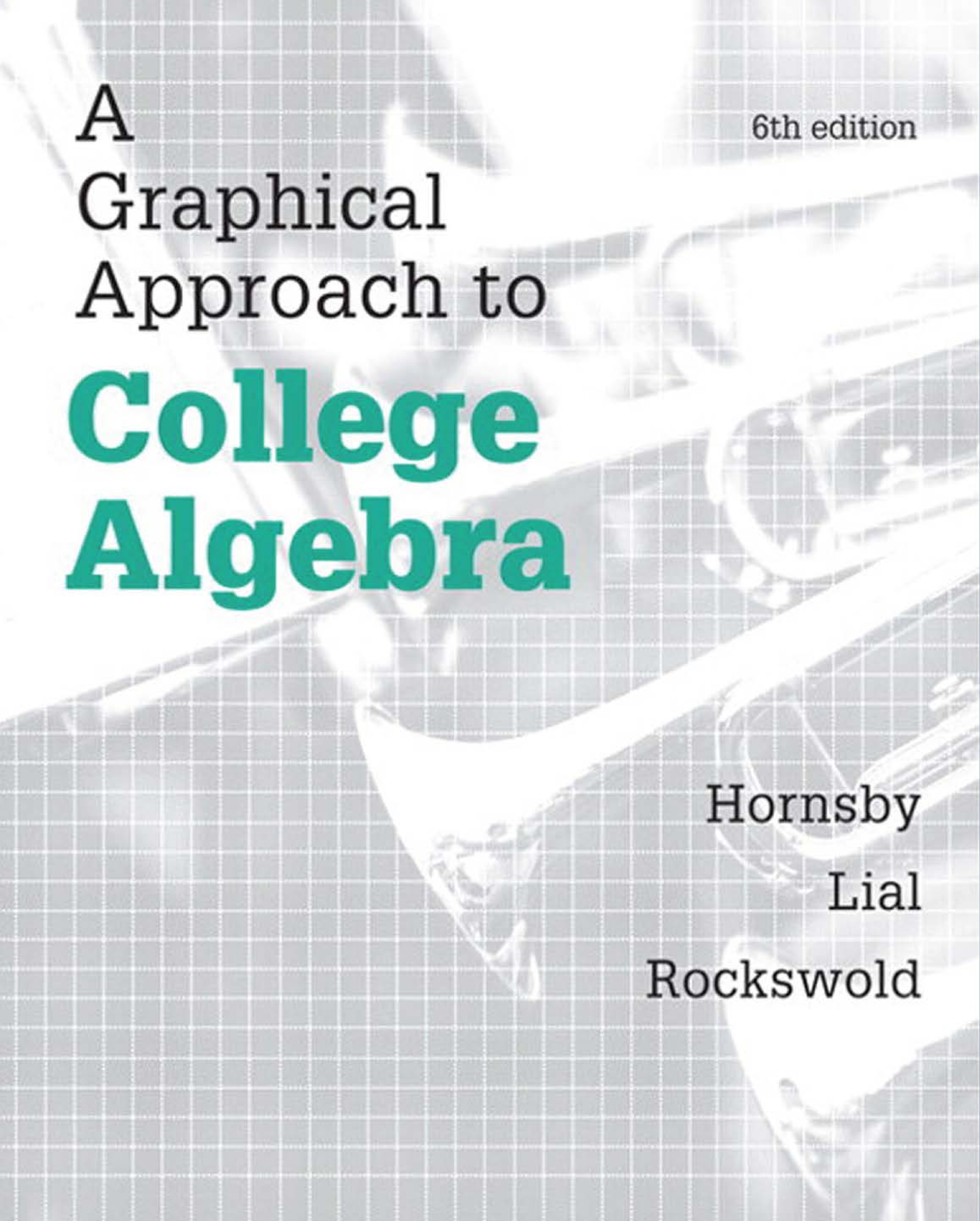


# A Graphical Approach to College Algebra

6th edition

Hornsby
Lial
Rockswold

# Our Unifying Approach to Functions

Our approach to studying the functions of algebra allows students to make connections between graphs of functions, their associated equations and inequalities, and related applications. To demonstrate this four-part process with quadratic functions (Chapter 3), consider the following illustrations.

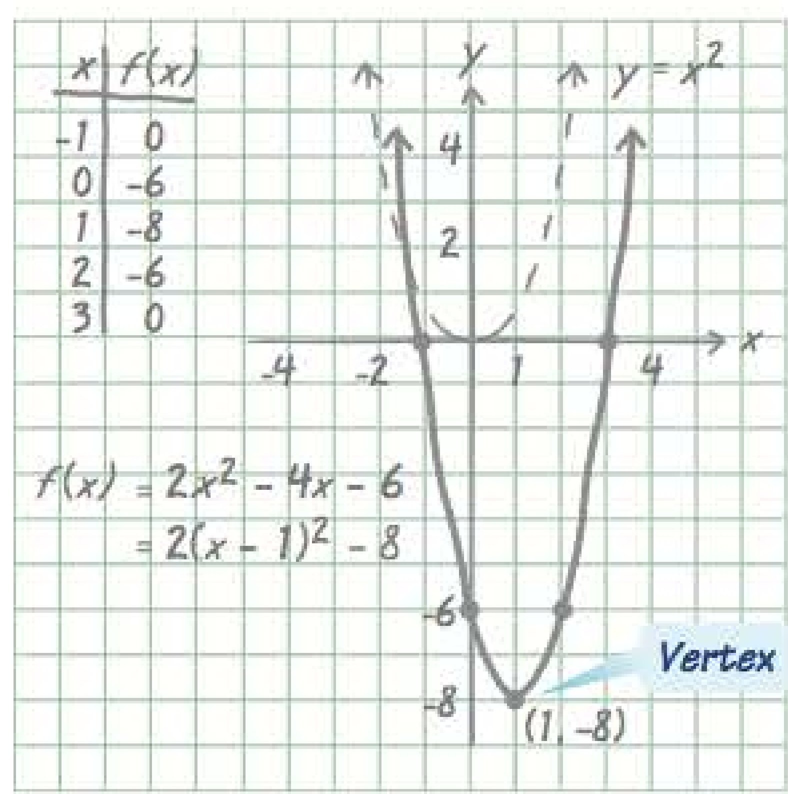
## 1 Examine the nature of the graph.

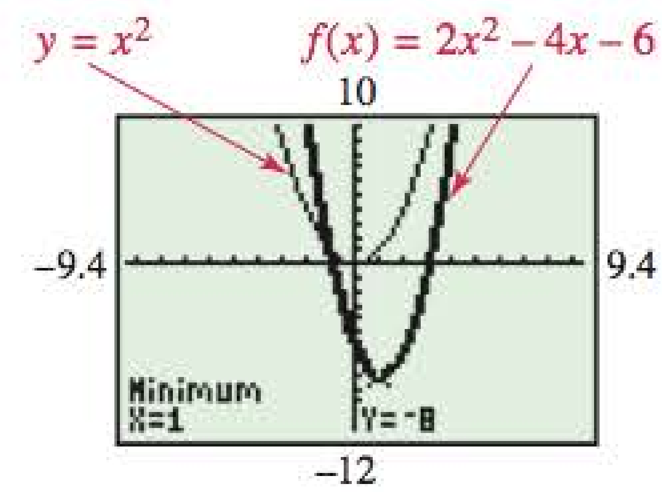
**ILLUSTRATION:** Graph $f(x) = 2x^2 - 4x - 6$.

**Solution** Because the function is quadratic, its graph is a parabola. By completing the square, it can be written in the form

$$f(x) = 2(x - 1)^2 - 8.$$

Compared with the graph of $y = x^2$, its graph is shifted horizontally 1 unit to the right, stretched by a factor of 2, and shifted vertically 8 units down. Its vertex has coordinates $(1, -8)$, and the axis of symmetry has equation $x = 1$. The domain is $(-\infty, \infty)$, and the range is $[-8, \infty)$.




## 2 Solve a typical equation analytically and graphically.

**ILLUSTRATION:** Solve the equation $2x^2 - 4x - 6 = 0$.

### Analytic Solution

$$2x^2 - 4x - 6 = 0$$

$$x^2 - 2x - 3 = 0 \quad \text{Divide by 2.}$$

$$(x + 1)(x - 3) = 0 \quad \text{Factor.}$$

$$x + 1 = 0 \quad \text{or} \quad x - 3 = 0 \quad \text{Zero-product property}$$

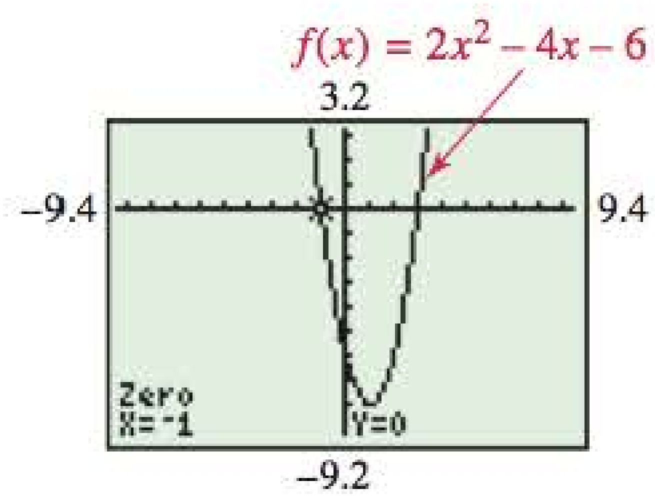
$$x = -1 \quad \text{or} \quad x = 3 \quad \text{Solve each equation.}$$

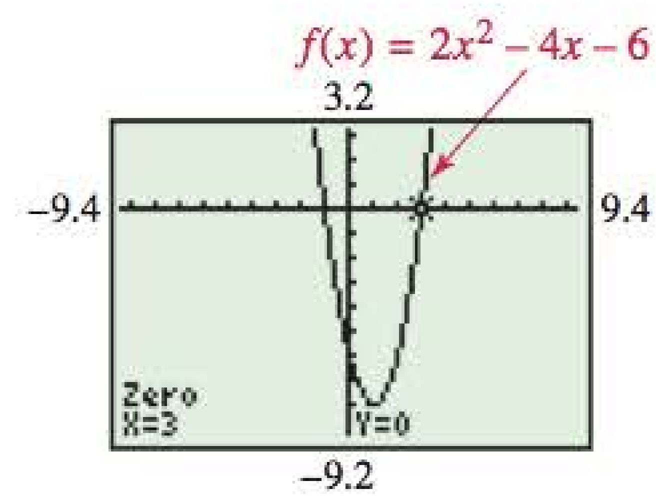
Check by substituting the solutions $-1$ and 3 for $x$ in the original equation.

The solution set is $\{-1, 3\}$.

