set is to use **set-builder notation**, where the set  $D$  of digits is written as

$$D = \{ x \mid x \text{ is a digit} \}$$

Read as “ $D$  is the set of all  $x$  such that  $x$  is a digit.”

### EXAMPLE 1

#### Using Set-builder Notation and the Roster Method

- (a)  $E = \{x \mid x \text{ is an even digit}\} = \{0, 2, 4, 6, 8\}$
- (b)  $O = \{x \mid x \text{ is an odd digit}\} = \{1, 3, 5, 7, 9\}$

Because the elements of a set are distinct, we never repeat elements. For example, we would never write  $\{1, 2, 3, 2\}$ ; the correct listing is  $\{1, 2, 3\}$ . Because a set is a collection, the order in which the elements are listed is immaterial.  $\{1, 2, 3\}$ ,  $\{1, 3, 2\}$ ,  $\{2, 1, 3\}$ , and so on, all represent the same set.

If every element of a set  $A$  is also an element of a set  $B$ , then  $A$  is a **subset** of  $B$ , which is denoted  $A \subseteq B$ . If two sets  $A$  and  $B$  have the same elements, then  $A$  **equals**  $B$ , which is denoted  $A = B$ .

For example,  $\{1, 2, 3\} \subseteq \{1, 2, 3, 4, 5\}$  and  $\{1, 2, 3\} = \{2, 3, 1\}$ .

### DEFINITION

If  $A$  and  $B$  are sets, the **intersection** of  $A$  with  $B$ , denoted  $A \cap B$ , is the set consisting of elements that belong to both  $A$  and  $B$ . The **union** of  $A$  with  $B$ , denoted  $A \cup B$ , is the set consisting of elements that belong to either  $A$  or  $B$ , or both.

### EXAMPLE 2

#### Finding the Intersection and Union of Sets

Let  $A = \{1, 3, 5, 8\}$ ,  $B = \{3, 5, 7\}$ , and  $C = \{2, 4, 6, 8\}$ . Find:

- (a)  $A \cap B$
- (b)  $A \cup B$
- (c)  $B \cap (A \cup C)$

- Solution**
- (a)  $A \cap B = \{1, 3, 5, 8\} \cap \{3, 5, 7\} = \{3, 5\}$   
 (b)  $A \cup B = \{1, 3, 5, 8\} \cup \{3, 5, 7\} = \{1, 3, 5, 7, 8\}$   
 (c)  $B \cap (A \cup C) = \{3, 5, 7\} \cap [\{1, 3, 5, 8\} \cup \{2, 4, 6, 8\}]$   
 $= \{3, 5, 7\} \cap \{1, 2, 3, 4, 5, 6, 8\} = \{3, 5\}$

 **Now Work** PROBLEM 15

Usually, in working with sets, we designate a **universal set**  $U$ , the set consisting of all the elements that we wish to consider. Once a universal set has been designated, we can consider elements of the universal set not found in a given set.

**DEFINITION**

If  $A$  is a set, the **complement** of  $A$ , denoted  $\bar{A}$ , is the set consisting of all the elements in the universal set that are not in  $A$ .\*

**EXAMPLE 3**

**Finding the Complement of a Set**

If the universal set is  $U = \{1, 2, 3, 4, 5, 6, 7, 8, 9\}$  and if  $A = \{1, 3, 5, 7, 9\}$ , then  $\bar{A} = \{2, 4, 6, 8\}$ .

It follows from the definition of complement that  $A \cup \bar{A} = U$  and  $A \cap \bar{A} = \emptyset$ . Do you see why?

