Day By Day Notes for MATH 206
Spring 2013

Day 1

Activity: Go over syllabus. Take roll. Functions activities.

Goals: Review course objectives: summarize data with models and analyze how functions change.

I have divided this course into three “units”. Unit 1 (Days 1 through 14) is about basic functions. Unit 2 (Days 15 through 32) is about derivatives and their uses. Unit 3 (Days 33 through 56) is about integration and multi-variable functions.

I believe to be successful in this course, you must READ the text carefully, working many practice problems. Our activities in class will sometimes be unrelated to the homework you practice and/or turn in for the homework portion of your grade; instead they will be for understanding of the underlying principles. For example, on Day 16 you will draw sample graphs and derivatives, then try to reconstruct the original graph. This is something you would never do in practice, but which I think will demonstrate several lessons for us. In these notes, I will try to point out to you when we’re doing something to gain understanding, and when we’re doing something to gain skills.

An important prerequisite for this course is an understanding of algebra. Algebra is the set of rules and procedures associated with basic arithmetic. We are all adept at arithmetic, so we should all be familiar with how algebra works. Unfortunately, the abstraction of arithmetic with letters instead of numbers confuses many of us. If you have weaker algebra skills, due to getting a lower grade in previous algebra classes, or not having had an algebra class for some time, you may want to consider taking a refresher course before tackling the more difficult topic of calculus. I have found in the past that students who are struggling with algebra concepts tend to be overwhelmed by the more rigorous calculus concepts. Incidentally, several years ago the Mathematics Department collected some data on student success in Math 204 and Math 206, and we found the grades of those students who completed Math 104 were a half grade point higher than those without Math 104 (GPA of 2.8 for those with Math 104 and 2.3 for those without).

Each semester, I am disappointed with the small number of students who come to me for help outside of class. I suspect some of you are embarrassed to seek help, or you may feel I will think less of you for not “getting it” on your own. Personally, I think that if you are struggling and cannot make sense of what we are doing, and don’t seek help, you are cheating yourself out of your own education. I am here to help you learn mathematics. Please ask questions when you have them; there is no such thing as a stupid question. Often other students have the same questions but are also too shy to ask them in class. If you are still too shy to ask questions in class, come to my office hours or make an appointment. You should also consider using the Math Tutor Lab, located on the first floor of Swart Hall. The lab is free to all students, and many students have benefitted from studying there and having a tutor handy for questions.
I believe you get out of something what you put into it. Very rarely will someone fail a class by attending every day, doing all the assignments, and working many practice problems; typically people fail by not applying themselves enough - either through missing classes, or by not allocating enough time for the material. Obviously I cannot tell you how much time to spend each week on this class; you must all find the right balance for you and your life’s priorities. One last piece of advice: don’t procrastinate. I believe mathematics is learned best by daily exposure. Cramming for exams may get you a passing grade, but you are only cheating yourself out of understanding and learning.

Functions:

Today we will begin by discussing functions. Quite simply, a function is a rule. From an input value, a function gives the output value. The set of possible inputs is called the domain, and the set of output values is called the range. The input value is sometimes called the independent value, and the output value the dependent value. One of the chief goals of mathematics is to model real world phenomena with functions. Therefore it is important for us to be familiar with their uses and roles.

Throughout the course, we will try to look at functions from four different viewpoints. Data will be presented to us in tabular form, graphical form, algebraic form, or verbally. It will be up to us to determine the most appropriate method of describing the function. A common misconception that I hope to dispel is that equations are synonymous with functions. Equations are only one method of describing functions. Our text makes an honest effort to display functions for us in all four forms.

Today and tomorrow I would like to explore functions graphically, verbally, and algebraically. We will begin with a discussion of a hypothetical flight between two cities. Then I will have you work in groups.

In these notes, I will put the daily task in gray background.

**Activity 1: Graphical Description.**

The value of a car decreases as the car gets older. We can think of the value of a car, $V$, in thousands of dollars, as a function of the age of a car, $a$, in years. In functional notation, we have $V = f(a)$ (read “$V$ equals $f$ of $a$”). Using this notation, we mean that $a$ is the independent or input value and $V$ is the dependent or output value. $f$ is the function or rule used to find $V$ based on $a$.

1) Draw a possible graph of $V$ versus $a$. You don’t need scales on the axes, but label each axis as $V$ or $a$. Traditionally we place the independent variable on the horizontal axis and the dependent variable on the vertical axis.

2) What does the statement $f(5) = 6$ tell you about the value of the car? Be sure to use units for 5 and for 6. Label this as a point on your graph, and mark the 5 and the 6 on the appropriate axes.

3) Put a vertical intercept of 15 on your graph of the function. Explain the meaning of this vertical intercept in terms of the value of the car.
4) Put a horizontal intercept of 10 on your graph of the function. Explain the meaning of this horizontal intercept in terms of the value of the car.

5) Given the three points above, would it make sense to say the value of the car has depreciated at a constant rate? We will talk about this more when we discuss linear functions.

Goals: (In these notes, I will summarize each day’s activity with a statement of goals for the day.)

Introduce the course, and the idea of a function.

Skills: (In these notes, each day I will identify skills I believe you should have after working the day’s activity, reading the appropriate sections of the text, and practicing exercises in the text.)

- Use the “Guess and Check” method of problem solving. This technique is the essence of the scientific method. There is nothing bad about guessing in order to learn. The better guessers, of course, tend to get quicker results, but if you have appropriate tools to evaluate your guesses, then even poor guesses can be refined adequately. By the way, your calculator in this class will essentially use this guess and check method to solve equations. It’s just that your calculator works a bit faster than you can. Another related idea is using test numbers to start a process. That is, perhaps making up a sample situation will help you see what is going on. I encourage you to use this approach often; it is the most basic lesson my advisor taught me in graduate school. He used to say, “Start with a simple example.” That often meant assuming some specific values for some variables, and working from there to understand the problem.

- Physical modeling. Many times being stuck on a real world problem can be alleviated by modeling the situation with physical items or by other simulations. Of course many situations are infeasible; you can’t fly airplanes to simulate scheduling airline routes, but you can use appropriate diagrams or tokens representing airplanes. Sometimes actually physically representing something will get you over a mental block.

Reading: (The reading mentioned in these notes refers to what reading you should do for the next day’s material.)

Section 1.1. Bring your calculator to class every day. It will be an invaluable tool.

Day 2

Activity: Today we continue to explore functions graphically, verbally, and algebraically. I will have you work in groups again. For each activity, when you come up with a solution, put it on the board and we will compare notes before class ends.

Activity 1: Algebraic and Verbal Description.

From a letter-sized 8.5” by 11” piece of cardstock you are to form a box to hold candy. Your design plan is to cut squares from each of the 4 corners and fold up the resulting flaps to form sides of the candy box. (The top will come from a separate piece of cardstock.) Your goal is to maximize the volume of your box. What size square should you cut from each corner? To begin this solution, I recommend trying some specific square sizes and calculating the
resulting volume. From a chart of such values, an answer should emerge. The pièce de résistance will be converting your table into a formula and graphing to find the optimal value.

**Activity 2: Graphical and Algebraic Description.**

With our calculators, we have the tools available to explore limits. Specifically, we hope to hone our intuition about this important topic in calculus.

1) Calculate \((1 + \frac{1}{n})\) for \(n = 1, 10, 100, 1000, \) etc. What seems to be happening to the values? Are they approaching an upper bound, or limit? Can you explain (prove) it?

2) Calculate \((1 + \frac{1}{n})^n\) for \(n = 1, 10, 100, 1000, \) etc. What seems to be happening to the values? Are they approaching a limit? This limit we see here is a very important limit in calculus and mathematics. We will encounter it and study it in more detail later.

3) Consider this series of terms: 1, 1/2, 1/3, 1/4, etc. Add the successive terms to get a new series of partial sums. That is, find 1, 1 + 1/2, 1 + 1/2 + 1/3, 1 + 1/2 + 1/3 + 1/4, etc. What seems to be happening to this sum?

4) Now try this series of terms and repeat the sums you did in 3): 1, 1/2, 1/4, 1/8, 1/16, 1/32, etc. (These are successively smaller powers of two.) What seems to be happening to this sum?

5) Using \(f(x) = \frac{x + 1}{x^2 - x - 2}\), find the limits as you approach \(x = 2\) from the right and left. (Approaching from the right means using values just greater than 2 and approaching from the left means using values just smaller than 2.) Also find the value right at \(x = 2\).

6) Repeat 5) using \(g(x) = \frac{x^2 - x - 2}{x + 1}\).

In these notes, I will put sections of computer commands in boxes, like this one. I’m actually hoping that you already are quite familiar with this machine, many of you having already taken Math 204. In these notes, I refer to the calculator as the TI-83, but the same commands apply to the TI-84.

\textbf{Y} = is found on the top row of buttons, on the left. You enter equations into whichever Y-variable you want to use. Be careful to enter what you want, that is, pay attention to parentheses, typos, etc! Each Y-variable whose = sign is highlighted will be graphed when the \textbf{GRAPH} button is pressed. In addition, if any plots at the top of the display are highlighted, those too will be plotted, whether you intended them to be or not!

\textbf{GRAPH} is found on the top row of buttons, on the right. This button toggles between the data / numerical entry screens and the graphing window. To leave the graphing window, press any key, or press \textbf{QUIT}, (found by pressing 2nd \textbf{MODE}).
**WINDOW** is found on the top row of buttons, second from the left. This opens the windows setting screen, which tells you the dimensions and characteristics of the current graphing window. We will mostly change only 4 items: $X_{\text{min}}$, $X_{\text{max}}$, $Y_{\text{min}}$, and $Y_{\text{max}}$. If you like, you may tinker with the other settings.

**TRACE** is on the top row of buttons, second from the right. This key puts a cursor on the graphing window on one of your y-variables / functions. You may push right and left arrow to move sideways on the selected curve, or up and down arrow to select other curves (if you have entered more than one y-variable.) Be careful: **TRACE** is dependent on the current window settings. If you need specific values, after pressing **TRACE**, type the $x$-value you need evaluated. **TRACE** will calculate the functional value exactly.

**ZoomFit (Zoom 0)** Many times, you do not know which is the best viewing window. If you first specify the horizontal endpoints in the **WINDOW** settings screen ($X_{\text{max}}$ and $X_{\text{min}}$), then you can press **ZoomFit** (under ZOOM menu, item 0) to have the calculator find the appropriate $Y_{\text{min}}$ and $Y_{\text{max}}$ values. This function is quite handy; I use it a lot myself.

**ZStandard (Zoom 6)** If you are in love with the numbers between $-10$ and $+10$, you should use **ZStandard** in the ZOOM menu. Otherwise, you may find this key useless!

**Goals:** Appreciate the dynamics of collaboration. Understand the different problem solving strategies. Explore some basic limits.

**Skills:**

- **Collaboration.** One of the biggest problems I see semester after semester with math students is their reluctance to talk about their math frustration. Talk about things with each other! If you are too timid to talk to me, (or if you have other reasons for not wanting to chat with me) at least talk to your peers. Sometimes simply saying something out loud will open up doors you might not have otherwise opened, or an offhand remark may inspire someone else’s imagination. Of course this doesn’t mean that one person in a group of problem solvers should do all the work; but even if only one group member “gets” a solution, the sharing is beneficial to all concerned. The sharer gets to really learn the concept as he/she is required to explain it; the others get to see a solution they missed. Ideally, everyone should be able to explain a group solution; until you can explain the solution, you haven’t quite understood the method.

- **Evaluate limits numerically and graphically.** By using numbers closer and closer to the value in question, whether it is finite or infinite, your calculator or computer can help you to evaluate limits. There is a caution, however: you must still use your analytic skills to avoid being fooled. You may have observed this in Exercise 2 of Activity 2. Some limits are easy to evaluate (simply plug in and evaluate) while others are more complicated (the partial sums we saw in Exercises 3 and 4 of Activity 2 are often quite difficult to evaluate or to even
One of the “big ideas” in calculus is differentiation, and we need to be comfortable with limits to understand derivatives. Another of the “big ideas” in calculus is integration, and we need to understand limits such as partial sums to understand integrals.

- Recognize the harmonic series. Even though terms in a series may be getting smaller and smaller, their partial sums may not converge to a finite number. The sequence in Exercise 3 of Activity 2 above is called the harmonic series and demonstrates this seeming paradox. Many partial sums will converge, though, as you saw in Exercise 4 of Activity 2, which is an example of a geometric series.

- Understand the definition of the number $e$ (approximately 2.7182818). Exercise 2 of Activity 3 is the definition of the number $e$, which we will use again and again in calculus. Remember, though, $e$ is just a number, nothing more. Don’t be afraid of it!

Reading: Section 1.2.

Day 3

Activity: Using the Olympic data, fit a regression line to predict the 2016 race results. Interpreting Rates of Change.

Unit 1 is about building up a library of functions. To be an effective mathematical modeler, we must have a working knowledge of basic functions. These include linear functions, exponential functions, polynomials, and combinations of these. The simplest and most used is the linear function (it is the basis for the derivative we will master in Chapter 2). You should already know a lot about linear functions. Just to make sure we all have the same background, today we will explore linear functions in detail.

To begin, I will list the useful forms for linear equations.

1) Slope/Intercept form: $y = mx + b$ . In this form, $m$ is the slope and $b$ is the y-intercept.

2) Point/Slope form: $y - y_1 = m(x - x_1)$ . In this form, $m$ is the slope, and $(x_1, y_1)$ is an ordered pair on the line.

3) Two Point form: $y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$ . In this form, $(x_1, y_1)$ and $(x_2, y_2)$ are two sets of ordered pairs on the line.

I will use do the Celsius/Fahrenheit conversion in class to demonstrate using these forms.

The chief technique for summarizing a linear relationship given data points on a scatter plot is Least Squares Linear Regression. This technique is also known as Least Squares Regression, Best Fit Regression, Linear Regression, etc. The important point is that we are going to describe the relationship with a straight line, so if the scatter plot shows some other shape, this technique will be inappropriate. Your tasks are to 1) come up with a line, either by hand or with technology, that “goes through” the data in some appropriate way, 2) to be able to use this model to describe the relationship verbally, and 3) to predict numerically $y$-values for particular $x$-values of interest.