### Graphing Calculator Solution

Using the $x$-intercept method, we find that the zeros of $f$ are the solutions of the equation.

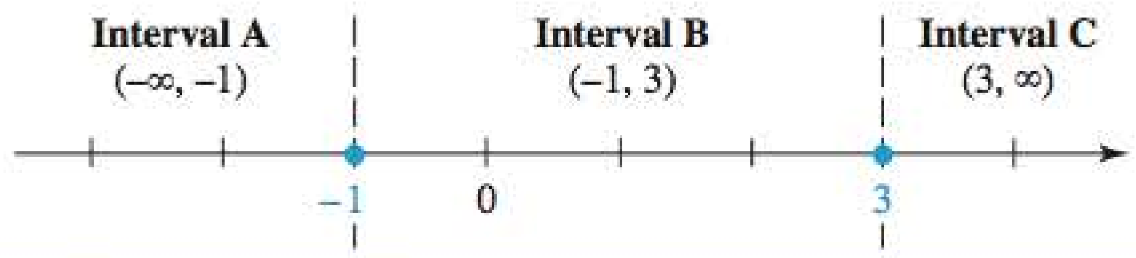


## 3 Solve the related inequality analytically and graphically.

**ILLUSTRATION:** Solve the inequality $2x^2 - 4x - 6 \le 0$.

**Solution** Divide a number line into intervals determined by the zeros of $f(x) = 2x^2 - 4x - 6$, (found in Illustration 2), which are $-1$ and 3. Choose a test value from each interval to identify values for which $f(x) \le 0$.




| Interval | Test Value $x$ | Is $f(x) = 2x^2 - 4x - 6 \le 0$ True or False? |
|---|---|---|
| **A:** $(-\infty, -1)$ | $-2$ | $f(-2) = 2(-2)^2 - 4(-2) - 6 \le 0$ ? <br> $10 \le 0$ False |
| **B:** $(-1, 3)$ | 0 | $f(0) = 2(0)^2 - 4(0) - 6 \le 0$ ? <br> $-6 \le 0$ True |
| **C:** $(3, \infty)$ | 4 | $f(4) = 2(4)^2 - 4(4) - 6 \le 0$ ? <br> $10 \le 0$ False |

From the table, the polynomial $2x^2 - 4x - 6$ is negative or *zero* on the interval $[-1, 3]$. The calculator graph in Illustration 2 supports this solution, since the graph lies *on* or *below* the $x$-axis on this interval.

## 4 Apply analytic and graphical methods to solve an application of that class of function.

**ILLUSTRATION:** If an object is projected directly upward from the ground with an initial velocity of 64 feet per second, then (neglecting air resistance) the height of the object $x$ seconds after it is projected is modeled by

$$s(x) = -16x^2 + 64x,$$

where $s(x)$ is in feet. After how many seconds does it reach a height of 28 feet?

### Analytic Solution

We must solve the equation $s(x) = 28$.

$$s(x) = -16x^2 + 64x$$

$$28 = -16x^2 + 64x \quad \text{Let } s(x) = 28.$$

$$16x^2 - 64x + 28 = 0 \quad \text{Standard form}$$

$$4x^2 - 16x + 7 = 0 \quad \text{Divide by 4.}$$

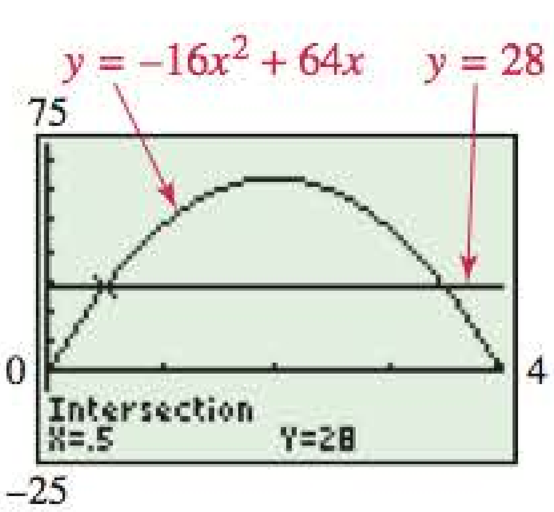
$$(2x - 1)(2x - 7) = 0 \quad \text{Factor.}$$

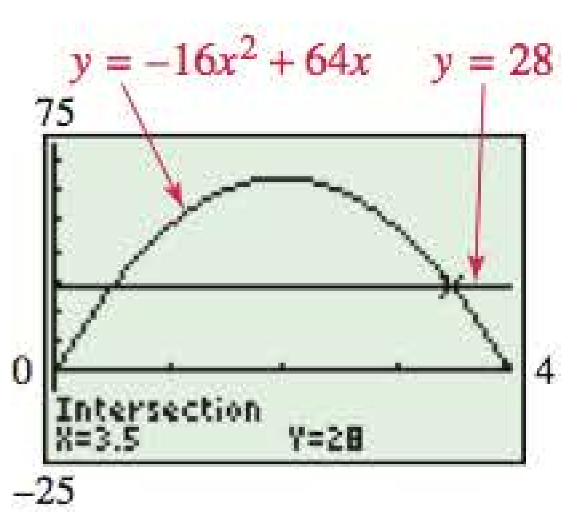
$$x = 0.5 \quad \text{or} \quad x = 3.5 \quad \text{Zero-product property}$$

The object reaches a height of 28 feet twice, at 0.5 second (on its way up) and at 3.5 seconds (on its way down).

### Graphing Calculator Solution

Using the intersection-of-graphs method, we see that the graphs of $y = -16x^2 + 64x$ and $y = 28$ intersect at points whose coordinates are (0.5, 28) and (3.5, 28), confirming our analytic answer.



# A Graphical Approach to College Algebra

SIXTH EDITION

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# A Graphical Approach to College Algebra

SIXTH EDITION

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On March 16, 2012, the mathematics education community lost one of its most influential members with the passing of our beloved mentor, colleague, and friend, Marge Lial. On that day, Marge lost her long battle with ALS. Throughout her illness, she showed the remarkable strength and courage that characterized her entire life.

**Margaret L. Lial**

We would like to share a few comments from among the many messages we received from friends, colleagues, and others whose lives were touched by our beloved Marge:

"What a lady"
"A remarkable person"
"Gracious to everyone"
"One of a kind"
"Truly someone special"
"A loss in the mathematical world"
"A great friend"
"Sorely missed but so fondly remembered"
"Even though our crossed path was narrow, she made an impact and I will never forget her."
"There is talent and there is Greatness. Marge was truly Great."
"Her true impact is almost more than we can imagine."

In the world of college mathematics publishing, Marge Lial was a rock star. People flocked to her, and she had a way of making everyone feel like they truly mattered. And to Marge, they did. She and Chuck Miller began writing for Scott Foresman in 1970. Not long ago she told us that she could no longer continue because "just getting from point A to point B" had become too challenging. That's our Marge—she even gave a geometric interpretation to her illness.

It has truly been an honor and a privilege to work with Marge Lial these past two decades. While we no longer have her wit, charm, and loving presence to guide us, so much of who we are as mathematics educators has been shaped by her influence. We will continue doing our part to make sure that the work that she and Chuck began represents excellence in mathematics education. We remember daily the little ways she impacted us, including her special expressions, "Margisms," as we like to call them. She often ended emails with one of them—the single word "Onward."

We conclude with a poem penned by another of her coauthors, Callie Daniels.

*Your courage inspires me*
*Your strength…impressive*
*Your wit humors me*
*Your vision…progressive*

*Your determination motivates me*
*Your accomplishments pave my way*
*Your vision sketches images for me*
*Your influence will forever stay.*

*Thank you, dearest Marge.*
*Knowing you and working with you has been a divine gift.*

Onward.

John Hornsby
Gary Rockswold

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To the memory of my dad, Jack Hornsby—son, soldier,
businessman, outdoorsman, husband, and father

E.J.H.

# Foreword

The first edition of *A Graphical Approach to College Algebra* was published in 1996. Our experience was that the usual order in which the standard topics were covered did not foster students' understanding of the interrelationships among graphs, equations, and inequalities. The table of contents for typical college algebra texts did not allow for maximum effectiveness in implementing our philosophy because graphs were not covered early enough in the course. Thus, we reorganized the standard topics with early introduction to the graphs of functions, followed by solutions of equations, inequalities, and applications. While the material is reorganized, ***we still cover all traditional topics and skills.*** The underlying theme was, and still is, to illustrate how the graph of a typical function can be used to support the solutions of equations and associated inequalities involving the function.

Using linear functions in Chapter 1 to introduce the approach that follows in later chapters, we apply a four-step process of analysis.

1. We examine the nature of the graph of the function, using both hand-drawn and calculator-generated versions. Domain and range are established, and any further characteristics are discussed.
2. We solve equations analytically, using the standard methods. Then we support our solutions graphically using the **intersection-of-graphs method** and the ***x*-intercept method** (pages 53–54).
3. We solve the associated inequalities analytically, again using standard methodology, supporting their solutions graphically as well.
4. We apply analytic and graphical methods to modeling and traditional applications involving the class of function under consideration.

After this procedure has been initially established for linear functions, we apply it to absolute value, quadratic, higher-degree polynomial, rational, root, exponential, and logarithmic functions in later chapters. The chapter on systems of equations ties in the concept of solving systems with the aforementioned intersection-of-graphs method of solving equations.

This presentation provides a sound pedagogical basis. Because today's students rely on visual learning more than ever, the use of graphs promotes student understanding in a manner that might not occur if only analytic approaches were used. It allows the student the opportunity to see how the graph of a function is related to equations and inequalities involving that function. The student is presented with the same approach over and over, and comes to realize that the *type* of function $f$ defined by $y = f(x)$ under consideration does not matter when providing graphical support. For example, using the $x$-intercept method, the student sees that $x$-intercepts of the graph of $y = f(x)$ correspond to real solutions of the equation $f(x) = 0$, $x$-values of points above the $x$-axis correspond to solutions of $f(x) > 0$, and $x$-values of points below the $x$-axis correspond to solutions of $f(x) < 0$.

The final result, in conjunction with the entire package of learning tools provided by Pearson, is a course that covers the standard topics of college algebra. It is developed in such a way that graphs are seen as pictures that can be used to interpret analytic results. We hope that you will enjoy teaching this course, and that your students will come away with an appreciation of the impact and importance of graphs in the study of college algebra.

*John Hornsby*
*Gary Rockswold*

# Contents

# Preface

Although *A Graphical Approach to College Algebra* has evolved significantly from earlier editions, it retains the strengths of those editions and provides new and relevant opportunities for students and instructors alike. We realize that today's classroom experience is evolving and that technology-based teaching and learning aids have become essential to address the ever-changing needs of instructors and students. As a result, we've worked to provide support for all classroom types—traditional, hybrid, and online. In the sixth edition, text and online materials are more tightly integrated than ever before. This enhances flexibility and ease of use for instructors and increases success for students. See pages xviii–xix for descriptions of these materials.

