

# Unit 3 - Function Transformations, Quadratic, Polynomial and Rational Functions

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## General Notes

# Module 10 - Function Transformation & Quadratic Functions

## Transformations Activity

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Functions can be transformed in various ways:

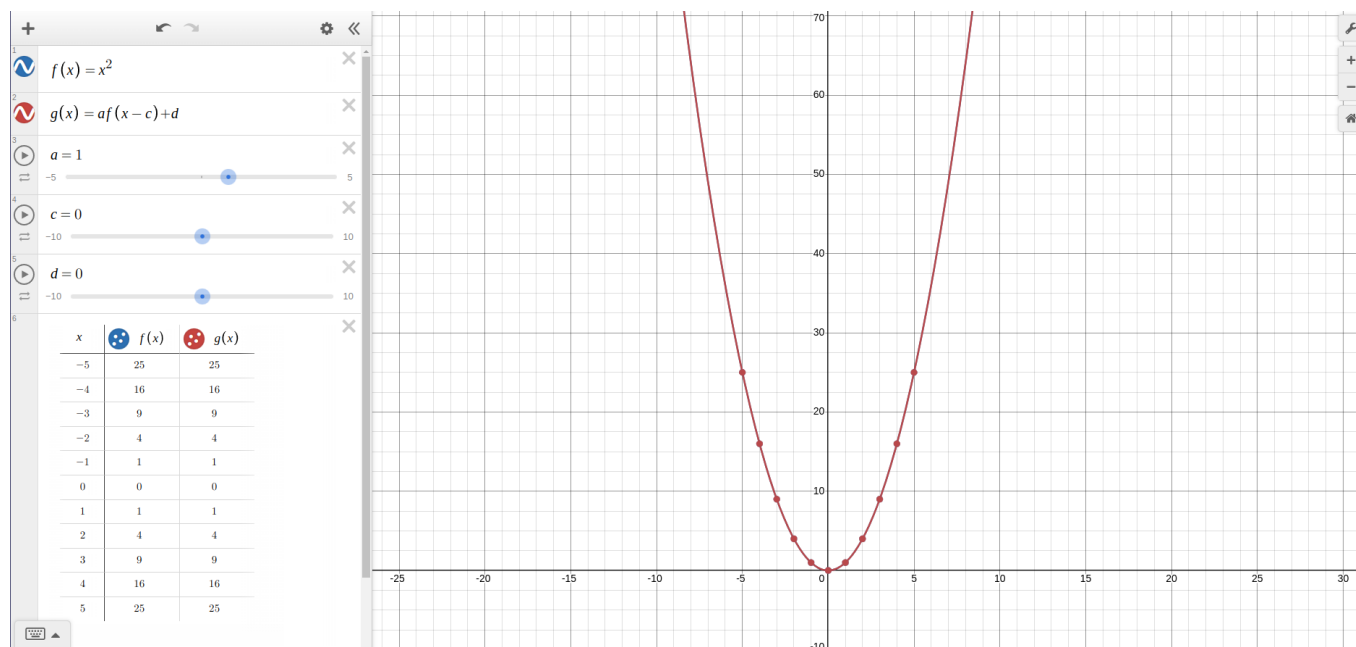
- Stretched or compressed vertically or horizontally
- Shifted up or down, or left or right

Transformation Activity: <https://www.desmos.com/calculator/fneiikwfiy>

Two defined functions:

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

2.  $g(x) = af(x - c) + d$



- **a**, **c**, and **d** are parameters.
- In this scenario, **f** is the **parent function** and **g** is the **transformed / image function**.
- **d** moves the vertical offset by **d** and shifts the graph up or down.
- **a** is the slope and stretches or compresses the graph vertically by a factor of **a** and can create a **vertical reflection**.
  - **1 < a**: The graph is stretched vertically (narrower than original)
  - **0 < a < 1**: The graph is compressed vertically (wider than original graph)
  - **a < 0**: Creates a vertical reflection.
- **c** moves the horizontal intercept by **c** and shifts the graph left or right.
  - **c < 0**: The shift is to the left.
  - **c > 0**: The shift is to the right.
  - In a table, the output of the parent function is moved by **c** places down or up.

# Writing a Function In Terms of a Function

When setting  $a = 2$ :

x	f(x)	g(x)
-5	25	50
-4	16	32
-3	9	18
-2	4	8
-1	1	2
0	0	0
1	1	2
2	4	8
3	9	18
4	16	32
5	25	50

- A formula for the function **g** in terms of **f**:  
 **$g(x) = 2f(x)$**
  - Given that  **$f(x) = x^2$** , a formula for the function **g** in terms of **f**:  
 **$g(x) = 2x^2$**
-

When setting  $d = 2$ :

$x$	$f(x)$	$g(x)$
-5	25	27
-4	16	18
-3	9	11
-2	4	6
-1	1	3
0	0	2
1	1	3
2	4	6
3	9	11
4	16	18
5	25	27

- A formula for the function  $g$  in terms of  $f$ :  
 $g(x) = f(x) + 2$
  - Given that  $f(x) = x^2$ , a formula for the function  $g$  in terms of  $f$ :  
 $g(x) = x^2 + 2$
-

When setting  $c = 1$ :

$x$	$f(x)$	$g(x)$
-5	25	36
-4	16	25
-3	9	16
-2	4	9
-1	1	4
0	0	1
1	1	0
2	4	1
3	9	4
4	16	9
5	25	16

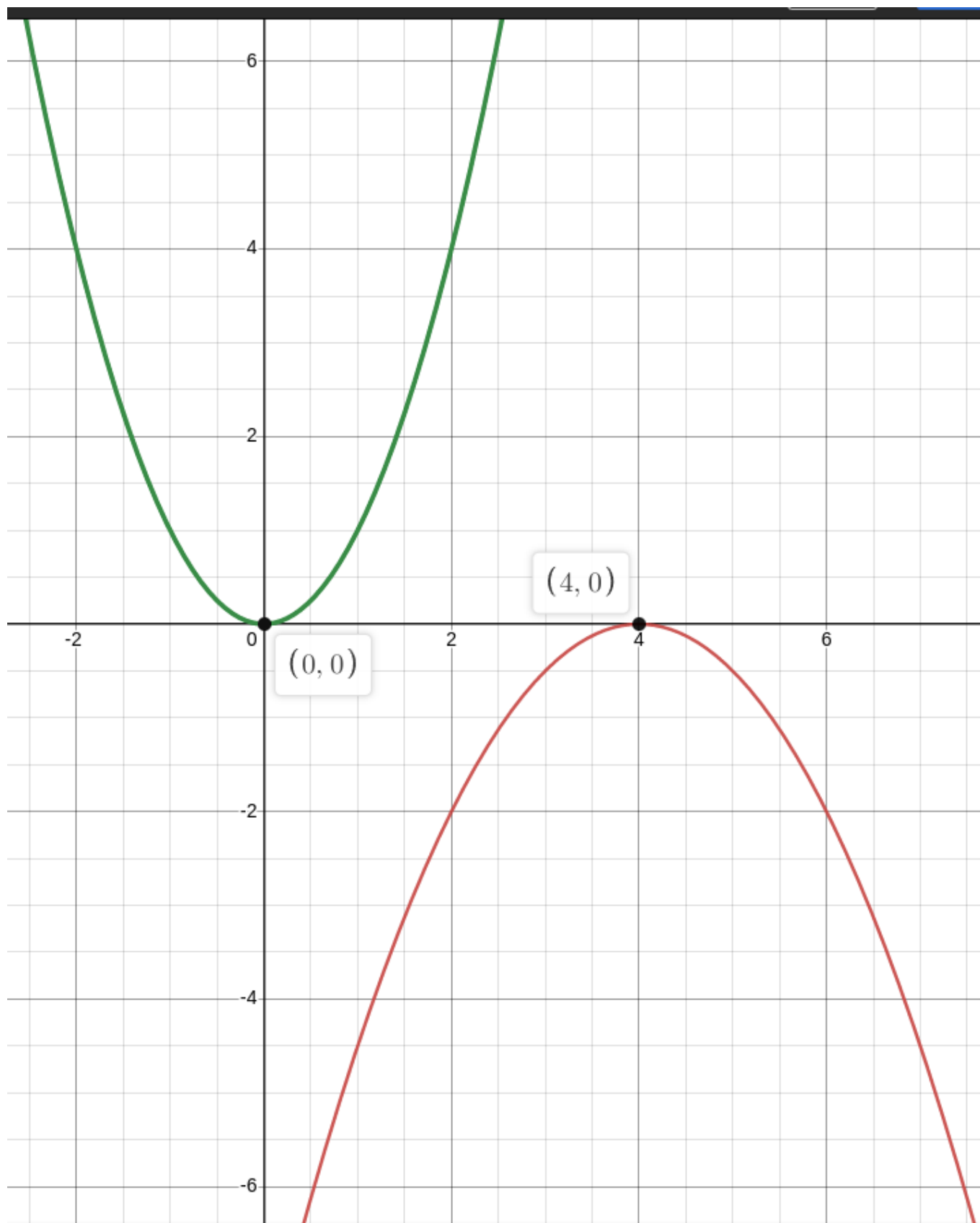
- A formula for the function  $g$  in terms of  $f$ :  
 $g(x) = f(x - 1)$
- Given that  $f(x) = x^2$ , a formula for the function  $g$  in terms of  $f$ :  
 $g(x) = (x - 1)^2$

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## Vertex of a Function

The vertex is the point where the maximum or minimum occurs of the function.

