Section 5: Quadratic Equations and Functions – Part 1

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Real-World Examples of Quadratic Functions

Let's revisit linear functions.

Imagine that you are driving down the road at a constant speed of 40 mph. This is a linear function.

We can represent the distance traveled versus time on a table (to the right).

<table>
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<tr>
<th>Time (in hours)</th>
<th>Distance Traveled (in miles)</th>
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<tbody>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
</tr>
<tr>
<td>4</td>
<td>160</td>
</tr>
</tbody>
</table>

We can represent the scenario on a graph:
The following Mathematics Florida Standards will be covered in this section:

<table>
<thead>
<tr>
<th>A-CED.1.1 –</th>
<th>Create equations and inequalities in one variable and use them to solve problems. Include equations arising from linear and quadratic functions, and simple rational and exponential functions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-REI.2.4 -</td>
<td>Solve quadratic equations in one variable.</td>
</tr>
<tr>
<td>a. Use the method of completing the square to transform any quadratic equation in ( x ) into an equation of the form ((x - p)^2 = q) that has the same solutions. Derive the quadratic formula from this form.</td>
<td></td>
</tr>
<tr>
<td>b. Solve quadratic equations by inspection (e.g., for ( x^2 = 49 )), taking square roots, completing the square, the quadratic formula and factoring, as appropriate to the initial form of the equation. Recognize when the quadratic formula gives complex solutions and write them as ( a \pm bi ) for real numbers ( a ) and ( b ).</td>
<td></td>
</tr>
<tr>
<td>A-SSE.1.2 -</td>
<td>Use the structure of an expression to identify ways to rewrite it. For example, see ( x^4 - y^4 ) as ((x^2)^2 - (y^2)^2) thus recognizing it as a difference of squares that can be factored as ((x^2 - y^2)(x^2 + y^2)).</td>
</tr>
<tr>
<td>A-SSE.2.3ab -</td>
<td>Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.</td>
</tr>
<tr>
<td>a. Factor a quadratic expression to reveal the zeros of the function it defines.</td>
<td></td>
</tr>
<tr>
<td>b. Complete the square in a quadratic expression to reveal the maximum or minimum value of the function it defines.</td>
<td></td>
</tr>
<tr>
<td>F-IF.2.4 -</td>
<td>For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship. Key features include: intercepts; intervals where the function is increasing, decreasing, positive, or negative; relative maximums and minimums; symmetries; end behavior; and periodicity.</td>
</tr>
<tr>
<td>F-IF.3.8 -</td>
<td>Write a function defined by an expression in different but equivalent forms to reveal and explain different properties of the function.</td>
</tr>
<tr>
<td>a. Use the process of factoring and completing the square in quadratic function to show zeros, extreme values, and symmetry of the graph, and interpret these in terms of a context.</td>
<td></td>
</tr>
</tbody>
</table>
Section 5: Quadratic Equations and Functions – Part 1

Section 5 – Topic 1
Real-World Examples of Quadratic Functions

Let’s revisit linear functions.

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We can represent the distance traveled versus time on a table (to the right).

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<td>120</td>
</tr>
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<td>4</td>
<td>160</td>
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</table>

We can represent the scenario on a graph.

We can represent the distance traveled $d(t)$, in terms of time, $t$ hours, with the equation $d(t) = 40t$.

Linear functions always have a constant rate of change. In this section, we are going to discover a type of non-linear function.

Consider the following situation.

Liam dropped a watermelon from the top of a 300 ft tall building. He wanted to know if the watermelon was falling at a constant rate over time. He filmed the watermelon’s fall and then recorded his observations in the following table.

<table>
<thead>
<tr>
<th>Time (in seconds)</th>
<th>Height (in feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>300.0</td>
</tr>
<tr>
<td>1</td>
<td>283.9</td>
</tr>
<tr>
<td>2</td>
<td>235.6</td>
</tr>
<tr>
<td>3</td>
<td>155.1</td>
</tr>
<tr>
<td>4</td>
<td>42.4</td>
</tr>
</tbody>
</table>

What do you notice about the rate of change?