This text incorporates an open design, helpful features, careful explanations of topics, and a comprehensive package of supplements and study aids. We continue to offer an *Annotated Instructor's Edition,* in which answers to both even- and odd-numbered exercises are provided either beside the exercises (if space permits) or in the back of the text for the instructor.

*A Graphical Approach to College Algebra* was one of the first texts to reorganize the typical college algebra table of contents to maximize the use of graphs to support solutions of equations and inequalities. It maintains its unique table of contents and functions-based approach (as outlined in the Foreword and in front of the text) and includes additional components to build skills, address critical thinking, solve applications, and apply technology to support traditional analytic solutions.

This text is part of a series that also includes the following titles:

- *A Graphical Approach to Algebra and Trigonometry, Sixth Edition,* by Hornsby, Lial, and Rockswold
- *A Graphical Approach to Precalculus with Limits: A Unit Circle Approach, Sixth Edition*, by Hornsby, Lial, and Rockswold

The book is written to accommodate students who have access to graphing calculators. We have chosen to use screens from the TI-84 Plus Silver Edition. However, we do not include specific keystroke instructions because of the wide variety of models available. Students should refer to the guides provided with their calculators for specific information.

## New to This Edition

There are many places in the text where we have polished individual presentations and added examples, exercises, and applications based on reviewer feedback. Some of the changes you may notice include the following.

- At the request of many reviewers, we now define increasing and decreasing functions over *open* intervals, and define intercepts to be *points*, or *ordered pairs.*
- We have added more titles on graphs, captions, pointers (bubbles), color, and side comments to increase clarity and understanding for students.
- To better reflect the content covered in the exercise sets, the chapter tests have been revised.

- In several chapters, new examples and exercises have been added to better prepare students for the analytic skills necessary to be successful in calculus.
- Graphing calculator screens have been updated to the TI-84 Plus (Silver Edition) with MATHPRINT.
- Throughout the text, data have been updated to increase student interest in mathematics. Some new application topics include half-life of a Twitter link, iPads, social networks, accuracy of professional golfers, and smartphone demographics.
- Exercise sets have been revised so that odd and even exercises are paired appropriately.
- **Chapter 1** has increased emphasis on evaluating function notation, interpreting slope as a rate of change, and evaluating average rate of change using graphs.
- **Chapter 2** now has clearer explanations of how to transform graphs and also how to write transformations in terms of function notation. Additional exercises covering the domain and range of shifted functions have been included.
- **Chapter 3** includes more examples and exercises that cover curve fitting by hand, solving quadratic equations by completing the square, and solving polynomial equations and inequalities.
- **Chapter 4** includes an increased discussion of limit notation near asymptotes, circles, horizontal parabolas, rational equations and inequalities, and rational expressions with fractional exponents.
- **Chapter 5** has additional examples and exercises related to graphing inverse functions by hand, solving exponential equations with negative exponents, simplifying logarithmic expressions, and solving logarithmic equations.
- **Chapter 6** now covers matrices and linear systems. It has updated consumer spending applications, a 4-step process for solving linear systems, additional examples and exercises covering systems with no solution, and a new example to better explain the technique of finding partial fraction decompositions.
- **Chapter 7** now covers conic sections and nonlinear systems of equations and inequalities. Additional examples and exercises have been added.
- **Chapter 8** has additional examples and exercises to better explain writing series in summation notation, evaluating recursive sequences, and summing series.

## Features

We are pleased to offer the following enhanced features.

**Chapter Openers** Chapter openers provide a chapter outline and a brief discussion related to the chapter content.

**Enhanced Examples** We have replaced and included new examples in this edition, and have polished solutions and incorporated more side comments and pointers.

**Hand-Drawn Graphs** We have incorporated many graphs featuring a "hand-drawn" style that simulates how a student might actually sketch a graph on grid paper.

**Dual-Solution Format** Selected examples continue to provide side-by-side analytic and graphing calculator solutions, to connect traditional analytic methods for solving problems with graphical methods of solution or support.

**Pointers** Comments with pointers (bubbles) provide students with on-the-spot explanations, reminders, and warnings about common pitfalls.

**Highlighted Section and Figure References** Within text we use boldface type when referring to numbered sections and exercises (e.g., **Section 2.1, Exercises 15–20**), and also corresponding font when referring to numbered figures (e.g., **FIGURE 1**). We thank Gerald M. Kiser of Woodbury (New Jersey) High School for this latter suggestion.

**Figures and Photos** Today's students are more visually oriented than ever. As a result, we have made a concerted effort to provide more figures, diagrams, tables, and graphs, including the "hand-drawn" style of graphs, whenever possible. We also include photos accompanying applications in examples and exercises.

**Function Capsules** These special boxes offer a comprehensive, visual introduction to each class of function and serve as an excellent resource for reference and review. Each capsule includes traditional and calculator graphs and a calculator table of values, as well as the domain, range, and other specific information about the function. Abbreviated versions of function capsules are provided on the inside back cover of the text.

**What Went Wrong?** This popular feature anticipates typical errors that students make when using graphing technology and provides an avenue for instructors to highlight and discuss such errors. Answers are included on the same page as the "What Went Wrong?" boxes.

**Cautions and Notes** These warn students of common errors and emphasize important ideas throughout the exposition.

**Looking Ahead to Calculus** These margin notes provide glimpses of how the algebraic topics currently being studied are used in calculus.

**Algebra Reviews** This new feature, occurring in the margin of the text, provides "just in time" review by referring students to where they can receive additional help with important topics from algebra.

**Technology Notes** Also appearing in the margin, these notes provide tips to students on how to use graphing calculators more effectively.

**For Discussion** These activities appear within the exposition or in the margins and offer material on important concepts for instructors and students to investigate or discuss in class.

**Exercise Sets** We have taken special care to respond to the suggestions of users and reviewers and have added hundreds of new exercises to this edition on the basis of their feedback. The text continues to provide students with ample opportunities to practice, apply, connect, and extend concepts and skills. We have included writing exercises as well as multiple-choice, matching, true/false, and completion problems. Exercises marked ***Concept Check*** focus on mathematical thinking and conceptual understanding, while those marked ***Checking Analytic Skills*** specifically are intended for students to solve *without the use of a calculator*.

**Relating Concepts** These groups of exercises appear in selected exercise sets. They tie together topics and highlight relationships among various concepts and skills. All answers to these problems appear in the answer section at the back of the student book.

**Reviewing Basic Concepts** These sets of exercises appear every two or three sections and allow students to review and check their understanding of the material in preceding sections. All answers to these problems are included in the answer section.

**Chapter Review Material** One of the most popular features of the text, each end-of-chapter Summary features a section-by-section list of Key Terms and Symbols, in addition to Key Concepts. A comprehensive set of Chapter Review Exercises and a Chapter Test are also included.

## Acknowledgments

Previous editions of this text were published after thousands of hours of work, not only by the authors, but also by reviewers, instructors, students, answer checkers, and editors. To these individuals and to all those who have worked in some way on this text over the years, we are most grateful for your contributions. We could not have done it without you.

We especially wish to thank the following individuals who provided valuable input into this and previous editions of the text.

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Fred Worth, *Henderson State University*
Kevin Yokoyama, *College of the Redwoods*

Over the years we have come to rely on an extensive team of experienced professionals at Pearson: Greg Tobin, Anne Kelly, Katie O'Connor, Christine O'Brien, Kathy Manley, Judith Garber, Joe Vetere, Peggy Lucas, Justine Goulart, and Diahanne Lucas. Thank you to everyone.

In this edition we welcome the assistance of Jessica Rockswold, who provided excellent support throughout all phases of writing and production. Terry Krieger and Paul Lorczak deserve special recognition for their work with the answers and accuracy checking. Thanks are also due Kathy Diamond for her valuable help as project manager. Finally, we thank David Atwood, Leslie Cobar, and Mark Rockswold for checking answers and page proofs and Lucie Haskins for assembling the index.

As an author team, we are committed to providing the best possible text to help instructors teach effectively and have students succeed. As we continue to work toward this goal, we would welcome any comments or suggestions you might have via e-mail to *math@pearson.com*.

*John Hornsby*
*Gary Rockswold*

# Resources for Success

## MyMathLab®

MyMathLab from Pearson is the world's leading online resource in mathematics, integrating interactive homework, assessment, and media in a flexible, easy-to-use format. It provides **engaging experiences** that personalize, stimulate, and measure learning for each student. And it comes from an **experienced partner** with educational expertise and an eye on the future.

To learn more about how MyMathLab combines proven learning applications with powerful assessment, visit **www.mymathlab.com** or contact your Pearson representative.

### Getting Ready

Students refresh prerequisite topics through assignable skill review quizzes and personalized homework integrated in MyMathLab.

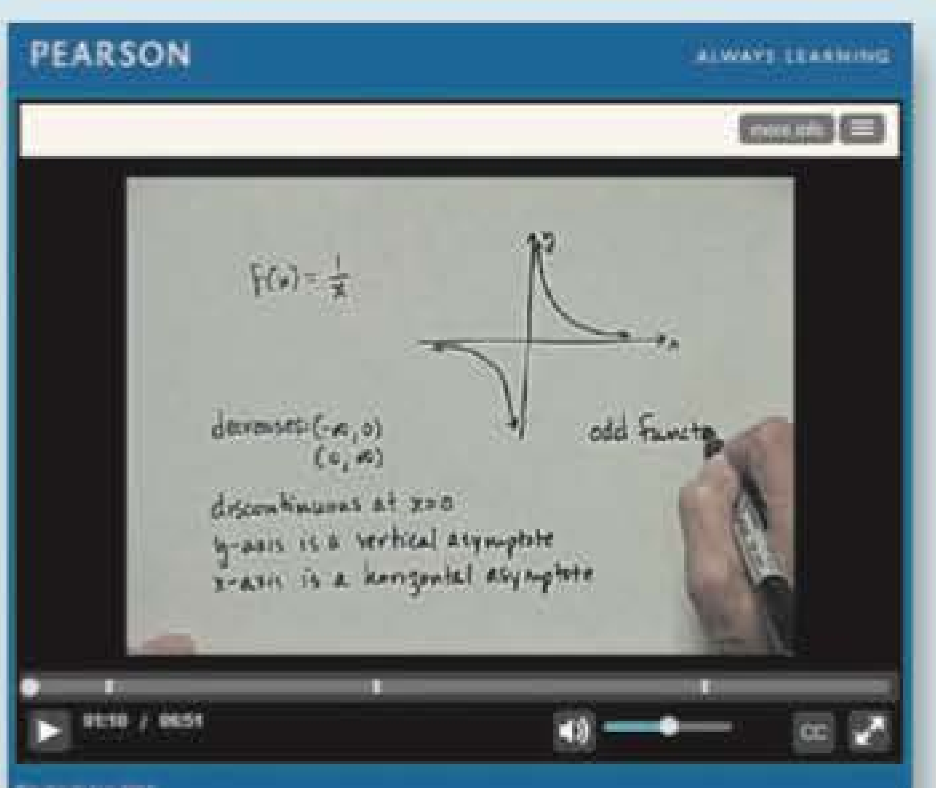


### Adaptive Study Plan

The Study Plan makes studying more efficient and effective for every student. Performance and activity are assessed continually in real time. The data and analytics are used to provide personalized content, reinforcing concepts that target each student's strengths and weaknesses.