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## Vertex Example 1

$$g(x) = 2f(x) + 3$$

- Vertical stretch by a factor of **2**
- Vertical stretch up **3**

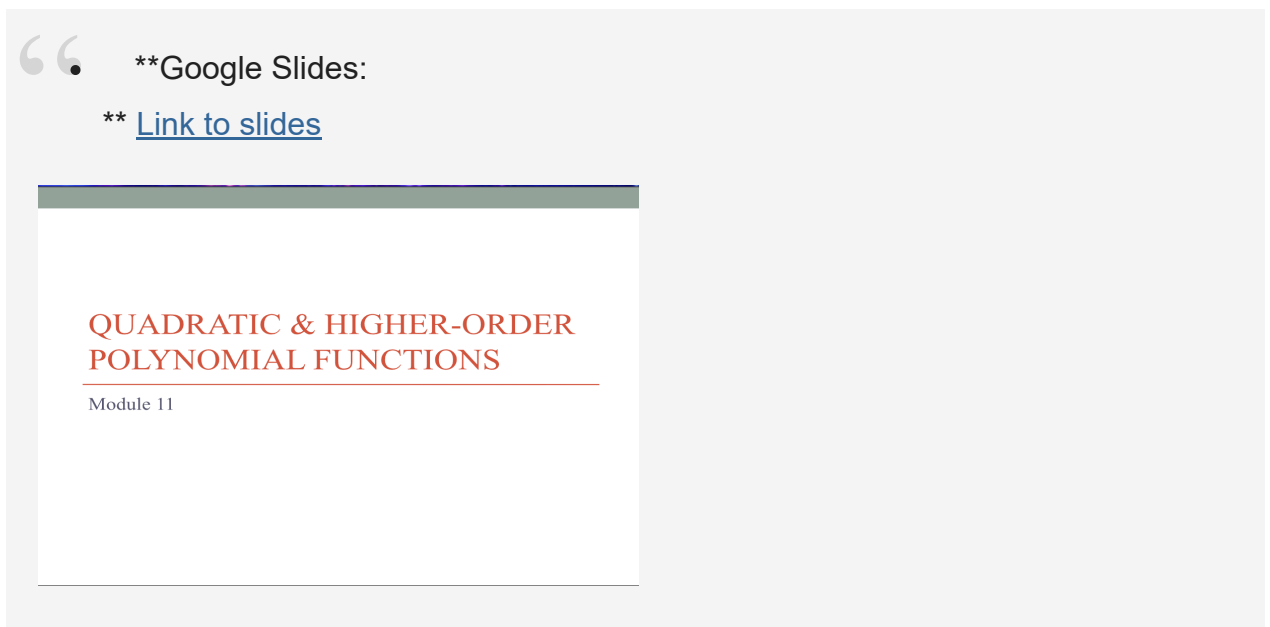
- Vertex: **(0, 3)**

## Vertex Example 2

$$h(x) = f(x + 2) - 1$$

- Horizontal shift left **2**
- Vertical shift down **1**
- Vertex: **(-2, -1)**

# Module 11 - Function Transformation and Quadratic Functions



## Quadratic Functions

Basic quadratic function:  $f(x) = x^2$

- Graph is called **parabolic**
- Shape is open *up* if  $f(x) = x^2$
- Shape is open *down* if  $f(x) = -x^2$
- Both ends point in the same direction
- The graph will have a maximum or a minimum
  - This occurs at the vertex
- They are symmetric
  - The axis of symmetry passes through the vertex



There are two types of parabolas:

- **Concave down**
  - Has a maximum value at the vertex
  - Does not have a minimum
- **Concave up**
  - Has a minimum value at the vertex
  - Does not have a maximum

## Vertex Form of a Quadratic Function


$$y = a(x - h)^2 + k$$

- The function above with  **$a \neq 0$**  is in **vertex form**.
- The point  $(h, k)$  is called the **vertex** of the parabola.
- The effect of the different variables:
  - **$a$**  is a vertical stretch/compression/reflection
  - **$h$**  is a horizontal shift left/right
  - **$k$**  is a vertical shift up/down
- **$h$**  is the input reference and  **$k$**  is the output reference
  - $(h, k)$  is the reference point

## Different Forms of a Quadratic Function


- In some forms, the **vertex** of a function is easier to determine.
- In other forms, vertical/horizontal intercept are easier to determine.

### Standard Form

 
$$y = ax^2 + bx + c$$

- In this form,  **$c$**  will always be the **vertical intercept**.

### Factored Form

 
$$y = a(x - x_1)(x - x_2)$$

- In this form,  $x - x_1 = 0$  and  $x - x_2 = 0$  can be used to find the **horizontal intercepts** (or **zeros**) of the graph.

## Vertex Form

$$y = a(x - h)^2 + k$$

- In this form,  $(h, k)$  will always be the **vertex** of the function and either the **minimum** or the **maximum** depending on if the graph is **concave up** or **concave down**.
  - The concavity can be determined by the sign of **a**.
    - **-x** is concave down
    - **x** is concave up

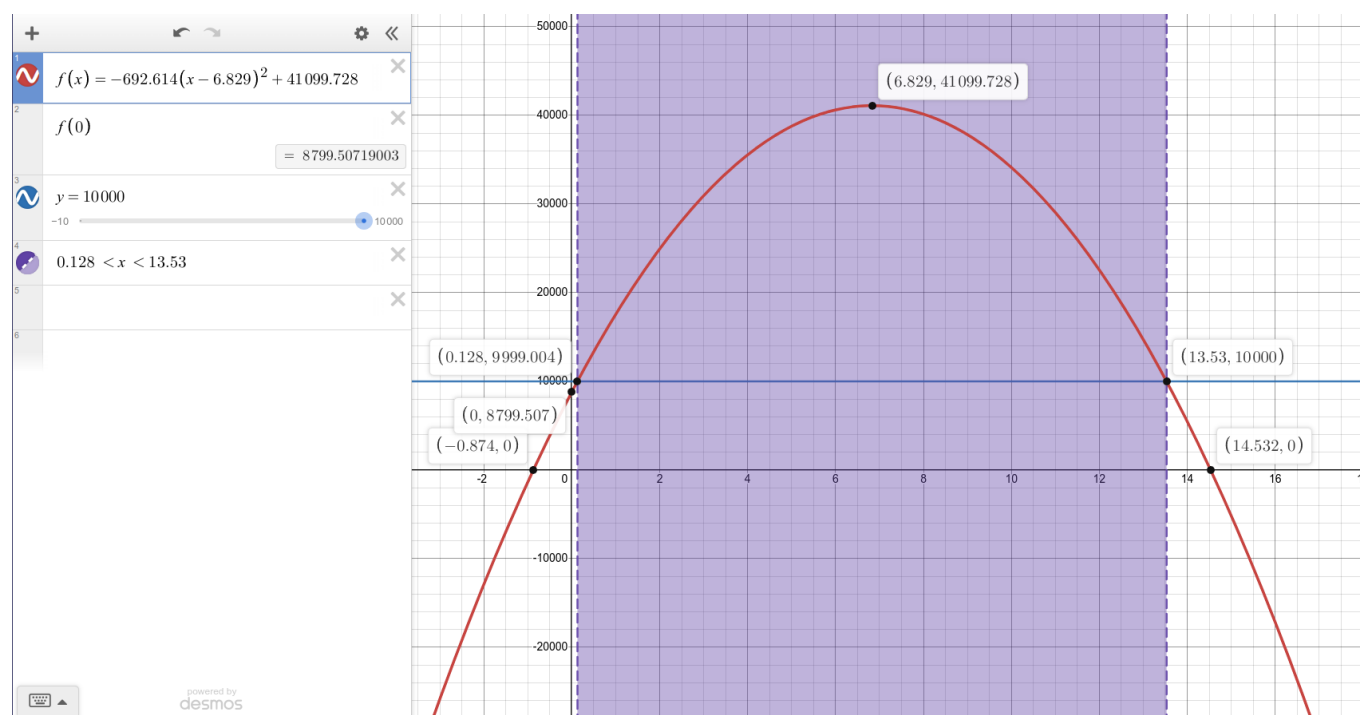
## Problems In Different Forms

### Problem in Vertex Form

According to the CDC, the number of AIDS cases among people aged 21 or younger in the US is finally starting to decline after seeing many years of increase.

