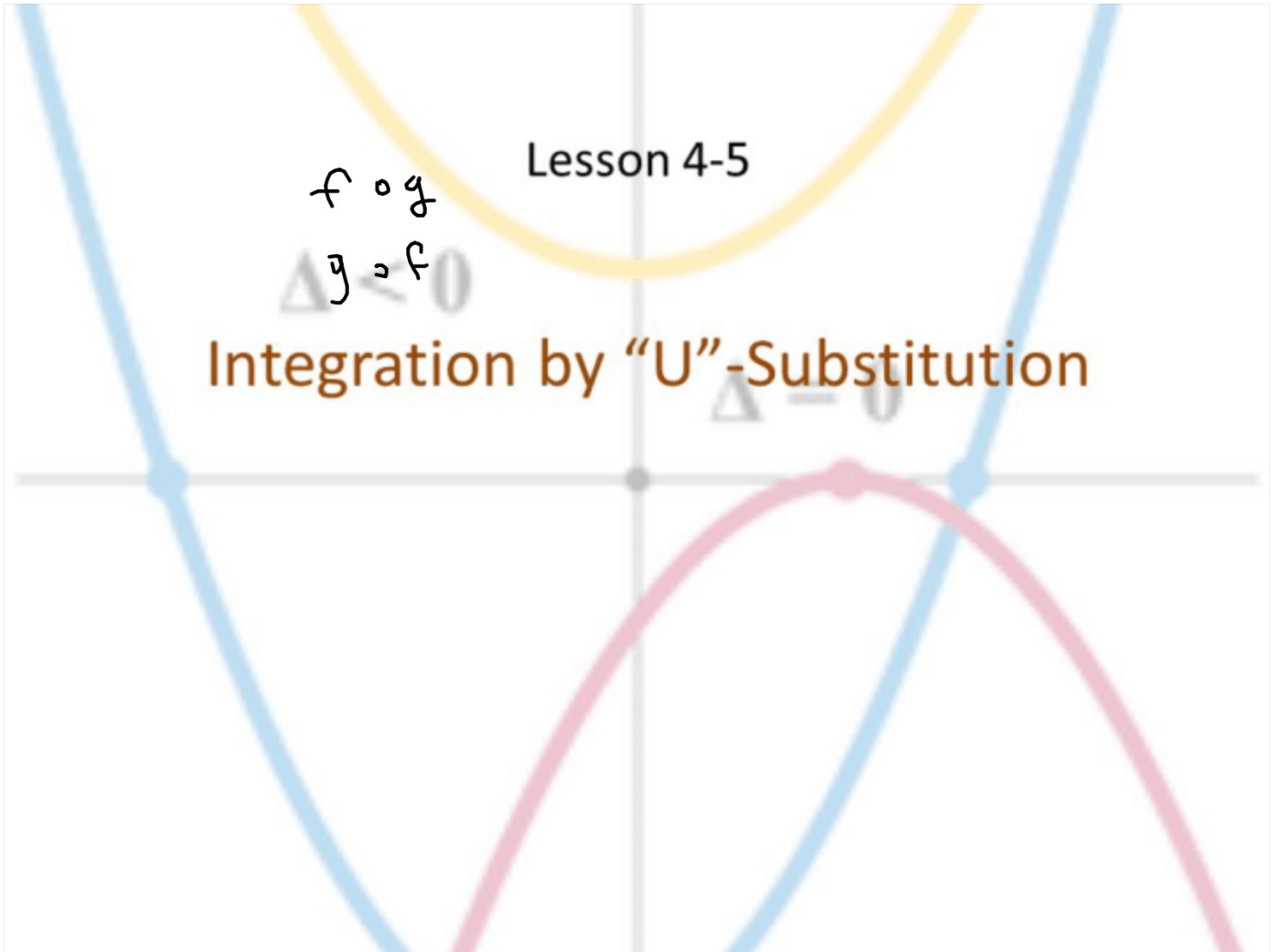


Lesson 4-5

$$f \circ g$$
$$\Delta y = f$$

Integration by "U"-Substitution

$$\Delta = 0$$



## Objective

Students will...

- Be able to recognize that the technique of “U”-Substitution is the “anti-chain rule.”
- Be able to use “U”-Substitution to find integrals.

## Chain Rule (Derivative)

**Chain Rule**- If  $f$  and  $g$  are differentiable functions, then the composite function  $f \circ g = f(g(x))$  is also differentiable such that...

$$\frac{d}{dx}f(g(x)) = f'(g(x)) \cdot g'(x)$$

In other words, the chain rule consists of first taking the derivative of the outer function, while leaving the inner function the same, multiplied by the derivative of the inner function.

The most challenging part of the chain rule being able to distinguish different functions that are being composed (i.e. outer and inner).