### Skills for Success Module

Integrated within MyMathLab, this module helps students succeed in collegiate courses and prepare for future professions.




### Ongoing Review

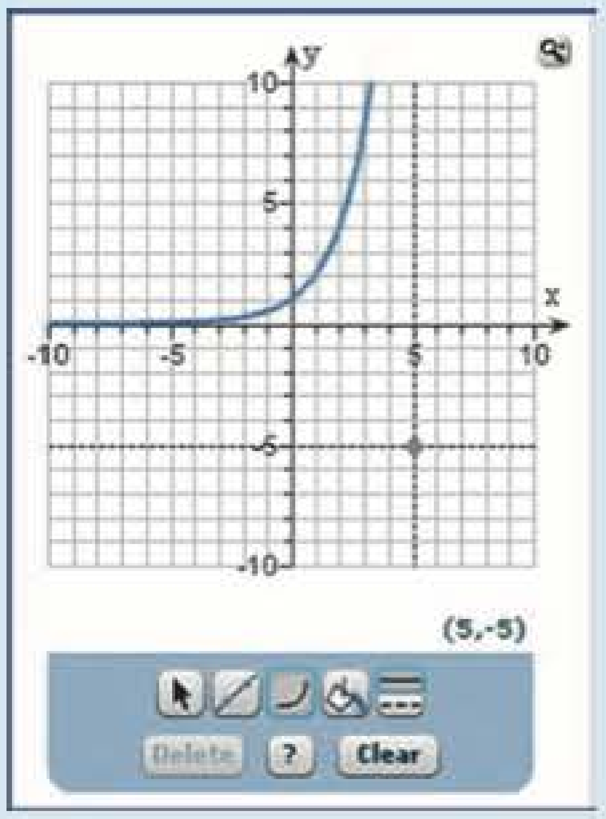
Reviewing Basic Concepts exercises in the text are now assignable in MyMathLab and require students to recall previously learned content and skills. These exercises help students maintain essential skills throughout the course, thereby enabling them to retain information in preparation for future math courses.

### Video Assessment

Video assessment is tied to the video lecture for each section of the book to check students' understanding of important math concepts. Instructors can assign these questions as a prerequisite to homework assignments.

### Enhanced Graphing Functionality

New functionality within the graphing utility allows graphing of 3-point quadratic functions, 4-point cubic functions, and transformations in exercises.




## Instructor Resources

Additional resources can be downloaded from www.pearson/highered.com, or hardcopy resources can be ordered from your sales representative.

### TestGen®

TestGen (www.pearsoned.com/testgen) enables instructors to build, edit, print, and administer tests using a computerized bank of questions developed to cover all the objectives of the text.

### PowerPoint® Lecture Slides

Classroom presentation slides are geared specifically to sequence the text. They are available in MyMathLab.

### Annotated Instructor's Edition

This edition provides answers beside the text for most exercises, and in an answer section at the back of the book for all others.

### Ready to Go Courses

Now it is even easier to get started with MyMathLab. The Ready to Go MyMathLab course option includes author-chosen preassigned homework, integrated review, and more.

### Instructor's Solutions Manual

This manual provides complete solutions to all text exercises.

## Student Resources

Additional resources are available to help student success.

### Lecture Videos

Example and content videos provide comprehensive coverage of each section and topic in the text in an engaging format that stresses student interaction. They include optional subtitles in English and Spanish. All videos are assignable within MyMathLab.

### Student's Solutions Manual

This manual provides detailed solutions to odd-numbered Section and Chapter Review Exercises, as well as to all Relating Concepts, Reviewing Basic Concepts, and Chapter Test Problems.

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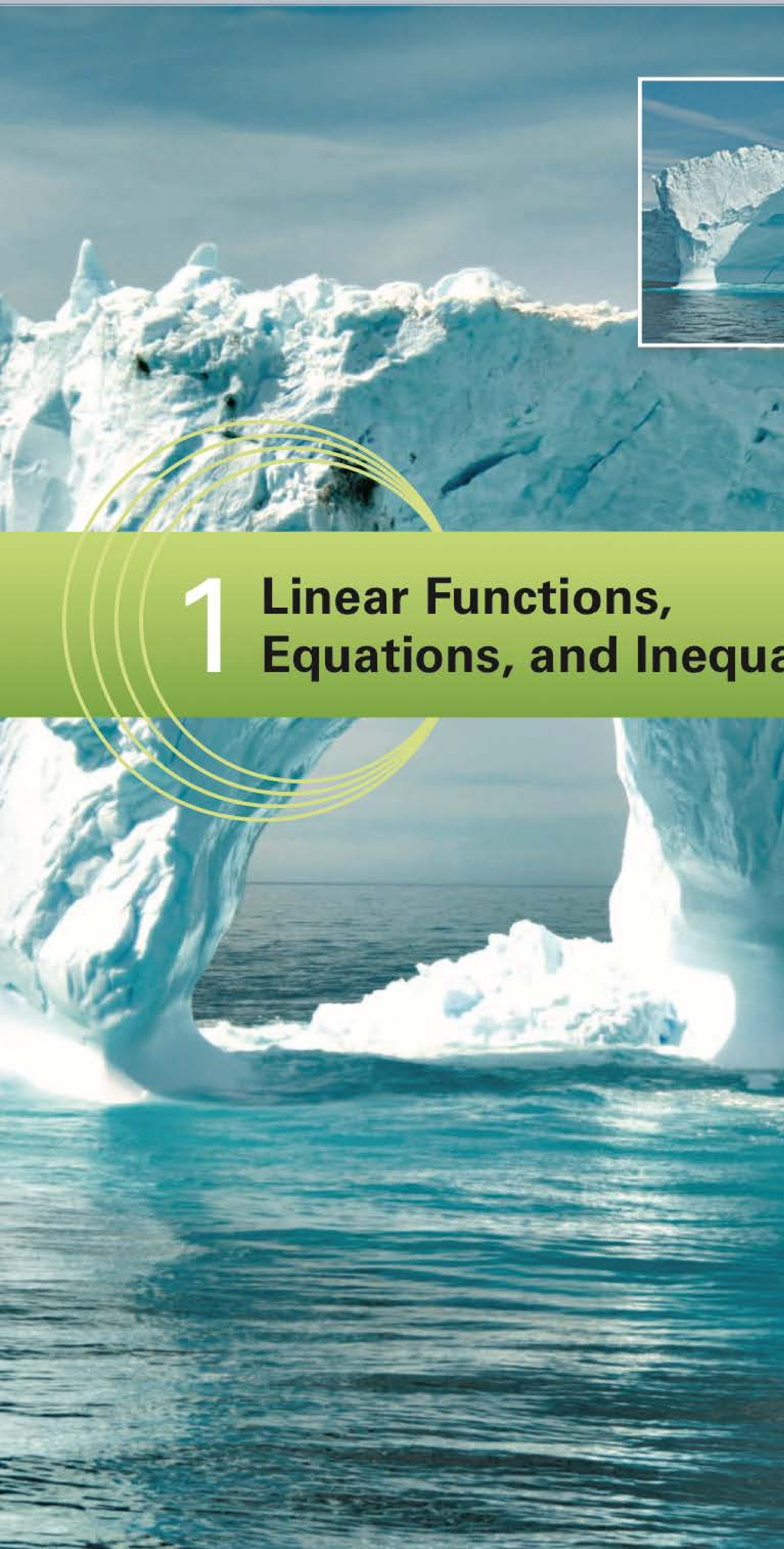


Understanding the future of ice caps in the Arctic and Antarctic regions requires the ability to describe climate change with functions and equations.

# 1 Linear Functions, Equations, and Inequalities

CHAPTER OUTLINE

# 1.1 Real Numbers and the Rectangular Coordinate System

Sets of Real Numbers • The Rectangular Coordinate System • Viewing Windows • Approximations of Real Numbers • Distance and Midpoint Formulas

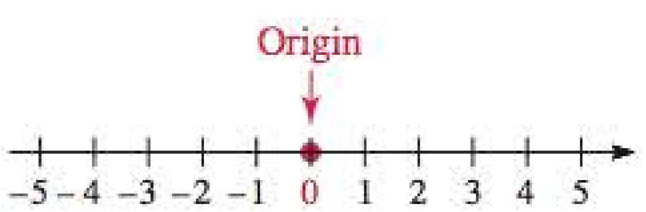
## Sets of Real Numbers

Several important sets of numbers are used in mathematics. Some of these sets are listed in the following table.

**Sets of Numbers**

| Set | Description | Examples |
|---|---|---|
| Natural Numbers | $\{1, 2, 3, 4, \dots\}$ | $1, 45, 127, 10^3$ |
| Whole Numbers | $\{0, 1, 2, 3, 4, \dots\}$ | $0, 86, 345, 2^3$ |
| Integers | $\{\dots, -2, -1, 0, 1, 2, \dots\}$ | $0, -5, -10^2, 99$ |
| Rational Numbers | $\{\frac{p}{q} \mid p \text{ and } q \text{ are integers}, q \neq 0\}$ | $0, -\frac{5}{6}, -2, \frac{22}{7}, 0.5$ |
| Irrational Numbers | $\{x \mid x \text{ is not rational}\}$ | $\sqrt{2}, \pi, -\sqrt[3]{7}$ |
| Real Numbers | $\{x \mid x \text{ is a decimal number}\}$ | $-\sqrt{6}, \pi, \frac{2}{3}, \sqrt{45}, 0.41$ |

**Whole numbers** include the **natural numbers; integers** include the whole numbers and the natural numbers. The result of dividing two integers (with a nonzero divisor) is a **rational number,** or *fraction*. Rational numbers include the natural numbers, whole numbers, and integers. For example, the integer $-3$ is a rational number because it can be written as $\frac{-3}{1}$. Every rational number can be written as a repeating or terminating decimal. For example, $0.\overline{6} = 0.66666\dots$ represents the rational number $\frac{2}{3}$.