The function that models the number of cases with respect to the number of years since 2004 is:

$$N(x) = -692.614(x - 6.829)^2 + 41099.728$$



1. Determine approximately when the number of AIDS cases was at its peak.

What was the maximum number?

1. Identify whether the graph is concave up or concave down based off if

**a** is negative. **It's concave down.**

2. Determine the maximum (because it's concave down) by finding the vertex

3. Vertex is **[6.829, 41099.728]**, so the answer is **6.829**

2. Identify and explain the vertical intercept of the function.

◦ **Option 1**

1. Graph the function

2. Create another entry using **0** as **f(x): f(0)**

◦ **Option 2**

1. Substitute **0** into the equation, because it turns into:

$$f(0) = -692.614(x - 6.829)^2 + 41099.728$$

$$2. f(0) = -692.614(0 - 6.829)^2 + 41099.728$$

$$3. f(0) = -692.614(6.829)^2 + 41099.728$$

$$4. f(0) = -692.614(46.635) + 41099.728$$

$$5. f(0) = -32300.221 + 41099.728$$

$$6. f(0) = 8799.507$$

$$7. f(0) = 8799.51 \leftarrow \text{Rounded Up}$$

3. Determine when the model would predict AIDS cases is zero.

1. Graph the function

2. Find the horizontal intercepts

3. Answer: **~1 year before 2004 and ~14.5 years after 2004**

4. Determine the range of years we would expect the number of cases to be at least 10,000.

1. Graph the function

2. Plot a separate line that is 10,000

3. Determine where the line intersects with the graph

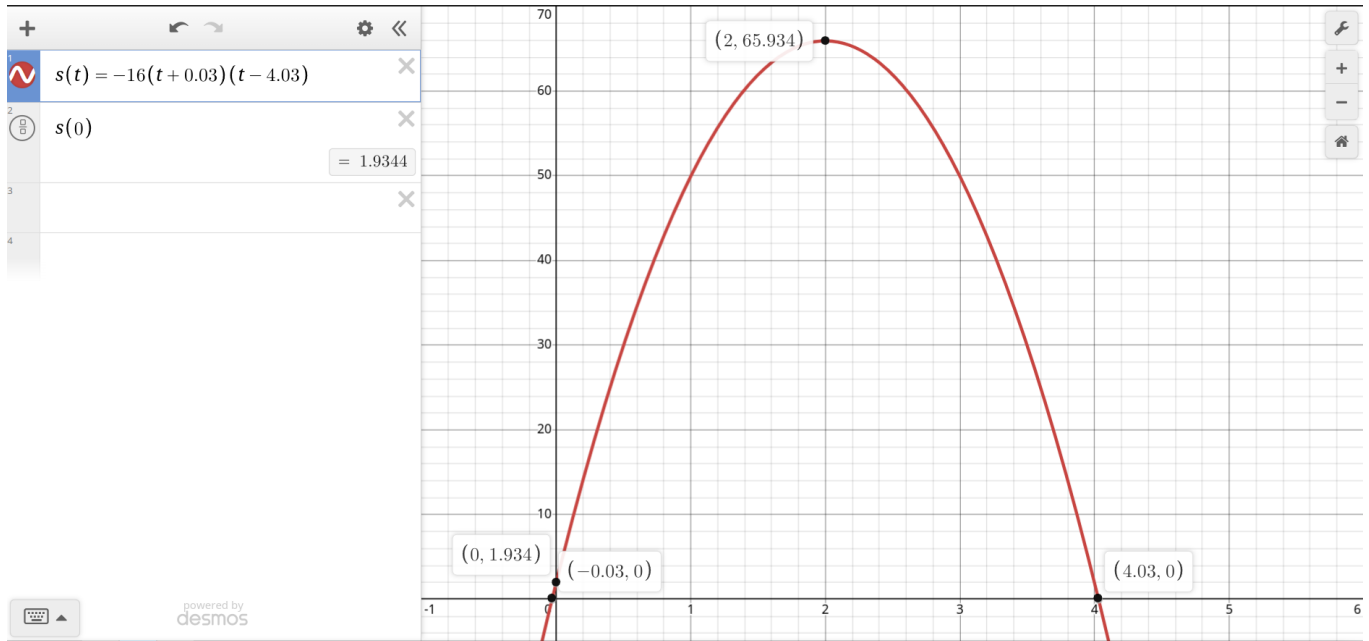
4. *Optional: Use inequalities to create a section visualizing it.*

5. **Answer:  $0.128 \leq x \leq 13.53$**

## Problem in Factored Form

A water rocket can be purchased at many toy stores. One company claims that the height above the ground (in feet) for their rocket  $t$  seconds after it is launched can be modeled by:

$$s(t) = -16(t + 0.03)(t - 4.03)$$



1. Determine the vertical intercept of the function and explain its meaning (if any) in the context of the problem.

1. Graph the chart
2. Find the vertical intercept
3. **[0, 1.934]**
4. At the start of the launch, before it has taken off, it is **1.934** feet above the ground.

2. Determine the horizontal intercepts of the function and explain their meaning (if any) in the context of the problem.

- **Option 1:**  $s(t)$  will equal 0 when any of the factors equal 0, so when  $t + 0.03 = 0$  or  $t - 4.03 = 0$ :
  1. Get the intercepts from the formula.
  2. **+0.03** → **-0.03** and **4.03**
  3. **[-0.03, 0]** and **[4.03, 0]**
- **Option 2**
  1. Graph the chart
  2. Find the horizontal intercepts
  3. **[-0.03, 0]** and **[4.03, 0]**
- The first intercept has no meaning **[-0.03, 0]**, the second intercept means that the rocket will hit the ground **4.03 seconds** after launching.

3. Determine the vertex of the function and explain its meaning in the context of the problem.

◦ **Option 1**

1. Graph the function
2. Find the vertex
3. **[2, 65.934]**
4. After 2 seconds from launching, the rocket will be at its highest point of 65.934 feet in the air.
5. Due to symmetry, the vertex will occur halfway between the two zeros:
  1.  $\frac{4.03 - 0.03}{2} = 2$
  2.  **$s(2) = 65.934$**  is the vertex.

◦ **Option 2**

1. Due to symmetry, the vertex will occur halfway between the 2 zeros and can be found by:
$$\frac{4.03 + (-0.03)}{2} = 2$$
2.  **$s(2) = 65.934$**  ← *After plugging 2 into the formula*
3. **[2, 65.934]** is the vertex

The horizontal intercepts (**[0.03, 0]** and **[4.03, 0]**) are often referred to as the **zeros** of the function.

## Problem in Standard Form

First, convert the previous Factored form to standard form:

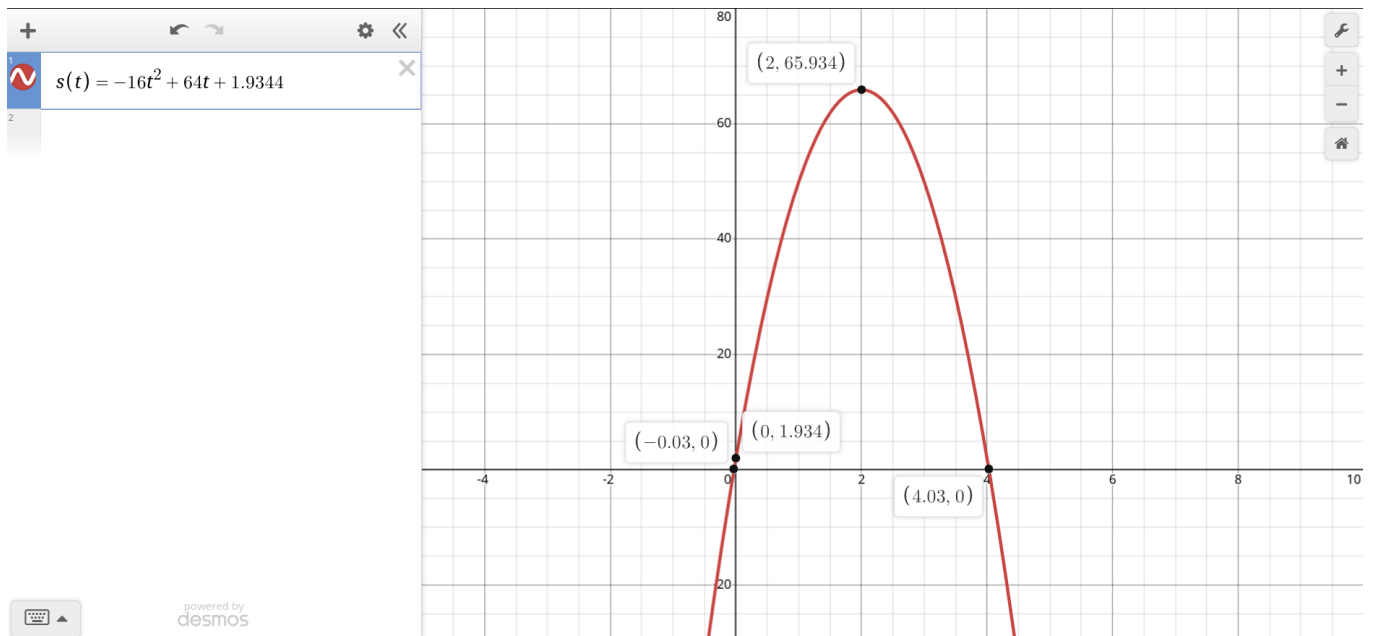
1.  **$s(t) = -16(t + 0.03)(t - 4.03)$**
2.  **$s(t) = -16(t^2 - 4.03t + 0.03t - 0.1209)$**
3.  **$s(t) = -16t^2 + 64t + 1.9344$**

Getting the vertical intercept  $s(0)$ :

The **c** value is always the output of the vertical intercept. In this case **1.9344**, so: **[0, 1.9344]**

You can determine the horizontal intercept and vertex by graphing the function:

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## Concavity

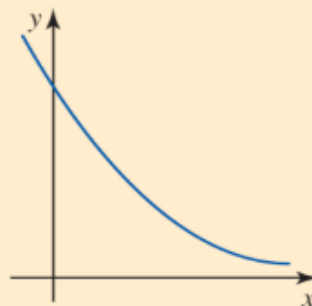
### CONCAVITY

- The graph of a function  $f$  is said to be **concave up** if its rate of change *increases* as the input values increase. Concave up functions curve upward.

Increasing/Concave Up



Decreasing/Concave Up

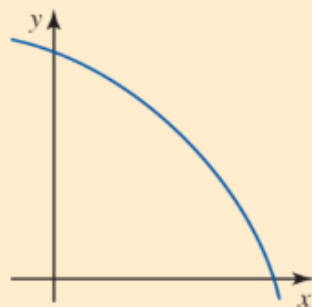


- The graph of a function  $f$  is said to be **concave down** if its rate of change *decreases* as the input values increase. Concave down functions curve downward.

Increasing/Concave Down



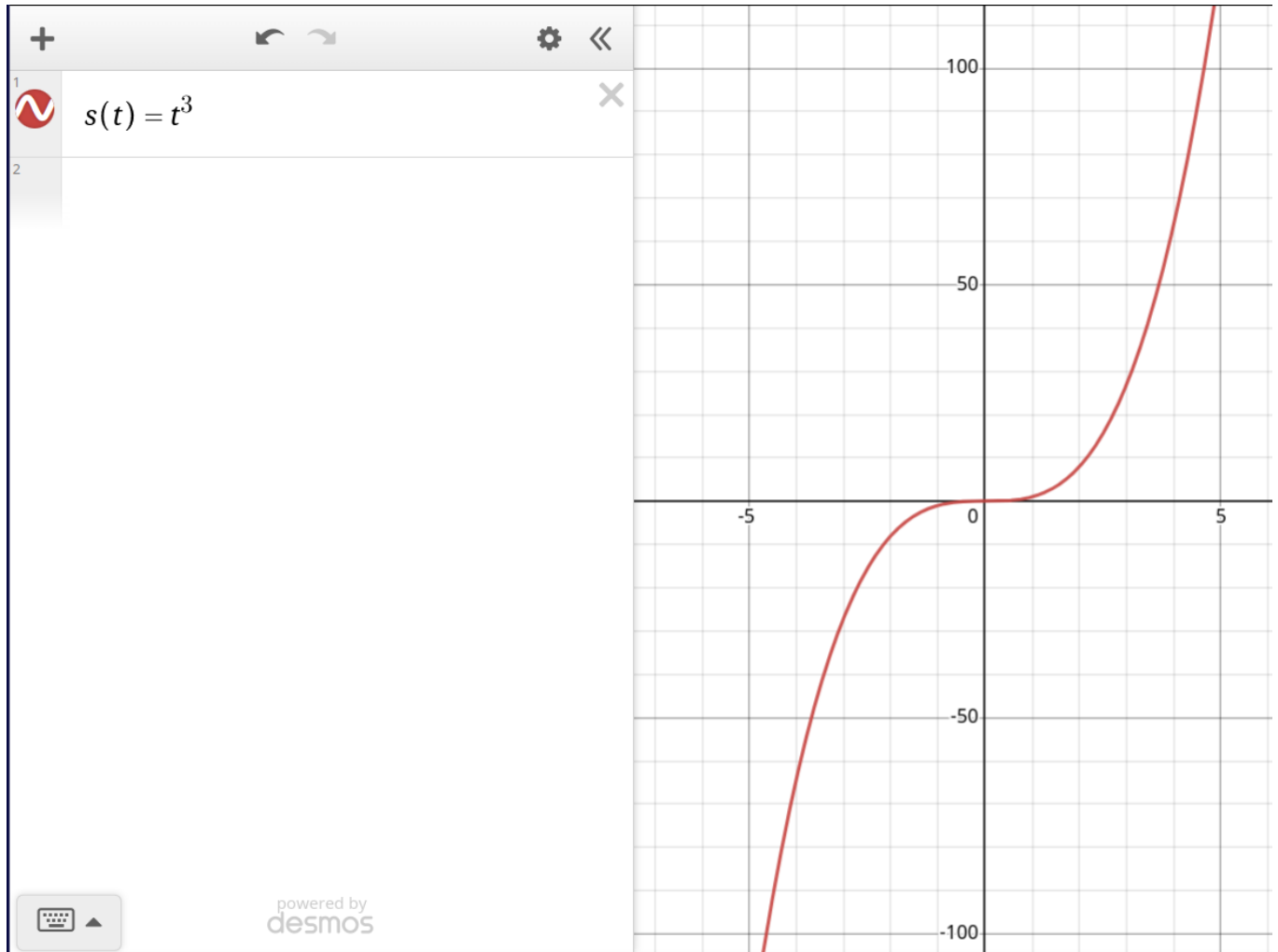
Decreasing/Concave Down



# Inflection Point

The point on a graph where the function changes concavity is called the inflection point.

Consider the following:  $x^3$



- An inflection point is a point where the curve changes from bending one way to bending the other way (*like the top of a hill*).
- The point where rate of change of the function changes from increasing to decreasing, or from decreasing to increasing.

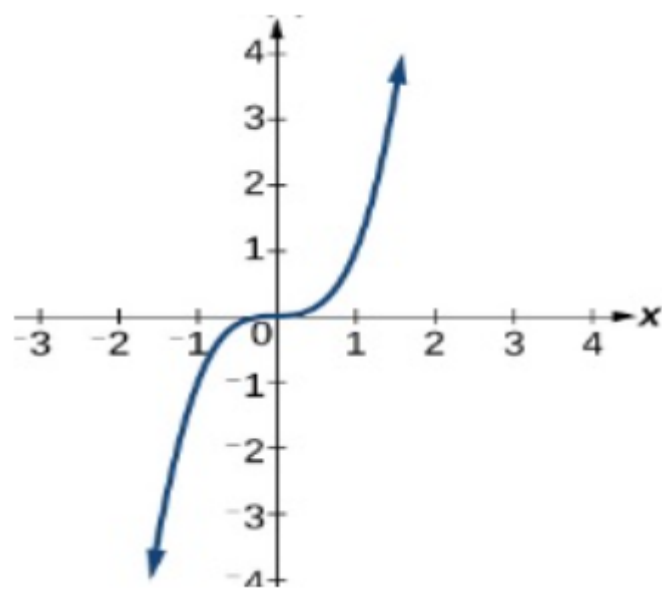
## Cubic Functions

Cubic functions are functions that have two concavities and one inflection point.

