

FIFTH EDITION

Precalculus with Limits

A Graphing Approach

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Precalculus with Limits
A Graphing Approach**Ron Larson**
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A Word from the Authors

Welcome to *Precalculus with Limits: A Graphing Approach*, Fifth Edition. We are pleased to present this new edition of our textbook in which we focus on making the mathematics accessible, supporting student success, and offering teachers flexible teaching options.

Accessible to Students

We have taken care to write this text with the student in mind. Paying careful attention to the presentation, we use precise mathematical language and a clear writing style to develop an effective learning tool. We believe that every student can learn mathematics, and we are committed to providing a text that makes the mathematics of the precalculus course accessible to all students.

Throughout the text, solutions to many examples are presented from multiple perspectives—algebraically, graphically, and numerically. The side-by-side format of this pedagogical feature helps students to see that a problem can be solved in more than one way and to see that different methods yield the same result. The side-by-side format also addresses many different learning styles.

We have found that many precalculus students grasp mathematical concepts more easily when they work with them in the context of real-life situations. Students have numerous opportunities to do this throughout this text. The *Make a Decision* feature further connects real-life data and applications and motivates students. It also offers students the opportunity to generate and analyze mathematical models from large data sets. To reinforce the concept of functions, we have compiled all the elementary functions as a *Library of Parent Functions*, presented in a summary on the endpapers of the text for convenient reference. Each function is introduced at the first point of use in the text with a definition and description of basic characteristics.

We have carefully written and designed each page to make the book more readable and accessible to students. For example, to avoid unnecessary page turning and disruptions to students' thought processes, each example and corresponding solution begins and ends on the same page.

Supports Student Success

During more than 30 years of teaching and writing, we have learned many things about the teaching and learning of mathematics. We have found that students are most successful when they know what they are expected to learn and why it is important to learn the concepts. With that in mind, we have incorporated a thematic study thread throughout this textbook.

Each chapter begins with a list of applications that are covered in the chapter and serve as a motivational tool by connecting section content to real-life situations. Using the same pedagogical theme, each section begins with a set of section learning objectives—*What You Should Learn*. These are followed by an engaging real-life application—*Why You Should Learn It*—that motivates students and illustrates an area where the mathematical concepts will be applied in an example or exercise in the section. The *Chapter Summary—What Did You Learn?*—at the end of each chapter includes *Key Terms* with page references and *Key Concepts*, organized by section, that were covered throughout the chapter. The *Chapter Summary* serves as a useful study aid for students.

Throughout the text, other features further improve accessibility. *Study Tips* are provided throughout the text at point-of-use to reinforce concepts and to help students learn how to study mathematics. *Explorations* reinforce mathematical concepts. Each example with worked-out solution is followed by a *Checkpoint*, which directs the student to work a similar exercise from the exercise set. The *Section Exercises* begin with a *Vocabulary Check*, which gives the students an opportunity to test their understanding of the important terms in the section. A *Prerequisite Skills* is offered in margin notes throughout the textbook exposition. Reviewing the prerequisite skills will enable students to master new concepts more quickly. *Synthesis Exercises* check students' conceptual understanding of the topics in each section. *Skills Review Exercises* provide additional practice with the concepts in the chapter or previous chapters. *Review Exercises*, *Chapter Tests*, and periodic *Cumulative Tests* offer students frequent opportunities for self-assessment and to develop strong study and test-taking skills. The *Progressive Summaries* and the *Study Capsules* serve as a quick reference when working on homework or as a cumulative study aid.

The use of technology also supports students with different learning styles, and graphing calculators are fully integrated into the text presentation. The *Technology Support Appendix* makes it easier for students to use technology. *Technology Support* notes are provided throughout the text at point-of-use. These notes guide students to the *Technology Support Appendix*, where they can learn how to use specific graphing calculator features to enhance their understanding of the concepts presented in the text. These notes also direct students to the *Graphing Technology Guide*, in the *Online Study Center*, for keystroke support that is available for numerous calculator models. *Technology Tips* are provided in the text at point-of-use to call attention to the strengths and weaknesses of graphing technology, as well as to offer alternative methods for solving or checking a problem using technology. Because students are often misled by the limitations of graphing calculators, we have, where appropriate, used color to enhance the graphing calculator displays in the textbook. This enables students to visualize the mathematical concepts clearly and accurately and avoid common misunderstandings.

Numerous additional text-specific resources are available to help students succeed in the precalculus course. These include “live” online tutoring, instructional DVDs, and a variety of other resources, such as tutorial support and self-assessment, which are available on the Web and in Eduspace®. In addition, the *Online Notetaking Guide* is a notetaking guide that helps students organize their class notes and create an effective study and review tool.

Flexible Options for Teachers

From the time we first began writing textbooks in the early 1970s, we have always considered it a critical part of our role as authors to provide teachers with flexible programs. In addition to addressing a variety of learning styles, the optional features within the text allow teachers to design their courses to meet their instructional needs and the needs of their students. For example, the *Explorations* throughout the text can be used as a quick introduction to concepts or as a way to reinforce student understanding.