Real number line with the origin plotted

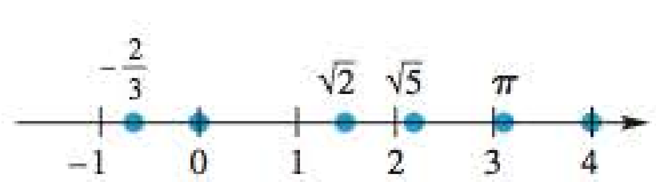
**FIGURE 1**

Numbers that can be written as decimal numbers are **real numbers.** Real numbers include rational numbers and can be shown pictorially—that is, **graphed**—on a **number line.** The point on a number line corresponding to 0 is called the **origin.** See **FIGURE 1.** Every real number corresponds to one and only one point on the number line, and each point corresponds to one and only one real number. This correspondence is called a **coordinate system.** The number associated with a given point is called the **coordinate** of the point. The set of all real numbers is graphed in **FIGURE 2.**

Graph of the set of real numbers

**FIGURE 2**

Some real numbers cannot be represented by quotients of integers or by repeating or terminating decimals. These numbers are called **irrational numbers.** Examples of irrational numbers include $\sqrt{3}$, $\sqrt{5}$, $\sqrt[3]{10}$, and $\sqrt[5]{20}$, but not $\sqrt{1}$, $\sqrt{4}$, $\sqrt{9}, \dots,$ which equal $1, 2, 3, \dots,$ and hence are rational numbers. If $a$ is a natural number but $\sqrt{a}$ is not a natural number, then $\sqrt{a}$ is an irrational number. Another irrational number is $\pi$, which is approximately equal to 3.14159. In **FIGURE 3** the irrational and rational numbers in the set $\{-\frac{2}{3}, 0, \sqrt{2}, \sqrt{5}, \pi, 4\}$ are located on a number line. Note that $\sqrt{2}$ is approximately equal to 1.41, so it is located between 1 and 2, slightly closer to 1.



Graph of $\{-\frac{2}{3}, 0, \sqrt{2}, \sqrt{5}, \pi, 4\}$

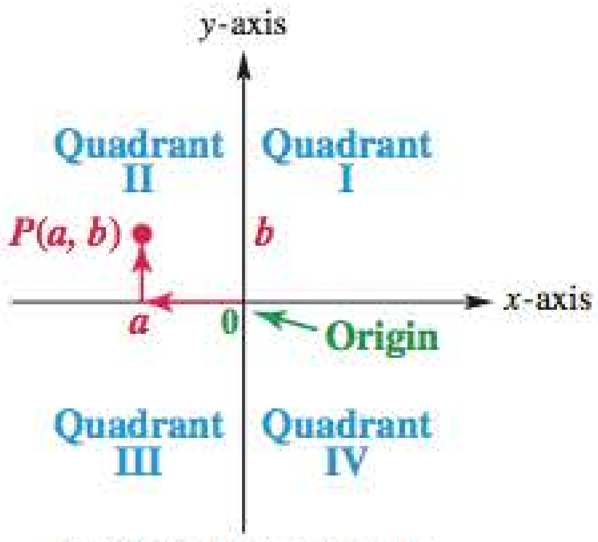
**FIGURE 3**

## The Rectangular Coordinate System

If we place two number lines at right angles, intersecting at their origins, we obtain a two-dimensional **rectangular coordinate system.** This rectangular coordinate system is also called the Cartesian coordinate system, which was named after

René Descartes (1596–1650). The number lines intersect at the *origin* of the system, designated 0. The horizontal number line is called the ***x*-axis,** and the vertical number line is called the ***y*-axis.** On the *x*-axis, positive numbers are located to the right of the origin, with negative numbers to the left. On the *y*-axis, positive numbers are located above the origin, with negative numbers below.

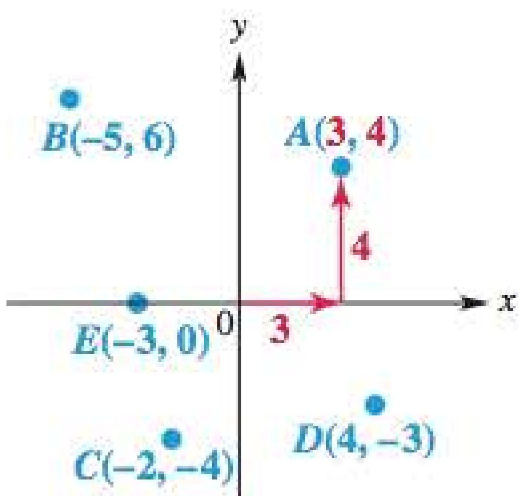
The plane into which the coordinate system is introduced is the **coordinate plane,** or ***xy*-plane.** The *x*-axis and *y*-axis divide the plane into four regions, or **quadrants,** as shown in FIGURE 4. ***The points on the x-axis or y-axis belong to no quadrant.***




Rectangular coordinate system

**FIGURE 4**

Each point $P$ in the $xy$-plane corresponds to a unique ordered pair $(a, b)$ of real numbers. We call $a$ the ***x*-coordinate** and $b$ the ***y*-coordinate** of point $P$. The point $P$ corresponding to the ordered pair $(a, b)$ is often written as $P(a, b)$, as in FIGURE 4, and referred to as "the point $(a, b)$." FIGURE 5 illustrates how to plot the point $A(3, 4)$. Additional points are labeled $B$–$E$. The coordinates of the origin are $(0, 0)$.

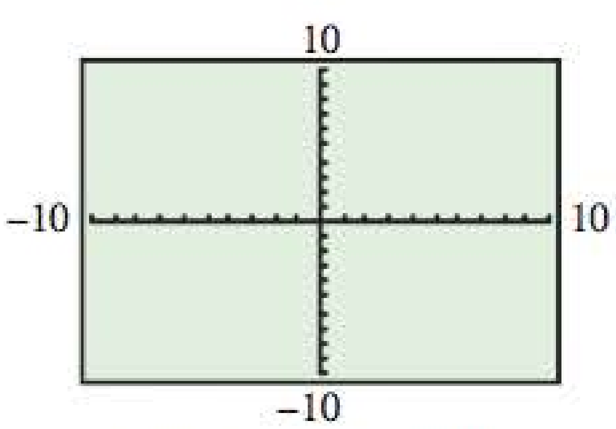



Plotting points in the *xy*-plane

**FIGURE 5**

## Viewing Windows

The rectangular (Cartesian) coordinate system extends indefinitely in all directions. We can show only a portion of such a system in a text figure. Similar limitations occur with the viewing "window" on a calculator screen. FIGURE 6 shows a calculator screen that has been set to have a minimum $x$-value of $-10$, a maximum $x$-value of 10, a minimum $y$-value of $-10$, and a maximum $y$-value of 10. The tick marks on the axes have been set to be 1 unit apart. Thus, there are 10 tick marks on the positive $x$-axis. This window is called the **standard viewing window.**




Standard viewing window

**FIGURE 6**

To convey information about a viewing window, we use the following abbreviations.

| | | | |
|---|---|---|---|
| **Xmin:** | minimum value of $x$ | **Ymin:** | minimum value of $y$ |
| **Xmax:** | maximum value of $x$ | **Ymax:** | maximum value of $y$ |
| **Xscl:** | scale (distance between tick marks) on the $x$-axis | **Yscl:** | scale (distance between tick marks) on the $y$-axis |

To further condense this information, we use the following symbolism, which gives viewing information for the window in FIGURE 6.

Xmin, Xmax, Ymin, Ymax

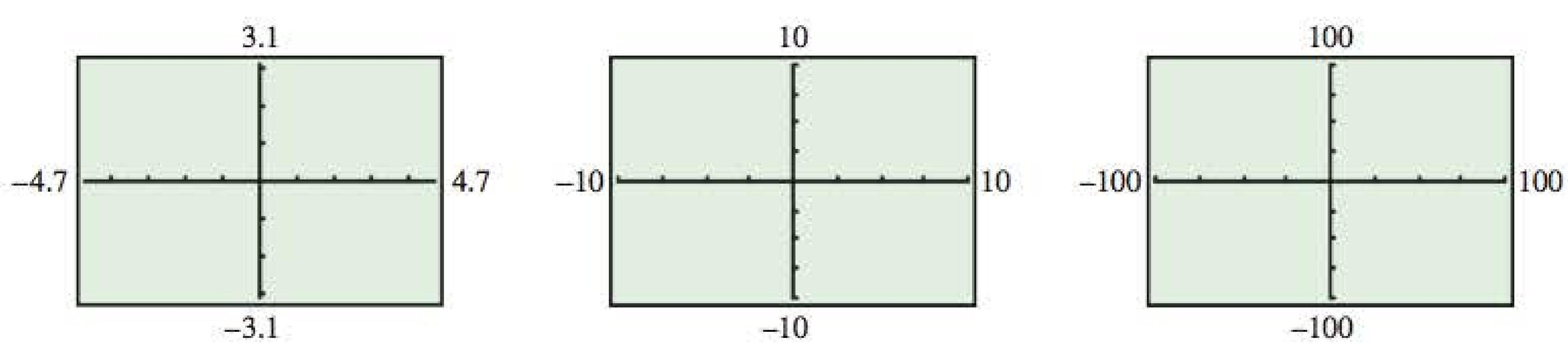
$$[-10, 10] \text{ by } [-10, 10]$$

$$\text{Xscl} = 1 \qquad \text{Yscl} = 1$$

**TECHNOLOGY NOTE**

You should consult your owner's guide to see how to set the viewing window on your screen. Remember that different settings will result in different views of graphs.

FIGURE 7 shows several other viewing windows. Notice that FIGURES 7(b) and 7(c) look exactly alike, and unless we are told what the settings are, we have no way of distinguishing between them. In FIGURE 7(b) Xscl $= 2.5$, while in FIGURE 7(c) Xscl $= 25$. The same is true for Yscl in both.




