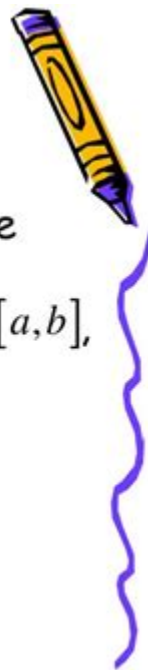


# Fundamental Theorem Of Calculus

## Theorem: The Fundamental Theorem of Calculus

- If a function  $f$  is continuous on the closed interval  $[a, b]$  and  $F$  is an antiderivative of  $f$  on the interval  $[a, b]$ , then

$$\int_a^b f(x) dx = F(b) - F(a)$$



Fundamental Theorem of Calculus is one of the cornerstones of mathematical analysis and a key link between the concepts of differentiation and integration. This theorem establishes a profound relationship between the derivative of a function and its integral, providing a unified framework for understanding the calculus. It consists of two main parts, often referred to as the First Fundamental Theorem of Calculus and the Second Fundamental Theorem of Calculus. In this article, we will explore these two parts in detail, delve into their implications, and discuss their significance in both theoretical and applied mathematics.

## Understanding the Fundamental Theorem of Calculus

The Fundamental Theorem of Calculus can be summarized in two main statements, each addressing a different aspect of calculus. It essentially connects the processes of differentiation and integration, showing how they are inverse operations.

### First Fundamental Theorem of Calculus

The First Fundamental Theorem of Calculus states that if  $f$  is a continuous real-valued function defined on the interval  $[a, b]$ , and  $F$

$F(x)$  is an antiderivative of  $f(x)$  on that interval, then:

$$\int_a^b f(x) \, dx = F(b) - F(a)$$

This theorem provides a method to evaluate definite integrals by finding an antiderivative of the integrand. Here's a breakdown of its significance:

- Continuity Requirement:** The continuity of  $f(x)$  over the interval  $[a, b]$  is crucial. If  $f(x)$  is not continuous, the conclusion of the theorem may not hold.
- Antiderivatives:** An antiderivative  $F(x)$  of  $f(x)$  is a function whose derivative is  $f(x)$ , i.e.,  $F'(x) = f(x)$ . There can be infinitely many antiderivatives for a given function differing by a constant.
- Definite Integral:** The expression  $\int_a^b f(x) \, dx$  represents the signed area under the curve of  $f(x)$  from  $a$  to  $b$ . The theorem provides a practical way to calculate this area.
- Applications:** This theorem is widely used in physics, engineering, and economics to compute quantities such as area, displacement, and total accumulation.

## Example of the First Fundamental Theorem

Let's illustrate the First Fundamental Theorem with an example:

Example: Consider  $f(x) = 2x$  on the interval  $[1, 3]$ .

1. Find an Antiderivative: An antiderivative  $F(x)$  of  $f(x) = 2x$  is  $F(x) = x^2$  (since  $\frac{d}{dx}(x^2) = 2x$ ).

2. Evaluate the Definite Integral:

$$\int_1^3 2x \, dx = F(3) - F(1) = 3^2 - 1^2 = 9 - 1 = 8$$

Thus, the area under the curve of  $f(x) = 2x$  between  $x = 1$  and  $x = 3$  is 8.

## Second Fundamental Theorem of Calculus

The Second Fundamental Theorem of Calculus provides a way to compute the derivative of an integral function. It states that if  $f(x)$  is a continuous function on  $[a, b]$ , then the function  $F(x)$  defined by:

$$F(x) = \int_a^x f(t) \, dt$$

is differentiable on  $((a, b))$ , and its derivative is given by:

$$F'(x) = f(x)$$

This theorem demonstrates that differentiation and integration are inverse processes. Key points about this theorem include:

1. **Function Definition:** The function  $F(x)$  is defined as the integral of  $f(t)$  from  $a$  to  $x$ .
2. **Continuity of  $f$ :** The requirement that  $f$  be continuous ensures that  $F$  is indeed differentiable.
3. **Link between Operations:** This theorem confirms that finding the derivative of an integral with respect to its upper limit yields the original function.