Our goal when developing the exercise sets was to address a wide variety of learning styles and teaching preferences. The *Vocabulary Check* questions are provided at the beginning of every exercise set to help students learn proper mathematical terminology. In each exercise set we have included a variety of

exercise types, including questions requiring writing and critical thinking, as well as real-data applications. The problems are carefully graded in difficulty from mastery of basic skills to more challenging exercises. Some of the more challenging exercises include the *Synthesis Exercises* that combine skills and are used to check for conceptual understanding, and the *Make a Decision* exercises that further connect real-life data and applications and motivate students. *Skills Review Exercises*, placed at the end of each exercise set, reinforce previously learned skills. The *Proofs in Mathematics*, at the end of each chapter, are proofs of important mathematical properties and theorems and illustrate various proof techniques. This feature gives the teachers the opportunity to incorporate more rigor into their course. In addition, Cengage Learning's Eduspace® website offers teachers the option to assign homework and tests online—and also includes the ability to grade these assignments automatically.

Other print and media resources are available to support teachers. The *Teacher's Edition* provides the complete student text plus point-of-use annotations for teachers in an easy-to-use, wrap-around format. The *Complete Solutions Guide* and its online version offer worked-out solutions to every exercise in the text. For flexibility, the *Test Item File* is available both in print and via Diploma Testing provides teachers all the tools they need to create, author/edit, customize, and deliver multiple types of tests. Teachers can use existing test bank questions, edit the content, and write new static or algorithmic questions all within *Diploma's* powerful electronic platform. The *Electronic Classroom* offers customizable PowerPoint presentations for the classroom. Also included are a variety of transparency masters—including warm-up, daily homework, and answers to section exercises. Finally, the *Online Teaching Center* offers an array of resources provided conveniently via the Web, and the *Online Instructor Success Organizer* is an invaluable aid throughout the year.

Teachers who stress applications and problem-solving, integrating technology into their course will find this program right for them.

Students find extra support in a number of special supplements that reinforce concepts and help them organize their study. First, the *Study and Solutions Guide* provides step-by-step solutions for all odd-numbered text exercises as well as chapter and cumulative tests. The manual also provides practice tests accompanied by a solution key. An invaluable study aid, the *Notetaking Guide* helps students prepare for chapter and/or cumulative tests. It features a lesson-by-lesson framework that allows students to take notes on and review key concepts throughout the text. The *Online Study Center* provides numerous interactive lessons, simulations, animations, and applications, as well as a glossary with flash cards and a graphing calculator program. An abundance of resources are contained in the *Online Study Center*, including the *Online Notetaking Guide*. Finally, Dana Mosely hosts the *Instructional DVDs*. They cover every section in the text, providing clear explanations of key concepts, examples, exercises, and applications in a lecture-based format. New to the DVDs is captioning for the hearing-impaired.

We hope you enjoy the Fifth Edition.

Ron Larson
Robert Hostetler
Bruce H. Edwards

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If you have suggestions for improving this text, please feel free to write us. Over the past two decades we have received many useful comments from both teachers and students, and we value these very much.

Ron Larson
Robert Hostetler
Bruce H. Edwards

Features Highlights

Chapter 2

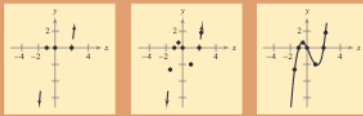
- 2.1 Quadratic Functions
- 2.2 Polynomial Functions of Higher Degree
- 2.3 Real Zeros of Polynomial Functions
- 2.4 Complex Numbers
- 2.5 The Fundamental Theorem of Algebra
- 2.6 Rational Functions and Asymptotes
- 2.7 Graphs of Rational Functions
- 2.8 Quadratic Models

Selected Applications

Polynomial and rational functions have many real-life applications. The applications listed below represent a small sample of the applications in this chapter.

- Automobile Aerodynamics, Exercise 58, page 101
- Revenue, Exercise 93, page 114
- U.S. Population, Exercise 91, page 129
- Impedance, Exercises 79 and 80, page 138
- Profit, Exercise 64, page 145
- Data Analysis, Exercises 41 and 42, page 154
- Wildlife, Exercise 43, page 155
- Comparing Models, Exercise 85, page 164
- Media, Exercise 18, page 170

Polynomial and Rational Functions



Polynomial and rational functions are two of the most common types of functions used in algebra and calculus. In Chapter 2, you will learn how to graph these types of functions and how to find the zeros of these functions.

David Madison/Getty Images



Aerodynamics is crucial in creating racecars. Two types of racecars designed and built by NASCAR teams are short track cars, as shown in the photo, and super-speedway (long track) cars. Both types of racecars are designed either to allow for as much downforce as possible or to reduce the amount of drag on the racecar.

91

“What You Should Learn” and “Why You Should Learn It”

Sections begin with *What You Should Learn*, an outline of the main concepts covered in the section, and *Why You Should Learn It*, a real-life application or mathematical reference that illustrates the relevance of the section content.

Chapter Opener

Each chapter begins with a comprehensive overview of the chapter concepts. The photograph and caption illustrate a real-life application of a key concept. Section references help students prepare for the chapter.

Applications List

An abridged list of applications, covered in the chapter, serve as a motivational tool by connecting section content to real-life situations.

2.2 Polynomial Functions of Higher Degree

Graphs of Polynomial Functions

You should be able to sketch accurate graphs of polynomial functions of degrees 0, 1, and 2. The graphs of polynomial functions of degree greater than 2 are more difficult to sketch by hand. However, in this section you will learn how to recognize some of the basic features of the graphs of polynomial functions. Using these features along with point plotting, intercepts, and symmetry, you should be able to make reasonably accurate sketches *by hand*.