 **Now Work** PROBLEM 19

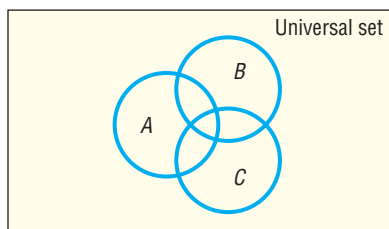
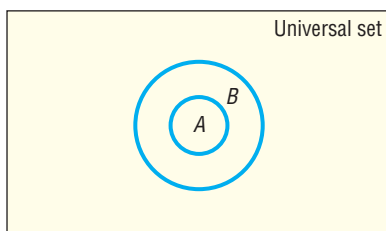


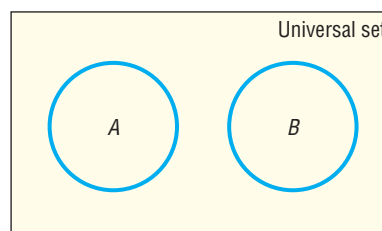
Figure 1 Venn diagram

It is often helpful to draw pictures of sets. Such pictures, called **Venn diagrams**, represent sets as circles enclosed in a rectangle, which represents the universal set. Such diagrams often help us to visualize various relationships among sets. See Figure 1.

If we know that  $A \subseteq B$ , we might use the Venn diagram in Figure 2(a). If we know that  $A$  and  $B$  have no elements in common—that is, if  $A \cap B = \emptyset$ —we might use the Venn diagram in Figure 2(b). The sets  $A$  and  $B$  in Figure 2(b) are said to be **disjoint**.



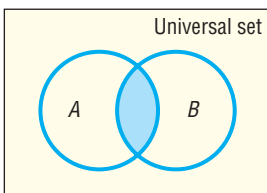
(a)  $A \subseteq B$   
subset



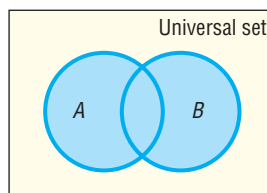
(b)  $A \cap B = \emptyset$   
disjoint sets

Figure 2

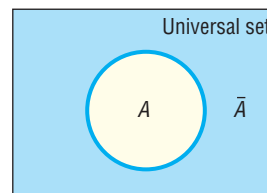
Figures 3(a), 3(b), and 3(c) use Venn diagrams to illustrate the definitions of intersection, union, and complement, respectively.



(a)  $A \cap B$   
intersection



(b)  $A \cup B$   
union



(c)  $\bar{A}$   
complement

Figure 3

\*Some texts use the notation  $A'$  for the complement of  $A$ .



## 2 Classify Numbers

It is helpful to classify the various kinds of numbers that we deal with as sets. The **counting numbers**, or **natural numbers**, are the numbers in the set  $\{1, 2, 3, 4, \dots\}$ . (The three dots, called an **ellipsis**, indicate that the pattern continues indefinitely.) As their name implies, these numbers are often used to count things. For example, there are 26 letters in our alphabet; there are 100 cents in a dollar. The **whole numbers** are the numbers in the set  $\{0, 1, 2, 3, \dots\}$ —that is, the counting numbers together with 0. The set of counting numbers is a subset of the set of whole numbers.

### DEFINITION

The **integers** are the set of numbers  $\{\dots, -3, -2, -1, 0, 1, 2, 3, \dots\}$ .

These numbers are useful in many situations. For example, if your checking account has \$10 in it and you write a check for \$15, you can represent the current balance as  $-\$5$ .

Each time we expand a number system, such as from the whole numbers to the integers, we do so in order to be able to handle new, and usually more complicated, problems. The integers enable us to solve problems requiring both positive and negative counting numbers, such as profit/loss, height above/below sea level, temperature above/below  $0^\circ\text{F}$ , and so on.

But integers alone are not sufficient for *all* problems. For example, they do not answer the question “What part of a dollar is 38 cents?” To answer such a question, we enlarge our number system to include *rational numbers*. For example,  $\frac{38}{100}$  answers the question “What part of a dollar is 38 cents?”

### DEFINITION

A **rational number** is a number that can be expressed as a quotient  $\frac{a}{b}$  of two integers. The integer  $a$  is called the **numerator**, and the integer  $b$ , which cannot be 0, is called the **denominator**. The rational numbers are the numbers in the set  $\left\{x \mid x = \frac{a}{b}, \text{ where } a, b \text{ are integers and } b \neq 0\right\}$ .

Examples of rational numbers are  $\frac{3}{4}$ ,  $\frac{5}{2}$ ,  $\frac{0}{4}$ ,  $-\frac{2}{3}$ , and  $\frac{100}{3}$ . Since  $\frac{a}{1} = a$  for any integer  $a$ , it follows that the set of integers is a subset of the set of rational numbers.