Why do you think that the rate of change is not constant?
Liam entered the data of the falling watermelon into his graphing calculator. The graph below displays the first quadrant of the graph.

What is the independent variable?

What is the dependent variable?

Liam then used his calculator to find the equation of the function, \( h(t) = -16t^2 + 300 \).

Important facts:

- We call this non-linear function a ____________________.
- The general form of the equation is ____________________.

The graph of \( f(x) = x^2 \) is shown below.

This graph is called a ____________________.

Why did we only consider the first quadrant of Liam’s graph?
In Liam’s graph, what was the watermelon’s height when it hit the ground?

The time when the watermelon’s height was at zero is called the solution to this quadratic equation. We also call this the __________ of the equation.

There was only one solution to Liam’s equation. Describe a situation where there could be two solutions.

What about no solutions?

To solve a quadratic equation using a graph:

> Look for the _________________ of the graph.

> The solutions are the values where the graph intercepts the _________________.

Let’s Practice!

1. What are the solutions to the quadratic equation graphed below?

Zeros = x-intercepts = Solutions
Try It!

2. Aaron shot a water bottle rocket from the ground. A graph of height over time is shown below.

![Graph of height over time]

a. What type of function best models the rocket's motion?

b. After how many seconds did the rocket hit the ground?

c. Estimate the maximum height of the rocket.

The maximum or minimum point of the parabola is called the ________________.

---

BEAT THE TEST!

1. Jordan owns an electronics business. During her first year in the business, she collected data and created the following graph showing the relationship between the selling price of an item and the profit.

![Graph showing profit vs. selling price]

Part A: Circle the solutions to the quadratic function graphed above.

Part B: What do the solutions represent?

Part C: Box the vertex of the graph.

Part D: What does the vertex represent?

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Section 5 – Topic 2
Factoring Quadratic Expressions

Let's review the two methods we used for multiplying polynomials.

Area Model:
\[
\begin{array}{ccc}
  x & 2y & -7z \\
  3 & & \\
\end{array}
\]

Distributive Property:
\[3(x + 2y - 7z)\]

We can use these same methods to factor out the greatest common factor of an expression.

Area Model:
\[
\begin{array}{ccc}
  10x^3 & -14x^2 & 12x \\
  & & \\
\end{array}
\]

Distributive Property:
\[10x^3 - 14x^2 + 12x\]

Use the area model to write an equivalent expression for \((2x + 5)(x + 3)\).

We can use this same area model to factor a quadratic expression. Look at the resulting trinomial and notice the following four patterns:

- The first term of the trinomial can always be found in the _______ __________ rectangle.
- The last term of the trinomial can always be found in the _______ __________ rectangle.
- The second term of the trinomial is the _______ of the _______ __________ and _______ __________ rectangles.
- The _______ of the _______ are always equal.
Use the distributive property to write an equivalent expression for $(2x + 5)(x + 3)$.

We can also use the distributive property to factor a quadratic expression.

What are the two middle terms of the expanded form?

Consider the resulting trinomial.

$$2x^2 + 11x + 15$$

Notice that the product of the two middle terms of expanded form are equal to the product of the first and last term of the trinomial. The middle terms also sum to the middle term of the trinomial.

Let’s consider how we can use this and the distributive property to factor a quadratic expression.

Factor $2x^2 + 3x - 5$ using the distributive property.

- Multiply the first term by the last term.
- Find two factors whose product is equal to $-10x^2$ and whose sum is equal to $3x$.
- Replace the middle term with these two factors.
- Factor the polynomial by grouping the first two terms and the last two terms.
Let's Practice!

1. Consider the quadratic expression $3x^2 + 4x - 4$.
   a. Factor using the area model.
   b. Factor using the distributive property.

Try It!