The graph of a polynomial function is **continuous**. Essentially, this means that the graph of a polynomial function has no breaks, holes, or gaps, as shown in Figure 2.14. Informally, you can say that a function is continuous if its graph can be drawn with a pencil without lifting the pencil from the paper.

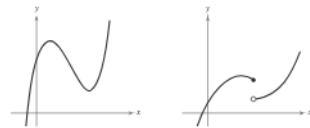


Figure 2.14 (a) Polynomial functions have continuous graphs. (b) Functions with graphs that are not continuous are not polynomial functions.

Another feature of the graph of a polynomial function is that it has only smooth, rounded turns, as shown in Figure 2.15(a). It cannot have a sharp turn such as the one shown in Figure 2.15(b).



Figure 2.15 (a) Polynomial functions have graphs with smooth, rounded turns. (b) Functions with graphs that have sharp turns are not polynomial functions.

What you should learn

- Use transformations to sketch graphs of polynomial functions.
- Use the Leading Coefficient Test to determine the end behavior of graphs of polynomial functions.
- Find and use zeros of polynomial functions as sketching aids.
- Use the Intermediate Value Theorem to help locate zeros of polynomial functions.

Why you should learn it

You can use polynomial functions to model various aspects of nature, such as the growth of a red oak tree, as shown in Exercise 94 on page 114.



Leonard Lee Rice/Getty Images

Example 4 Solving an Exponential Equation

Solve $2(3^{2t-5}) - 4 = 11$.

Solution

$$2(3^{2t-5}) - 4 = 11$$

$$2(3^{2t-5}) = 15$$

$$3^{2t-5} = \frac{15}{2}$$

$$\log_3 3^{2t-5} = \log_3 \frac{15}{2}$$

$$2t - 5 = \log_3 \frac{15}{2}$$

$$2t = 5 + \log_3 7.5$$

$$t = \frac{5}{2} + \frac{1}{2} \log_3 7.5$$

$$t \approx 3.42$$

The solution is $t = \frac{5}{2} + \frac{1}{2} \log_3 7.5 \approx 3.42$. Check this in the original equation.

Now try Exercise 49.

When an equation involves two or more exponential expressions, you can still use a procedure similar to that demonstrated in the previous three examples. However, the algebra is a bit more complicated.

Example 5 Solving an Exponential Equation in Quadratic Form

Solve $e^{2x} - 3e^x + 2 = 0$.

Algebraic Solution

$$e^{2x} - 3e^x + 2 = 0$$

$$(e^x)^2 - 3e^x + 2 = 0$$

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

$$e^x - 2 = 0$$

$$e^x = 2$$

$$x = \ln 2$$

$$e^x - 1 = 0$$

$$e^x = 1$$

$$x = \ln 1$$

$$x = 0$$

The solutions are $x = \ln 2 \approx 0.69$ and $x = 0$. Check these in the original equation.

Now try Exercise 61.

Write original equation.
Add 4 to each side.
Divide each side by 2.
Take log (base 3) of each side.
Inverse Property.
Add 5 to each side.
Divide each side by 2.
Use a calculator.

STUDY TIP

Remember that to evaluate a logarithm such as $\log_3 7.5$, you need to use the change-of-base formula.

$$\log_3 7.5 = \frac{\ln 7.5}{\ln 3} \approx 1.834$$

Graphical Solution

Use a graphing utility to graph $y = e^{2x} - 3e^x + 2$. Use the zero or root feature or the zoom and trace features of the graphing utility to approximate the values of x for which $y = 0$. In Figure 3.35, you can see that the zeros occur at $x = 0$ and at $x \approx 0.69$. So, the solutions are $x = 0$ and $x \approx 0.69$.

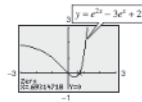


Figure 3.35

Library of Parent Functions

The *Library of Parent Functions* feature defines each elementary function and its characteristics at first point of use. The *Study Capsules* are also referenced for further review of each elementary function.

Explorations

The *Explorations* engage students in active discovery of mathematical concepts, strengthen critical thinking skills, and help them to develop an intuitive understanding of theoretical concepts.

New! Prerequisite Skills

A review of algebra skills needed to complete the examples is offered to the students at point of use throughout the text.

Examples

Many examples present side-by-side solutions with multiple approaches—algebraic, graphical, and numerical. This format addresses a variety of learning styles and shows students that different solution methods yield the same result.

Checkpoint

The *Checkpoint* directs students to work a similar problem in the exercise set for extra practice.

Study Tips

Study Tips reinforce concepts and help students learn how to study mathematics.

Library of Parent Functions: Polynomial Function

The graphs of polynomial functions of degree 1 are lines, and those of functions of degree 2 are parabolas. The graphs of all polynomial functions are smooth and continuous. A polynomial function of degree n has the form

$$f(x) = a_n x^n + a_{n-1} x^{n-1} + \dots + a_2 x^2 + a_1 x + a_0$$

where n is a positive integer and $a_n \neq 0$. The polynomial functions that have the simplest graphs are monomials of the form $f(x) = x^n$, where n is an integer greater than zero. If n is even, the graph is similar to the graph of $f(x) = x^2$ and touches the axis at the x -intercept. If n is odd, the graph is similar to the graph of $f(x) = x^3$ and crosses the axis at the x -intercept. The greater the value of n , the flatter the graph near the origin. The basic characteristics of the cubic function $f(x) = x^3$ are summarized below. A review of polynomial functions can be found in the *Study Capsules*.