Begin by making a scatter plot of the race times. (Use STAT PLOT. See calculator commands below. Put the years in L1 and the times in L2.) If you want a rough guess for the slope of the best fitting line through the data, you can connect two points spaced far apart (I will show you the details in class, using the two-point form.)

Next, use the TI-83’s regression features to calculate the best fit. The command is STAT CALC LinReg(ax+b), assuming the two lists are in L1 and L2. (L1 will be the horizontal variable, years in this case.) (For regression it is vital that you get the order of the variables correct; the idea here is that you are predicting the vertical variable from the known horizontal variable.)

Interpret what your two regression coefficients mean. Make sure you have units attached to your numbers to help with the meanings.

Have the calculator type this equation into your Y = menu (using VARS Statistics EQ RegEQ or use the commands below), and TRACE on the line to predict the future results. Specifically, see what your model says the 2012 times should have been and what the 2016 estimate is. Then compare to the actual 2012 time and check how predictive our model is. (You can also use the technique in the calculator commands section below.)

Men’s and Women’s 100-meter dash winning Olympic times:

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<tr>
<th>Year</th>
<th>Name</th>
<th>Country</th>
<th>Time</th>
</tr>
</thead>
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<td>1904</td>
<td>Archie Hahn</td>
<td>United States</td>
<td>11.0 sec</td>
</tr>
<tr>
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<td>South Africa</td>
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<tr>
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<td>United States</td>
<td>10.8 sec</td>
</tr>
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<td>United States</td>
<td>10.8 sec</td>
</tr>
<tr>
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<td>Harold Abrahams</td>
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<td>10.6 sec</td>
</tr>
<tr>
<td>1928</td>
<td>Percy Williams</td>
<td>Canada</td>
<td>10.8 sec</td>
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<td>10.3 sec</td>
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<td>Jesse Owens</td>
<td>United States</td>
<td>10.3 sec</td>
</tr>
<tr>
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<td>Harrison Dillard</td>
<td>United States</td>
<td>10.3 sec</td>
</tr>
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</tr>
<tr>
<td>1956</td>
<td>Bobby Morrow</td>
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</tr>
<tr>
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<tr>
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(a) A 1980 autopsy determined that Walsh was a man.
Men’s and Women’s 200-meter dash winning Olympic times:

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<th>Year</th>
<th>Name</th>
<th>Nation</th>
<th>Time</th>
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<td>Robert Kerr</td>
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<td>Percy Williams</td>
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<td>1932</td>
<td>Eddie Tolan</td>
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<td>2012</td>
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</tbody>
</table>

STAT EDIT To enter a list of numbers into your calculator, instead of an equation, use the STAT menu. EDIT is the display that allows you to enter lists of numbers. You may have up to 3 lists displayed in the EDIT window. It is convenient to use the built-in lists L1 to L6, but actually any named lists may be used. You may want to refer to the calculator manual if you are interested in naming and saving your lists. (It might save you having to constantly re-enter data.)

STAT PLOT 1 On Use this screen to designate the plot settings. You can have up to three plots on the screen at once.

ZOOMStat (Zoom 9) To view a scatter plot of two lists, ZoomStat will create an appropriate viewing window. To use the TI-83 to effectively view scatter plots, I recommend turning off or de-selecting all Y-variables before pressing ZoomStat. There will be times however, when you will want to have both a scatter plot and an equation on the same viewing window, so it is not required to always de-select all functions.

STAT CALC ???Reg After two lists of numbers have been entered, we can fit lines or curves to the data with the ???Reg commands. The TI-83 will fit 10 kinds of equations; the most common one is LinReg. Before you use any of the fitting routines,
perform the following: Press **CATALOG** (found by pressing 2nd 0), the letter D, down arrow eight times (to point to **DiagnosticOn**), and press **ENTER** twice.

If you want to store your fitted equation in the Y= list directly from the regression command, do this: press **STAT CALC ???Reg**, then indicate the lists (variables) you want to use, separated by commas, then press **VARS**, right arrow, 1, and choose the desired Y-variable. Your fitted equation then appears in your list of Y-variables. An example command is: **LinReg(ax+b) L1, L2, Y1**. This will use L1 as the x-values, L2 as the y-values, and Y1 as the equation to store the fitted equation in. Be aware though that this command will overwrite anything you already had stored in Y1. Make sure important stuff in Y1 is saved elsewhere before you perform this command.

Goals: Practice using regression with the TI-83. We want the regression equation, the regression line superimposed on the plot, and we want to be able to use the line to predict new values.

Skills:

• **Fit a line to data.** This may be as simple as “eyeballing” a straight line to a scatter plot. However, to be more precise, we will use least squares, **STAT CALC LinReg(ax+b)** on the TI-83, to calculate the coefficients, and **VARS Statistics EQ RegEQ** to type the equation in the Y = menu. You should also be able to sketch a line onto a scatter plot (by hand) by knowing the regression coefficients.

• **Interpret regression coefficients.** Usually, we want to only interpret slope, and slope is best understood by examining the units involved, such as inches per year or miles per gallon, etc. Because slope can be thought of as “rise” over “run”, we are looking for the ratio of the units involved in our two variables. More precisely, the slope tells us the change in the response variable for a unit change in the explanatory variable. We don’t typically bother interpreting the intercept, as zero is often outside of the range of experimentation.

• **Estimate/predict new observations using the regression line.** Once we have calculated a regression equation, we can use it to predict new responses. The easiest way to use the TI-83 for this is to **TRACE** on the regression line. You may need to use up and down arrows to toggle back and forth from the plot to the line. You may also just use the equation itself by multiplying the new x-value by the slope and adding the intercept. (This is exactly what **TRACE** is doing.) Note: when using **TRACE**, and the x-value you want is currently outside the window settings (lower than **Xmin** or above **Xmax**) you must reset the window to include your x-value first.

Reading: Section 1.3.

Day 4

Activity: Continue working with linear functions, described graphical and with a table of data.
Yesterday, we used the TI-83 to fit a straight line to the Olympic race data. Interpreting the slope was the most important part of describing that relationship. Today we will work more with linear functions, this time given verbally. The second activity today will be a preview of Chapter 2, as the rate of change of a function is an important concept in calculus. To find the rate of change of a function (or the average of the function) over an interval, we use the two-point form.

**Activity 1: Algebraic description: Using verbal description.**

Taxicab rates. Given the following information on the side of a cab, develop an equation that will let you calculate the fare for any distance $x$. (To test your work, make sure your equation gives proper answers for known values. For example, you know the cost of a 1/9 of a mile ride is $2.50, so your equation should give $f(1/9) = 2.50$.) Report your equation on the board.

Info on the side of a cab: $2.50 FOR THE FIRST 1/9 MILE, PLUS 25 CENTS FOR EACH ADDITIONAL 1/9 MILE OR FRACTION OF A MILE.

**Activity 2: Tabular description: Using average rates of change.**

Minimum wage was created by Congress in 1938. Has it been updated to reflect inflation fairly? From the following chart, for the adjusted minimum wage, calculate these rates of change: 1938 to 1980, 1990 to 2000, and 2000 to 2010. Report your answers on the board. Note: In this chart, CPI=100 in 1982. I have adjusted the figures to 2010 dollars.

<table>
<thead>
<tr>
<th>Year</th>
<th>Minimum Wage</th>
<th>CPI</th>
<th>Adjusted Minimum Wage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1938</td>
<td>$0.25</td>
<td>14.2</td>
<td>$3.82</td>
</tr>
<tr>
<td>1950</td>
<td>$0.75</td>
<td>23.5</td>
<td>$6.92</td>
</tr>
<tr>
<td>1970</td>
<td>$1.45</td>
<td>37.8</td>
<td>$8.31</td>
</tr>
<tr>
<td>1980</td>
<td>$3.10</td>
<td>77.8</td>
<td>$8.63</td>
</tr>
<tr>
<td>1990</td>
<td>$3.80</td>
<td>127.4</td>
<td>$6.46</td>
</tr>
<tr>
<td>2000</td>
<td>$5.15</td>
<td>168.8</td>
<td>$6.61</td>
</tr>
<tr>
<td>2010</td>
<td>$7.25</td>
<td>216.7</td>
<td>$7.25</td>
</tr>
</tbody>
</table>

**Goals:** Understand the slope of the line is the Rate of Change of the function.

**Skills:**

- **Convert a verbal description into an equation.** You should be able to recognize the ideas of slope / intercept or a description of several points on a line from a verbal description of a
linear function. By recognizing which information is present, you then should be able to choose the proper form for the linear equation.

- **Be able to calculate average rates of change from tabular data.** Given a table of values, you should be able to calculate various rates of change. The important concept is that the average rate of change is simply the slope from a line connecting two points.

**Reading:** Section 1.4.

**Day 5**

**Activity:** Economics Examples.

Several important business/economic applications use linear functions. Today we will look at profit, marginal costs, depreciation, and supply/demand curves. All of these topics can also be modeled with non-linear functions, so we will also encounter them later. For now, however, we will use only the linear functions.

Profit: In business settings, profit is calculated by subtracting costs from revenue. Because revenue is usually the unit sales price times the number of items, we can model revenue as a linear function.

Marginal Costs: The concept of marginal costs, revenues, etc. is a notion about the next item’s cost, revenue, etc. Recognizing the difference between a marginal cost and an average cost is critical to using derivatives appropriately later (Chapter 2). The marginal values we explore here can be viewed as the slope of a line connecting to adjacent quantities, spaced one unit apart.

Depreciation: Items lose value over time, and we model this with different functions. With linear depreciation, we basically use a two-point form. Sometimes the two points used are the initial purchase price and the eventual salvage value.

Supply/Demand Curves: Economists theorize that markets can be modeled with supply and demand curves, where the supply curve applies to producers of a commodity and the demand curve applies to the consumers. Today and tomorrow we will explore using linear functions with supply and demand theory.

Today we will look at examples of each of the above topics from the exercises on pages 30 to 32. For each exercise, put your solution on the board.


**Goals:** Recognize the application of linear functions to economic examples.
Skills:

- **Understand profit functions.** Profit is defined as the difference between Revenue and Cost. We often phrase these functions in terms of quantity produced, $q$. Revenue as a function of quantity is usually linear. Cost as a function of quantity is usually not linear, but today we will assume it is to make some calculations. Marginal cost (revenue, profit) is the cost (revenue, profit) of the next item produced. Marginal values are often different, based on current production levels. We will explore marginal values more in Chapter 2 on derivatives.

- **Understand linear depreciation.** In general, depreciation is the declining value of an item over time. The simplest form of depreciation is linear depreciation. The usual method of determining a linear equation for linear depreciation is to use the two-point form.

- **Understand supply and demand curves.** Economic theory suggests that prices and quantities produced or desired are related. The demand curve suggests that as price increases, fewer people will buy an item. The supply curve suggests that as price increases, more items will be produced. These two curves can be modeled with linear functions, and economic theory says they intersect at equilibrium. Later, we will explore non-linear supply and demand curves (Section 6.2, Day 40).

Reading:  Section 1.4.

Day 6

Activity:  Supply and Demand using linear functions.

One interesting modification we can make to the supply and demand setting is adding various kinds of taxes. The basic question is how taxation affects market equilibrium. For the problems today, consider various points of view. For example, when we charge the producer the tax on an item, as opposed to charging the consumer, the producer behaves as if the product sells for less than the cost the consumer pays. Therefore, in the supply equation we replace $p$ with $p - t$, where $t$ is the amount taxed per item. With the new equation, we now have a new equilibrium, and new total revenue, which we can now compare to the values before the tax.

When the tax is imposed on the consumer, we have a similar situation. Because the added tax makes the cost of the item higher, the consumer behaves differently, according to the demand curve. Therefore, in the demand equation we replace $p$ with $p (1 + r)$, where $r$ is the sales tax rate. With this new equation, we now have a new equilibrium, and new revenue, which we can now compare to the values before the sales tax.

**Supply/Demand using lines. Effect of taxes. Problems 35 to 37, page 32.**

Goals:  Continue working with supply and demand theory.

Skills:

- **Understand supply and demand curves.** Economic theory suggests that prices and quantities produced or desired are related. The demand curve suggests that as price
increases, fewer people will buy an item. The supply curve suggests that as price increases, more items will be produced. These two curves can be modeled with linear functions, and economic theory says they intersect at equilibrium. Later, we will explore non-linear supply and demand curves (Section 6.2, Day 40).

Reading: Section 1.5.

Activity: Exponential Functions.

In linear functions, as the $x$-value increases one unit, the $y$-value increases $m$ units, where $m$ is the slope of the line. This is additive growth. Another type of growth is multiplicative. In this kind of growth, when the $x$-value increases one unit, the $y$-value increases by a factor of $b$. That is, instead of adding a fixed value, we multiply by a fixed value. This kind of growth is called exponential growth.

Famous examples of exponential growth are populations. In class, I will look at the US population. In Presentation 1, you will select an individual state and model its growth, perhaps efficiently with exponential curves. (Some populations do not grow exponentially; you will have to explore the growth rates to see.)

Today we will use the calculator to fit exponential curves to growth functions, like the US population over time.

Activity: Modeling Population Growth.

The population for the US is on page 213. (I also have the data for each of the 50 states and the US at the end of these notes.) Using ratios, find periods of time when the US population grew approximately exponentially. For your candidate eras, fit an exponential model using regression.

\textbf{STAT CALC ExpReg} This regression function fits exponential curves. Again, the $x$-variable comes first, then the $y$-variable. The third parameter, if used, is the $Y$-variable where the equation will be stored. Example: \texttt{ExpReg(ax+b) L1, L2, Y1} uses data from lists \texttt{L1} and \texttt{L2} and stores the equation in \texttt{Y1}.

Goals: Explore exponential growth.

Skills:

- \textbf{Know the form of the exponential functions.} Exponential equations have two parameters, a $y$-intercept, and a base. The base is the multiplicative growth factor. The general equation is $y = ab^x$. You should be familiar with the shape of the exponential graphs, as well as the domain and range. One important point on the graph is the $y$-intercept, at the point $(0, a)$.

