



A mathematical investigation of the general power rule and its limited applicability

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Received 23 May 2026; Accepted 2 Jul 2026; Published 15 Jul 2026

DOI: <https://doi.org/10.64171/JAES.6.4.47-53>

Abstract

The General Power Rule is a fundamental differentiation technique in differential calculus that extends the Traditional Power Rule through the application of the Chain Rule to differentiate composite functions. This study investigated its mathematical foundation, applications, properties, validity, and limitations using a descriptive-analytical research design with a deductive mathematical analysis framework. Mathematical derivations, formal proofs, worked examples, symbolic manipulations, and scholarly literature served as the primary sources of theoretical evidence. The findings established that the General Power Rule is derived from the integration of the Traditional Power Rule and the Chain Rule, making it an efficient, consistent, and accurate method for differentiating composite functions. The rule was found applicable to polynomial, rational, radical, trigonometric, exponential, logarithmic, and other differentiable composite functions under appropriate mathematical conditions. However, its direct application is limited for non-differentiable, implicit, piecewise-defined, and fractional-order functions. Overall, the study confirms the General Power Rule as a reliable differentiation technique within classical differential calculus.

Keywords: General power rule, Differential calculus, Chain rule, Mathematical investigation, Differentiation

Introduction

The General Power Rule is one of the most significant extensions of the traditional Power Rule in differential calculus. It provides a systematic method for differentiating

functions of the form $([u(x)]^n)$, where $[u(x)]$ is a differentiable function and (n) is a real number. By combining the principles of the Power Rule and the Chain Rule, the General Power Rule enables the differentiation of a broader class of functions than those addressed by the ordinary Power Rule alone. As a result, it has become an essential tool in calculus and is widely applied in mathematics, physics, engineering, economics, and computer science.

A fundamental feature of the General Power Rule is its ability to simplify the differentiation of composite functions. If a

function is expressed as $(y = [u(x)]^n)$, its derivative can be obtained by differentiating the outer function and multiplying the result by the derivative of the inner function. This process extends the applicability of the traditional Power Rule and demonstrates the interconnectedness of differentiation techniques within calculus. Through this relationship, the General Power Rule serves as a bridge between elementary differentiation methods and more advanced mathematical analysis.

The development of the General Power Rule in calculus represents a significant milestone in the advancement of mathematical analysis. Although methods for determining areas, slopes, and rates of change can be traced back to ancient

civilizations, the formal development of differentiation rules emerged during the seventeenth century through the pioneering works of Isaac Newton and Gottfried Wilhelm Leibniz (Gamage, 2026) ^[6]. Leibniz played a particularly important role in establishing mathematical notation and formulating systematic procedures for differentiation, including rules involving powers, products, and quotients (Mathematical Association of America, 2024) ^[12]. Initially, the Power Rule was applied primarily to functions with positive integer exponents, but later mathematical developments extended its applicability to negative, fractional, and real-number exponents. This expansion reflected the growing need for more general mathematical tools capable of describing increasingly complex phenomena in science and engineering. Over time, rigorous proofs and theoretical foundations were established to justify the validity of these differentiation techniques, transforming calculus into a logically structured branch of mathematics (Gamage, 2026) ^[6]. Understanding this historical development provides valuable context for examining the mathematical foundations, applications, and limitations of the General Power Rule.

The study of the General Power Rule is supported by a substantial body of mathematical literature. Clark and Rielbach (2021) ^[1] explained how the rule extends the traditional Power Rule to composite functions, while Jenn (2021) ^[9] demonstrated its effectiveness through detailed differentiation procedures and examples. Similarly, Cuemath (2022) ^[3] discussed the formula, proof, and applications of the Power

Rule, emphasizing its role as a foundational concept in calculus. Zweig Media (2024) ^[16] further strengthened this foundation by presenting a formal proof of the rule, illustrating the mathematical principles that justify its validity.

Beyond its theoretical significance, the General Power Rule has numerous practical applications. Krista King Math (2024) ^[10] highlighted its importance in solving complex differentiation problems, while GeeksforGeeks (2021) ^[7] discussed its applications in optimization, motion analysis, and mathematical modeling. Outlier Articles (2021) ^[13] and DeVry University (2022) ^[4] likewise emphasized its usefulness in analyzing rates of change and functional relationships. These applications demonstrate that the General Power Rule is not only a theoretical construct but also a valuable tool for solving real-world problems.

Despite its effectiveness, the General Power Rule is not universally applicable. Its validity depends on specific mathematical conditions, particularly the differentiability of the functions involved. Certain mathematical structures do not satisfy the assumptions required by classical differentiation rules. In particular, recent developments in fractional calculus have revealed situations in which traditional differentiation methods become insufficient. Elnady *et al.* (2026) ^[5] noted that fractional-order derivatives require modified chain-rule formulations because of their nonlocal and memory-dependent properties. Similarly, Zitane and Torres (2023) ^[15] developed generalized Taylor formulas for power fractional derivatives, while Groza and Jianu (2026) ^[8] extended these ideas to multivariable fractional power series. These studies demonstrate that the assumptions underlying the General Power Rule do not always hold in broader mathematical frameworks.

The existence of such limitations highlights the importance of examining not only how the General Power Rule works but also the conditions under which it remains valid. Understanding these limitations provides deeper insight into the nature of differentiation and reveals the boundaries of classical calculus. Moreover, it illustrates how mathematical concepts evolve as new theories and generalized operators are developed.