Rational numbers may be represented as **decimals**. For example, the rational numbers  $\frac{3}{4}$ ,  $\frac{5}{2}$ ,  $-\frac{2}{3}$ , and  $\frac{7}{66}$  may be represented as decimals by merely carrying out the indicated division:

$$\frac{3}{4} = 0.75 \quad \frac{5}{2} = 2.5 \quad -\frac{2}{3} = -0.666\dots = -0.\overline{6} \quad \frac{7}{66} = 0.1060606\dots = 0.1\overline{06}$$

Notice that the decimal representations of  $\frac{3}{4}$  and  $\frac{5}{2}$  terminate, or end. The decimal representations of  $-\frac{2}{3}$  and  $\frac{7}{66}$  do not terminate, but they do exhibit a pattern of repetition. For  $-\frac{2}{3}$ , the 6 repeats indefinitely, as indicated by the bar over the 6; for  $\frac{7}{66}$ , the block 06 repeats indefinitely, as indicated by the bar over the 06. It can be shown that every rational number may be represented by a decimal that either terminates or is nonterminating with a repeating block of digits, and vice versa.

On the other hand, some decimals do not fit into either of these categories. Such decimals represent **irrational numbers**. Every irrational number may be represented by a decimal that neither repeats nor terminates. In other words, irrational numbers cannot be written in the form  $\frac{a}{b}$ , where  $a, b$  are integers and  $b \neq 0$ .

Irrational numbers occur naturally. For example, consider the isosceles right triangle whose legs are each of length 1. See Figure 4. The length of the hypotenuse is  $\sqrt{2}$ , an irrational number.

Also, the number that equals the ratio of the circumference  $C$  to the diameter  $d$  of any circle, denoted by the symbol  $\pi$  (the Greek letter pi), is an irrational number. See Figure 5.

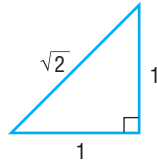
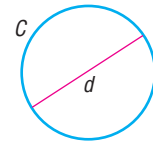


Figure 4

Figure 5  $\pi = \frac{C}{d}$ **DEFINITION**

The set of **real numbers** is the union of the set of rational numbers with the set of irrational numbers.

Figure 6 shows the relationship of various types of numbers.\*

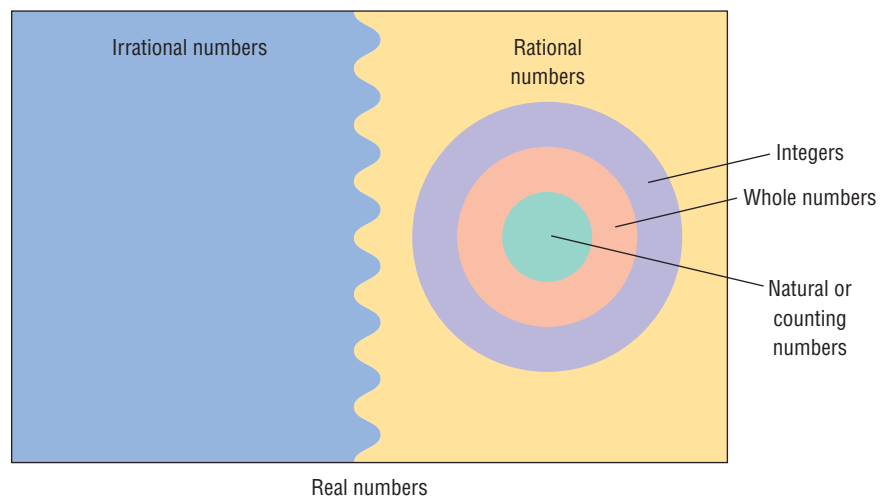


Figure 6

**EXAMPLE 4****Classifying the Numbers in a Set**

List the numbers in the set

$$\left\{ -3, \frac{4}{3}, 0.12, \sqrt{2}, \pi, 10, 2.151515 \dots \text{(where the block 15 repeats)} \right\}$$

that are

- (a) Natural numbers                      (b) Integers                      (c) Rational numbers  
 (d) Irrational numbers                  (e) Real numbers

**Solution**

- (a) 10 is the only natural number.  
 (b)  $-3$  and  $10$  are integers.  
 (c)  $-3$ ,  $10$ ,  $\frac{4}{3}$ ,  $0.12$ , and  $2.151515 \dots$  are rational numbers.  
 (d)  $\sqrt{2}$  and  $\pi$  are irrational numbers.  
 (e) All the numbers listed are real numbers.