- \textbf{Know the multiplicative nature of exponential functions.} In contrast to linear functions growing at a steady rate over time, exponential functions grow at an increasing rate. The
The ratio of successive y-values for equally spaced x-values is a constant. This fact is especially useful for checking whether tabled values grow exponentially, but only if the table has equally spaced values of the independent variable.

Reading: Sections 1.6.

Day 8

Activity: Explore the inverse of exponential growth, the logarithm. Homework 1 due today.

To use an exponential growth function, we start with a known x-value, such as a time. The exponential formula then gives us the height of the function, or the y-value. In many situations, however, we want to work in the other direction. That is, we know the height of the function (the y-value), but want the time when that happens (or the x-value). This inverse is called a logarithmic function. I have found that many students are rather confused by logarithms. I will try to alleviate this confusion by emphasizing the fact that exponentials and logarithms belong together, much like squares and square roots do, or multiplication and division do. There are rules we must learn to do algebra with exponential functions however; for example when we solve for time in an exponential growth model.

Today we will explore e, and the logarithm rules.

Activity 1: Discovering e.

As we saw on Day 2, the number e is a limit of the calculation \((1 + \frac{1}{n})^n\) as n gets large. However, you need to be careful not to let your calculator fool you. For example, try values of n from 10^10 to 10^14. With such large values for n, your calculator’s precision capabilities are exceeded. In your groups, try to come up with an explanation of what the calculator is having trouble with.

Activity 2: Rules.

Explore \(x^{(a^b)}\), \((x^{a+b})\), and \(x^{ab}\), using test values. For example, verify that \(2^{(3\times4)} = (2^3)^4\) Now look at \(\ln(a^b)\), \(\ln(ab)\), and \(\ln(a/b)\). I will “prove” each of the results using algebra. Practice the rules using 1 – 16 on page 43.

Goals: Understand the logarithmic functions.

Skills:

- Understand the relationship between exponential and logarithmic functions. Logarithmic functions are inverses to exponential functions. This means that we reverse the x and y values and their associated facts. For example, the range of the exponential functions is only positive numbers; therefore the domain of the logarithmic functions is also only positive numbers.

- Understand the definition of the number e (approximately 2.7182818). Exercise 2 of Activity 2 from Day 2 is the definition of the number e, which we will use again and again in
calculus. Remember, though, $e$ is just a number, nothing more. The importance of $e$ will become more clear when we explore derivative formulas in Chapter 3.

- **Know the exponential and logarithmic properties and be able to use them to solve equations.** To solve equations for variables that appear in exponents, we need logarithmic functions. Therefore, you must know the properties. In particular, you must be comfortable using $\ln(AB) = \ln(A) + \ln(B)$ and $\ln(A^p) = p\ln(A)$. The second property is how we “rescue” a variable from the exponent.

**Reading:** Section 1.7.

**Day 9**

**Activity:** Growth and Decay.

Doubling time in an exponential function is the length of time it takes the $y$-value to double. To find it algebraically, suppose that a function has doubled between times $x_1$ and $x_2$. So, $y_1 = ab^{x_1}$ (because it is an exponential function) and $y_2 = 2y_1$ because it has doubled. Putting these two expressions together gives $y_2 = ab^{x_2} = 2y_1 = 2ab^{x_1}$. If we now solve for the change in time, $x_2 - x_1$, we will have found the doubling time.

Examples of exponential functions that are quite useful in business are the Present Value and Future Value formulas on page 49. You may have had some experience with these functions in the finance section of Math 204. We will explore them briefly as examples of exponential growth or decay. By solving the FV formula $FV = Be^{rt}$ for $B$, we have the PV formula $B = PV = FVe^{-rt}$. The important distinction between these two formulas is that $FV$ is larger than $PV$. Therefore, if you are interested in calculating the Present Value of some investment, it will be smaller than the Future Value, and vice versa.

There are several hallmarks of growth functions, and you should be able to tell growth from decay just by looking at the formula. If the base of an exponential function is greater than 1, we have a growth function, and vice versa. The tricky part of checking this feature out is the case where we have negative exponents. For example, $2^{-x} = \left(2^{-1}\right)^x = (\frac{1}{2})^x = (0.5)^x$. So at first we might think this is growth function because $2 > 1$, but after the algebra we see the negative exponent shows this is a decay function, because $.5 < 1$.

**Today we will practice using exponential and logarithmic functions.**

**Activity 1: Doubling Times. Tripling Times. Etc.**

Using a graph, explore the relationship between doubling time and the base $b$. Choose a value for $b$; by guessing and checking, determine an interval where the $y$-value has doubled. Calculate the doubling time by subtracting the two $x$-values. Repeat this calculation with a different interval where the $y$-value has doubled. You should notice an interesting fact.

Repeat now for tripling time. Also, try a different value for the base. Make a conjecture about the effects of the base and the multiplier (doubling, tripling, etc) on the times. Can you support your conclusions using algebra?
Activity 2: Comparing compound interest rates.

A stock has current value $150 per share and is expected to increase in value by 8% each year. In each case below, find a formula for the value of the stock $t$ years from now and calculate the value of the stock in 10 years:

Interpret the 8% return as an annual (not continuous) rate.

Interpret the 8% return compounded daily.

Interpret the 8% return as a continuous annual rate.

Now graph both functions on the same axes. What is the effect of continuous versus annual compounding? Write a one-paragraph summary.

Activity 3: Using Present Value and Future Value formulas.

Work on problem 31 page 51. Hints: Treat each year as a separate investment. For example, the bonus is put into one account at the bank. Then after each year, that year’s salary is put into a separate account, etc. What is different about these accounts is the length of time they exist. Then add all the account balances together to get the total amount.

Goals: Become familiar with manipulating exponential functions.

Skills:

• **Know facts about Doubling Times.** The most important fact about doubling time is that for any exponential function, it is the same value. That is, if an exponential function doubles from time $t = 3$ to $t = 13$, it will also double between $t = 20$ to $t = 30$. From our algebraic work on Activity 1, the doubling time is $\ln 2/\ln b$.

• **Be able to use Present Value and Future Value formulas in practical settings.** The Present Value and Future Value formulas are examples of exponential functions. You should know facts about these formulas. For example, $B = P(1 + r)^t$ is an exponential function in the variable $t$. The base is $(1 + r)$, which is greater than one, so it is a growth function. $P$ is the $y$-intercept.

Reading: Section 1.8.

Day 10

Activity: Transformations.

Our topic today is transformations, or creating new functions from old. In particular, we will explore shifts, stretches/compressions, and compositions. When a constant is added to the $y$-value, we have a vertical shift. When a constant is added to the $x$-value, in parentheses, we have a horizontal shift. When the $y$-value is multiplied by a constant, we have a vertical stretch/compression. When the $x$-value is multiplied by a constant, we have a horizontal stretch/compression. Negative values cause reflections.
Composed functions are vital to understanding the chain rule later in Chapter 3. Often, when we have a function inside parentheses, we have a composed function. The important skill with these composed functions is identifying the “inner” and “outer” functions. See class notes for examples.

**Activity: Using the “Rule of Four” with various composed functions.**

We will use all four approaches (verbal, graphical, algebraic, and tabular) to become familiar with composed functions and transformations. Verbal: problem 35 page 56. Graphical: problems 32-34 page 56. Algebraic: problem 42 page 73. Tabular: problem 31 page 56.

**Goals:** Become familiar with transformations, especially composed functions.

**Skills:**

- **Recognize the basic functions in complicated functions, especially the shifts and stretches.** Adding and multiplying by constants creates shifts and stretches. You should be able to identify the basic function being manipulated, and also the shifts and stretches taking place.

- **Be able to decompose functions into the sequential steps.** To use the chain rule to take derivatives, in Chapter 3, we need to be able to recognize the components in composed functions. The “inner” function usually is inside parentheses, and the “outer” function is the function that results if you replace the expression inside the parentheses with $x$.

**Reading:** Section 1.9.

**Day 11**

**Activity:** Power functions and Polynomials.

Power functions have the form $y = ax^b$. Note the apparent similarity to exponentials. It is up to you to remember which is which. My personal reminder is that $x^2$ is a polynomial. You should be able to deal with fractional and negative exponents. Fractional exponents are radicals like square root (an exponent of 0.5 or $\frac{1}{2}$) while negative exponents are reciprocals ($x^{-1} = \frac{1}{x}$).

Polynomials are several power functions (with positive integer exponents) added together. The **degree** of the polynomial is the highest power of $x$. An $n^{th}$ degree polynomial can have up to $n – 1$ turning points. However, there are often fewer, such as with $x^3$, which has none, but is still a 3rd degree polynomial.

Today we will play around with polynomials, a versatile class of functions. They can take on a variety of shapes, but we should understand their behavior before settling on them as final models to our data.
Activity 1: Exploring polynomial turning points.

Using trial and error, create a cubic that has 1) zero turning points 2) one turning point, and 3) two turning points. Now try the same thing for a quartic (4th degree polynomial), with up to three turning points. In each case, explore the endpoint behavior by comparing the cubic or quartic to \(x^3\) or \(x^4\) with large \(x\)-values. The easiest way to accomplish this is to zoom out several times.

After we study Chapter 3, we will be able to better qualify when a polynomial has 0, 1, 2, etc. turning points.

Activity 2: Recognizing power functions versus exponentials.

Values of three functions are given below (the numbers have been rounded off to two decimal places). Two are power functions and one is an exponential. Classify them and find potential equations. You may find the regression functions especially helpful here. But you can also use algebra as a solution method. Note: this problem is quite artificial; in practice, you would not have any knowledge of the data being generated by a particular equation. My only purpose for having you look at this data is to practice fitting curves with regression or algebra.

<table>
<thead>
<tr>
<th>(x)</th>
<th>(f(x))</th>
<th>(x)</th>
<th>(g(x))</th>
<th>(x)</th>
<th>(h(x))</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.4</td>
<td>5.93</td>
<td>5</td>
<td>3.12</td>
<td>.6</td>
<td>3.24</td>
</tr>
<tr>
<td>9</td>
<td>7.29</td>
<td>5.5</td>
<td>3.74</td>
<td>1.0</td>
<td>9.01</td>
</tr>
<tr>
<td>9.6</td>
<td>8.85</td>
<td>6.0</td>
<td>4.49</td>
<td>1.4</td>
<td>17.66</td>
</tr>
<tr>
<td>10.2</td>
<td>10.61</td>
<td>6.5</td>
<td>5.39</td>
<td>1.8</td>
<td>29.19</td>
</tr>
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<td>10.8</td>
<td>12.60</td>
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<td>6.47</td>
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<td>43.61</td>
</tr>
<tr>
<td>11.4</td>
<td>14.82</td>
<td>7.5</td>
<td>7.76</td>
<td>2.6</td>
<td>60.91</td>
</tr>
</tbody>
</table>

Goals: Understand the features of polynomials and power functions.

Skills:

- **Know about power functions and their attributes.** Power functions have a number of features you should be aware of. Even-powered functions are non-negative and symmetric about \(x = 0\). Odd-powered functions are symmetric about the origin. The higher the power, the quicker the function goes to infinity. Certain fractional powers are only defined for positive \(x\)-values. Negative powers have a vertical asymptote at \(x = 0\).

- **Know the basic facts about polynomials.** Polynomials are sums of power functions with positive integer exponents. The degree is the largest power of \(x\). An \(n^{th}\) degree polynomial can have up to \(n - 1\) turning points. Endpoint behavior is determined by the term with the largest power.

Reading: Section 1.9.
Day 12

Activity: Polynomial endpoint behavior. **Homework 2 due today.**

We should also understand the asymptotic behavior of polynomials. As \( x \) gets large, only the term with the largest exponent matters. To see this, start with a polynomial that has turns and gradually increase the \( x \)-values until the graph looks like only the leading term. (See Activity 1 from Day 11.)

**Activity: Explore the asymptotic dominance of exponentials to polynomials.**

No matter the degree, no matter the base of a growth model, an exponential function will be larger than a power function for large enough values of \( x \). First look at problem 28 page 96. Then change the base to 1.5 and the power to 10. Zoom out sufficiently to verify that \( 1.5^x > x^{10} \), for large enough \( x \). (If you are having trouble finding a window that verifies this, look at the answer below, in the reading.)

When you finish the activity, you may use any extra time to work on your presentations for next time.

Goals: Understand the comparison of exponential and polynomial growth.

Skills:

- **Know the asymptotic dominance of exponentials over polynomials.** Slowly growing exponentials may be dominated by polynomials for small \( x \)-values. However, for large enough \( x \)-values, exponentials (growth models) will always exceed polynomials. We call this “endpoint behavior” and it is important in analyzing functions qualitatively.

Reading: Chapter 1. (Activity window: \( x: 100 \) to 130 \( y: 0 \) to 2\( \times \)21.)

Day 13

Activity: Presentation 1.

Pick one of the 50 states. (The data is at the end of these notes.) Fit a model to its population growth. You have two goals: describe the growth, and predict the 2020 census. Compare linear, exponential, and polynomial models. Your presentation should convince us that you have chosen the most appropriate descriptive model and that your estimate for 2020 is believable.

Reading: Chapter 1.

Day 14

Activity: Exam 1.

This first exam will cover the elementary functions of Chapter 1. Some of the questions may be multiple choice or T/F. Others will require you to show your worked out solution.
Today we begin Chapter 2, the derivative. The derivative at a point is the slope of a line that is “parallel” to the curve at that spot. We will use a variety of techniques to approximate this slope, depending on the sort of information available to us. With equations, we can use more and more precise “two point” estimates, or slopes of secant lines; after Chapter 3, we will use formulas instead. If we have tabled data, we will not have precise estimates, as we can only “zoom in” as much as the table allows. If we have graphs, we will have to guess using a straightedge. In any case, we’re seeking the slope of the line, and therefore the units are a ratio, like miles per gallon, or feet per second, depending on the units used for the two variables.

I have two activities today to explore instantaneous change, or derivative. Both relate to the fact that if we zoom in close enough on any continuously differentiable (or smoothly curving) function, the function will resemble a straight line. This phenomenon is called local linearity.