2. Consider the quadratic expression $4w^2 - 21w + 20$.
   a. Factor using the area model.
   b. Factor using the distributive property.

You can check your answer by using the distributive property. The product of the factors should always result in the original trinomial.
1. Identify all factors of the expression $18x^2 - 9x - 5$. Select all that apply.

- $2x + 5$
- $6x - 5$
- $18x - 5$
- $3x + 5$
- $3x + 1$

Section 5 – Topic 3
Solving Quadratic Equations by Factoring

Once a quadratic equation is factored, we can use the **zero product property** to solve the equation.

The zero product property states that if the product of two factors is zero, then one (or both) of the factors must be ____________.

- If $ab = 0$, then either $a = 0, b = 0$, or $a = b = 0$.

To solve a quadratic equation by factoring:

1. Set the equation equal to zero.
2. Factor the quadratic.
3. Set each factor equal to zero and solve.
4. Write the solution set.

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Let's Practice!

1. Solve for \( b \) by factoring \( b^2 + 8b + 15 = 0 \).

2. Solve for \( f \) by factoring \( 10f^2 + 17f + 3 = 0 \).

Try It!

3. Solve for \( j \) by factoring \( 6j^2 - 19j + 14 = 0 \).
BEAT THE TEST!

1. Tyra solved the quadratic equation $x^2 - 10x - 24 = 0$ by factoring. Her work is shown below:

   \begin{align*}
   \text{Step 1:} & \quad x^2 - 10x - 24 = 0 \\
   \text{Step 2:} & \quad x^2 - 4x - 6x - 24 = 0 \\
   \text{Step 3:} & \quad (x^2 - 4x) + (-6x - 24) = 0 \\
   \text{Step 4:} & \quad x(x - 4) - 6(x - 4) = 0 \\
   \text{Step 5:} & \quad (x - 4)(x - 6) = 0 \\
   \text{Step 6:} & \quad x - 4 = 0, x - 6 = 0 \\
   \text{Step 7:} & \quad x = 4 \text{ or } x = 6 \\
   \text{Step 8:} & \quad \{4, 6\}
   \end{align*}

Tyra did not find the correct solutions. Investigate the steps, decipher her mistakes, and explain how to correct Tyra’s work.

Section 5 – Topic 4
Solving Other Quadratic Equations by Factoring

Many quadratic equations will not be in standard form.

- The equation won’t always equal zero.
- There may be a greatest common factor (GCF) within all of the terms.

Let’s Practice!

1. Solve for $m$: $3m^2 + 30m - 168 = 0$.

2. Solve for $x$: $(x + 4)(x - 5) = -8$. 

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Try It!


BEAT THE TEST!

1. What are the solutions to $40x^2 - 30x = 135$? Select all that apply.

- $\frac{9}{2}$
- $\frac{3}{4}$
- $\frac{9}{4}$
- $\frac{9}{2}$
- $\frac{3}{4}$

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Section 5 – Topic 5
Solving Quadratic Equations by Factoring – Special Cases

There are a few special cases when solving quadratic equations by factoring.

Perfect Square Trinomials:

- \( x^2 + 6x + 9 \) is an example of a **perfect square trinomial**. We see this when we factor.

- A perfect square trinomial is created when you square a __________________________.

Recognizing a Perfect Square Trinomial:

A quadratic expression can be factored as a perfect square trinomial if it can be re-written in the form \( a^2 + 2ab + b^2 \).

Factoring a Perfect Square Trinomial:

- If \( a^2 + 2ab + b^2 \) is a perfect square trinomial, then \( a^2 + 2ab + b^2 = (a + b)^2 \).

- If \( a^2 - 2ab + b^2 \) is a perfect square trinomial, then \( a^2 - 2ab + b^2 = (a - b)^2 \).

Let’s Practice!