Graph of $f(x) = x^3$

Domain: $(-\infty, \infty)$

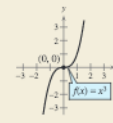
Range: $(-\infty, \infty)$

Intercept: $(0, 0)$

Increasing on $(-\infty, \infty)$

Odd function

Origin symmetry



Exploration

Use a graphing utility to graph $y = x^n$ for $n = 2, 4$, and 8 . (Use the viewing window $-1.5 \leq x \leq 1.5$ and $-1 \leq y \leq 6$.) Compare the graphs. In the interval $(-1, 1)$, which graph is on the bottom?

Outside the interval $(-1, 1)$, which graph is on the bottom?

Use a graphing utility to graph $y = x^n$ for $n = 3, 5$, and 7 . (Use the viewing window $-1.5 \leq x \leq 1.5$ and $-4 \leq y \leq 4$.) Compare the graphs. In the intervals $(-\infty, -1)$ and $(0, 1)$, which graph is on the bottom? In the intervals $(-1, 0)$ and $(1, \infty)$, which graph is on the bottom?

Example 1 Transformations of Monomial Functions

Sketch the graphs of (a) $f(x) = -x^2$, (b) $g(x) = x^2 + 1$, and (c) $h(x) = (x + 1)^2$.

Solution

a. Because the degree of $f(x) = -x^2$ is odd, the graph is similar to the graph of $y = x^2$. Moreover, the negative coefficient reflects the graph in the x -axis, as shown in Figure 2.16.

b. The graph of $g(x) = x^2 + 1$ is an upward shift of one unit of the graph of $y = x^2$, as shown in Figure 2.17.

c. The graph of $h(x) = (x + 1)^2$ is a left shift of one unit of the graph of $y = x^2$, as shown in Figure 2.18.

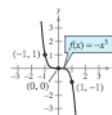


Figure 2.16

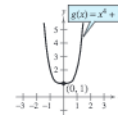


Figure 2.17

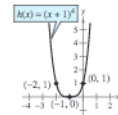


Figure 2.18

Now try Exercise 9.

Section 2.2 Polynomial Functions of Higher Degree 109

Note in Example 6 that there are many polynomial functions with the indicated zeros. In fact, multiplying the functions by any real number does not change the zeros of the function. For instance, multiply the function from part (b) by 1 to obtain $f(x) = \frac{1}{2}x^3 - \frac{3}{2}x^2 + \frac{3}{2}x - \frac{3}{2}$. Then find the zeros of the function. You will obtain the zeros $3, 2 + \sqrt{11}$, and $2 - \sqrt{11}$, as given in Example 6.

Example 7 Sketching the Graph of a Polynomial Function
Sketch the graph of $f(x) = 3x^4 - 4x^3$ by hand.

Solution

- Apply the Leading Coefficient Test. Because the leading coefficient is positive and the degree is even, you know that the graph eventually rises to the left and to the right (see Figure 2.25).
- Find the Real Zeros of the Polynomial. By factoring

$f(x) = 3x^4 - 4x^3$

you can see that the x -axis is a line of odd multiplicity points to your graph.

- Plot a Few Additional Points. Plot a few additional points, as shown to the left and right.
- Draw the Graph. Figure 2.26. Because the graph should cross the x -axis at the origin, the graph should cross the x -axis at the origin.

Figure 2.25

Figure 2.26

Section 2.6 Rational Functions and Asymptotes 151

Example 7 Ultraviolet Radiation

For a person with sensitive skin, the amount of time T (in hours) the person can be exposed to the sun with minimal burning can be modeled by

$$T = \frac{0.37s + 23.8}{s}, \quad 0 < s \leq 120$$

where s is the Sunnor Scale reading. The Sunnor Scale is based on the level of intensity of UVB rays. (Source: Sunnor, Inc.)

- Find the amounts of time a person with sensitive skin can be exposed to the sun with minimal burning when $s = 10$, $s = 25$, and $s = 100$.
- If the model were valid for all $s > 0$, what would be the horizontal asymptote of this function, and what would it represent?

Algebraic Solution

- When $s = 10$, $T = \frac{0.37(10) + 23.8}{10} = 2.75$ hours.
- When $s = 25$, $T = \frac{0.37(25) + 23.8}{25} \approx 1.32$ hours.
- When $s = 100$, $T = \frac{0.37(100) + 23.8}{100} \approx 0.61$ hour.

Because the degrees of the numerator and denominator are the same for

$$T = \frac{0.37s + 23.8}{s}$$

the horizontal asymptote is given by the ratio of the leading coefficients of the numerator and denominator. So, the graph has the line $T = 0.37$ as a horizontal asymptote. This line represents the shortest possible exposure time with minimal burning.

Graphical Solution

- Use a graphing utility to graph the function $y_1 = \frac{0.37x + 23.8}{x}$ using a viewing window similar to that shown in Figure 2.55. Then use the trace or value feature to approximate the values of y_1 when $x = 10$, $x = 25$, and $x = 100$. You should obtain the following values.

When $x = 10$, $y_1 \approx 2.75$ hours.
When $x = 25$, $y_1 \approx 1.32$ hours.
When $x = 100$, $y_1 \approx 0.61$ hour.

Figure 2.55

- Continue to use the trace or value feature to approximate values of $f(x)$ for larger and larger values of x (see Figure 2.56). From this, you can estimate the horizontal asymptote to be $y = 0.37$. This line represents the shortest possible exposure time with minimal burning.