**Activity 1: Exploring Local Linearity. Using **Tangent** on the TI-83.**

Graph the function \( y = 5(x^3 - x) \) on the standard window. Zoom in on what you think is the curviest spot. Keep zooming in, say 8 times. Using two points on the “line”, estimate the equation of the line this zoomed-in function is close to. Graph your candidate in the same window.

Now, at your selected \( x \)-value, use the **Tangent** function to get an equation of the line. Compare to your estimate from the “two point” method above. Note the **Tangent** function reports the entire equation of the tangent line; often we are only interested in the slope.

**Activity 2: Estimating the derivative at a point using secant lines.**

The derivative at a point can be approximated with an appropriately chosen secant line, a line between two well-chosen points on the curve. The following exercise should help you see what the calculator is doing when it calculates **Tangent**.

Fill in the table, using \( x = 7 \), and \( f(x) = \sin(x) \). Compare your answers with the others in your group. You may be getting different answers. If so, explain whose values are “correct”. (Note that the two \( y \)-values forming the numerator of the secant slope are \( y = f(x - h) \) and \( y = f(x + h) \). Also note the \( x \)-values in these two points are \( x - h \) and \( x + h \).)

<table>
<thead>
<tr>
<th>( h )</th>
<th>( f(x - h) )</th>
<th>( f(x + h) )</th>
<th>Secant slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Now graph $f(x) = \sin(x)$, making sure that your window includes the point where $x = 7$. Use the DRAW - Tangent feature and draw a tangent line on your window. Now, use the $dy/dx$ key on the CALC menu. How do these two techniques compare numerically? Graphically? Is one preferable over the other?

Compare the definition of the derivative (page 135) with your calculations when filling out the table. Observe how the calculator computes derivative values with $dy/dx$. However, sometimes we cannot use our calculators (perhaps a parameter in the equation has an unknown or variable value) and we must use our algebra skills. Specifically, notice how our authors do algebraic derivatives on page 137. Don’t fear, though, you won’t be able to use this method for all problems, so we will need other tools (theorems) to help us, and when we actually calculate derivatives, we will use rules, not this definition.

Zoom In (ZOOM 2) allows us to make the window “closer” by a factor of four. To use it, press ZOOM 2, then move the cursor to where you want the new window to be centered, then again press ENTER.

The CALC menu (found by pressing 2nd TRACE) is most useful for calculus. The functions in this menu will allow us to find minimum and maximum values, find roots of equations, and perform the differentiation and integration activities of calculus. We will explore the syntax of these commands as we use them. Today we use $dy/dx$, which gives the slope of the tangent line at that point.

The DRAW menu (found by pressing 2nd PRGM) will allow you to draw various lines and shapes on your window. In particular, we will want to draw tangent lines to curves. These tangent lines are straight lines that just touch a curve at a point, and are in some sense parallel to the curve at that point. DRAW - Tangent can be used in two ways: from an existing graph, or from the calculation screen. To use it for an existing graph in the graphing window, make sure you have the point of interest on-screen. Then press DRAW - Tangent. (Select the curve you want using up or down arrow, if you have more than one curve graphed.) Choose the $x$-value you want by using right or left arrow or by typing the $x$-value of interest. Finally press ENTER. The command syntax from the calculation screen is: DRAW - Tangent($Y\#, x$), where $Y\#$ is the curve of interest (such as $Y1$, or $Y2$, etc.) and $x$ is the point at which you want to have the tangent line drawn.

Goals: Understand that most functions we look at are “locally linear”. Understand slopes of secant lines as approximations for the slope of the tangent line.

Skills:

• Understand the definition of derivative as the slope of the tangent line. The tangent line just touches a curve at the point of interest, and is in a loose sense parallel to the line. The slope of this line is the derivative at that point. Because it is the slope of a straight line, we
know much about its features: it is a rate of change (rise over run), it is important to know the sign, etc.

- **Evaluate derivatives numerically.** If your calculator can produce numerical values for a function (whether from a formula or just from some calculation), and the input values can be arbitrarily close together (that is what \( h \) approaching zero means), then you can calculate a derivative numerically. You must calculate the slopes of some secant lines, and should evaluate several such slopes, making sure the limit in fact does exist. You must also realize you may have the only estimated the value of the derivative, and the exact value may only be close to the value you have. For more exact values, either use the algebraic approach, or look ahead to the theorems we will encounter in Chapter 3.

- **Evaluate derivatives graphically.** If you can phrase a function in the form of an equation, then your graphing calculator can help you calculate a derivative at specific input values. The TI-83 can draw tangent lines at various places on a curve, and can calculate derivatives numerically as well, displayed on the graphing window.

- **Understand the definition of the derivative.** You should be comfortable with the notion of a limit of slopes of secant line. You should also be comfortable with the equations:
  
  \[
  \frac{\Delta y}{\Delta t} = \frac{f(b) - f(a)}{b - a} \quad \text{and} \quad \lim_{h \to 0} \frac{f(x+h) - f(x)}{h}.\]

  (Note that the second equation is precisely the limit of slopes of secant line. See page 135.) This last expression differs slightly from Activity 2 today; I personally think it makes more sense to center the secant line on the \( x \)-value instead of favoring the right side. It should make no difference in the limit, but practically we can only make \( h \) so small using our TI-83.

- **Know several methods of estimating the derivative at a point.** If we have a formula, we can use successively narrower intervals and use the “two point” form for a line to estimate a slope at a point. After Chapter 3, we may be able to use a formula approach. If we have tabular data, we can only estimate roughly the slope of the tangent line, using secant lines. If we have a graph, we can estimate slopes using a straightedge.

**Reading:** Section 2.2.

**Activity:** Interpreting the derivative function.

The derivative is a slope of a function at a particular point. If we evaluate the derivative at many such \( x \)-values, and graph the result, we have the derivative function. This is a graph, just like the original function, but with different interpretations, as the \( y \)-values on the derivative graph are now the slopes from the original graph at each \( x \)-value, instead of the original functional values. Today we will begin by estimating the derivative function from tabular data. Then we will estimate functional values by knowing the derivative at a point.

Comment on notations: There are two main notations mathematicians have used to designate derivatives. I will use them interchangeably, without thinking, as it is second nature to me. These notations are:
1) Prime notation. $f'(x)$.

2) Leibniz notation. This notation reminds us that derivative is a ratio of differences, a slope. Either we use $\Delta y/\Delta x$ or $dy/dx$. One advantage of Leibniz notation is that we get to see the actual variables involved. Many times with the “f-prime” notation we just say “f-prime”. This isn’t very illuminative. What are the variables! Unfortunately, though, Leibniz notation doesn’t allow us to specify which $x$-value we’re talking about. In fact, to designate which $x$-value we’re using becomes quite cumbersome. Page 113 shows you the messiness.

After the activities, we will look at a handy function on the calculator that will approximate the derivative at all $x$-values in the graphing window. See calculator commands below.

**Activity 1: Estimating the derivative using tabular data.**

Minimum wage was created by Congress in 1938. Has it been updated to reflect inflation fairly? From the following chart, for the adjusted minimum wage, find the estimated derivative function. Note it will be difficult to estimate the slope at the beginning and end. You don’t have the luxury of points before and after. Discuss with your group members what is reasonable. (In this chart, CPI=100 in 1982. I have adjusted the figures to 2010 dollars.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Minimum Wage</th>
<th>CPI</th>
<th>Adjusted Minimum Wage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1938</td>
<td>$0.25</td>
<td>14.2</td>
<td>$3.82</td>
</tr>
<tr>
<td>1950</td>
<td>$0.75</td>
<td>23.5</td>
<td>$6.92</td>
</tr>
<tr>
<td>1970</td>
<td>$1.45</td>
<td>37.8</td>
<td>$8.31</td>
</tr>
<tr>
<td>1980</td>
<td>$3.10</td>
<td>77.8</td>
<td>$8.63</td>
</tr>
<tr>
<td>1990</td>
<td>$3.80</td>
<td>127.4</td>
<td>$6.46</td>
</tr>
<tr>
<td>2000</td>
<td>$5.15</td>
<td>168.8</td>
<td>$6.61</td>
</tr>
<tr>
<td>2010</td>
<td>$7.25</td>
<td>216.7</td>
<td>$7.25</td>
</tr>
</tbody>
</table>

**Activity 2: Estimating using local linearity.**

Work on problem 2, parts d and e, on page 133. These parts are about predicting new values using local linearity (or in this case extrapolating as 7 feet is beyond the available data).

**Goals:** Seeing the derivative as a function. Estimating using local linearity.

**Skills:**
- **Evaluate derivatives from tabular data.** When information is available in tabular form, we cannot “zoom in” to get a limit of secant slopes. We have only a few choices to estimate the derivative at each $x$-value. Generally, the best option is to average the secant slope before the point with the secant slope after the point. This is algebraically equivalent to finding the secant slope for the two points before and after.
**Understand local linearity and how to use it estimate new values.** If we are close enough to a point where we know the tangent slope, we can **project** the tangent line a short way and use it to **estimate** the value of the function at that new point. Caution: if the line is very “curvy” at this spot, our tangent line will poorly represent the function, so it is important to only use this method **very close** to the known derivative value.

Reading: Section 2.3.

**Day 17**

**Activity:** Sketching the derivative function.

Today we will try an exercise using graphs.

After the activity, we will look at a handy function on the calculator that will approximate the derivative at all \( x \)-values in the graphing window. See calculator commands below.

**Activity: Estimating the derivative using a graph, and translating back.**

Each of you will sketch an arbitrary function on a piece of paper, labeling it “Original Curve” and putting your name on it. You will then pass your graph to someone else; they will graph the derivative function on a separate sheet of paper, labeled with “Derivative Curve for <insert name here>”. The person drawing the derivative will have to carefully estimate the slopes, so a scale is needed. I will show you in class the method I use to estimate these slopes. It involves placing a straight edge tangent to the curve, and finding the rise over run for that angle. This is repeated for a number of \( x \)-values.

After sketching the derivative, the second person will pass the derivative graph to a third person (keep the original aside to compare with later); the third person will attempt to redraw the original graph based solely on the information from the derivative graph. Caution: this last part is tricky, as the starting location is not unique. You need to arbitrarily pick a \( y \)-intercept to get started. From there, the derivative graph shows you how steep the graph needs to be at that point, so draw a little line segment with that slope. Move over slightly, and repeat the process.

I will show you an example in class before you attempt this activity. If everyone has done the estimates correctly, the graph the third person draws should match the “Original Curve” graph. If there are discrepancies, the two sketchers should resolve them. It might be that the person drawing the derivative made poor estimates, or it may be that the third person didn’t translate the information well.

\[
\text{nDeriv( (MATH 8) will produce an estimate for the derivative at a point. The syntax is nDeriv( expression, variable, value). expression is the formula for the function. I will often use Y#, having already stored the function in a Y variable. variable is generally x, but you have some flexibility here in case you want another letter to be the variable. value is whatever number you’re interested in. When using}\]

24
Goals: Realize that the derivative can be viewed as a function.

Skills:

- **Interpret the derivative verbally.** For problems with a real-world setting, you should be able to use the value of the derivative at a point in an English sentence. For example, you may say, “At a production level of 1,000 car seats, we can expect profits to rise $10 for every additional car seat produced.” If you are having trouble with this verbal description of the derivative, one thing that may help is to pay close attention to the units involved, for instance dollars, or number of car seats produced. The examples in Section 2.3 should help you understand this verbal phrasing and interpretations of the derivative.

- **Know how to use the TI-83 to produce a graph of the estimated derivative of a formula.** The command `nDeriv(` will estimate the derivative numerically with a small secant line. If we use this in the `Y=` window, we can graph the entire derivative function on the graphing window. The syntax for this is `nDeriv( Y#, x, x)`. 

Reading: Section 2.4.

**Day 18**

**Activity:** Introduction to the Second Derivative.

After discovering that the derivative is a function just like the original curve, there is no reason we cannot take the derivative of the derivative. This is called the **second derivative**, and often reflects useful information in real world problems. It is the **change** in the **change** of a function. The second derivative also can be thought of as the curvature of a function. You have probably seen this idea already in terms of **concavity**. In particular, if the second derivative is positive, we say we have **positive concavity**, and the other way around for negative values.

When we look at the information from the first and second derivatives, there are four main situations of interest. The first derivative can be either positive or negative (or zero, but we will address that situation later) and the second derivative can be either positive or negative.

1) Positive first derivative, positive second derivative: an increasing curve that is getting steeper.

2) Positive first, negative second: an increasing curve that is leveling off, approaching a peak or an asymptote.

3) Negative first, positive second: a decreasing curve that is leveling off, approaching a minimum or an asymptote.

4) Negative first, negative second: a decreasing curve that is falling faster.
The Leibniz notation gets a little messy for second derivatives. The best way to phrase them is to use the prime notation, adding another prime for the second derivative. We usually say “f double prime”, referring to $f''(x)$. Note the messy Leibniz notation on page 119.

One important application of the derivative is the idea of marginal analysis. In fact, the term **marginal** is synonymous with derivative. If either the cost function or the revenue function is a straight line, then the marginal cost or revenue is simply the slope of that line. We will look at this topic again in Section 4.4 (Day 28), after we explore the shortcut formulas to differentiation.

**Activity 1: Comparing a function to its first and second derivatives.**

Enter $y = xe^{-x^2}$, along with its first and second derivatives, in the $Y=$ window. (See calculator commands below.) Select only the second derivative and use the window $-2 < x < 2$ and $-2 < y < 2$. Make statements about the original function given what you see about the second derivative. Repeat using just the first derivative. Before graphing the original function, make a sketch that satisfies your statements. Then compare and see how close you were. If you are off in any of your statements, closely examine where you went wrong.

**Activity 2: Interpreting derivatives in a real world setting.**

Problem 30 page 132. Parts c and d are especially important; you **must** be able to convert the mathematical info into real world uses. In this case, the context of declining graduation rates is very important to school officials.