1. Determine whether \( 16x^2 + 88x + 121 \) is a perfect square trinomial. Justify your answer.

2. Solve for \( q \): \( q^2 - 10q + 25 = 0 \).
Try It!

3. Determine whether $x^2 - 8x + 64$ is a perfect square trinomial. Justify your answer.

4. Solve for $w$: $4w^2 + 49 = -28w$.

5. What do you notice about the number of solutions to perfect square quadratic equations?

6. Sketch the graph of a quadratic equation that is a perfect square trinomial.

Difference of Squares:

Use the distributive property to multiply the following binomials.

$(x + 5)(x - 5)$

$(5x + 3)(5x - 3)$

Describe any patterns you notice.

- When we have a binomial in the form $a^2 - b^2$, it is called the difference of two squares. We can factor this as $(a + b)(a - b)$. 
Let’s Practice!

7. Solve the equation $49k^2 = 64$ by factoring.

Try It!

8. Solve the equation $0 = 121p^2 - 100$.

BEAT THE TEST!

1. Which of the following expressions are equivalent to $8a^3 - 98a^2$? Select all that apply.

- $2(4a^3 - 49a)$
- $2a(4a^2 - 49)$
- $2a(4a^3 - 49a)$
- $(2a - 7)(2a + 7)$
- $2(2a - 7)(2a + 7)$
- $2a(2a - 7)(2a + 7)$

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Section 5 – Topic 6
Solving Quadratic Equations by Taking Square Roots

Consider the following quadratic equation.

\[ 2x^2 - 36 = 0 \]

When quadratic equations are in the form \( ax^2 + c = 0 \), solve by taking the square root.

Step 1: Get the variable on the left and the constant on the right.

Step 2: Take the square root of both sides of the equation. (Don’t forget the negative root!)

Solve for \( x \) by taking the square root.

\[ 2x^2 - 36 = 0 \]

Let’s Practice!

1. Solve \( x^2 - 121 = 0 \).

Try It!

2. Solve \( -5x^2 + 80 = 0 \).
1. What is the smallest solution to the equation $2x^2 + 17 = 179$?

- A $-9$
- B $-3$
- C $3$
- D $9$

2. A rescuer on a helicopter that is 50 feet above the sea drops a lifebelt. The distance from the lifebelt to the sea can be modeled by the equation $h(t) = -16t^2 + s$, where $t$ is the time, in seconds, after the lifebelt is dropped, and $s$ is the initial height, in feet, of the lifebelt above the sea.

How long will it take for the lifebelt to reach the sea? Round your answer to the nearest tenth of a second.

Section 5 – Topic 7
Solving Quadratic Equations by Completing the Square

Sometimes you won’t be able to solve a quadratic equation by factoring. However, you can rewrite the quadratic equation so that you can complete the square to factor and solve.

Let’s start by determining what number we can add to a quadratic expression to make it a perfect square trinomial.

What value could be added to the quadratic expression to make it a perfect square trinomial?

$x^2 + 6x + ____$

$x^2 + 8x + 3 + ____$

$x^2 - 22x - 71 + ____$

Let’s see how this can be used to solve quadratic equations.
Recall how we factored perfect square trinomials. If \( a^2 + 2ab + b^2 \) is a perfect square trinomial, then \( a^2 + 2ab + b^2 = (a + b)^2 \) and \( a^2 - 2ab + b^2 = (a - b)^2 \).

Solve \( f(x) = ax^2 + bx + c \) by completing the square.

Step 1: Group \( ax^2 \) and \( bx \) together.

\[
f(x) = (ax^2 + bx + \_\_\_) + c
\]

Step 2: If \( a \neq 1 \), then factor out \( a \).

\[
f(x) = a(x^2 + \frac{b}{a}x + \_\_\_) + c
\]

Step 3: Divide \( \frac{b}{a} \) by two and square the result. Add that number to the grouped terms. Subtract the product of that number and \( a \) from \( c \) so that you have not changed the equation.

\[
f(x) = a(x^2 + \frac{b}{a}x + \frac{b^2}{4a^2}) + c - \frac{b^2}{4a}
\]

Step 4: Factor the trinomial.

\[
f(x) = a\left(x + \frac{b}{2a}\right)^2 + \frac{4ac - b^2}{4a}
\]

Step 5: This is vertex form. Now we can solve the equation by setting the function equal to zero, moving the constant to the opposite side, and taking the square root of both sides.