# Cubic Function Example 1



# Cubic Function Example 2





## Cubic Function Example 3



## Polynomial Functions

Linear, quadratic, and cubic are all types of **polynomial functions**, defined as follows:

### POLYNOMIAL FUNCTION

For whole number  $n$ , a function of the form

$$y = a_n x^n + a_{n-1} x^{n-1} + a_{n-2} x^{n-2} + \cdots + a_1 x + a_0$$

with  $a_n \neq 0$  is called a **polynomial function of degree  $n$** . Each  $a_i x^i$  is called a **term**. The  $a_i$  are real-number values called the **coefficients** of the terms.

- $a_n x^n$  is the **leading term** of the polynomial.
- $n$  is the **degree** of the polynomial.
- $a_n$  is the **leading coefficient** of the polynomial.
- The leading term is **always** the term with the largest exponent.

# Polynomial Function Examples

## Polynomial Example 1

“  $f(x) = 2x^2 + 3x - 10$

- $2x^2$  is the leading term
- $2$  is the LC (Leading Coefficient)
- $2$  is the degree

## Polynomial Example 2

“  $g(x) = 2x^5 + 4x^4 - 13x^2 + 8$

- $2x^5$  is the leading term
- $2$  is the LC
- $5$  is the degree

## Polynomial Example 3

“  $h(x) = -8x^2 + 3x^5 - 7x^7 - 9$

- $-7x^7$  is the leading term
- $-7$  is the LC
- $7$  is the degree

## Polynomial Example 4

“  $j(x) = 14x^2 - 6x^2 - x$

- $14x^2$  is the leading term
- $14$  is the LC
- $2$  is the degree

## Polynomial Example 5

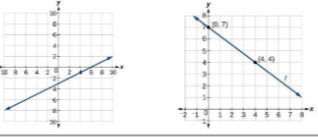
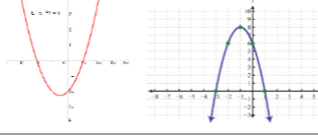
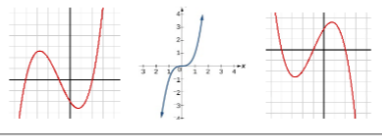
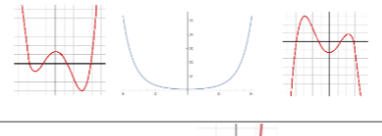
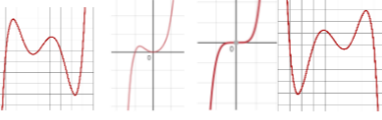
“  $k(x) = 2 + 6x + 18x^2 - 2x^6$

- $-2x^6$  is the leading term
- $-2$  is the LC
- $6$  is the degree

# Graphs of Polynomial Functions

## Polynomial Summary

[Polynomial Summary PDF](#)

Polynomial Function Patterns Summary					
	Degree and Constant Differences	Concavity & Inflection Points & Extrema & Zeros	Sample Graph	End Behavior if leading coefficient > 0	End Behavior if leading coefficient < 0
Linear	1st degree constant 1st differences	0 concavity 0 inflection points 0 extrema 1 zero		As $x \rightarrow \infty$ $f(x) \rightarrow \infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow -\infty$	As $x \rightarrow \infty$ $f(x) \rightarrow -\infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow \infty$
Quadratic	2nd degree constant 2nd differences	1 concavity 0 inflection points 1 extrema up to 2 zeros		As $x \rightarrow \infty$ $f(x) \rightarrow \infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow \infty$	As $x \rightarrow \infty$ $f(x) \rightarrow -\infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow -\infty$
Cubic	3rd degree constant 3rd differences	2 concavities 1 inflection point 0 or 2 extrema up to 3 zeros		As $x \rightarrow \infty$ $f(x) \rightarrow \infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow -\infty$	As $x \rightarrow \infty$ $f(x) \rightarrow -\infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow \infty$
Quartic	4th degree constant 4th differences	1 or 3 concavities 0 or 2 inflection points 1 or 3 extrema up to 4 zeros		As $x \rightarrow \infty$ $f(x) \rightarrow \infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow \infty$	As $x \rightarrow \infty$ $f(x) \rightarrow -\infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow -\infty$
Quintic	5th degree constant 5th differences	2 or 4 concavities 1 or 3 inflection points 0, 2 or 4 extrema up to 5 zeros		As $x \rightarrow \infty$ $f(x) \rightarrow \infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow -\infty$	As $x \rightarrow \infty$ $f(x) \rightarrow -\infty$ As $x \rightarrow -\infty$ $f(x) \rightarrow \infty$

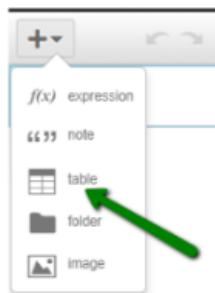
# Regression Using Desmos

## Regression Using Desmos

### 1. Enter the Data by adding a table

$x_1$  is the input data

$y_1$  is the output data



### 2. Create the regression equation

a. The overall syntax is:

$y_1 \sim$  (function choice with any letter choice parameters  $a, b, c, \dots$ ) and  $x_1$  as the input variable

#### Samples:

#### Linear

$$y_1 \sim ax_1 + b \quad \text{or} \quad y_1 \sim hx_1 + z$$

#### Quadratic

$$y_1 \sim ax_1^2 + bx_1 + c$$

#### Cubic

$$y_1 \sim ax_1^3 + bx_1^2 + cx_1 + d$$

#### Logistic

$$y_1 \sim \frac{a}{1 + be^{(-cx_1)}}$$

#### Quartic

$$y_1 \sim ax_1^4 + bx_1^3 + cx_1^2 + dx_1 + f$$

Do NOT use "e" as a parameter; desmos reserves "e" as 2.71828...  
Use any other letter

#### Exponential

$$y_1 \sim a \cdot b^{x_1}$$

☒ Log Mode

Click the "Log Mode" button

#### Power

$$y_1 \sim a \cdot x_1^b$$

The parameters and correlation coefficient will populate below the model of choice as shown:

Correlation Coefficient

STATISTICS

$R^2 = 0.7857$

RESIDUALS

$e_1$  plot

PARAMETERS

$a = 0.0959797$

$c = 0.107432$

$b = -0.422125$

$d = 2.21871$


Model Parameters

- Because polynomial functions are fairly predictable, we can summarize the characteristics and appearance of the graphs of polynomial functions of the first through fifth degree.

# End Behavior of Polynomial Functions

For any polynomial function, as  $x$  approaches  $\pm\infty$ ,  $f(x)$  approaches  $\pm\infty$ .

- As the magnitude (absolute value) of  $x$  gets larger and larger, the magnitude of the function values will also get larger and larger.
- Symbolically, we write:

 
$$\text{as } x \rightarrow \pm\infty, f(x) \rightarrow \pm\infty$$

## Determining End-Behavior

Rather than graphing out each individual polynomial function, instead locate the leading term and determine the end-behavior based off it.