- **Goals:** Investigate the properties of the second derivative.
- **Skills:**
  - **Be able to graph the second derivative on the TI-83.** Using `nDeriv` will produce a numerical derivative of a formula. If we repeat the command on the new formula, we will approximate the second derivative. I recommend keeping these two commands in $Y2$ and $Y3$ for the rest of the semester. Put the formula you want to analyze in $Y1$. Use $Y4$ to $Y0$ for any other functions you want to graph.
  - **Understand what the second derivative says about the concavity of a function.** The second derivative measures the concavity of a function. When it is positive, we know the original function is bowl-shaped (concave up); when it is negative, the original function is humped (concave down). When the second derivative is zero, it is neither bowl-shaped nor humped; rather it is very nearly linear at that point. Earlier we talked about local linearity; when the second derivative is zero, we might think of that point of the curve being even **more** locally linear!
• Be able to convert second derivative facts into everyday English. Because the second derivative is a change in the first derivative, when we convert to an English description, we have to talk about the rate of change in the rate of change. For example, the speed of the car is increasing. Sometimes we have special words for these derivatives. With the motion of an object, the first derivative is speed and the second derivative is acceleration.

Reading: Section 2.5.

Day 19

Activity: Economic Examples.

Today we revisit the concepts of marginal cost and marginal revenue. The important notion is that we are talking about the cost or revenue of the next item only. Because quantity is our independent variable, this marginal cost is the same as the derivative of cost, expressed in units of dollars per item. Usually, quantity can only be expressed as integers, so to calculate marginal cost or revenue directly, we subtract two sequential values, for example the difference between the cost to make 10 items and 11 items represents the marginal cost of the 10th item (or the 11th item). We can also approximate marginal cost using the derivative.

Activity: Marginal cost and revenue.

Problem 10 page 129. Estimate values for the marginal cost and revenue at both 50 and 90. Use these figures in your answers.

Goals: See the correspondence between marginal cost and revenue and the derivative.

Skills:

• Realize that marginal costs/revenues/etc. are simply derivatives. Marginal costs, revenues, profit, etc. are important ideas in economics. Because the marginal cost is the cost of the next item, we are just talking about the slope of the tangent line, which is the derivative. Similarly for revenue, the derivative is the marginal revenue. We will explore these ideas more in Section 4.4 (Day 28).

Reading: Section 3.1.

Day 20

Activity: Using Polynomial derivative formulas. Homework 3 due today.

A calculator approximation for the derivative function is convenient, but there will be times when we would rather have an exact formula. Fortunately, there are theorems (shortcuts) we can use. We won’t prove many of these results, but we will use them to produce formulas. Chapter 3, therefore, is only concerned with the algebraic point of view. When we have tabular data, graphs, or verbal descriptions, we cannot use these theorems.

Several of the theorems apply to any function. Others are specific to particular forms. The general rules are the additive constant rule, the multiplicative constant rule, the
addition/subtraction rule, the product rule, the quotient rule, and the chain rule. The specific functions are the power rule, the exponential rule, and the logarithmic rule.

**Additive constant rule:** For this rule, we can make a quick argument to see the answer. What happens to the slope of a curve when we add a constant to it? Adding the same constant to every value simply lifts or lowers the entire curve that much, but doesn’t change the shape at all. Thus, the additive constant rule is that there is no change to the derivative.

\[
\frac{d(f(x)+a)}{dx} = f'(x).
\]

**Multiplicative constant rule:** It is a little harder to verbally prove this rule, but we can see for straight lines that multiplying by a constant increases the slope by that constant. With algebra, and the definition of derivative on page 135, we can discover that the derivative of a multiplied function is multiplied by the same amount. \[
\frac{d(af(x))}{dx} = af'(x).
\] The result of this rule is that we factor out constants from our derivatives.

**Addition/subtraction rule:** Again, using algebra is the easiest way to prove this rule, but we will accept the result on faith. (If you would like to see the algebra, see me after class.) Basically, the derivative of a sum is the sum of the derivatives.

\[
\frac{d(f(x) + g(x))}{dx} = f'(x) + g'(x).
\] This rule allows us to find the derivatives of polynomials.

**Power rule:** To prove the power rule, we need the binomial theorem, and lots of algebra. Again, we will accept this result on faith. \[
\frac{d(x^n)}{dx} = nx^{n-1}.
\] When we combine this rule with the multiplicative constant rule, we get the most common rule we’ll use: \[
\frac{d(ax^n)}{dx} = anx^{n-1}.
\] We need to use this rule for reciprocals and radicals, as they can be written as exponents. This means you will have to recognize that square roots, and reciprocals, are power functions. We will do some examples in class.

**Activity: Try some basic expressions.**

For each of the following functions, plot the function in \(\text{Y1}\), its \text{nDeriv} in \(\text{Y2}\), and your candidate answer in \(\text{Y4}\). Using trace, check to see if your answer is right. (Compare \(\text{Y2}\) to \(\text{Y4}\).)

1) \(y = 3x^4\)

2) \(y = 3 - x^{2.7}\)

3) \(y = x^3 - 2x + e\)
4) \( y = \frac{1}{x^2} + \sqrt{x} - \sqrt[3]{4} \)

Goals: Learn and use the basic rules for differentiation shortcuts.

Skills:

- **Know the Rule for Sums.** \( \frac{d}{dx}(f(x) + g(x)) = f'(x) + g'(x) \).

- **Know the Rule for Powers.** \( \frac{d}{dx}(x^n) = nx^{n-1} \). Note that \( n \) can be any number, including fractions and negatives.

- **Realize that your nDeriv( function will verify that you have a correct derivative.** By graphing the numerical derivative on your calculator (nDeriv), along with what you think the answer is, you can verify if your answer is correct. You can either compare the values for a few haphazardly chosen values, or you can graph their difference on a separate window. If they are the same, the difference should be zero (or very close but not exact due to rounding).

Reading: Section 3.2.

Day 21

Activity: Using Exponential derivative formulas.

**Exponential rule:** The exponential class of functions is quite unique. They are their own derivatives, multiplied by a constant. Activity 2 below will hopefully convince you of this.

The required constant is the natural logarithm of the base. Using notation: \( \frac{d}{dx}(a^x) = \ln(a)a^x \).

When the base is \( e \), \( \ln(e) = 1 \), so the rule is even simpler: \( \frac{d}{dx}(e^x) = e^x \) One additional note: functions of the form \( e^{kx} \) can be thought of as \( (e^x)^k \) so their derivatives have \( k \) in front as a multiplier (\( \ln(e^k) = k \)). Example: \( \frac{d}{dx}(e^{4x}) = 4e^{4x} \).

**Logarithmic rule:** The logarithmic rule is very simple: \( \frac{d}{dx}(\ln(x)) = \frac{1}{x} \).

Activity 1: Discovering the unique character of the exponential functions.

Graph \( y = 2^x \) and its derivative in the same window. What is the doubling time for \( y = 2^x \)? What is the doubling time for its derivative? These two doubling times imply an important result. Use this result to deduce the formula for the derivative of \( y = 2^x \).
Activity 2: Practice.

For each of the following functions, plot the function in Y1, its nDeriv( in Y2, and your candidate answer in Y4. Using trace, check to see if your answer is right. (Compare Y2 to Y4.) (Note in problem 2 you will have to make up values for $k$ and $a$. This sort of problem is why knowing algebra is still important.)

1) $y = 3e^{4x} + 3\ln(x)$
2) $y = ke^{-ax}$

Goals: Learn and use the basic rules for differentiation shortcuts.

Skills:

- **Know the Rules for Exponential Functions.** $\frac{d(a^x)}{dx} = \ln(a)a^x$. This rule is even simpler than the power rule, because exponential functions are their own derivatives, multiplied by a constant. With the power rule, you must decrease the power, which is more complicated.

- Know the Rules for Logarithmic Functions. $\frac{d(\ln(x))}{dx} = \frac{1}{x}$.

- **Realize that your nDeriv( function will verify that you have a correct derivative.** By graphing the numerical derivative on your calculator (nDeriv), along with what you think the answer is, you can verify if your answer is correct. You can either compare the values for a few haphazardly chosen values, or you can graph their difference on a separate window. If they are the same, the difference should be zero (or very close but not exact due to rounding).

Reading: Section 3.3.

Day 22

Activity: Practicing the Chain Rule.

Today we practice formulas. I will show you how the chain rule works. Then we will spend time practicing.

The chain rule is used in composed functions. The idea is that you first must calculate one function’s result before you can finish the calculation. This first function, often called the “inner” function, can be substituted with another letter. But the key is that the “outer” function (what we do to the inner function’s result) must be evaluated at the inner function’s result. If we use the symbol $x$ for the input to the inner function, then we can’t use $x$ as the input to the outer function. We still do the derivative rules the same, we just evaluate the outer function at the inside function’s result, not at $x$. Hopefully, our class discussion will make this clearer.
A note that seems to help people understand how to use the chain rule: ultimately, the chain rule is a product of the derivatives of the inner and outer functions. To use the rule effectively, you must be able to decompose the function into its parts. This is why understanding composed functions from Chapter 1 is critical to success in this section of the material.

Activity: Practicing the Chain Rule.

Calculate the derivatives of the following functions. Then check your answers on your calculator using nDeriv.

1) \( f(x) = (x^3 - 3x^2)^2 \). (Expand first, then use the power rule.)

2) \( f(x) = (x^3 - 3x^2)^2 \). (Use the chain rule.)

3) \( f(x) = e^{(3x+x^2)} \).

4) \( f(x) = \ln(\sqrt{x+2}) \). (This should require two substitutions, or two uses of the chain rule.)

Goals: Become familiar with the chain rule.

Skills:

- **Know the Rule for Compositions (Chain Rule).** \( \frac{d}{dx} f(g(x)) = g'(x)f'(g(x)) \). You must understand composed functions to use this rule correctly. If you cannot identify what \( g(x) \) is, you can’t get the correct derivative in front. You also need to be able to “replace” \( g(x) \) with \( x \) in the \( f \) function to get the proper derivative there, then again “replace” \( x \) with \( g(x) \).

Reading: Section 3.4.

Day 23

Activity: Practicing the Product, and Quotient Rules.

Today we continue practicing formulas. I will show you how the product and quotient rules work. Then we will spend time practicing.

Activity: Practicing the Product and Quotient Rules.

Calculate the derivatives of the following functions. Then check your answers on your calculator using nDeriv.

1) \( f(x) = (x+3)(x^3 - 3x^2) \). (Use the product rule.)
2) \( f(x) = (x+3)(x^3 - 3x^2) \). (Expand first, then use the power rule.)

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

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

Goals: Become familiar with the product and quotient rules.

Skills:

- **Know the Rule for Products.** \( \frac{d(f(x)g(x))}{dx} = f(x)g'(x) + f'(x)g(x) \). It is important to note that the product rule is **definitely** not the product of the derivatives. That is actually closer to what the chain rule says.

- **Know the Rule for Quotients.** \( \frac{d(f(x)/g(x))}{dx} = \frac{g(x)f'(x) - f(x)g'(x)}{(g(x))^2} \). To remember this rule, I’ve memorized the little ditty “Low dee high, less high dee low, square the bottom down below”. I’ve never forgotten the quotient rule because of it! Here, “dee high” means the derivative of the numerator and “dee low” means the derivative of the denominator.

Reading: Chapter 3.

Day 24

Activity: Practicing the Derivative Formulas.

Today we will practice using all the derivative formulas.

**Activity: Practicing the Rules.**

Calculate the derivatives of the following functions. Be sure to first decide whether the function requires the product rule, the chain rule, the addition rule, etc. Then check your answers on your calculator using *nDeriv*.

1) \( f(x) = \pi^3 x^2 + 2x + \pi \).

2) \( f(x) = e^{x^2} \).

3) \( f(x) = \sqrt{4x^4 + 9} \).

4) \( f(x) = \frac{3^x}{x} \).
Goals: Be adept at using the derivative formulas, especially problems involving the chain rule.

Skills:

- **Identify the particular derivative rule needed for a problem.** For many functions, only one of the derivative rules we have learned is actually used. (Of course, for some functions, more than one type of rule might be present.) Your task, then, is to be able to identify which particular rule or rules are needed. This skill will come with practice. It is up to you to put in the time so that you have the experience to choose the proper rules. There are a lot of problems on page 173 for you to practice on.

Reading: Section 4.1.

Day 25

Activity: Exploring Local Extrema.

Now that we have learned some formulas, we can make use of this information algebraically to find interesting places on curves. In particular, we can find peaks and valleys, or more formally, local maxima and minima (together called **extrema**). You may think at first with our powerful calculator that we don’t need algebra any more. While our machines help us in many circumstances, there is still a use for analytical results. For example, the calculator will help us find the turns in a polynomial, but only if we have a suitable window already. Algebraic results help us find the proper window. We will explore this in Activity 1.

Another circumstance where algebra is necessary is when the parameters of a model are unspecified. Activity 2 today addresses this situation.

**Activity 1: Analyzing polynomial turns.**

Without doing calculus, try to find the part of this cubic where the critical points are. \( f(x) = x^3 - 63x^2 + 1320x \). Now, find the critical points algebraically. Use the first derivative test to classify the critical points. Use the second derivative test to classify the critical points.

**Activity 2: Finding the conditions on a cubic so it has two turns.**

The general form for a cubic polynomial is \( f(x) = ax^3 + bx^2 + cx + d \). However, we know that some cubics have no extrema, such as \( f(x) = x^3 \). What conditions on the parameters cause a cubic to have none, one, or two critical points? Hint: you will need to use the quadratic formula and note where the discriminant is negative, zero, or positive.

**Activity 3: Critical points of a non-polynomial.**

Without doing calculus, try to find the part of this function where the critical points are. \( f(x) = xe^{-x} \). Now, find the critical points algebraically. Use the first derivative test to classify the critical points. Use the second derivative test to classify the critical points.
Activity 4: Using a table of derivative values to find the maximum and minimum.

Problem 20 page 181.

Goals: Understand critical points, and how to classify them.

Skills:

• **Know the definition of a Critical Point.** Locations on the graph of a function where the derivative is either zero, or undefined, are critical points. Places where the slope equals zero might be maxima, minima, or neither. Important examples to keep in mind are the cubic power function, which has a critical point that is neither a maximum nor a minimum, and the absolute value function, which has a critical point with an undefined derivative.