Figure 2.56

Now try Exercise 43.


Technology Tip

Technology Tips point out the pros and cons of technology use in certain mathematical situations. Technology Tips also provide alternative methods of solving or checking a problem by the use of a graphing calculator.


Technology Support

The Technology Support feature guides students to the Technology Support Appendix if they need to reference a specific calculator feature. These notes also direct students to the Graphing Technology Guide, in the Online Study Center, for keystroke support that is available for numerous calculator models.

Real-Life Applications

A wide variety of real-life applications, many using current real data, are integrated throughout the examples and exercises. The  indicates an example that involves a real-life application.

Algebra of Calculus

Throughout the text, special emphasis is given to the algebraic techniques used in calculus. Algebra of Calculus examples and exercises are integrated throughout the text and are identified by the symbol .

22 Chapter 1 Functions and Their Graphs

Applications

Example 7 Cellular Communications Employees

The number N (in thousands) of employees in the cellular communications industry in the United States increased in a linear pattern from 1998 to 2001 (see Figure 1.17). In 2002, the number dropped, then continued to increase through 2004 in a different linear pattern. These two patterns can be approximated by the function

$$N(t) = \begin{cases} 23.5t - 53.6, & 8 \leq t \leq 11 \\ 16.8t - 10.4, & 12 \leq t \leq 14 \end{cases}$$

where t represents the year, with $t = 8$ corresponding to 1998. Use this function to approximate the number of employees for each year from 1998 to 2004. (Source: Cellular Telecommunications & Internet Association)

Solution

From 1998 to 2001, use

$$N(t) = 23.5t - 53.6$$

From 2002 to 2004, use

$$N(t) = 16.8t - 10.4$$

Now try Exercise 87.

Example 8 The Path of a Baseball

A baseball is hit at a speed of 100 feet per second and an angle of $\theta = 30^\circ$ with the horizontal. The path of the ball is modeled by the function

$$f(x) = -0.0032x^2 + 0.032x$$

where x and $f(x)$ are the horizontal distance and the height of the ball, respectively, in feet.

Algebraic Solution

The height of the ball from home plate, where $x = 0$, is

$$f(0) = -0.0032(0)^2 + 0.032(0) = 0$$

When $x = 300$, the ball will clear a 10-foot fence.

Figure 1.17

Section 1.2 Functions 29

86. Data Analysis The graph shows the retail sales (in billions of dollars) of prescription drugs in the United States from 1995 through 2004. Let $f(x)$ represent the retail sales in year x . (Source: National Association of Chain Drug Stores)

Figure 1.18

(a) Find $f(2000)$.

(b) Find $\frac{f(2004) - f(1995)}{2004 - 1995}$ and interpret the result in the context of the problem.

(c) An approximate model for the function is

$$P(t) = -0.0982t^2 + 3.365t - 18.85t + 94.8, \quad 5 \leq t \leq 14$$

where P is the retail sales (in billions of dollars) and t represents the year, with $t = 5$ corresponding to 1995. Complete the table and compare the results with the data in the graph.

t	5	6	7	8	9	10	11	12	13	14
$P(t)$										

(d) Use a graphing utility to graph the model and the data in the same viewing window. Comment on the validity of the model.

In Exercises 87–92, find the difference quotient and simplify your answer.

87. $f(x) = 2x$, $\frac{f(x+h) - f(x)}{h}$, $h \neq 0$

88. $g(x) = 3x - 1$, $\frac{g(x+h) - g(x)}{h}$, $h \neq 0$

89. $f(x) = x^2 - x + 1$, $\frac{f(x+h) - f(x)}{h}$, $h \neq 0$

90. $f(x) = x^3 + x$, $\frac{f(x+h) - f(x)}{h}$, $h \neq 0$

91. $f(t) = \frac{1}{t}$, $\frac{f(t+h) - f(t)}{h}$, $h \neq 0$

92. $f(x) = \frac{4}{x+1}$, $\frac{f(x+h) - f(x)}{h}$, $h \neq 0$

Synthesis

True or False? In Exercises 93 and 94, determine whether the statement is true or false. Justify your answer.

93. The domain of the function $f(x) = x^4 - 1$ is $(-\infty, \infty)$, and the range of $f(x)$ is $(0, \infty)$.

94. The set of ordered pairs $\{(-8, -2), (-6, 0), (-4, 0), (-2, 2), (0, 4), (2, -2)\}$ represents a function.

Library of Parent Functions In Exercises 95–98, write a piecewise-defined function for the graph shown.

95.

96.

97.

98.

99. Writing In your own words, explain the meanings of domain and range.

100. Think About It Describe an advantage of function notation.


Skills Review

In Exercises 101–104, perform the operation and simplify.

101. $12 - \frac{x}{x+2}$ 102. $\frac{3}{x+20} + \frac{x}{x^2+4x-5}$

103. $\frac{2x^3+11x^2-6x}{5x} - \frac{x+10}{2x^2+5x-3}$

104. $\frac{x+7}{2(x-9)} - \frac{x-7}{2(x-9)}$

The symbol  indicates an example or exercise that highlights algebraic techniques specifically used in calculus.

Section 2.1 Quadratic Functions 99

2.1 Exercises See www.CalcChat.com for worked-out solutions to odd-numbered exercises.

Vocabulary Check

Fill in the blanks.