[−4.7, 4.7] by [−3.1, 3.1]
(a)

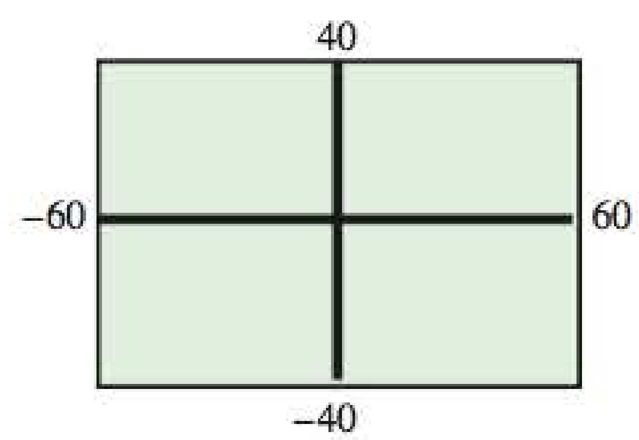
[−10, 10] by [−10, 10]
(b)

[−100, 100] by [−100, 100]
(c)

**FIGURE 7**

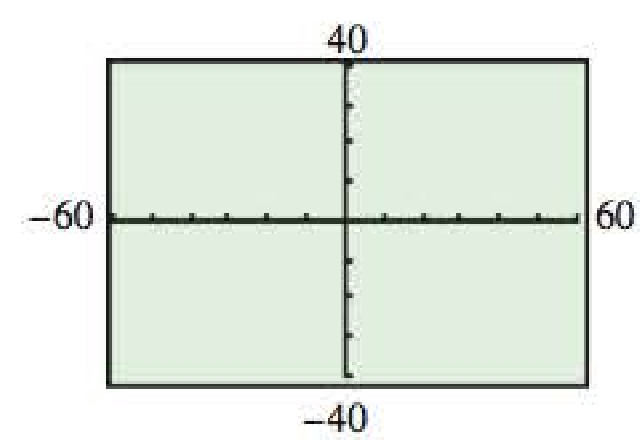
**WHAT WENT WRONG?**

A student learning how to use a graphing calculator could not understand why the axes on the graph were so "thick," as seen in **FIGURE A,** while those on a friend's calculator were not, as seen in **FIGURE B.**




Xscl = 1, Yscl = 1

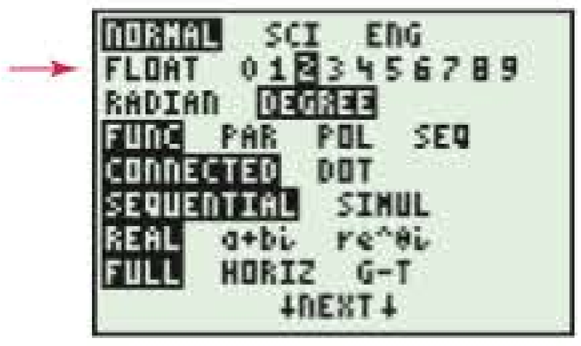
**FIGURE A**




Xscl = 10, Yscl = 10

**FIGURE B**

**What Went Wrong?** How can the student correct the problem in **FIGURE A** so that the axes look like those in **FIGURE B?**




TI-84 Plus (Silver Edition)

**FIGURE 8**

## Approximations of Real Numbers

Although calculators have the capability to express numbers like $\sqrt{2}$, $\sqrt[3]{5}$, and $\pi$ to many decimal places, we often ask that answers be rounded. The following table reviews rounding numbers to the nearest tenth, hundredth, or thousandth.

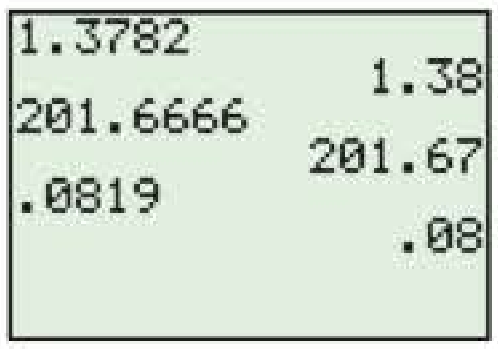



**FIGURE 9**

**Rounding Numbers**

| Number | Nearest Tenth | Nearest Hundredth | Nearest Thousandth |
|---|---|---|---|
| 1.3782 | 1.4 | 1.38 | 1.378 |
| 201.6666 | 201.7 | 201.67 | 201.667 |
| 0.0819 | 0.1 | 0.08 | 0.082 |

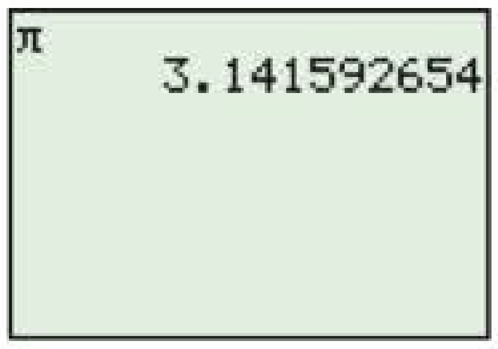



**FIGURE 10**

In **FIGURE 8,** the TI-84 Plus graphing calculator is set to round values to the nearest hundredth (two decimal places). In **FIGURE 9,** the numbers from the preceding table are rounded to the nearest hundredth.

The symbol $\approx$ indicates that two expressions are *approximately equal.* For example, $\pi \approx 3.14$, but $\pi \neq 3.14$, since $\pi = 3.141592654\ldots$. When using $\pi$ in calculations, be sure to use the built-in key for $\pi$ rather than 3.14. See **FIGURE 10.**

---

*Answer to What Went Wrong?*

Since Xscl = 1 and Yscl = 1 in **FIGURE A,** there are 120 tick marks along the $x$-axis and 80 tick marks along the $y$-axis. The resolution of the graphing calculator screen is not high enough to show all these tick marks, so the axes appear as heavy black lines instead. The values for Xscl and Yscl need to be larger, as in **FIGURE B.**

## EXAMPLE 1 Finding Roots on a Calculator

Approximate each root to the nearest thousandth. (*Note:* You can use the fact that $\sqrt[n]{a} = a^{1/n}$ to find roots.)

**(a)** $\sqrt{23}$ **(b)** $\sqrt[3]{87}$ **(c)** $\sqrt[4]{12}$

### Solution

**(a)** The screen in **FIGURE 11(a)** shows an approximation for $\sqrt{23}$. To the nearest thousandth, it is 4.796. The approximation is displayed twice, once for $\sqrt{23}$ and once for $23^{1/2}$.

**(b)** To the nearest thousandth, $\sqrt[3]{87} \approx 4.431$. See **FIGURE 11(b)**.

**(c)** **FIGURE 11(c)** indicates $\sqrt[4]{12} \approx 1.861$ in three different ways.

**TECHNOLOGY NOTE**

Many graphing calculators have built-in keys for calculating square roots and menus for calculating other types of roots. The TI-84 Plus (Silver Edition) has two print modes that will be used in this text: MATHPRINT and CLASSIC.

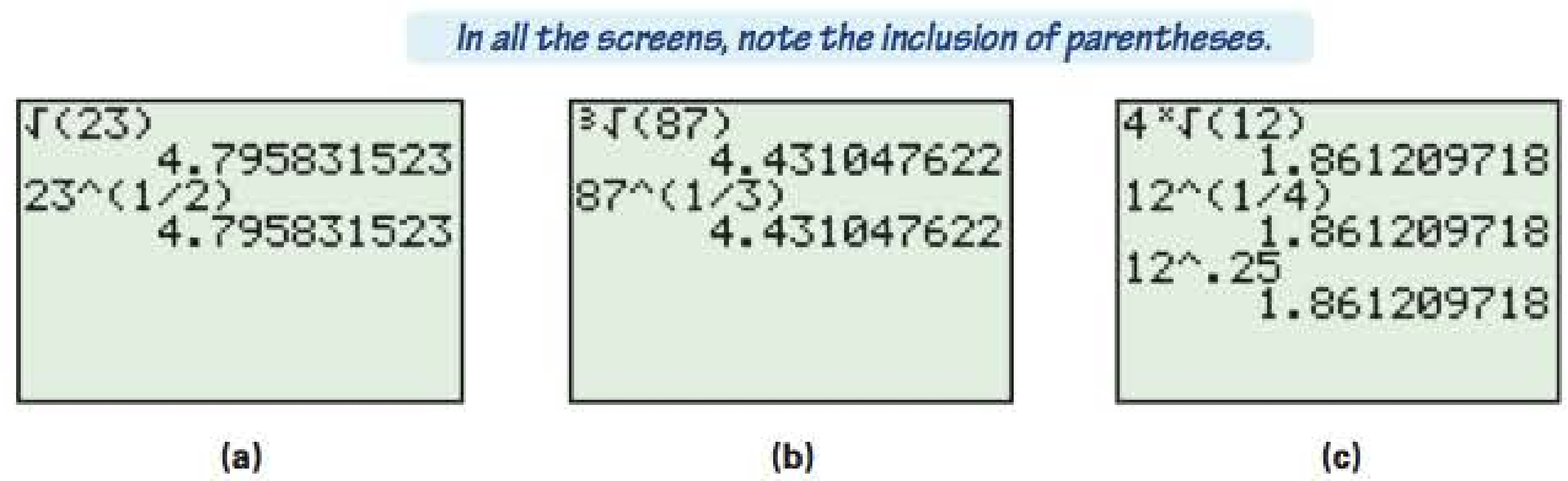



**FIGURE 11**

## EXAMPLE 2 Approximating Expressions with a Calculator

Approximate each expression to the nearest hundredth.

**(a)** $\dfrac{3.8 - 1.4}{5.4 + 3.5}$ **(b)** $3\pi^4 - 9^2$ **(c)** $\sqrt{(4-1)^2 + (-3-2)^2}$

### Solution

**(a)** See **FIGURE 12(a)**. To the nearest hundredth,

$$\frac{3.8 - 1.4}{5.4 + 3.5} \approx 0.27.$$

**(b)** Many calculators also have a special key to calculate the square of a number. To the nearest hundredth, $3\pi^4 - 9^2 \approx 211.23$. See **FIGURE 12(b)**.

**(c)** From **FIGURE 12(c)**, $\sqrt{(4-1)^2 + (-3-2)^2} \approx 5.83$.

**TECHNOLOGY NOTE**

Some graphing calculators display leading zeros in decimal numbers, whereas others do not. For example, $\frac{1}{4}$ might be displayed as either 0.25 or .25. In this text, graphing calculator screens do not usually show leading zeros. See **FIGURES 9** and **12(a)**.