• **Be able to use the First and Second Derivative Tests for classifying extrema.** The second derivative test is useful for determining whether a critical point is a maximum or a minimum. Simply evaluate the second derivative at the candidate point, and classify it as a maximum, a minimum, as it is negative or positive. If the second derivative is zero, we must resort to the first derivative test. To perform this test, we assess whether the first derivative is positive or negative around the critical point. If it is negative to the left and positive to the right, we have a minimum. If it is positive to the left and negative to the right, we have a maximum. If it is positive on both sides of a critical point or if it is negative on both sides of the critical point, then we have a “saddle point”, which is neither a maximum nor a minimum.

Reading: Section 4.2.

Day 26

Activity: Exploring Inflection Points. **Homework 4 due today.**

We have seen that the critical points of a function describe that function’s extrema, if any exist. The critical points of the derivative function represent places where the concavity of the original function changes sign. These points are called inflection points. We discover them in just the same way we found critical points, but working with the second derivative instead of the first derivative. Remember that it is possible for the second derivative to be zero and yet the concavity doesn’t change. The fourth degree power function is one example.

**Activity: Finding inflection points.**

Find inflection points for these functions. Remember, we don’t always have to use algebra to find our inflection points.

1) \( f(x) = \frac{3}{8} x^4 + x^3 \)

2) \( f(x) = x(x^2 + x - 2) \)

3) \( f(x) = (x + \pi)(x - 2)(x^2 - 9) \)  [Hint: Use the TI-83 instead of algebra.]
Goals: Be able to find and interpret points of inflection.

Skills:

• **Know the definition of Inflection Points.** Points on a graph where the concavity changes sign are inflection points. We normally detect these points by examining where the second derivative is zero. However, we still must check on each side of such candidates, as simply equaling zero is not the same as changing sign. The best example to keep in mind of this phenomenon is \( y = x^4 \), which has no inflection points but does have a point where the second derivative equals zero \( (x = 0) \).

Reading: Section 4.3.

**Day 27**

Activity: Identifying Global Extrema.

In addition to determining inflection points and critical points, we also want to determine **global** extrema. We have already talked about **relative** (or local) extrema. The overall maximum (or minimum) must be either one of the critical points, unbounded (such as with a vertical asymptote), or one of the endpoints (if the region is bounded). When you look for global extrema, I recommend making a list of the critical points, and endpoints. Then, after looking at the graph for places where the graph goes off to infinity in either direction, choose the largest for the maximum, and the smallest for the minimum. If the graph does go to infinity (or negative infinity), the best phrase to use is “There is no global maximum (or minimum).”

**Asymptotes** are straight lines that a graph approaches arbitrarily closely. \( y = 1/x \) is an example with two asymptotes; there is a horizontal asymptote on the \( x \)-axis and a vertical asymptote on the \( y \)-axis. We will mostly be concerned with only horizontal and vertical asymptotes, but there could also be oblique (diagonal) asymptotes. Generally, when the denominator of a rational function is zero, we have a possible vertical asymptote. While these are not critical points, they are important to identify, as a function is unbounded at a vertical asymptote.

Before beginning today’s activity, we can revisit our function from Day 2 and show how calculus solves the problem. Recall that the volume of the candy box is \( f(x) = (11 - 2x)(8.5 - 2x)x \). To take this derivative, we probably should expand to get

\[
\begin{align*}
4) \quad f(x) &= \ln\left(x^2 + 2e^x\right) \quad [\text{Hint: Use the TI-83 instead of algebra.}] \\
\text{Goals:} & \quad \text{Be able to find and interpret points of inflection.} \\
\text{Skills:} & \quad \text{• Know the definition of Inflection Points.} \\
& \quad \text{Points on a graph where the concavity changes sign are inflection points. We normally detect these points by examining where the second derivative is zero. However, we still must check on each side of such candidates, as simply equaling zero is not the same as changing sign. The best example to keep in mind of this phenomenon is } y = x^4, \text{ which has no inflection points but does have a point where the second derivative equals zero } (x = 0). \\
\text{Reading:} & \quad \text{Section 4.3.} \\
\text{Activity:} & \quad \text{Identifying Global Extrema.} \\
\text{In addition to determining inflection points and critical points, we also want to determine global extrema. We have already talked about relative (or local) extrema. The overall maximum (or minimum) must be either one of the critical points, unbounded (such as with a vertical asymptote), or one of the endpoints (if the region is bounded). When you look for global extrema, I recommend making a list of the critical points, and endpoints. Then, after looking at the graph for places where the graph goes off to infinity in either direction, choose the largest for the maximum, and the smallest for the minimum. If the graph does go to infinity (or negative infinity), the best phrase to use is “There is no global maximum (or minimum).”} \\
\text{Asymptotes} & \quad \text{are straight lines that a graph approaches arbitrarily closely. } y = 1/x \text{ is an example with two asymptotes; there is a horizontal asymptote on the } x\text{-axis and a vertical asymptote on the } y\text{-axis. We will mostly be concerned with only horizontal and vertical asymptotes, but there could also be oblique (diagonal) asymptotes. Generally, when the denominator of a rational function is zero, we have a possible vertical asymptote. While these are not critical points, they are important to identify, as a function is unbounded at a vertical asymptote.} \\
\text{Before beginning today’s activity, we can revisit our function from Day 2 and show how calculus solves the problem. Recall that the volume of the candy box is } f(x) = (11 - 2x)(8.5 - 2x)x. \text{ To take this derivative, we probably should expand to get } f(x) = (11 \times 8.5 - 2x(8.5) - 11(2x) + (-2x)(-2x) )x = 93.5x - 39x^2 + 4x^3. \text{ Now take the derivatives and solve for the critical point(s) and classify them.} \\
\end{align*}
\]
Activity 1: Describing the interesting points in a function.

For each of the following functions, find all the interesting points/features, including critical points, extrema, inflection points, asymptotes, increasing and decreasing intervals, and positive and negative concavity. (Note: you found the inflection points on Day 26.)

1) \( f(x) = \frac{3}{5} x^4 + x^3 \)

2) \( f(x) = x(x^2 + x - 2) \)

3) \( f(x) = x(x^2 + x - 2), x \geq 0 \)

4) \( f(x) = (x + \pi)(x - 2)(x^2 - 9) \) [Hint: Use the TI-83 instead of algebra.]

5) \( f(x) = \ln(x^2 + 2e^x) \) [Hint: Use the TI-83 instead of algebra.]

Goals: Understand the difference between relative extrema and global extrema.

Skills:

• **Understand the overall strategy for analyzing and sketching functions.** Our overall strategy is to find the critical points, the asymptotes (both vertical and horizontal), inflection points, intercepts, and any other easy-to-find points. You should be able to make both quantitative and qualitative descriptions of functions/graphs/equations.

• **Sketch graphs for equations with unspecified parameters.** Using the skills acquired in classifying critical points, and using the skills for finding asymptotes, you should be able to sketch curves with unspecified parameters. You may need to be told whether the values of the coefficients are positive or negative, or over what range the coefficients can have values. For example, for parabolas we know the vertex has an \( x \)-coordinate of \(-\frac{b}{2a}\), where \( y = ax^2 + bx + c \). It may be difficult or impossible to graph the family of curves in general, as different coefficients may yield differently shaped curves, but in most cases you can construct an effective sketch.

• **Be able to find global extrema.** To find the overall extrema (global extrema), we examine all the critical points, as well as any endpoints of the domain or any points with undefined derivative. Caution: only looking at the critical points will not be sufficient, as many functions have no global maximum or minimum due to the function’s values approaching infinity. \( y = x^2 \) is a good example; there is one critical point, and it turns out to be a global minimum, but because both sides of the parabola rise without bound there is no global maximum.

Reading: Section 4.4.
Day 28

Activity: Economic Examples.

Today we return to economic applications. Recall that profit is the difference between revenue and cost. The first thing to notice is that the quantity that maximizes revenue is not the same quantity that maximizes the profit. We have several approaches to solving the maximum profit problem. We can simply calculate profit at all quantities and then choose the maximum. This can be tedious and time consuming. It might be much easier to use the calculus rules we have learned. Specifically, we know that when a derivative is zero, the function has a relative maximum or minimum. Because profit is a difference \( \pi = R - C \), we can use the formulas from Chapter 3 to show that \( \pi' = R' - C' \). Now, if we set the derivative to zero and solve, we find \( R' - C' = 0 \Rightarrow R' = C' \). We use this strategy now to solve problems with only a graph, or a table of marginal values: find where marginal cost and marginal revenue are equal. We will practice with all three approaches (tabular, graphical, algebraic) today.

Activity: Profit maximization.

We will maximize profit using three sets of information: tabular, graphical, and algebraic.

Tabular: problem 8 page 200.
Algebraic: problem 16 page 201.

Goals: Understand some uses of the derivative in economics and business.

Skills:

- **Know that maximum (or minimum) profit occurs where marginal cost equals marginal revenue.** Because profit is cost subtracted from revenue, and because maximum profit occurs when its derivative is zero, we can conclude that profit is a maximum when marginal cost equals marginal revenue. In equation form: \( \pi = R - C \), \( \pi' = R' - C' \), \( \pi' = 0 \Rightarrow R' - C' = 0 \Rightarrow R' = C' \). We don’t have a guarantee that such spots are maxima; we must check to make sure using the first derivative test, for example.

Reading: Section 4.5.

Day 29

Activity: Economic Examples.

Another example using derivatives in economics is average cost. By dividing the cost function by quantity, we have the formula for average cost. Using the quotient rule (which I will do in class), we discover that the minimum cost occurs where average cost equals marginal cost. If we have the formulas, this will just be an algebra problem. If we have graphs, it will be easier, as there is a handy geometric solution (see page 204 figure 4.60).
**Activity: Exploring Average Cost.**

Find the minimum average cost for the following problems.


Algebraic: problem 16 page 201.

**Goals:** Understand some uses of the derivative in economics and business.

**Skills:**

- **Know that average cost is a minimum when average cost equals marginal cost.** By using the quotient rule to find the derivative of the average cost, we find that average cost is minimized when average cost equals marginal cost.

**Reading:** Sections 4.7 and 4.8.

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**Day 30**

**Activity:** Logistic Growth, Surge Functions. **Homework 5 due today.**

We saw that some state populations grow nearly exponentially for periods of time. However, we also know that this exponential growth cannot occur forever, due to real world constraints, such as available space and resources. A more realistic model would account for this eventual upper bound. The logistic function is such a model. Today we will explore this function, by taking its derivatives, finding its interesting points, and sketching graphs for its various parameters.

The surge function is often used to model drug concentration problems. We will explore this function today also. I will work out the derivatives and the graph during class; then you will practice yourself.

**Activity 1: Revisiting state populations.**

Pick one of the 50 states and fit a logistic regression curve using the TI-83. You will find the function in the STAT CALC menu of the calculator, at the bottom of the menu. There are some data sets for which the TI-83 will fail to find a good fit. I haven’t figured out when it will and will not work; it may have to do with the shape of the data not looking “logistic” enough.

**Activity 2: Surge function example.**

Problem 8, page 226. In addition to answering the questions asked, try to come up with estimates of the formulas.

**Goals:** Examine two further examples of derivatives, the logistic function in population growth and the surge function in drug concentrations.
Skills:

- **Know the form of the logistic growth function.** One formulation of the logistic function is $P(t) = \frac{L}{1 + Ce^{-kt}}$. This curve models population growth realistically. The domain is all real numbers, and the range is 0 to $L$.

- **Know facts about the logistic growth function.** Through our calculus results, we find that there are no critical points, but there is an inflection point where $P = L / 2$, also called the point of diminishing returns. $L$ is the carrying capacity, or the value of the horizontal asymptote as $x$ approaches infinity.

- **Know the form of the surge function.** The surge function is $y = ate^{bt}$. The domain is all positive real numbers, and the range is 0 to $1 / be$.

- **Know facts about the surge function.** The surge function begins at the origin, increases to a peak at $x = 1 / b$, then decreases to a horizontal asymptote at zero. The curve is often used to model drug concentration curves.

Reading: Chapters 2, 3, and 4.

**Day 31**

Activity: Presentation 2.

Pick one of these functions (first come, first served): 1) $y = e^{-x} - e^{-2x}$, 2) $y = x^3 + 1/x$, 3) $y = x \ln x + x$, 4) $y = \ln(1 + x^2)$, 5) $y = 2^x + 2^{-x}$, 6) $y = e^{-x^2}$, 7) $y = x^2 - 1/x$. Completely describe the interesting behavior, without graphing. Be sure to include critical points, inflection points, global extremes, endpoint behaviors, etc. After your description, show us a graph with an appropriate window that demonstrates the correctness of your analysis.

Reading: Chapters 2, 3, and 4.

**Day 32**

Activity: Exam 2.

This second exam is on Derivatives and Applications, Chapters 2, 3, and 4. Some of the questions might be multiple choice. Others will require you to show your worked out solution.

Reading: Section 5.1.

**Day 33**

Activity: Introduction to Definite Integrals, using horse speeds.
We will base our initial discussion on the formula “Distance equals speed times time”. In many cases, we will not know the speed at any arbitrary time, but at fixed intervals. Thus we must guess the values in between. We usually assume smoothness, and therefore pretend our functions are monotonic, or either only increasing or only decreasing. So, for each interval, we will have an upper and lower estimate of the distance covered, depending on whether we use the speed before or after the current time period.

In the following data, we have the time of a horse race, and the speed of the horse at that moment. Use this information to estimate the total distance the horse has traveled.

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (mpg)</td>
<td>0</td>
<td>40</td>
<td>38</td>
<td>35</td>
<td>37</td>
</tr>
</tbody>
</table>

Goals: Understand how distance can be estimated by knowing speed.

Skills:

- **Be able to estimate distance given speed.** By knowing that “Distance equals speed times time”, we can calculate distance traveled over an interval with knowledge of the speed. This fact is the basis for all of our distance calculations, even for speeds that are not constant, as we shall see in the upcoming material.