- A polynomial function of degree n and leading coefficient a_n is a function of the form $f(x) = a_n x^n + a_{n-1} x^{n-1} + \dots + a_1 x + a_0$, $a_n \neq 0$ where n is a _____ and $a_0, a_1, \dots, a_{n-1}, a_n$ are _____ numbers.
- A _____ function is a second-degree polynomial function, and its graph is called a _____.
- The graph of a quadratic function is symmetric about its _____.
- If the graph of a quadratic function opens upward, then its leading coefficient is _____ and the vertex of the graph is a _____.
- If the graph of a quadratic function opens downward, then its leading coefficient is _____ and the vertex of the graph is a _____.

In Exercises 1–4, match the quadratic function with its graph. [The graphs are labeled (a), (b), (c), and (d).]

(a)

(b)

(c)

(d)

- $f(x) = (x - 2)^2$
- $f(x) = 3 - x^2$
- $f(x) = x^2 + 3$
- $f(x) = -(x - 4)^2$

In Exercises 5 and 6, use a graphing utility to graph each function in the same viewing window. Describe how the graph of each function is related to the graph of $y = x^2$.

- (a) $y = \frac{1}{2}x^2$ (b) $y = \frac{1}{2}x^2 - 1$
- (c) $y = \frac{1}{2}(x + 3)^2$ (d) $y = -\frac{1}{2}(x + 3)^2 - 1$
- (a) $y = \frac{1}{2}x^2$ (b) $y = \frac{1}{2}x^2 + 1$
- (c) $y = \frac{1}{2}(x - 3)^2$ (d) $y = -\frac{1}{2}(x - 3)^2 + 1$

In Exercises 7–20, sketch the graph of the quadratic function. Identify the vertex and x -intercept(s). Use a graphing utility to verify your results.

- $f(x) = 25 - x^2$
- $f(x) = x^2 - 7$
- $f(x) = \frac{1}{2}x^2 - 4$
- $f(x) = 16 - \frac{1}{2}x^2$
- $f(x) = (x + 4)^2 - 3$
- $f(x) = (x - 6)^2 + 3$
- $g(x) = x^2 - 8x + 16$
- $g(x) = x^2 + 2x + 1$
- $f(x) = x^2 - x + \frac{1}{2}$
- $f(x) = x^2 + 3x + \frac{1}{2}$
- $f(x) = -x^2 + 2x + 5$
- $f(x) = -x^2 - 4x + 1$
- $h(x) = 4x^2 - 4x + 21$
- $f(x) = 2x^2 - x + 1$
- $f(x) = -(x^2 + 2x - 3)$
- $f(x) = -(x^2 + x - 30)$
- $g(x) = x^2 + 8x + 11$
- $f(x) = x^2 + 10x + 41$
- $f(x) = -2x^2 + 16x - 31$
- $f(x) = -4x^2 + 24x - 41$

In Exercises 21–26, use a graphing utility to graph the quadratic function. Identify the vertex and x -intercept(s). Then check your results algebraically by writing the quadratic function in standard form.

- $f(x) = -(x^2 + 2x - 3)$
- $f(x) = -(x^2 + x - 30)$
- $g(x) = x^2 + 8x + 11$
- $f(x) = x^2 + 10x + 41$
- $f(x) = -2x^2 + 16x - 31$
- $f(x) = -4x^2 + 24x - 41$

In Exercises 27 and 28, write an equation for the parabola in standard form. Use a graphing utility to graph the equation and verify your result.

-
-

Section Exercises

The section exercise sets consist of a variety of computational, conceptual, and applied problems.

Vocabulary Check

Section exercises begin with a *Vocabulary Check* that serves as a review of the important mathematical terms in each section.

New! Calc Chat

The worked-out solutions to the odd-numbered text exercises are now available at www.CalcChat.com.

Synthesis and Skills Review Exercises

Each exercise set concludes with three types of exercises.

Synthesis exercises promote further exploration of mathematical concepts, critical thinking skills, and writing about mathematics. The exercises require students to show their understanding of the relationships between many concepts in the section.

Skills Review Exercises reinforce previously learned skills and concepts.

New! *Make a Decision* exercises, found in selected sections, further connect real-life data and applications and motivate students. They also offer students the opportunity to generate and analyze mathematical models from large data sets.

- Data Analysis** The factory sales S of VCRs (in millions of dollars) in the United States from 1990 to 2004 can be modeled by $S = -28.80t^2 + 218.1t + 2435$, for $0 \leq t \leq 14$, where t is the year, with $t = 0$ corresponding to 1990. (Source: Consumer Electronics Association)
 - According to the model, when did the maximum value of factory sales of VCRs occur?
 - According to the model, what was the value of the factory sales in 2004? Explain your result.
 - Would you use the model to predict the value of the factory sales for years beyond 2004? Explain.

Synthesis

True or False? In Exercises 63 and 64, determine whether the statement is true or false. Justify your answer.

- The function $f(x) = -12x^2 - 1$ has no x -intercepts.
- The graphs of $f(x) = -4x^2 - 10x + 7$ and $g(x) = 12x^2 + 30x + 1$ have the same axis of symmetry.

Library of Parent Functions In Exercises 65 and 66, determine which equation(s) may be represented by the graph shown. (There may be more than one correct answer.)