 **Now Work** PROBLEM 25

\*The set of real numbers is a subset of the set of complex numbers. We discuss complex numbers in Chapter 1, Section 1.4.

## Approximations

Every decimal may be represented by a real number (either rational or irrational), and every real number may be represented by a decimal.

In practice, the decimal representation of an irrational number is given as an approximation. For example, using the symbol  $\approx$  (read as “approximately equal to”), we can write

$$\sqrt{2} \approx 1.4142 \quad \pi \approx 3.1416$$

In approximating decimals, we either *round off* or *truncate* to a given number of decimal places.\* The number of places establishes the location of the *final digit* in the decimal approximation.

**Truncation:** Drop all of the digits that follow the specified final digit in the decimal.

**Rounding:** Identify the specified final digit in the decimal. If the next digit is 5 or more, add 1 to the final digit; if the next digit is 4 or less, leave the final digit as it is. Then truncate following the final digit.

### EXAMPLE 5

#### Approximating a Decimal to Two Places

Approximate 20.98752 to two decimal places by

- Truncating
- Rounding

#### Solution

For 20.98752, the final digit is 8, since it is two decimal places from the decimal point.

- To truncate, we remove all digits following the final digit 8. The truncation of 20.98752 to two decimal places is 20.98.
- The digit following the final digit 8 is the digit 7. Since 7 is 5 or more, we add 1 to the final digit 8 and truncate. The rounded form of 20.98752 to two decimal places is 20.99. ■

### EXAMPLE 6

#### Approximating a Decimal to Two and Four Places

Number	Rounded to Two Decimal Places	Rounded to Four Decimal Places	Truncated to Two Decimal Places	Truncated to Four Decimal Places
(a) 3.14159	3.14	3.1416	3.14	3.1415
(b) 0.056128	0.06	0.0561	0.05	0.0561
(c) 893.46125	893.46	893.4613	893.46	893.4612

#### Now Work PROBLEM 29

## Significant Digits

There are two types of numbers—*exact* and *approximate*. **Exact numbers** are numbers whose value is known with 100% certainty and accuracy. For example, there are 12 donuts in a dozen donuts, or there are 50 states in the United States.

\*Sometimes we say “correct to a given number of decimal places” instead of “truncated.”

**Approximate numbers** are numbers whose value is not known with 100% certainty or whose measurement is inexact. When values are determined from measurements they are typically approximate numbers because the exact measurement is limited by the accuracy of the measuring device and the skill of the individual obtaining the measurement. The **number of significant digits** in a number represents the level of accuracy of the measurement.

The following rules are used to determine the number of significant digits in approximate numbers.

### The Number of Significant Digits

- Leading zeros are not significant. For example, 0.0034 has two significant digits.
- Embedded zeros are significant. For example, 208 has three significant digits.
- Trailing zeros are significant only if the decimal point is specified. For example, 2800 has two significant digits. However, if we specify the measurement is accurate to the ones digit, then 2800 has four significant digits.

When performing computations with approximate numbers, it is important not to report the result with more accuracy than the measurements used in the computation.

When performing computations using significant digits, proceed with the computation as you normally would, then round the final answer to the number of significant digits as the least accurately known number. For example, suppose we want to find the area of a rectangle whose width is 1.94 inches (three significant digits) and whose length is 2.7 inches (two significant digits). Because the length has two significant digits, we report the area to two significant digits. The area,  $(1.94 \text{ inches})(2.7 \text{ inches}) = 5.238$  square inches, can only be written to two significant digits and is reported as 5.2 square inches.

## Calculators

Calculators are incapable of displaying decimals that contain a large number of digits. For example, some calculators are capable of displaying only eight digits. When a number requires more than eight digits, the calculator either truncates or rounds. To see how your calculator handles decimals, divide 2 by 3. How many digits do you see? Is the last digit a 6 or a 7? If it is a 6, your calculator truncates; if it is a 7, your calculator rounds.