## Anti-Chain Rule

Based on the definition of chain rule, we then have that

$$\int \underbrace{[f'(g(x)) \cdot g'(x) dx]} = f(g(x)) + C$$

Have you ever wondered what the  $dx$  means at the end of every integral? By definition, the  $dx$  represents the width of the rectangles (remember Riemann Sum?). In terms of the arithmetic side of things, the  $dx$  simply represents the derivative of the function of  $x$ . This makes sense if you understand that every derivative rule is really the chain rule.

$$\text{Power Rule: } \frac{d}{dx} x^a = ax^{a-1} \cdot \frac{d}{dx} x = ax^{a-1} \cdot 1$$

So, since integration can only be done on a function that is first differentiable whatever follows the integral is something that has been differentiated, hence  $\int f(x) dx$

## Anti-Chain Rule

With the said, the way to reverse the chain rule is to find or identify the correct  $g(x)$  so that you can **replace**  $g'(x) dx$ . Namely, if you were to set  $u = g(x)$ , then  $du = g'(x) dx$  (chain rule). So, we end up with...

$$du = g'(x) dx$$

$$\int [f'(g(x)) \cdot g'(x) dx] = \int f'(u) du = f(u) = f(g(x))$$

Or using the  $F$  notation

$$\int [f(g(x)) \cdot g'(x) dx] = \int f(u) du = F(u) = F(g(x))$$

This technique is known as the **“U”-Substitution**. The challenge here is finding the  $g(x)$ . Unfortunately, you can only get better at this with practice!! If you pick the right expression for  $u$ , then you should only end up with one variable, non-composite function with  $du$ .

Example

"inside"



Find  $\int (x^2 + 1)^2 \underline{(2x)} dx$

$$u = x^2 + 1$$

$$u' = du = \underline{2x dx}$$

$$\Rightarrow \int u^2 du = \frac{1}{3} u^3 + C$$

$$= \boxed{\frac{1}{3} (x^2 + 1)^3 + C}$$

### Example

Find  $\int \underline{5} \cos(\underline{5x}) \underline{dx}$

$$u = 5x$$

$$du = 5 dx \Rightarrow$$

$$\int \cos u \, du = \sin u + C$$

$$= \boxed{\sin 5x + C}$$

## Example

Find  $\int x(x^2 + 1)^2 dx$

$$u = x^2 + 1$$

$$\frac{du}{2} = \cancel{2}x \, dx$$

$$\frac{1}{2} du = x \, dx$$

$$\Rightarrow \int u^2 \left(\frac{1}{2}\right) du \Rightarrow \frac{1}{2} \int u^2 du$$

$$= \frac{1}{2} \left( \frac{1}{3} u^3 + C \right)$$

$$= \boxed{\frac{1}{6} (x^2 + 1)^3 + C}$$



### Example

$$\text{Find } \int \sqrt{2x-1} \, dx = \int (2x-1)^{1/2} \, dx$$

$$u = 2x-1$$

$$du = 2 \, dx$$

$$\frac{1}{2} du = dx$$

$$\Rightarrow \frac{1}{2} \int u^{1/2} \, du = \frac{1}{2} \left( \frac{2}{3} u^{3/2} + C \right)$$

$$= \frac{1}{3} (2x-1)^{3/2} + C$$

$$= \frac{1}{3} (2x-1) \sqrt{2x-1} + C$$

$$\downarrow (\sin 3x)^2$$

Example

Find  $\int \sin^2 3x \cos 3x dx$

$$u = \sin 3x$$

$$du = 3 \cos 3x dx$$

$$\frac{1}{3} du = \cos 3x dx$$

$$\Rightarrow \frac{1}{3} \int u^2 du = \frac{1}{3} \left( \frac{1}{3} u^3 + C \right)$$

$$= \frac{1}{9} (\sin^3 3x) + C$$

$$= \frac{1}{9} \sin^3 3x + C$$

$$= \frac{\sin^3 3x}{9} + C$$

### Example

$$\text{Find } \int x\sqrt{2x-1} dx = \int x(2x-1)^{1/2} dx.$$

$$u = 2x-1 \Rightarrow x = \frac{1}{2}u + \frac{1}{2}$$

$$du = 2 dx$$

$$\frac{1}{2} du = dx$$

$$\Rightarrow \int \left(\frac{1}{2}u + \frac{1}{2}\right) (u^{1/2}) du$$

$$= \frac{1}{4} \int u^{3/2} + u^{1/2} du = \frac{1}{4} \left( \int u^{3/2} du + \int u^{1/2} du \right)$$

$$= \frac{1}{4} \left( \frac{2}{5} u^{5/2} + \frac{2}{3} u^{3/2} + C \right) = \frac{1}{10} (2x-1)^{5/2} + \frac{1}{6} (2x-1)^{3/2} + C$$

Homework Due 11/15

4.5 #1-6, 7-19(e.o.o), 29, 43-53(e.o.o),  
65, 67