- **Know there are upper and lower bounds for the distance estimate.** Because speed changes over an interval, and we do not know the values in between two time points, we must make assumptions about how speed varies. Generally we will assume that the speed does not go above or below the two values that bracket a time interval. This leads to two estimates of distance in one time interval, an “upper” and a “lower” estimate. We add all the lower estimates and all the upper estimates over an entire set of intervals to find the accumulated distance traveled.

Reading: Section 5.2.

Activity: Definite Integrals.

How could we improve this estimate of distance? The most important conclusion we will make today is that the idea of distance turns out to be an area, not a length. It is critical that you understand this point in the upcoming material.

We will typically talk about left and right sums, but these represent the lower and upper estimates only on monotone intervals. If the speed bounces up and down (as in the horse race example) then we will have to be careful about which estimate is the lower one and which is the upper one.

To find the value of the definite integral, we take smaller and smaller intervals (if we can) and eventually the limit as this interval width approaches zero. These Riemann sums are
mostly a conceptual notion; in practice we will use a different approach (antiderivatives in Section 7.1, Day 42).

**Activity 1: Did they hit the skunk?**

Jan and Pat are driving along a country road at 45 miles per hour (about 66 ft/sec). As the car rounds a curve, Jan sees a skunk in the middle of the road about 100 feet ahead. Jan immediately applies the brakes, and Pat notices that the speed of the car drops from 66 ft/sec to 51 ft/sec to 34 ft/sec to 0 ft/sec over the next three seconds. (Pat is a bit strange.) Does the car hit the skunk?

**Goals:** Explore Reimann sums and definite integrals.

**Skills:**

- **Realize the distance estimate can be viewed as an area under a curve.** A very important observation to make about our distance calculations is that these distances can be thought of as areas under the curve of the speed values. In general, when we have a rate function, and are interested in the cumulative change in the “distance” function for that rate, we will calculate an area.

- **Know that the definite integral is a limit of converging upper and lower estimates.** If we have the luxury of “refining” our intervals (that is, making them narrower), then we can force the lower and upper estimates to converge to the true value of the distance traveled. The value to which the estimates converge is called the **definite integral**.

- **Realize that if the function isn’t monotone, the upper and lower estimates won’t be identical to right and left sums.** If we use a graph and carefully keep track of which rectangle represents the lower estimate and which represents the upper estimate, then we see that “upper” and “lower” are also “right” and “left” only on an interval that is **monotone** (either always increasing or always decreasing).

**Reading:** Section 5.3.

**Day 35**

**Activity:** Exploring Areas and Integrals.

Obviously using smaller and smaller intervals is tedious work by hand. Fortunately we have a calculator command that saves us. `fnInt( (MATH 9)` accomplishes the task for us. Keep in mind that this command calculates the **integral**, not necessarily the **area** (due to the sign on the y-values). Note the implications: There **is** a difference between positive and negative values on the integral. If we want **area** we must keep track separately of regions above and below the x-axis.

**Activity: Finding areas under curves.**

For each of the following functions, find the area indicated.
1) The area bounded between \( f(x) = x(x-1)^3 + 1 \), \( y = 0 \), \( x = 0 \), and \( x = 2 \).

2) The area enclosed between \( g(x) = xe^{-x} \) and \( h(x) = -xe^{-x} \), between \( x = 0 \) and \( x = 5 \).

3) The area between the \( x \)-axis and \( f(x) = \frac{1}{(x-3)(x+2)} \) between \( x = 0 \) and \( x = 2 \). Note: make sure you know how to enter this formula correctly into the calculator. The point \((1, -\frac{1}{6})\) should be on the graph, not \((1, -\frac{1}{5})\).

In the same menu as \texttt{nDeriv()} is our chief tool for integration: \texttt{fnInt( MATH 9)}. The syntax is \texttt{fnInt( expression, variable, start, end)}. \texttt{expression} is the formula for the derivative that we want the (signed) area underneath, \texttt{variable} is usually \( x \), just as in \texttt{nDeriv()}, and \texttt{start} and \texttt{end} are the boundaries of the interval we want. We can also access this function from the \texttt{CALC} menu while on the graphing screen (\texttt{CALC 7} or \( \int f(x)dx \)).

Goals: Know the graphical interpretation of the definite integral.

Skills:

- **Be able to use integrals to find areas bounded by curves.** Areas can be calculated using integrals. However, you must be aware that integrals can be negative, if the function is negative. So to find areas, we must ensure that all functions are positive. If we have to, we multiply by -1 to make a function positive. This amounts to adding a minus sign to an integral to find the corresponding area. If we are dealing with the area between two curves, we subtract the lower curve from the higher curve, and the resulting integral is the area between them. If they cross and therefore switch roles, we reverse the subtraction.

- **Know the calculator commands to find areas.** We can calculate definite integrals (or areas under curves) with \texttt{fnInt()} or \( \int f(x)dx \). \texttt{fnInt()} requires proper syntax while \( \int f(x)dx \) requires the area be currently on the graphing window.

Reading: Section 5.3.

**Day 36**

Activity: Exploring Areas and Integrals.

We will continue calculating areas under curves today.

**Activity 1: Heart pumping rate.**

If \( r(t) \) represents the rate at which the heart is pumping blood, in liters per second, and \( t \) is time in seconds, give the units and meaning of the following integral: \( \int_0^t r(t)dt \). Even though we don’t know the equation of \( r(t) \), graph a generic sketch of this integral.
Activity 2: Growth of a population.

Assume \( f(t) = 60\sqrt{t} \) gives the rate of change of the population of a city, in people per year, at time \( t \) years since 2000. If the population of the city is 5,000 people in 2000, what is the population in 2009?

Goals: Know the graphical interpretation of the definite integral.

Skills:

- **Know the calculator commands to find areas.** We can calculate definite integrals (or areas under curves) with \( \text{fnInt}( \) or \( \int f(x)dx \). \( \text{fnInt}( \) requires proper syntax while \( \int f(x)dx \) requires the area be currently on the graphing window.

Reading: Section 5.4.

Day 37

Activity: Interpret the Fundamental Theorem of Calculus in real world settings. **Homework 6 due today.**

The Fundamental Theorem of Calculus lets us talk about accumulated change of a function using its derivative information. This is pretty much what we have been doing the last few sessions. Today we will work on some examples where we make sure we’re putting the information in context. I will start with a hypothetical bicycle trip (Problem 26 page 267). Then you will work on several problems yourself.

Activity 1: Bicycle trip.

Problem 30 page 261.

Activity 2: Balloon flight.

Problem 38 page 262.

Goals: Using the Fundamental Theorem of Calculus in real world settings.

Skills:

- **Know the Fundamental Theorem of Calculus.** The Fundamental Theorem of Calculus relates integral and derivative as inverses. To find the integral, we use the derivative, but for a function we might not yet know. Fortunately, the integral can be interpreted as an area, so we don’t need to know the original function explicitly if we can approximate it using areas.

Reading: Section 5.5.

Day 38

Activity: Interpret the Fundamental Theorem of Calculus in real world settings.
The Fundamental Theorem of Calculus relates derivatives and integrals. To find the accumulated area under a curve, we can find the values directly with Riemann sums. The difference between two accumulated sums can be interpreted as the definite integral over an interval.

**Activity: Theater line.**

Here is the graph of the rate (in arrivals per hour) at which patrons arrive at the theater to get rush seats for the evening performance. The first people arrive at 8 a.m. and the ticket windows open at 9 a.m. Suppose that once the windows open, people can be served at an average rate of 200 per hour. Use the graph to approximate:

1) The length of the line at 9 a.m. when the windows open.
2) The length of the line at 10 a.m. and 11 a.m.
3) The rate at which the line is growing at 10 a.m.
4) The time when the line is longest.
5) The length of time a person who arrives at 9 a.m. has to stand in line.
6) The time the line disappears.
7) Suppose you were given a formula for \( r \) in terms of \( t \). Explain how you would answer the above.

**Goals:** Using the Fundamental Theorem of Calculus in real world settings.

**Skills:**
- Be able to approximate areas under curves using graphs. In the examples today we calculated areas given graphs. This is usually best accomplished with a suitable grid on graph paper, and counting boxes. But if other approximations work (like triangles) you
should use them. The important part is being able to find a good answer for how much area is bounded by the curve. Later (Chapter 7) we will focus more on formulas.

**Reading:** Section 6.1.

**Day 39**

**Activity:** Examples using integrals.

If we could replace a function over an interval with a constant, so that the areas are equal, then we would have the **average value** over that interval. The key idea is that the areas are equal. Because a constant function makes a rectangular area, all we need to calculate average area is the width of the interval and the area (the definite integral). In Activity 1 you will practice this rephrasing.

**Activity: Average Value.**

Is the average of the maximum and minimum over an interval equal to the average value over the interval? Work Problems 12 and 18 on page 279, which address this.

**Goals:** Use integrals in economics settings.

**Skills:**

- **Know the Average Value of a function over an interval.** Graphically, we can interpret the definite integral as the area of a rectangle over an interval. The height of this rectangle represents the **average value** of the function over the interval.

**Reading:** Section 6.2.

**Day 40**

**Activity:** Examples using integrals.

**Consumer surplus** is the amount of money **not** spent that would have been spent at higher prices. This is different for each consumer, as there are many different “demand” levels. So, for each price level, we determine how much money was “saved” from the actual price versus the willing price, as determined by the demand curve, and total this over all prices (down to the current price). Similarly, we can figure a **producer surplus**, but using the supply curve. Again the reasoning is that if the price were lower, fewer items would be made, and therefore sold. It is important to note that at equilibrium, both producers **and** consumers are “gaining” from the transaction.

Geometrically, the consumer surplus is the area bounded by the price (horizontal line) and the demand curve (integral area if the demand curve isn’t linear). The producer surplus is the area below the price line bounded by the supply curve.

The interesting work comes when we (perhaps the government) impose non-equilibrium prices. What effect does this have on the economic interpretations? We will explore this idea in Activity 2. In class, I will work on Problem 10 page 285.
Activity: Consumer and Producer surplus.
Problem 9, page 285. I recommend graphing the curves in addition to using \( \text{fnInt} \).

Now suppose a price **greater** than equilibrium is imposed. (Invent one.) Calculate the change in the two surpluses.

Now suppose a price **lower** than equilibrium is imposed. (Invent one.) Calculate the change in the two surpluses.

Goals: Use integrals in economics settings.

Skills: 

- **Understand the Consumer and Produce Surplus examples.** Equilibrium price is lower than many consumers are willing to pay. The difference between what they **would** have paid and what they **are** paying is called the consumer surplus. Similarly, the equilibrium price is higher than many producers are willing to produce. The difference in the equilibrium price and the supplier’s willing price is the producer surplus.

Reading: Section 6.3.

Day 41

Activity: Present and Future Values of income streams.

Any process that can be summed can be approximated with an integral. The idea behind the Reimann sums that form our integrals is the shrinking rectangle widths. An analogous situation is the compounding period for interest in annuities. We have looked at continuous compounding, and this corresponds to the definite integral. Today we will look at adding up a continuous income stream.

Activity: Understanding continuous income streams.

Compare several income streams, adding up the total income each time. Then calculate the definite integral, using the continuous compound interest formula.

Goals: Use integrals in economics settings.

Skills: 

- **Know how to calculate the total income given an income stream.** Because the definite integral is akin to a sum, we can use it to find sums with continuous compound interest problems.

Reading: Section 7.1.

Day 42

Activity: Antiderivatives.
We have explored how to interpret definite integrals. The techniques we’ve been using involve estimating areas under curves. The Fundamental Theorem of Calculus guided us, but it also shows us another approach to the solution, if we have a formula for the rate function (the derivative). The FTC says all we have to do is come up with a formula whose derivative is the formula we’ve started with. This sounds easier than it often is.

However, when such a formula does exist, the solution to a definite integral is then simply the difference of two values in this new function, which, because it is an inverse function, is called an antiderivative. It is important to note right away that antiderivatives are not unique functions. We know from Chapter 3 that when we add a constant to a function we don’t change the derivative at all. So there are many antiderivatives to any problem, but they only differ by adding a different constant.

To find antiderivatives we need to recognize a few features of the rules we learned in Chapter 3. First, derivatives add together, so we can work on each part in a sum separately. Second, derivatives of power functions are themselves power functions. So we just need to work backwards. Exponential functions are also their own derivatives. Composed functions are another matter. They may or may not have simple solutions. We will use substitution to see if we can discover the answers to them.

**Activity: Working “backwards”.
Work as many of the problems on page 304 as you can.**

**Goals:** Realize that antiderivatives are the inverses of derivatives.

**Skills:**

- **Realize that an antiderivative is a function whose derivative is the original expression.** The Fundamental Theorem of Calculus shows us that accumulated change in a function is an area under the derivative curve. Conversely, if we know the original function’s formula, we can simply subtract two values to find the definite integral.

- **Know how to find antiderivatives of simple functions.** Power functions, exponential functions, constants, and the reciprocal function \(1/x\) are all simple functions that have simple antiderivatives. Section 7.1 enumerates them in the various boxed formulas.

**Reading:** Section 7.2.

**Day 43**

**Activity:** Integration by Substitution. **Homework 7 due today.**

Composed functions do not have simple antiderivatives. We will use substitution to see if we can discover their antiderivatives. But substitution doesn’t always work; we must have functions that match the chain rule exactly. Substitution gives us a chance at least. It might require trial and error to find the right substitution to make. The strategy is to try \(w\) as an “inner” function; then \(dw = w'dx\). Replacing what we can, we see if we have made the
problem into something simpler and solvable. I will work problems in class to show you the
gist of it. Then you will practice with the composed functions.

Activity: Integration by Substitution.
Work as many of the problems on page 308 as you can.

Goals: Know how to do integration by substitution.

Skills:

• **Know how to find antiderivatives using substitution.** The antiderivatives for composed
  functions can sometimes be found using substitution. This technique only works if the
derivative of the proposed substitution appears in the formula in just the right way. If the
substitution is chosen well, then the problem after substitution will be of a simpler nature.

Reading: Section 7.3.

Day 44

Activity: Analyzing Antiderivatives.