There are different kinds of calculators. An **arithmetic** calculator can only add, subtract, multiply, and divide numbers; therefore, this type is not adequate for this course. **Scientific** calculators have all the capabilities of arithmetic calculators and contain **function keys** labeled  $\ln$ ,  $\log$ ,  $\sin$ ,  $\cos$ ,  $\tan$ ,  $x^y$ ,  $\text{inv}$ , and so on. **Graphing** calculators have all the capabilities of scientific calculators and contain a screen on which graphs can be displayed. As you proceed through this text, you will discover how to use many of the function keys.

Figure 7 shows  $\frac{2}{3}$  on a TI-84 Plus C graphing calculator. How many digits are displayed? Does a TI-84 Plus C round or truncate? What does your calculator do?

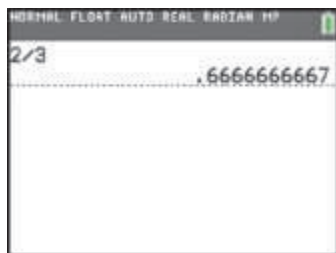


Figure 7

## Operations

In algebra, we use letters such as  $x$ ,  $y$ ,  $a$ ,  $b$ , and  $c$  to represent numbers. The symbols used in algebra for the operations of addition, subtraction, multiplication, and division are  $+$ ,  $-$ ,  $\cdot$ , and  $/$ . The words used to describe the results of these

operations are **sum**, **difference**, **product**, and **quotient**. Table 1 summarizes these ideas.

Operation	Symbol	Words
Addition	$a + b$	Sum: $a$ plus $b$
Subtraction	$a - b$	Difference: $a$ minus $b$
Multiplication	$a \cdot b$ , $(a) \cdot b$ , $a \cdot (b)$ , $(a) \cdot (b)$ , $ab$ , $(a)b$ , $a(b)$ , $(a)(b)$	Product: $a$ times $b$
Division	$a/b$ or $\frac{a}{b}$	Quotient: $a$ divided by $b$

In algebra, we generally avoid using the multiplication sign  $\times$  and the division sign  $\div$  so familiar in arithmetic. Notice also that when two expressions are placed next to each other without an operation symbol, as in  $ab$ , or in parentheses, as in  $(a)(b)$ , it is understood that the expressions, called **factors**, are to be multiplied.

We also prefer not to use mixed numbers in algebra. When mixed numbers are used, addition is understood; for example,  $2\frac{3}{4}$  means  $2 + \frac{3}{4}$ . In algebra, use of a mixed number may be confusing because the absence of an operation symbol between two terms is generally taken to mean multiplication. The expression  $2\frac{3}{4}$  is therefore written instead as  $2.75$  or as  $\frac{11}{4}$ .

The symbol  $=$ , called an **equal sign** and read as “equals” or “is,” is used to express the idea that the number or expression on the left of the equal sign is equivalent to the number or expression on the right.

### EXAMPLE 7

#### Writing Statements Using Symbols

- (a) The sum of 2 and 7 equals 9. In symbols, this statement is written as  $2 + 7 = 9$ .  
 (b) The product of 3 and 5 is 15. In symbols, this statement is written as  $3 \cdot 5 = 15$ .

 **Now Work** PROBLEM 41

### 3 Evaluate Numerical Expressions

Consider the expression  $2 + 3 \cdot 6$ . It is not clear whether we should add 2 and 3 to get 5, and then multiply by 6 to get 30; or first multiply 3 and 6 to get 18, and then add 2 to get 20. To avoid this ambiguity, we have the following agreement.

#### In Words

Multiply first, then add.

We agree that whenever the two operations of addition and multiplication separate three numbers, the multiplication operation will always be performed first, followed by the addition operation.

For  $2 + 3 \cdot 6$ , then, we have

$$2 + 3 \cdot 6 = 2 + 18 = 20$$

### EXAMPLE 8

#### Finding the Value of an Expression

Evaluate each expression.

(a)  $3 + 4 \cdot 5$

(b)  $8 \cdot 2 + 1$

(c)  $2 + 2 \cdot 2$