- (a) $f(x) = -(x - 4)^2 + 2$
- (b) $f(x) = -(x + 2)^2 + 4$
- (c) $f(x) = -(x + 2)^2 - 4$
- (d) $f(x) = -x^2 - 4x - 8$
- (e) $f(x) = -(x - 2)^2 - 4$
- (f) $f(x) = -x^2 + 4x - 8$



- (a) $f(x) = (x - 1)^2 + 3$
- (b) $f(x) = (x + 1)^2 + 3$
- (c) $f(x) = (x - 3)^2 + 1$
- (d) $f(x) = x^2 + 2x + 4$
- (e) $f(x) = (x + 3)^2 + 1$
- (f) $f(x) = x^2 + 6x + 10$

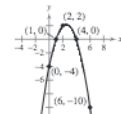


Think About It: In Exercises 67–70, find the value of b such that the function has the given maximum or minimum value.

- $f(x) = -x^2 + bx - 75$; Maximum value: 25
- $f(x) = -x^2 + bx - 16$; Maximum value: 48
- $f(x) = x^2 + bx + 26$; Minimum value: 10
- $f(x) = x^2 + bx - 25$; Minimum value: -50

- Profit** The profit P (in millions of dollars) for a recreational vehicle retailer is modeled by a quadratic function of the form $P = at^2 + bt + c$, where t represents the year. If you were president of the company, which of the following models would you prefer? Explain your reasoning.
 - a is positive and $t \geq -b/(2a)$.
 - a is positive and $t \leq -b/(2a)$.
 - a is negative and $t \geq -b/(2a)$.
 - a is negative and $t \leq -b/(2a)$.

- Writing** The parabola in the figure below has an equation of the form $y = ax^2 + bx - 4$. Find the equation of this parabola in two different ways, by hand and with technology (graphing utility or computer software). Write a paragraph describing the methods you used and comparing the results of the two methods.



Skills Review

In Exercises 73–76, determine algebraically any point(s) of intersection of the graphs of the equations. Verify your results using the *intersect* feature of a graphing utility.

- $x + y = 8$ $y = 3x - 10$
- $-3x + y = 6$ $y = \frac{1}{2}x + 1$
- $y = 9 - x^2$ $76. y = x^3 + 2x - 1$
- $y = x + 3$ $y = -2x + 15$

- Make a Decision** To work an extended application analyzing the height of a basketball after it has been dropped, visit this textbook's Online Study Center.

82 Chapter 1 Functions and Their Graphs

What Did You Learn?

Key Terms

- slope, p. 3
- points-slope form, p. 5
- slope-intercept form, p. 7
- parallel lines, p. 9
- perpendicular lines, p. 9
- function, p. 16
- domain, p. 16
- range, p. 16
- independent variable, p. 18
- dependent variable, p. 18
- function notation, p. 18
- graph of a function, p. 20
- Vertical Line Test, p. 31
- even function, p. 35
- odd function, p. 35
- rigid transformation, p. 47
- inverse function, p. 62
- one-to-one, p. 66
- Horizontal Line Test, p. 66
- positive correlation, p. 74
- negative correlation, p. 74

Key Concepts

- Find and use the slopes of lines to write and graph linear equations.
 - The slope m of the line passing through the points (x_1, y_1) and (x_2, y_2) , where $x_1 \neq x_2$, is $m = \frac{y_2 - y_1}{x_2 - x_1}$.
 - The point-slope form of the equation of a line passing through the point (x_1, y_1) and having slope m is $y - y_1 = m(x - x_1)$.
 - The graph of the equation $y = mx + b$ is a line with slope m and y -intercept $(0, b)$.
- Evaluate functions.
 - To evaluate a function f at a value x , substitute x for the independent variable x in the function's formula.
 - The domain of a function is the set of all real numbers for which the function is defined.
- Analyze graphs.
 - The graph of a function f is a set of points (x, y) such that $y = f(x)$.
 - The points at which the graph intersects the x -axis are the x -intercepts of the function.
 - An even function is a function f such that $f(x) = f(-x)$ for all x in the domain of f .
- Identify and graph nonrigid transformations.
 - Vertical and horizontal stretches and compressions of a function f are $af(x)$ and $f(bx)$, respectively, where $a > 1$ and $b > 1$ for stretches and $0 < a < 1$ and $0 < b < 1$ for compressions.
 - A reflection of a function f across the x -axis is $-f(x)$.

Review Exercises

1.1 In Exercises 1 and 2, sketch the lines with the indicated slopes through the point on the same set of the coordinate axes.

Point	Slope
1. $(1, 1)$	(a) 2 (b) 0
	(c) -1 (d) Undefined
2. $(-2, -3)$	(a) 1 (b) $-\frac{1}{2}$
	(c) 4 (d) 0

In Exercises 3–8, plot the two points and find the slope of the line passing through the points.

Point	Slope
3. $(-3, 2), (8, 2)$	$m = 1$
4. $(7, -1), (7, 12)$	$m = -\frac{1}{2}$
5. $(\frac{1}{2}, 1), (5, 3)$	$m = \frac{1}{2}$
6. $(-\frac{1}{2}, \frac{1}{2}), (\frac{1}{2}, -\frac{1}{2})$	$m = -1$
7. $(-4.5, 6), (2.1, 3)$	$m = 0$
8. $(-2.7, -6.3), (-1, -1.2)$	m is undefined.

In Exercises 9–18, (a) use the point on the line and the slope of the line to find the general form of the equation of the line, and (b) find three additional points through which the line passes. (There are many correct answers.)