## Example of the Second Fundamental Theorem

Let's consider an example to clarify the Second Fundamental Theorem:

Example: Let  $f(x) = \sin(x)$ .

1. Define  $F$ :

$$F(x) = \int_0^x \sin(t) \, dt$$

2. Differentiate  $F$ :

By the Second Fundamental Theorem, we have:

$$F'(x) = \sin(x)$$

This shows that the rate of change of the area under the sine curve from 0 to  $x$  is equal to the value of the sine function at  $x$ .

## Implications of the Fundamental Theorem of Calculus

The implications of the Fundamental Theorem of Calculus are far-reaching in

the fields of mathematics and applied sciences.

## Bridging Differentiation and Integration

1. Unified Perspective: The theorem provides a unified perspective on two seemingly different operations. It shows that integration can be viewed as a process of accumulation, while differentiation reveals instantaneous rates of change.
2. Simplifying Calculations: By allowing the evaluation of definite integrals through antiderivatives, it simplifies many calculations and provides a straightforward method for finding areas and total quantities.

## Applications in Real-World Problems

1. Physics: In physics, the Fundamental Theorem is used to relate distance and velocity. For example, if position is given by  $s(t)$ , then velocity  $v(t) = s'(t)$  and the total distance traveled over a time interval can be calculated using the integral of velocity.
2. Economics: In economics, the theorem can be applied to find consumer surplus and producer surplus by integrating demand and supply functions.
3. Engineering: Engineers use the theorem in various applications, such as calculating work done by a variable force or determining center of mass.

## Conclusion

The Fundamental Theorem of Calculus forms the backbone of calculus, beautifully connecting the concepts of differentiation and integration into a coherent framework. It not only enables the evaluation of definite integrals through antiderivatives but also affirms the inverse relationship between these two fundamental operations. Its applications span across numerous disciplines, making it one of the most significant theorems in mathematics. Understanding this theorem is essential for anyone looking to delve deeper into the world of calculus and its myriad of applications in both theoretical and practical contexts.

## Frequently Asked Questions

## **What is the Fundamental Theorem of Calculus?**

The Fundamental Theorem of Calculus links the concept of differentiation and integration, stating that if a function is continuous on the interval  $[a, b]$ , then the integral of its derivative over that interval equals the difference of its values at the endpoints:  $\int_a^b f'(x) dx = f(b) - f(a)$ .

## **How does the Fundamental Theorem of Calculus apply to finding areas under curves?**

The Fundamental Theorem of Calculus allows us to compute the area under a curve  $f(x)$  from  $a$  to  $b$  by evaluating the integral:  $\text{Area} = \int_a^b f(x) dx$ , which gives the total accumulation of the function's values across the interval.

## **What are the two parts of the Fundamental Theorem of Calculus?**

The theorem has two parts: Part 1 states that if  $F$  is an antiderivative of  $f$  on  $[a, b]$ , then  $\int_a^b f(x) dx = F(b) - F(a)$ . Part 2 states that if  $f$  is continuous on  $[a, b]$ , then the function  $F$  defined by  $F(x) = \int_a^x f(t) dt$  is continuous on  $[a, b]$  and differentiable on  $(a, b)$ , with  $F'(x) = f(x)$ .

## **Why is the Fundamental Theorem of Calculus important in mathematics?**

The Fundamental Theorem of Calculus is crucial because it provides a powerful connection between the two main branches of calculus—differentiation and integration—allowing for the evaluation of integrals using antiderivatives and enabling the application of calculus in various fields such as physics, engineering, and economics.

## **Can the Fundamental Theorem of Calculus be applied to improper integrals?**

Yes, the Fundamental Theorem of Calculus can be extended to improper integrals, but it requires careful handling of limits. One must evaluate the limit of the definite integral as the bounds approach infinity or as they approach a point of discontinuity to ensure that the integral converges.

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