---

**Let's Practice!**

1. Consider the following quadratic expression \( 2x^2 - 8x + 5 \).
   
   a. Complete the square to write the quadratic expression in vertex form.

   b. If the expression represents a function, find the solutions to the quadratic function.

**Try It!**

2. Consider the quadratic expression \( 3x^2 + 12x + 31 \).
   
   a. Complete the square to write the quadratic expression in vertex form.

   b. If the expression represents a function, find the solutions to the quadratic function.
We can use the process of completing the square to derive a formula to solve any quadratic equation.

Consider the quadratic equation, \( f(x) = ax^2 + bx + c \), where \( a \neq 0 \). Recall our steps for completing the square as a method for solving \( f(x) \).

**Step 1:** Group \( ax^2 \) and \( bx \) together.

**Step 2:** If \( a \neq 1 \), then factor out \( a \).

**Step 3:** Divide \( \frac{b}{a} \) by two and square the result. Add that number to the grouped terms. Subtract the product of that number and \( a \) from \( c \) so that you have not changed the equation.

**Step 4:** Factor the trinomial.

---

**BEAT THE TEST!**

1. The equations shown below are steps to solve the function \( g(x) = 2x^2 + 24x - 29 \) by completing the square.

   - A. \( g(x) = 2(x^2 + 12x + 36) - 29 - 72 \)
   - B. \( x + 6 = \pm\sqrt{50.5} \)
   - C. \( g(x) = 2(x^2 + 12x + ____) - 29 \)
   - D. \( x = -6 \pm \sqrt{50.5} \)
   - E. \( 2(x + 6)^2 - 101 = 0 \)
   - F. \( (x + 6)^2 = 50.5 \)
   - G. \( \sqrt{(x + 6)^2} = \pm\sqrt{50.5} \)
   - H. \( g(x) = 2(x + 6)^2 - 101 \)

Place the equations in the correct order by writing the letter corresponding to each step in the boxes below.

Step 1  \( \rightarrow \)  Step 2  \( \rightarrow \)  Step 3  \( \rightarrow \)  Step 4

Step 8  \( \leftarrow \)  Step 7  \( \leftarrow \)  Step 6  \( \leftarrow \)  Step 5

---

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Step 5: Solve the equation.

BEAT THE TEST!

1. Complete the missing steps in the derivation of the quadratic formula:

\[ f(x) = ax^2 + bx + c \]

\[ f(x) = a \left( x^2 + \frac{b}{a}x + \frac{b^2}{4a^2} \right) + c - \frac{b^2}{4a} \]

\[ f(x) = a \left( x + \frac{b}{2a} \right)^2 + \frac{4ac - b^2}{4a} \]

\[ a \left( x + \frac{b}{2a} \right)^2 + \frac{4ac - b^2}{4a} = 0 \]

\[ \left( x + \frac{b}{2a} \right)^2 = \frac{b^2 - 4ac}{4a^2} \]

\[ x + \frac{b}{2a} = \pm \frac{\sqrt{b^2 - 4ac}}{2a} \]

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Section 5 – Topic 9
Solving Quadratic Equations Using the Quadratic Formula

For any quadratic equation $ax^2 + bx + c = 0$, where $a \neq 0$,

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

To use the quadratic formula:

Step 1: Set the quadratic equation equal to zero.

Step 2: Identify $a$, $b$, and $c$.

Step 3: Substitute $a$, $b$, and $c$ into the quadratic formula and evaluate to find the zeros.

Let's Practice!