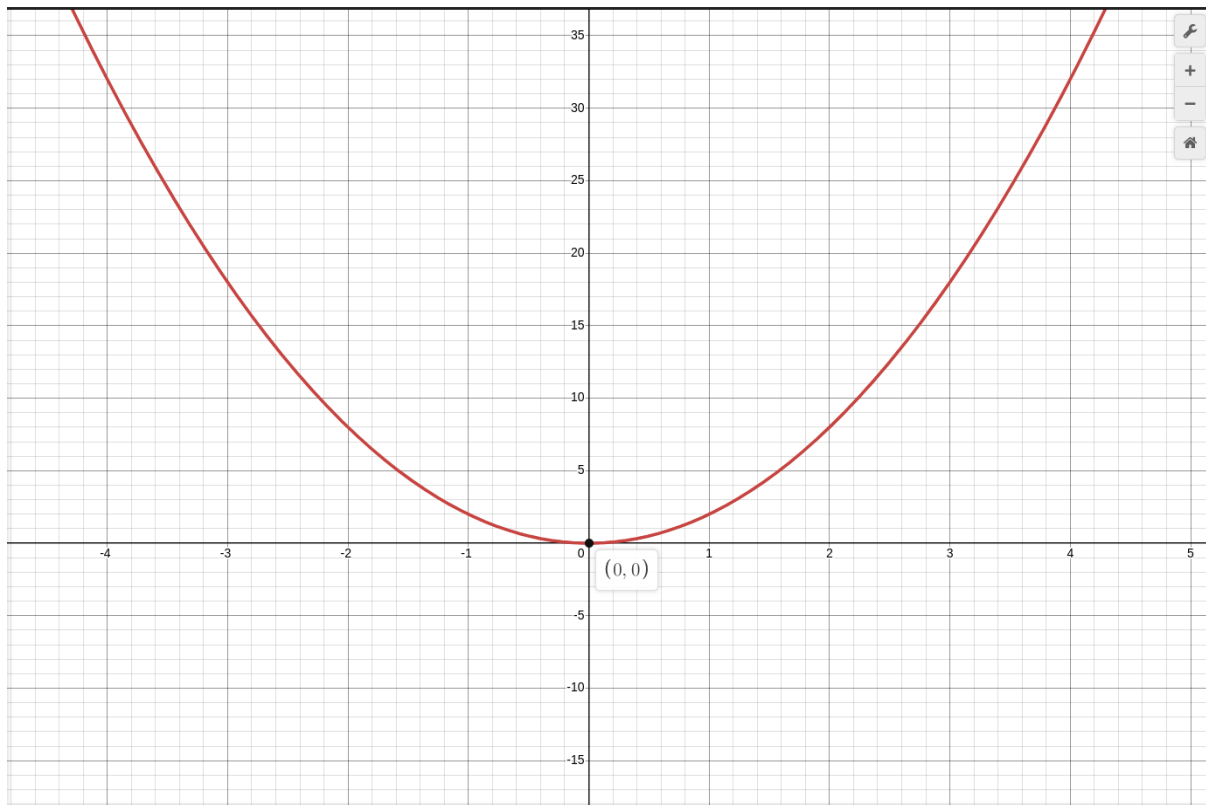
Some general rules for the end behavior of polynomial functions:

- If the degree of the polynomial is even, the end behavior will be the same, going to either positive or negative infinity, based on the sign of the leading coefficient.
- If the degree of the polynomial is odd, the function will have opposite end-behavior of the sign of the leading coefficient, going to either positive or negative infinity, based on the sign of the leading coefficient.

The value of the output is impacted the most by the leading term of the function.

- Because of this, you only need to graph the leading term.
- The end-behaviors are referring to each concavity and how the end-behaviors will be either the same or opposite of each-other.

# Function 1



“  $f(x) = 2x^2 + 3x - 10$

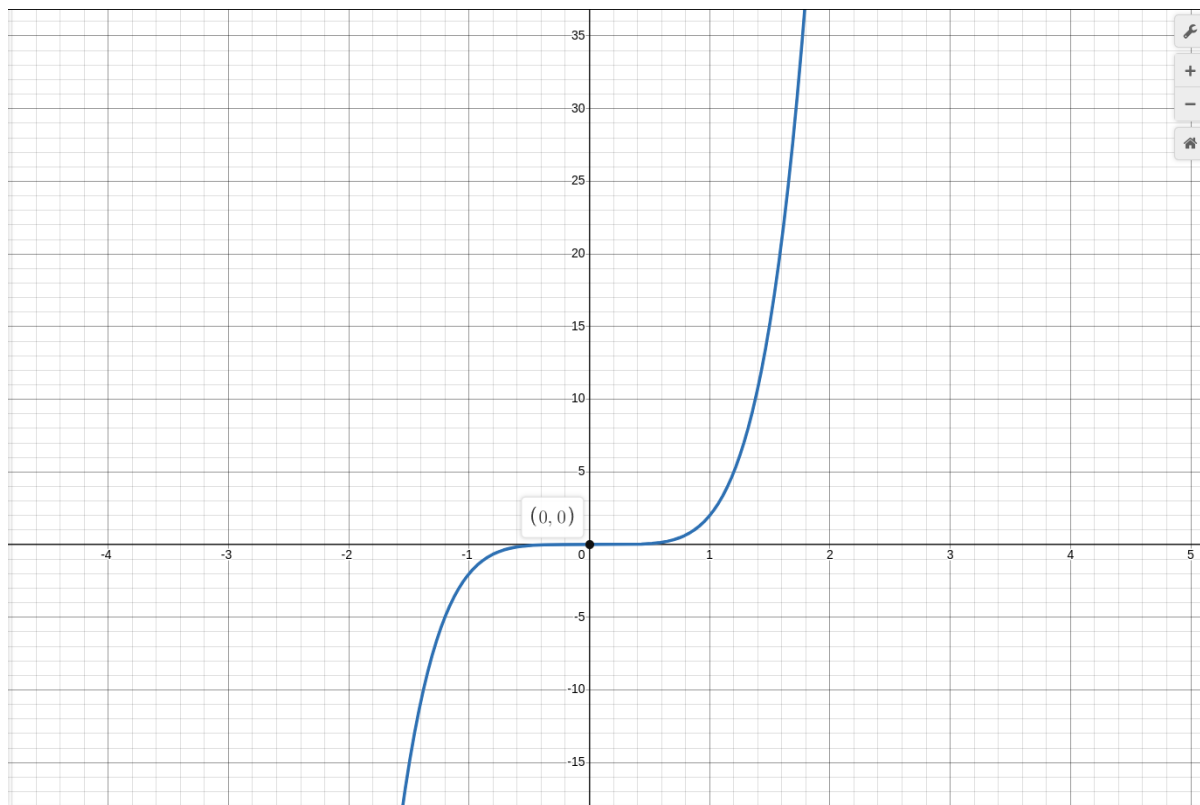
“ As  $x \rightarrow \pm\infty$ ,  $f(x) \approx 2x^2$

As  $x \rightarrow \pm\infty$ ,  $f(x) \rightarrow \infty$

- Only  $2x^2$  was graphed because it is the leading term.

---

## Function 2



‘  $g(x) = 2x^5 + 4x^4 - 13x^2 + 8$

‘ As  $x \rightarrow \pm\infty$ ,  $g(x) \approx 2x^5$

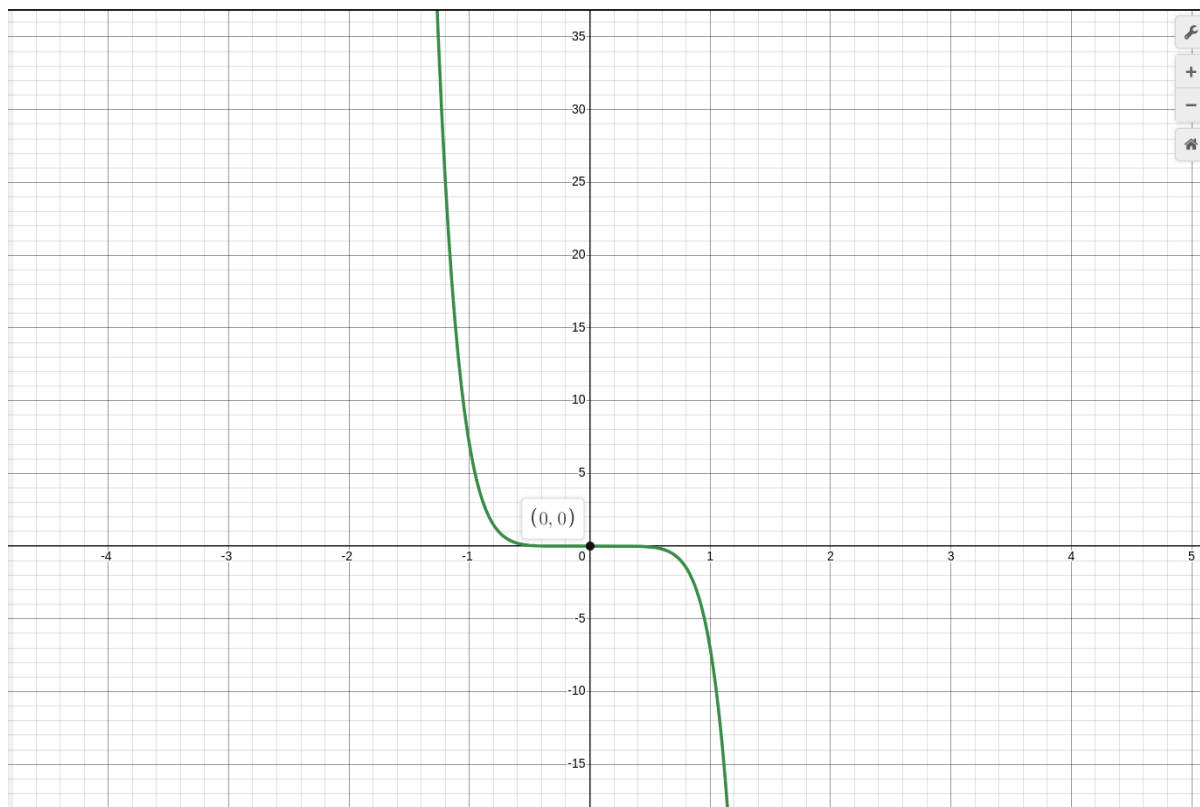
As  $x \rightarrow +\infty$ ,  $g(x) \rightarrow \infty$

As  $x \rightarrow -\infty$ ,  $g(x) \rightarrow -\infty$

- Only  $2x^5$  was graphed because it is the leading term.