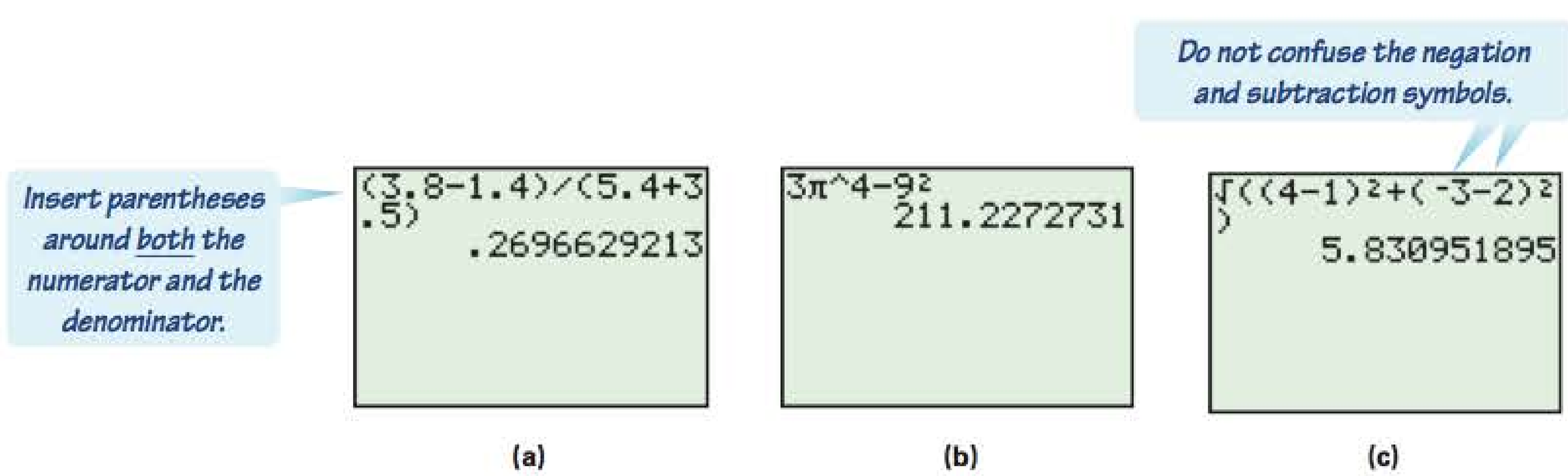



**FIGURE 12**

**WHAT WENT WRONG?**

Two students were asked to compute the expression $(2 + 9) - (8 + 13)$ on a TI-84 Plus calculator. One student obtained the answer $-10$, as seen in **FIGURE A**, while the other obtained $-231$, as seen in **FIGURE B**.

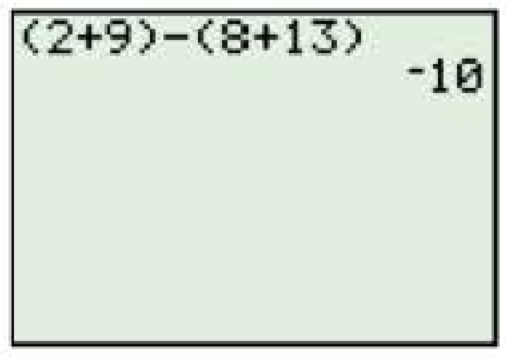



FIGURE A

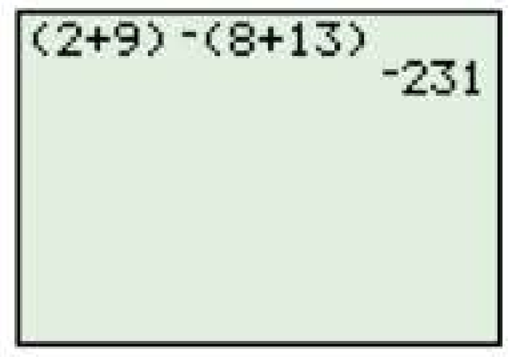



FIGURE B

**What Went Wrong?** Compute the expression by hand to determine which screen gives the correct answer. Why is the answer on the other screen incorrect?

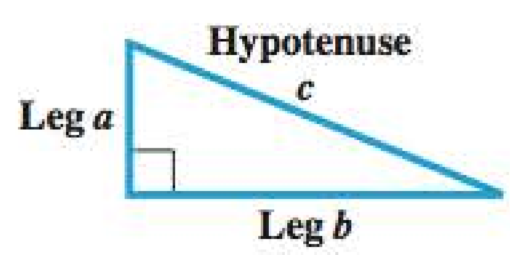
## Distance and Midpoint Formulas

The Pythagorean theorem can be used to calculate the lengths of the sides of a right triangle.

### Pythagorean Theorem

In a right triangle, the sum of the squares of the lengths of the legs is equal to the square of the length of the hypotenuse.

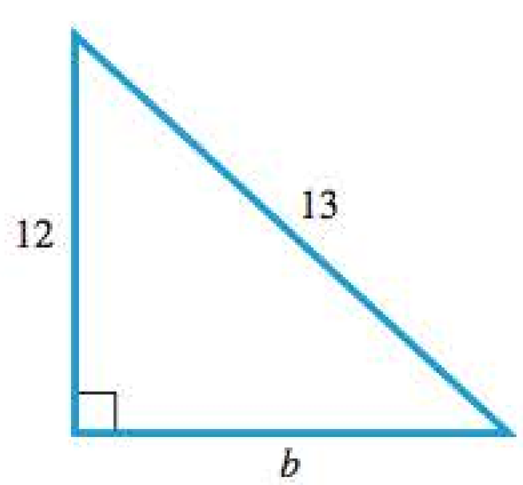
$$a^2 + b^2 = c^2$$




**NOTE** *The converse of the Pythagorean theorem is also true.* That is, if $a$, $b$, and $c$ are lengths of the sides of a triangle and $a^2 + b^2 = c^2$, then the triangle is a right triangle with hypotenuse $c$. For example, if a triangle has sides with lengths 3, 4, and 5, then it is a right triangle with hypotenuse of length 5 because $3^2 + 4^2 = 5^2$.

### EXAMPLE 3 Using the Pythagorean Theorem

Using the right triangle shown in the margin, find the length of the unknown side $b$.




**Solution** Let $a = 12$ and $c = 13$ in the Pythagorean theorem.

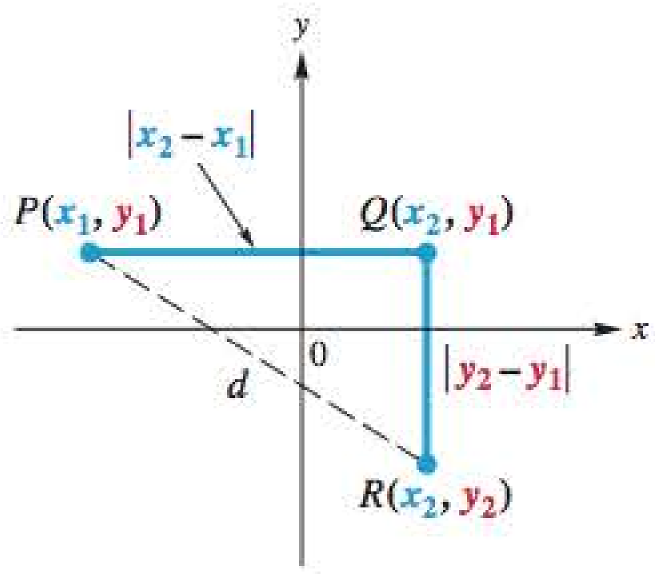
| | |
|---|---|
| $a^2 + b^2 = c^2$ | Pythagorean theorem |
| $12^2 + b^2 = 13^2$ | Substitute. |
| $b^2 = 13^2 - 12^2$ | Subtract $12^2$. |
| $b^2 = 25$ | Simplify. |
| $b = 5$ | Take positive square root. |

*Answer to What Went Wrong?*

The correct answer is $-10$, as shown in FIGURE A. FIGURE B gives an incorrect answer because the negation symbol is used, rather than the subtraction symbol. The calculator computed $2 + 9 = 11$ and then *multiplied* by the negative of $8 + 13$ (that is, $-21$), to obtain the incorrect answer, $-231$.

To derive a formula to find the distance between two points in the $xy$-plane, let $P(x_1, y_1)$ and $R(x_2, y_2)$ be any two distinct points in the plane, as shown in **FIGURE 13.** Complete a right triangle by locating point $Q$ with coordinates $(x_2, y_1)$. The Pythagorean theorem gives the distance between $P$ and $R$ as

$$d(P, R) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}.$$




$d(P, R) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$

**FIGURE 13**

**NOTE** Absolute value bars are not necessary in this formula, since for all real numbers $a$ and $b$, $|a - b|^2 = (a - b)^2$.

### Distance Formula

Suppose that $P(x_1, y_1)$ and $R(x_2, y_2)$ are two points in a coordinate plane. Then the distance between $P$ and $R$, written $d(P, R)$, is given by the **distance formula.**

$$\mathbf{d(P, R) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$$

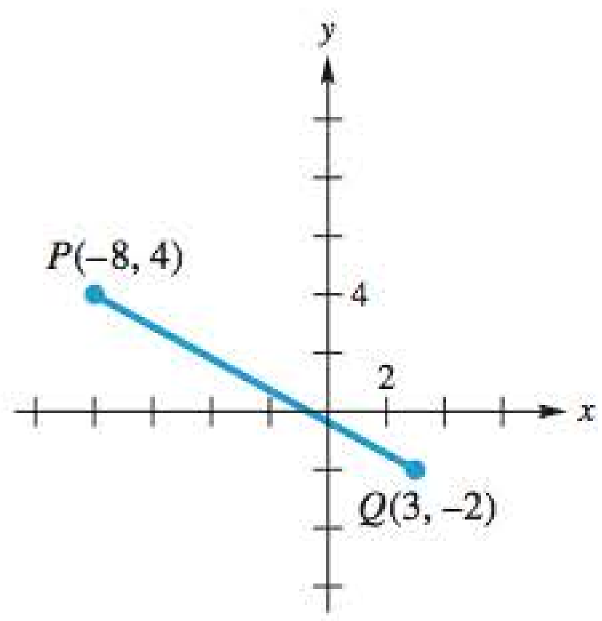



**FIGURE 14**

## EXAMPLE 4 Using the Distance Formula

Use the distance formula to find $d(P, Q)$ in **FIGURE 14.**

### Solution

$$d(P, Q) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad \text{Distance formula}$$

$$= \sqrt{[3 - (-8)]^2 + (-2 - 4)^2} \quad x_1 = -8,\ y_1 = 4,\ x_2 = 3,\ y_2 = -2$$

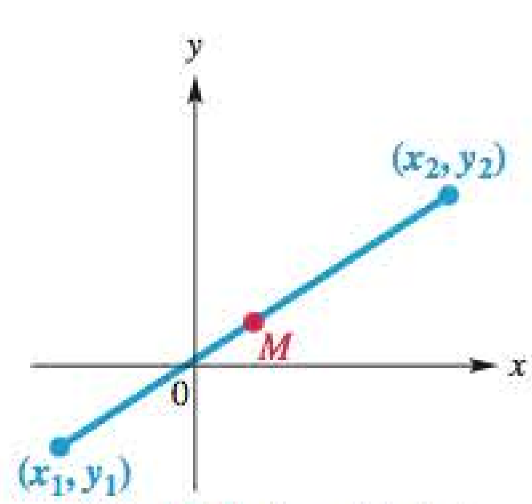
*To subtract a negative number, add the opposite. That is, $3 - (-8) = 3 + 8$.*

$$= \sqrt{11^2 + (-6)^2}$$

$$= \sqrt{121 + 36} \quad \text{Apply exponents.}$$

$$= \sqrt{157} \quad \text{Leave in radical form.}$$

The *midpoint* $M$ of a line segment is the point on the segment that lies the same distance from both endpoints. See **FIGURE 15.** ***The coordinates of the midpoint are found by calculating the average of the x-coordinates and the average of the y-coordinates of the endpoints of the segment.***




Point $M$ is the midpoint of the segment joining $(x_1, y_1)$ and $(x_2, y_2)$.