Point	Slope
9. $(2, -1)$	$m = 1$
10. $(-3, 5)$	$m = -\frac{1}{2}$
11. $(0, -5)$	$m = \frac{1}{2}$
12. $(3, 0)$	$m = -\frac{1}{2}$
13. $(\frac{1}{2}, -5)$	$m = -1$
14. $(0, \frac{1}{2})$	$m = -\frac{1}{2}$
15. $(-2, 5)$	$m = 0$
16. $(-8, 8)$	$m = 0$
17. $(10, -6)$	m is undefined.
18. $(5, 4)$	m is undefined.

In Exercises 19–22, find the slope-intercept form of the equation of the line that passes through the points. Use a graphing utility to graph the line.

Point	Line
19. $(2, -1), (4, -1)$	29. $(3, -2)$ $5x - 4y = 8$
20. $(0, 0), (0, 10)$	30. $(-8, 3)$ $2x + 3y = 5$
21. $(-1, 0), (6, 2)$	31. $(-8, 2)$ $x = 4$
22. $(1, 6), (4, 2)$	32. $(3, -4)$ $y = 2$

Chapter Tests and Cumulative Tests

Chapter Tests, at the end of each chapter, and periodic Cumulative Tests offer students frequent opportunities for self-assessment and to develop strong study and test-taking skills.

Chapter Summary

The Chapter Summary “What Did You Learn?” includes Key Terms with page references and Key Concepts, organized by section, that were covered throughout the chapter.

Review Exercises

The chapter Review Exercises provide additional practice with the concepts covered in the chapter.

88 Chapter 1 Functions and Their Graphs

1 Chapter Test

Take this test as you would take a test in class. After you are finished, check your work against the answers in the back of the book.

1. Find the equations of the lines that pass through the point $(0, 4)$ and are (a) parallel to and (b) perpendicular to the line $5x + 2y = 3$.

2. Find the slope-intercept form of the equation of the line that passes through the points $(2, -1)$ and $(-3, 4)$.

3. Does the graph at the right represent y as a function of x ? Explain.

4. Evaluate $f(x) = |x + 2| - 15$ at each value of the independent variable and simplify. (a) $f(-8)$ (b) $f(14)$ (c) $f(0 - 6)$

5. Find the domain of $f(x) = 10 - \sqrt{3 - x}$.

6. An electronics company's fixed costs are \$5000. The total cost C of producing x units is given by $C(x) = 5000 + 25x$. (a) Find the total cost of producing 100 units. (b) Find the total cost of producing 200 units. (c) Find the total cost of producing 300 units. (d) Find the total cost of producing 400 units. (e) Find the total cost of producing 500 units.

1–3 Cumulative Test

Take this test to review the material in Chapters 1–3. After you are finished, check your work against the answers given in the back of the book.

In Exercises 1–3, (a) write the general form of the equation of the line that satisfies the given conditions and (b) find three additional points through which the line passes.

- The line contains the points $(-5, 8)$ and $(-1, 4)$.
- The line contains the point $(-\frac{1}{2}, 1)$ and has a slope of -2 .
- The line has an undefined slope and contains the point $(-\frac{1}{2}, \frac{1}{2})$.

In Exercises 4 and 5, evaluate the function at each value of the independent variable and simplify.

4. $f(x) = \frac{x-2}{x+2}$ (a) $f(5)$ (b) $f(2)$ (c) $f(5 + 4)$ (d) $f(-8)$ (e) $f(0)$ (f) $f(4)$

5. $f(x) = \begin{cases} 3x - k, & x < 0 \\ k^2 + 4, & x \geq 0 \end{cases}$ (a) $f(-8)$ (b) $f(2)$ (c) $f(5 + 4)$ (d) $f(-8)$ (e) $f(0)$ (f) $f(4)$

6. Does the graph at the right represent y as a function of x ? Explain.

7. Use a graphing utility to graph the function $f(x) = 2|x - 5| - |x + 5|$. Then determine the open intervals over which the function is increasing, decreasing, or constant.

8. Compare the graphs of each function with the graph of $f(x) = \sqrt{x}$. (a) $g(x) = \frac{1}{2}\sqrt{x}$ (b) $h(x) = \sqrt{x} + 2$ (c) $g(x) = -\sqrt{x} + 2$

In Exercises 9–12, evaluate the indicated function for $f(x) = -x^2 + 3x - 10$ and $g(x) = 4x + 1$.

9. $(f + g)(-4)$ 10. $(g - f)(0)$ 11. $(g \circ f)(-2)$ 12. $(fg)(-1)$

13. Determine whether $h(x) = 5x - 2$ has an inverse function. If so, find it.

In Exercises 14–16, sketch the graph of the function. Use a graphing utility to verify the graph.

14. $f(x) = -\frac{1}{2}(x^2 + 4x)$ 15. $f(x) = \frac{1}{3}(x - 2)^2$

16. $f(x) = x^2 + 2x^2 - 9x - 18$

17. Find all the zeros of $f(x) = x^3 + 2x^2 + 4x + 8$.

18. Use a graphing utility to approximate any real zeros of $g(x) = x^3 + 4x^2 - 11$ accurate to three decimal places.

19. Divide $(4x^3 + 14x - 9)$ by $(x + 3)$ using long division.

20. Divide $(2x^3 - 5x^2 + 6x - 20)$ by $(x - 6)$ using synthetic division.

21. Plot the complex number $-5 + 4i$ in the complex plane.

22. Find a polynomial function with real coefficients that has the zeros $0, -3$, and $1 + \sqrt{3}i$.

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