## Function 3



‘  $h(x) = -8x^2 - 3x^5 - 7x^7 - 9$

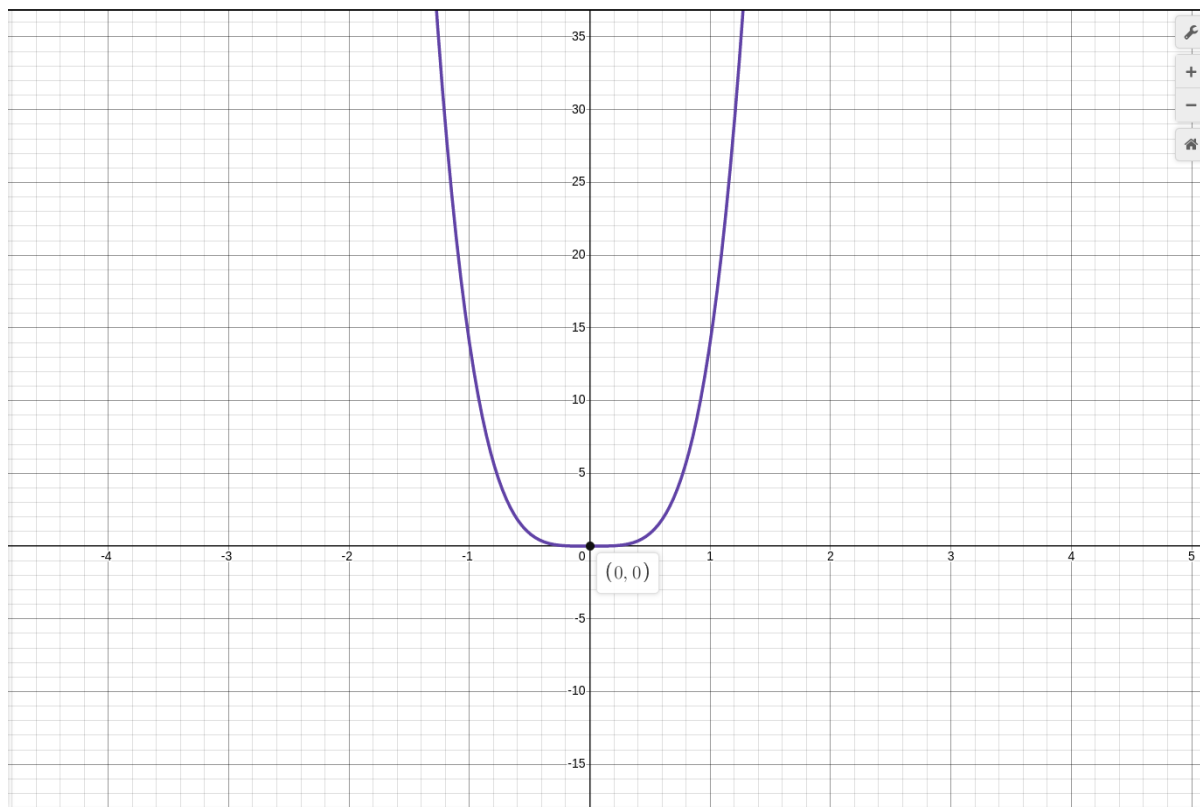
‘ As  $x \rightarrow \pm\infty$ ,  $h(x) \approx -7x^7$

As  $x \rightarrow +\infty$ ,  $g(x) \rightarrow -\infty$

As  $x \rightarrow -\infty$ ,  $g(x) \rightarrow \infty$

- Only  $7x^7$  was graphed because it is the leading term.

## Function 4



‘  $j(x) = 14x^4 - 6x^2 - x$

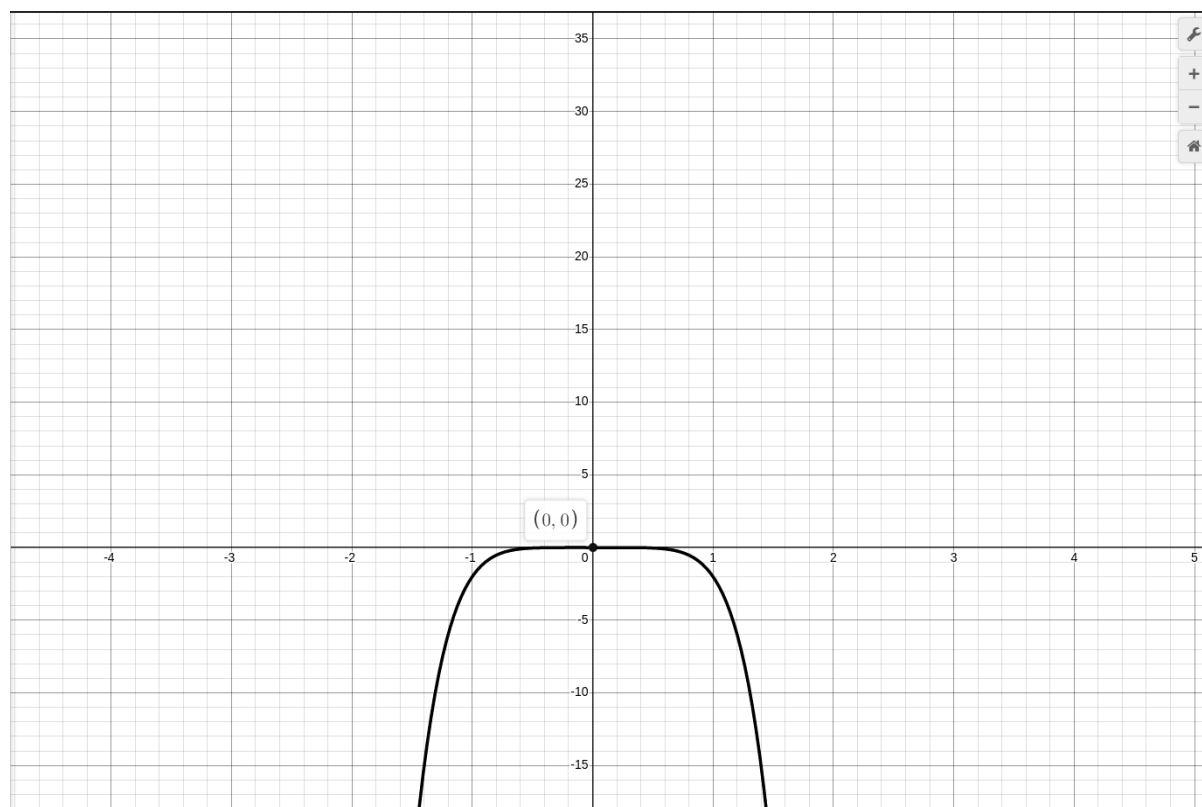
‘ As  $x \rightarrow \pm\infty$ ,  $j(x) \approx 14x^4$

As  $x \rightarrow \pm\infty$ ,  $j(x) \rightarrow \infty$

- Only  $14x^4$  was graphed because it is the leading term.

---

## Function 5



“  $k(x) = 2 + 6x + 18x^2 - 2x^6$

“ As  $x \rightarrow \pm\infty$ ,  $k(x) \approx -2x^6$

As  $x \rightarrow \pm\infty$ ,  $k(x) \rightarrow -\infty$

- Only  $2x^6$  was graphed because it is the leading term.