**FIGURE 15**

### Midpoint Formula

The **midpoint** $M$ of the line segment with endpoints $(x_1, y_1)$ and $(x_2, y_2)$ has the following coordinates.

$$M = \left(\frac{\mathbf{x_1 + x_2}}{\mathbf{2}}, \frac{\mathbf{y_1 + y_2}}{\mathbf{2}}\right)$$

### EXAMPLE 5 Using the Midpoint Formula

Find the coordinates of the midpoint $M$ of the segment with endpoints $(8, -4)$ and $(-9, 6)$.

**Solution** Let $(x_1, y_1) = (8, -4)$ and $(x_2, y_2) = (-9, 6)$ in the midpoint formula.

$$M = \left(\frac{x_1 + x_2}{2}, \frac{y_1 + y_2}{2}\right) = \left(\frac{8 + (-9)}{2}, \frac{-4 + 6}{2}\right) \quad \text{Substitute.}$$

$$= \left(-\frac{1}{2}, 1\right) \quad \text{Simplify.}$$

### EXAMPLE 6 Estimating iPad Sales

Four quarters after the launch of the iPad, about 19.5 million were sold. After 10 quarters, about 99 million iPads were sold. Use the midpoint formula to estimate how many iPads were sold 7 quarters after launch. Compare your estimate with the actual value of 50 million. (*Source:* Business Insider.)

**Solution** Quarter 7 lies midway between quarters 4 and 10. Therefore, we can find the midpoint of the line segment joining the points (4, 19.5) and (10, 99).

$$\left(\frac{4 + 10}{2}, \frac{19.5 + 99}{2}\right) = (7, 59.25)$$

The midpoint formula estimates the number of iPads sold after 7 quarters to be 59.25 million. This is 9.25 million higher than the actual value.

## 1.1 Exercises

*For each set, list all elements that belong to the* **(a)** *natural numbers,* **(b)** *whole numbers,* **(c)** *integers,* **(d)** *rational numbers,* **(e)** *irrational numbers, and* **(f)** *real numbers.*

**1.** $\left\{-6, -\frac{12}{4}, -\frac{5}{8}, -\sqrt{3}, 0, 0.31, 0.\overline{3}, 2\pi, 10, \sqrt{17}\right\}$

**2.** $\left\{-8, -\frac{14}{7}, -0.245, 0, \frac{6}{2}, 8, \sqrt{81}, \sqrt{12}\right\}$

**3.** $\left\{-\sqrt{100}, -\frac{13}{6}, -1, 5.23, 9.\overline{14}, 3.14, \frac{22}{7}\right\}$

**4.** $\{-\sqrt{49}, -0.405, -0.\overline{3}, 0.1, 3, 18, 6\pi, 56\}$

*Classify each number as one or more of the following:* natural number, integer, rational number, *or* real number.

**5.** 16,351,000,000,000 (The federal debt in dollars in January 2013)

**6.** 700,000,000,000 (The federal 2008 bailout fund in dollars)

**7.** −25 (The percent change in the number of Yahoo searches from 2011 to 2012)

**8.** −3 (The annual percent change in the area of tropical rain forests)

**9.** $\frac{7}{3}$ (The fractional increase in online sales on Thanksgiving Day from 2006 to 2011)

**10.** −3.5 (The amount in billions of dollars that the Motion Picture Association of America estimates is lost annually due to piracy)

**11.** $5\sqrt{2}$ (The length of the diagonal of a square measuring 5 units on each side)

**12.** $\pi$ (The ratio of the circumference of a circle to its diameter)

***Concept Check*** *For each measured quantity, state the set of numbers that is most appropriate to describe it. Choose from the* natural numbers, integers, *and* rational numbers.

**13.** Populations of cities

**14.** Distances to nearby cities on road signs

**15.** Shoe sizes

**16.** Prices paid (in dollars and cents) for gasoline tank fill-ups

**17.** Daily low winter temperatures in U.S. cities

**18.** Golf scores relative to par

*Graph each set of numbers on a number line.*

**19.** $\{-4, -3, -2, -1, 0, 1\}$

**20.** $\{-6, -5, -4, -3, -2\}$

**21.** $\left\{-0.5, 0.75, \frac{5}{3}, 3.5\right\}$

**22.** $\left\{-0.6, \frac{9}{8}, 2.5, \frac{13}{4}\right\}$

**23.** Explain the distinction between a rational number and an irrational number.

**24.** ***Concept Check*** Using her calculator, a student found the decimal 1.414213562 when she evaluated $\sqrt{2}$. Is this decimal the exact value of $\sqrt{2}$ or just an approximation of $\sqrt{2}$? Should she write $\sqrt{2} = 1.414213562$ or $\sqrt{2} \approx 1.414213562$?

*Locate each point on a rectangular coordinate system. Identify the quadrant, if any, in which each point lies.*

**25.** $(2, 3)$ **26.** $(-1, 2)$ **27.** $(-3, -2)$ **28.** $(1, -4)$ **29.** $(0, 5)$

**30.** $(-2, -4)$ **31.** $(-2, 4)$ **32.** $(3, 0)$ **33.** $(-2, 0)$ **34.** $(3, -3)$

*Name the possible quadrants in which the point* $(x, y)$ *can lie if the given condition is true.*

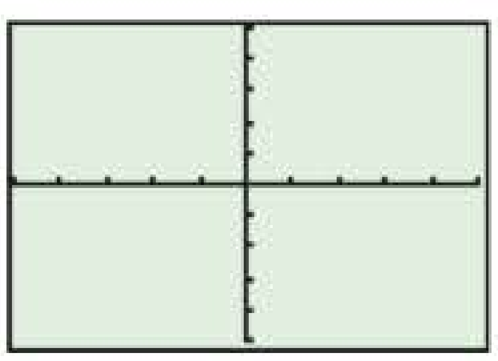
**35.** $xy > 0$ **36.** $xy < 0$ **37.** $\frac{x}{y} < 0$ **38.** $\frac{x}{y} > 0$

**39.** ***Concept Check*** If the $x$-coordinate of a point is 0, the point must lie on which axis?

**40.** ***Concept Check*** If the $y$-coordinate of a point is 0, the point must lie on which axis?

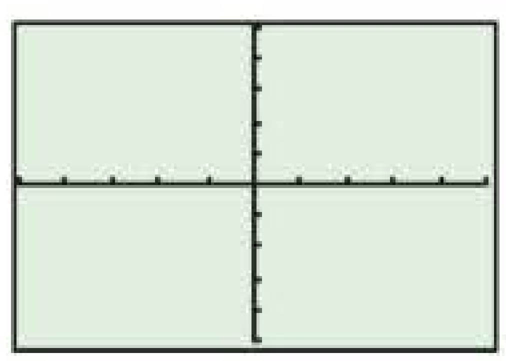
*Give the values of* Xmin, Xmax, Ymin, *and* Ymax *for each screen, given the values for* Xscl *and* Yscl. *Use the notation described in this section.*

**41.**



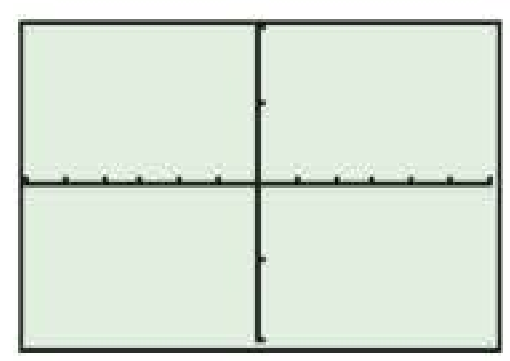
Xscl = 1, Yscl = 5

**42.**



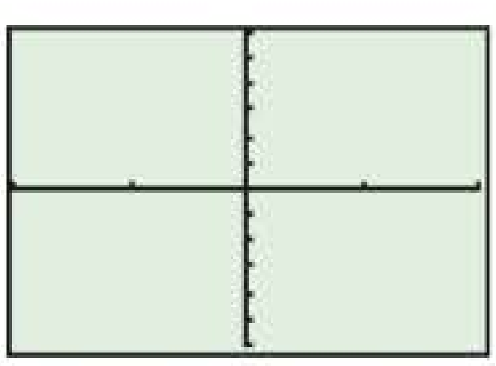
Xscl = 5, Yscl = 1

**43.**



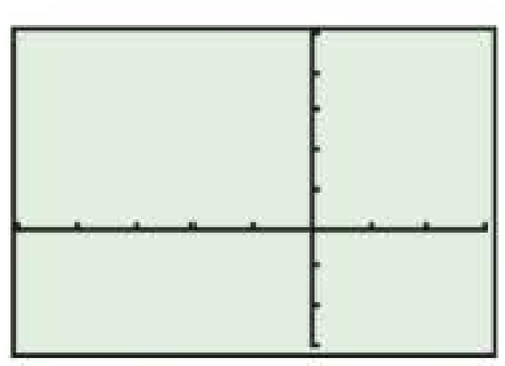
Xscl = 10, Yscl = 50

**44.**



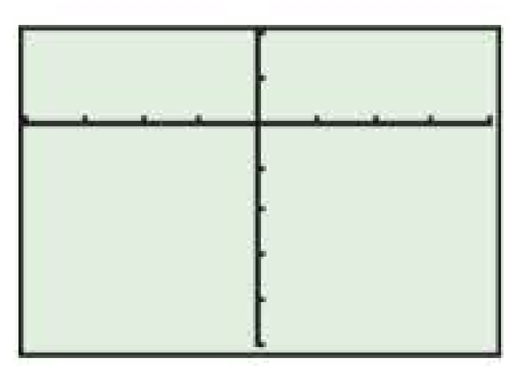
Xscl = 50, Yscl = 10

**45.**



Xscl = 100, Yscl = 100

**46.**



Xscl = 75, Yscl = 75

*Set the viewing window of your calculator to the given specifications. Make a sketch of your window.*

**47.** $[-10, 10]$ by $[-10, 10]$
Xscl = 1 Yscl = 1

**48.** $[-40, 40]$ by $[-30, 30]$
Xscl = 5 Yscl = 5

**49.** $[-5, 10]$ by $[-5, 10]$
Xscl = 3 Yscl = 3

**50.** $[-3.5, 3.5]$ by $[-4, 10]$
Xscl = 1 Yscl = 1

**51.** $[-100, 100]$ by $[-50, 50]$
Xscl = 20 Yscl = 25

**52.** $[-4.7, 4.7]$ by $[-3.1, 3.1]$
Xscl = 1 Yscl = 1