1. Use the quadratic formula to solve $x^2 - 4x + 3 = 0$.

2. Consider the graph of the quadratic equation $y = x^2 - 4x + 3$.

Does the graph verify the solutions we found using the quadratic formula?
3. Use the quadratic formula to solve $2w^2 + w = 5$.

Try It!

4. Use the quadratic formula to solve $3q^2 - 11 = 20q$.

BEAT THE TEST!

1. Your neighbor’s garden measures 12 meters by 16 meters. He plans to install a pedestrian pathway all around it, increasing the total area to 285 square meters. The new area can be represented by $4w^2 + 56w + 192$. Use the quadratic formula to find the width, $w$, of the pathway.

Part A: Write an equation that can be used to solve for the width of the pathway.

Part B: Use the quadratic formula to solve for the width of the pathway.

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Section 5 – Topic 10
Quadratic Functions in Action

Let’s consider solving real-world situations that involve quadratic functions.

Consider an object being launched into the air. We compare the height versus time elapsed.

From what height is the object launched?

Once the object is launched, how long does it take to reach its maximum height?

What is the maximum height?

Once the object is launched, how long does it take for it to hit the ground?

Once the object is launched, when does it return to a height of three meters?

### Question

<table>
<thead>
<tr>
<th>Question</th>
<th>How to Answer It</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. From what height is the object launched?</td>
<td>This is the $y$-intercept. In the standard form, $ax^2 + bx + c$, $c$ is the $y$-intercept.</td>
</tr>
<tr>
<td>2. How long does it take for the object to reach its maximum height?</td>
<td>This is the $x$-coordinate of the vertex, $x = \frac{-b}{2a}$, where values of $a$ and $b$ come from the standard form of a quadratic equation. $x = \frac{-b}{2a}$ is also the equation that represents the axis of symmetry.</td>
</tr>
<tr>
<td>3. What is the maximum height?</td>
<td>This is the $y$-coordinate of the vertex. Substitute the $x$-coordinate from the step above and evaluate to find $y$. In vertex form, the height is $k$ and the vertex is $(h, k)$.</td>
</tr>
<tr>
<td>4. How long does it take for the object to hit the ground?</td>
<td>The $x$-intercept(s) are the solution(s), or zero(s), of the quadratic function. Solve by factoring, using the quadratic formula, or by completing the square. In a graph, look at the $x$-intercept(s).</td>
</tr>
<tr>
<td>5. When does the object return to a height of three meters?</td>
<td>In function $H(t) = at^2 + bt + c$, if height is given, then substitute the value for $H(t)$. If time is given, then substitute for $t$.</td>
</tr>
</tbody>
</table>
Let's Practice!

1. Ferdinand is playing golf. He hits a shot off the tee box that has a height modeled by the function \( h(t) = -16t^2 + 80t \), where \( h(t) \) is the height of the ball, in feet, and \( t \) is the time in seconds it has been in the air. The graph that models the golf ball’s height over time is shown below.

   a. When does the ball reach its maximum height?
   
   b. What is the maximum height of the ball? When will the ball reach that same height again?

   c. What is the height of the ball at 3 seconds? When will the ball reach that same height again?

   ![Golf Ball's Height Over Time](image)

Try It!

2. Recall exercise 1.

   a. When is the ball 65 feet in the air? Explain.

   b. How long does it take until the ball hits the ground?
1. A neighborhood threw a fireworks celebration for the 4th of July. A bottle rocket was launched upward from the ground with an initial velocity of 160 feet per second. The formula for vertical motion of an object is

\[ h(t) = 0.5at^2 + vt + s, \] where the gravitational constant, \( a \), is \(-32\) feet per square second, \( v \) is the initial velocity, \( s \) is the initial height, and \( h(t) \) is the height in feet modeled as a function of time, \( t \).

**Part A:** What function describes the height, \( h \), of the bottle rocket after \( t \) seconds have elapsed?

**Part B:** What was the maximum height of the bottle rocket?