## Relative and Absolute Extrema of Polynomial Functions

- The term **relative extrema** is used to refer to maxima and minima simultaneously.
- The graph of a polynomial function of degree  $n$  will have at most  $n - 1$  relative extrema but it may have fewer.
- An **odd** function will **never** have an absolute max or min
- An **even** function will **always** have an absolute max or min

# Relative Extrema of Polynomial Functions

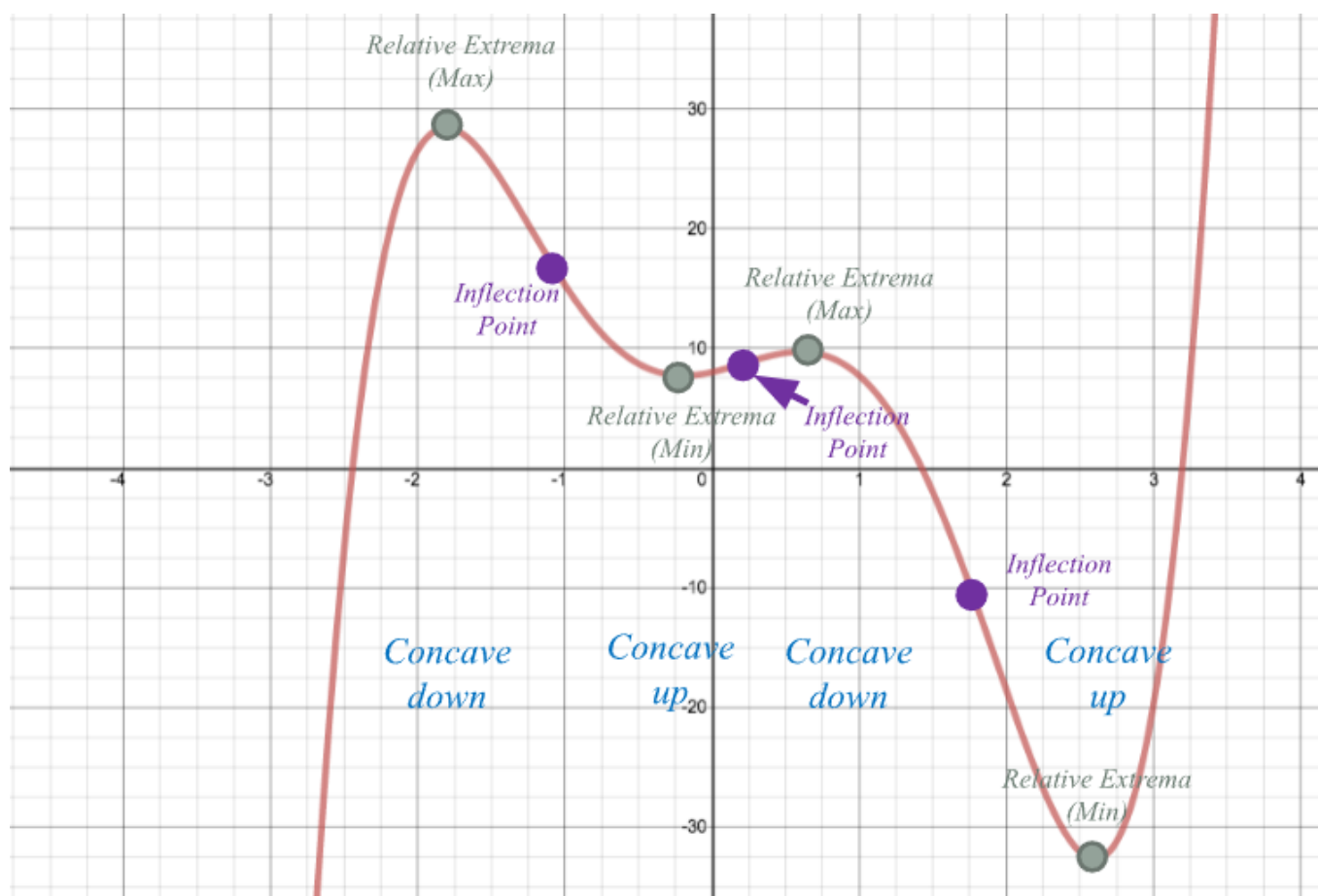
- A **relative maximum** occurs at the point where a graph changes from increasing to decreasing.
- A **relative minimum** occurs at the point where a graph changes from decreasing to increasing.

## Absolute Extrema of Polynomial Functions

- A relative maximum is called an **absolute maximum** if the function value is never larger than at this point for all inputs.
- A relative minimum is called an **absolute minimum** if the function value is never smaller than at this point for all inputs.

## Identifying All Points On a Graph

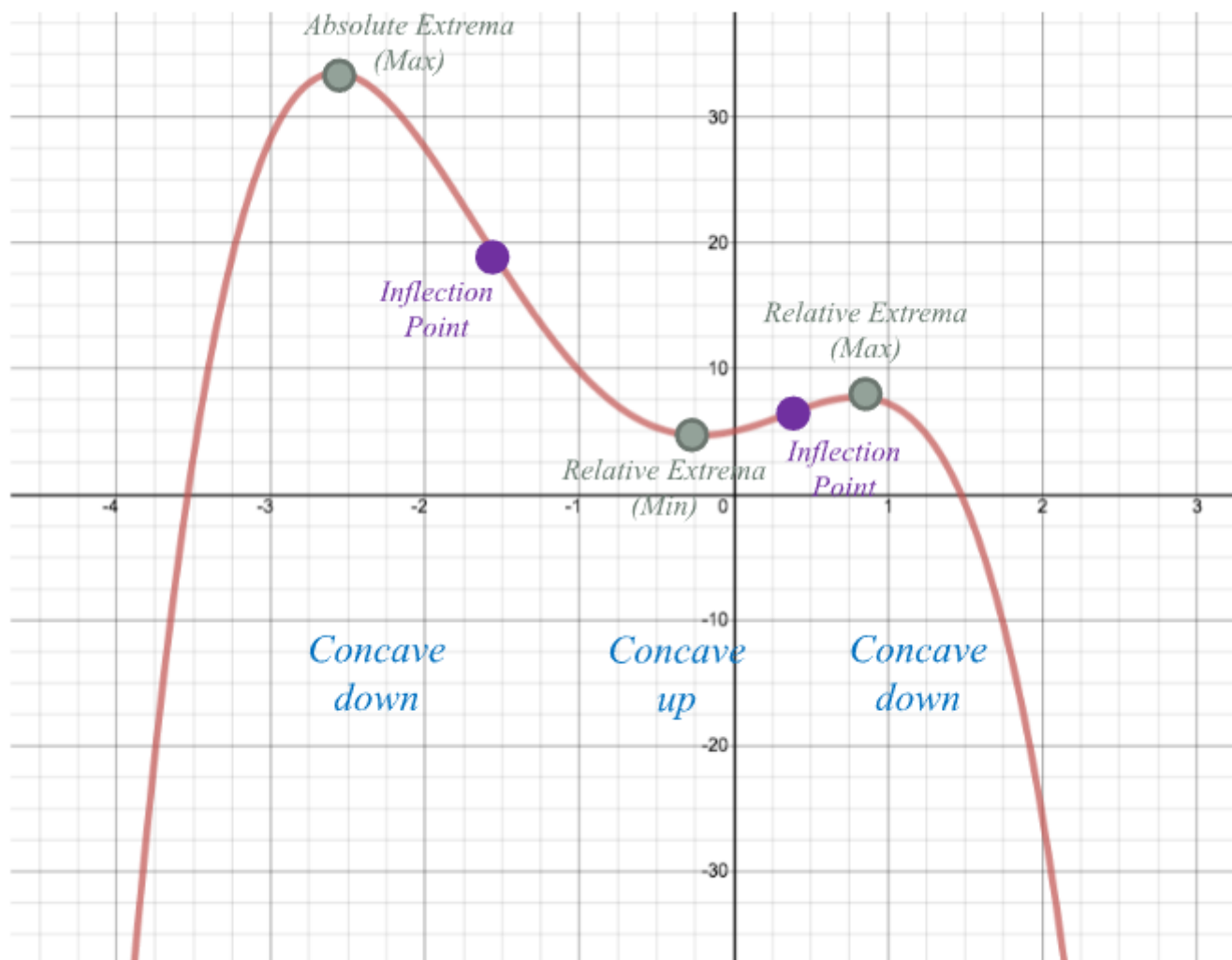
### Example 1



- This could be a 5<sup>th</sup> degree polynomial because the function has opposite end behavior (so the degree must be odd), there are 4 concavities, 3 inflection points, and 4 relative extrema.

- The inflection points are halfway between each extrema

## Example 2



- This could be a 4<sup>th</sup> degree polynomial because the function has the same end behavior (so the degree must be even), there are 3 concavities, 2 inflection points, and 3 relative extrema (one absolute)

## Computing and Graphing a Cubic Function

Use the following formula to graph a cubic function:

$$y_1 \sim ax_1^3 + bx_1^2 + cx_1 + d$$



# Module 12 - Rational Functions

# Module 13 - Power Functions