Definite integrals, as we have seen, are specific areas under a curve. If we have a formula for
the derivative that we can find an antiderivative for, we can use the Fundamental Theorem of
Calculus to find the area exactly. Today we will do work very similar to yesterday’s work,
but we will move on to do the actual subtractions specified by the FTC.

In addition to finite integrals, we can also try our hand at **improper integrals**, or those with
infinity in either integrand. These problems will be solved with limits, and therefore may be
tricky to conclude convergence with (recall the harmonic series of Day 2). However, the
FTC saves us, if we are able to evaluate the antiderivative as \( x \) approaches infinity.

Activity: Evaluating definite integrals exactly using the FTC.

For each of the following functions, find an antiderivative. Then, evaluate the definite
integral using your calculator (**fnInt**), and by using the Fundamental Theorem of Calculus.
Compare answers. Which one is “right” and which one is only an approximation?

1) \( \int_{0}^{10} x(x+1)^{10} \, dx \). Integrate from 0 to 10.

2) \( \int_{1}^{\infty} \frac{1}{x} \, dx \). Note: you will have to decide how to “get” your calculator to do infinity.

3) \( \int_{1}^{\infty} \frac{1}{x} \, dx \). This integral is one way to prove that the harmonic series diverges.

Goals: Calculate and interpret integrals using antiderivatives.
Skills:

- **Evaluate definite integrals using both antiderivatives and the TI-83.** The definite integral can be calculated with antiderivatives (using the Fundamental Theorem of Calculus) or by numerical methods (using \texttt{fnInt} on the TI-83). You can also use \texttt{CALC 7} \( \int f(x) \, dx \) on the graphing window.

- **Be able to calculate an improper integral.** An improper integral involves infinity as one of the integrands. Therefore, to evaluate an improper integral exactly, we must use the FTC and some limit ideas.

Reading: Section 7.4.

Day 45

Activity: Analyzing Antiderivatives.

We will revisit an activity from Chapter 2 (Day 17), and notice (hopefully) how much simpler the last part is now that we know about integration.

### Activity 2: Estimating the derivative using a graph, and translating back.

Our next activity is a repeat of what we did on Day 17. It will take less time than before, hopefully.

Each of you will sketch an arbitrary function on a piece of paper, labeling it “Original Curve” and putting your name on it. You will then pass your graph to someone else; they will graph the derivative function on a separate sheet of paper, labeled with “Derivative Curve for <insert name here>”. The person drawing the derivative will have to carefully estimate the slopes, so a scale is needed. Finally, the second person will pass the derivative graph to a third person (keep the original aside to compare with later); the third person will attempt to redraw the original graph based solely on the information from the derivative graph. Caution: this last part is tricky.

Note that the last part isn’t nearly as tricky now as it was on Day 17; we now have the FTC to guide us in exactly how much to make the original graph rise or fall.

Goals: Be able to draw an antiderivative from a graph.

Skills:

- **Be able to draw an antiderivative given a derivative graph.** On Day 17 it was difficult during our exercise to reconstruct the original function from the derivative graph, because we didn’t know how much to increase or decrease the function just knowing the derivative. Now, after studying the FTC, we know the area is the important missing factor. With this knowledge, you should now be able to draw accurate antiderivatives, as this is really what they are.

Reading: Section 9.1.
Activity: Introduction to Multivariate Functions.

The real world is rarely explained by simple one-variable functions. Everything depends on everything else. The complexity is sometimes daunting. However, we can try to model things with mathematical formulas, and these often prove useful. For example, we know that the amount of money in a bank account can be represented by the formula \( B = Pe^{rt} \). We can view \( B \) as a function of three variables: \( P \), \( r \), and \( t \). Of course, in the real world the account balance won’t always be predicted by this formula unless the account is left completely alone, and the bank doesn’t close the account. In Activity 1, we will explore how to describe a multi-variable function with a table.

After you work on your activity today, I will explore \( z = xy^3 + x^2 \). This function is tougher than the one you’re working on, but we should see all the same issues.

Activity: Describing a multivariate function with a table.

In your groups, create tables of values for this two-variable function: \( B = Pe^{0.2t} \). The goal is to convey to a reader what the various values of \( B \) might be. I will let each group decide how to make the table; we will compare among groups to see if you chose similar methods.

Is \( B \) an increasing or a decreasing function?

Goals: Introduce multivariate functions.

Skills:

- **Understand how to represent a multivariate function with a table of values.** Tables can describe multivariate functions, but they are not as good as graphs. On the other hand, graphs can be difficult to produce or interpret, and sometimes having the raw numbers is better. The best approach is to have a formula, but many real world settings don’t yield known formulas (daily highs across the country is one example).

Reading: Section 9.1.

Day 47

Activity: Graphing with cross sections. **Homework 8 due today.**

Graphically, we view multivariate functions by holding all but two variables constant, and then graphing the remaining two variables using plotting techniques we already know. Because we view the dependent variable differently than the independent variables, the techniques fall into two basic types.

Cross-sections occur when the dependent variable is one of the two variables we graph. In a three-dimensional setting, we can imagine we have “sliced” the surface vertically and are looking at the surface from the side, in a cross-section. If we line up a series of cross-sections, we may be able to visualize the three-dimensional surface accurately. Cross-
sections can be done from any dimension, as long as the dependent variable is on the vertical axis.

After you work on your activity today, I will continue to explore \( z = xy^3 + x^2 \). This function is tougher than the one you’re working on, but we should see all the same issues.

**Activity: Describing a multivariate function with cross-sections.**

Using \( B = Pe^{0.2t} \) hold \( P \) constant (choose some values) and draw the resulting \( B \) vs. \( t \) graphs. Then repeat holding \( t \) constant and drawing the \( B \) vs. \( P \) graphs. Do they give you the same impression of the surface? Is it the same as the impression you got in the activity from Day 46?

When graphing cross-sections or contours, we may want to graph a whole series of values for \( x \), or \( z \). In our calculators, we can replace the variable with a list that will accomplish this for us, saving a lot of typing. For example, if we wanted to graph \( y = z^2 - x - 3 \) for \( z = -20, -10, 0, 10, \) and \( 20 \), we can enter this: \( Y1=\{-20,-10,0,10,20\}^2-x-3 \). The calculator will graph first \( y = 400 - x - 3 \), then \( y = 100 - x - 3 \), etc. One drawback to this approach is that when you TRACE, you won’t know which value in the list the curve represents.

**Goals:**

Explore cross-sections as a way to view multivariate functions.

**Skills:**

- **Be able to produce cross-sections for a multivariate function.** To make a cross-section of a multivariate function, hold all but one of the independent variables constant; then graph the dependent variable versus that last independent variable. Naturally, if there are many independent variables held constant, it will be difficult to visualize the entire surface. In the three-dimensional case, we can think of this approach as vertical “slices” of the surface, viewed from the side.

**Reading:** Section 9.2.

**Day 48**

**Activity:** Graphing with contours.

Contours occur in a three-dimensional surface when the dependent variable is held constant, and the other two variables are graphed. Due to the nature of functions, cross-sections will always create graphable formulas, but contours may result in something quite difficult to create. For example, it’s not at all clear when we begin what values to use for the dependent variable. Common uses for contours are maps. You have seen weather maps that highlight temperatures. Instead of simply showing the isotherms (lines of equal temperatures) color is commonly used.

After you work on your activity today, I will continue to explore \( z = xy^3 + x^2 \). This function is tougher than the one you’re working on, but we should see all the same issues.
Activity: Describing a multivariate function with contours.

In practice, you will most likely not be producing contours. More often you will interpret them. But we want to be able to produce contours for simpler functions. Again, using $B = Pe^{0.2t}$, create some contours. You will need to choose some values of $B$ to make the contours for. It is not always clear what values will make the most sense. Trial and error may be in order. Does this contour graph give you the same impression that you got in the activities from Days 46 and 47?

When graphing cross-sections or contours, we may want to graph a whole series of values for $x$, or $z$. In our calculators, we can replace the variable with a list that will accomplish this for us, saving a lot of typing. For example, if we wanted to graph $y = z^2 - x - 3$ for $z = -20, -10, 0, 10,$ and $20$, we can enter this: $Y1={-20,-10,0,10,20}^2-x-3$. The calculator will graph first $y = 400 - x - 3$, then $y = 100 - x - 3$, etc. One drawback to this approach is that when you TRACE, you won’t know which value in the list the curve represents.

Goals: 
Explore contours as a way to view multivariate functions.

Skills:

- Be able to read and interpret contours for a multivariate function. Contour diagrams are views from above, basically. Imagine looking down on the surface, in the case of three dimensions. Contours represent horizontal “slices”. Contours may be difficult to produce, as the curves traced out may not be functions at all (for example: circles at a relative maximum).

Reading: Section 9.3.

Day 49

Activity: Calculating Partial Derivatives.

Just as for one-variable functions, we can talk about derivatives with multivariate functions. Basically, we will let one of the variables remain constant and explore how the other variable changes. This technique is called partial derivatives. All that we know about derivatives from earlier chapters apply here. One new aspect is that there are several possible derivatives. We also use different notations (see page 361).

Activity: Calculate partial derivatives from tabular data.

Problem 8 page 366.

Goals: Calculate partial derivatives from tabular data.

Skills:

- Be able to estimate partial derivatives from tabular data. Calculating a derivative from a table in two or more dimensions is no different than it was in Chapter 2. We use slopes of
secant lines, and due to the nature of tabular data, we can only “zoom in” so much. The only trick is to pay attention to which variable is being held constant.

Reading: Section 9.4.

Activity: Second partial derivatives.

There is another new idea about derivatives that we haven’t encountered before: the mixed second partial derivative. The regular second partial derivatives measure concavity, the same as the one-variable second derivatives. But when we take the mixed second partial derivative (see page 370) we are really estimating how the change in one direction changes as we move in the other direction. We are more estimating a kind of “twisting” in the surface. We will make more use of this on Day 51 when we classify the extrema.

Activity 1: Calculate partial derivatives from graphs, both cross-sections and contours.

Using your graphs from $B = P e^{0.2t}$ from the activities on Days 46 and 47, estimate some values of the partial derivatives.

Activity 2: Calculate partial derivative formulas.

Verify your answers in Activity 1 using algebra. Then work on a few of problems 26 to 37 on page 372.

Goals: Calculate partial derivatives from graphs (both cross-sections and contours), and from formulas.

Skills:

• **Be able to estimate partial derivatives from graphs.** From cross-section graphs, we can estimate the partial derivative for that variable in just the same way as in Chapters 2 and 3. For the contour graphs, we must use a different approach. Typically, we will estimate the difference between two contours, and express the ratio of the change in contours to distance between contours as the derivative in that direction.

• **Be able to calculate partial derivatives from formulas.** Using the formulas from Chapter 4, we can calculate partial derivatives exactly. The only difficulty is keeping track of which variable is allowed to vary; our notation is intended to remind us of this (see page 361).

Reading: Section 9.5.

Activity: Multivariate Optimization.

To maximize or minimize a multivariate function, we use the same criteria we did for one-variable function: critical points and the second derivative test. The details are slightly different for the second derivative test, and we will do several problems today practicing this
technique. First we solve the first derivatives jointly by setting them to zero. This will give us candidates for extrema. Now we use the second derivative test (page 376) to help classify the candidates as maxima, minima, or neither. It is also possible the test is inconclusive. In those situations, we must use some other approach, perhaps something akin to the first derivative test, although using that approach is a bit trickier in multiple dimensions. Note: solving the first derivative formulas simultaneously for all variables present may be very difficult. One special case is when all the derivatives are linear. Then you can use techniques from MATH 204 (the linear algebra/matrix results).

In addition to using formulas, make sure you can use graphs also to find extrema. Problems 1 and 2, and 14 to 16 on page 377 are good practice.

**Activity: Optimizing multivariate functions.**

I will work problems 3 and 6 in class. Try as many of the others as you can. Problems 3 through 12 page 377.

**Goals:** Understand how the derivatives can be used to find the extrema in multivariate functions.

**Skills:**

- **Be able to find the extrema using a contour graph.** Extrema on contour graphs are represented with closed loops. To find whether they are maxima or minima entails paying attention to the values of the contours around the points.

- **Be able to find extrema using algebra.** Using the second derivative test, you should be able to classify the extrema as maxima, minima, or neither. In some cases, the second derivative test is inconclusive.

**Reading:** Section 9.5.

**Day 52**

**Activity:** Continued Optimization.

A new sort of critical point occurs in multiple dimensions called a **saddle point**. You can think of a mountain pass as one example; in one direction (going over the pass) the function is a maximum but in the other direction (going from one mountain to the other through the pass) the function is a minimum. The second derivative test will classify these saddle points as “neither”.

**Goals:** Understand how a function can have a critical point but not be a maximum or a minimum.

**Skills:**

- **Understand the saddle point in multivariate functions.** In one direction, a saddle point is a maximum, but in another direction it is a minimum. If we are trying to optimize a function, it is critical to know if our critical points are maxima, minima, saddle points, ridges, etc.
Day 53

Activity: Review. **Homework 9 due today.**

Reading: Chapters 5, 6, 7, and 9.

Day 54

Activity: Presentation 3.

| Pick one of these functions (first come, first served): | 1) $z = x^2 + 3y^2 - 4x + 6y + 10$, 2) $z = x^3 - 3x + y^2$, 3) $z = xy^2 e^{-x}$, 4) $z = x^3 + y + xy$, 5) $z = (x - y)^3$, 6) $z = \frac{1}{(x^2 + y^2 + 1)}$, 7) $z = x(1 + y) + y^2$. Graph some cross-sections, a contour graph, and classify the critical points. Show how your critical points appear in each of your displays. |
|----------------------------------------------------------|

Reading: Chapters 5, 6, 7, and 9.

Day 55

Activity: Review.

Reading: Chapters 5, 6, 7, and 9.

Day 56

Activity: Exam 3.

This last exam covers integrals, including antiderivatives, and multivariate functions, Chapters 5, 6, 7, and 9. Some of the questions might be multiple choice. Others will require you to show your worked out solution.
Populations for the 50 states, DC, and the USA, by decade. (in thousands)

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Managed by chris edwards
Last updated January 18, 2013