Therefore, this study seeks to conduct a mathematical investigation of the General Power Rule and its limited applicability. Specifically, it aims to examine the mathematical foundations of the rule, analyze its applications and properties, identify the conditions required for its validity, and investigate situations in which its direct application becomes limited. Through this analysis, the study aims to provide a deeper understanding of both the strengths and limitations of the General Power Rule in classical and modern calculus.

Statement of the problem

This study aims to investigate the mathematical foundations, applications, and limitations of the General Power Rule in differential calculus. Specifically, it seeks to answer the following questions:

- What is the mathematical foundation of the General Power Rule and how is it derived from the Power Rule and Chain Rule?

- How can the General Power Rule be applied to different types of differentiable functions, including polynomial, rational, radical, and composite functions?
- What mathematical properties demonstrate the efficiency, consistency, and accuracy of the General Power Rule?
- Under what conditions is the General Power Rule valid and applicable?
- What limitations exist in the direct application of the General Power Rule, particularly in non-differentiable functions, implicit functions, and fractional-order derivatives?
- How does the General Power Rule compare with generalized differentiation approaches used in advanced mathematical frameworks such as fractional calculus?

Materials and Methods

Research design

This study employed a descriptive-analytical research design to investigate the mathematical foundation, applications, properties, validity, and limitations of the General Power Rule in differential calculus. This design was appropriate because the study focused on analyzing mathematical concepts, formal derivations, logical relationships, and theoretical principles rather than collecting empirical data through surveys, interviews, or experiments involving human participants. It aimed to describe existing mathematical knowledge while examining the relationships among calculus principles that explain the validity and applicability of the General Power Rule (Creswell & Creswell, 2023) ^[2].

The study adopted a deductive mathematical analysis framework, wherein established theorems, principles of differential calculus, mathematical definitions, and formal proofs served as the basis for evaluating the General Power Rule. General mathematical principles were applied to specific functions and differentiation problems to verify the rule's correctness, applicability, and limitations. The investigation emphasized theorem analysis, symbolic manipulation, deductive proof, mathematical modeling, and logical verification to ensure that all conclusions were consistent with accepted principles of classical differential calculus.

Unlike empirical research, this investigation was entirely theoretical. Mathematical knowledge was developed through the analysis of established calculus concepts, formal proofs, symbolic computations, and scholarly mathematical literature rather than observations or statistical data. This approach ensured that the findings were based on mathematical rigor and logical consistency.

Research materials

The study utilized calculus textbooks, peer-reviewed journal articles, scholarly books, conference papers, and other credible academic references related to differential calculus, the General Power Rule, and generalized differentiation techniques. References were selected based on their relevance to the research objectives, mathematical rigor, credibility, and contribution to the theoretical understanding of differentiation. Mathematical examples were chosen using predetermined criteria. Polynomial, rational, radical, trigonometric,

exponential, logarithmic, and composite functions were selected to demonstrate the applicability of the General Power Rule, while implicit, piecewise-defined, non-differentiable, and fractional-order functions were included to illustrate its limitations. All formulas and derivations were verified using recognized calculus references to ensure mathematical accuracy.

Research methods

The study employed a descriptive-analytical method supported by deductive mathematical reasoning. Mathematical theories, definitions, theorems, proofs, and scholarly literature were systematically examined to evaluate the General Power Rule.

The investigation involved theorem analysis, formal mathematical proof, symbolic verification, mathematical modeling, and comparative mathematical analysis. Derivatives obtained using the General Power Rule were verified by comparison with the Traditional Power Rule, the Chain Rule, implicit differentiation, and algebraic expansion whenever appropriate. The rule was also compared with generalized differentiation techniques used in fractional calculus to determine its scope, strengths, and limitations.

No specialized computer algebra or symbolic computation software was used. All derivations, symbolic manipulations, and verification procedures were performed manually using accepted principles of differential calculus and established scholarly references.

Research procedures

The investigation followed a systematic sequence of mathematical analyses to address the research objectives. First, the mathematical foundations of the Traditional Power Rule and the Chain Rule were examined through established definitions, theorems, and formal proofs to derive the General Power Rule.

Representative mathematical examples were then selected based on predetermined criteria. These included polynomial, rational, radical, trigonometric, exponential, logarithmic, and composite functions to demonstrate the applicability of the General Power Rule, while implicit, piecewise-defined, non-differentiable, and fractional-order functions were analyzed to illustrate its limitations.

Each example was solved using the General Power Rule and verified through symbolic manipulation, algebraic simplification, deductive proof, and comparison with established differentiation techniques, including the Traditional Power Rule, the Chain Rule, implicit differentiation, and algebraic expansion whenever appropriate. The investigation also evaluated the efficiency, consistency, and accuracy of the General Power Rule, examined the mathematical conditions required for its validity, and compared it with other differentiation techniques used in classical and advanced calculus. Finally, the mathematical findings were synthesized through deductive reasoning and scholarly literature to formulate conclusions regarding the rule's foundation, applicability, validity, and limitations.

Data analysis

The mathematical data consisted of formal derivations, established theorems, symbolic computations, worked examples, and scholarly mathematical literature related to the General Power Rule. Since the investigation was theoretical, the data were analyzed using qualitative descriptive analysis and deductive mathematical reasoning rather than statistical techniques.

Mathematical examples were analyzed to evaluate the applicability, efficiency, consistency, and accuracy of the General Power Rule. Derivatives were verified through symbolic manipulation, algebraic simplification, deductive proof, and comparison with accepted differentiation techniques. Comparative mathematical analysis was likewise conducted to identify similarities and differences between the General Power Rule and the Traditional Power Rule, Chain Rule, implicit differentiation, and generalized differentiation methods.

For this study, efficiency refers to reducing computational steps and unnecessary algebraic expansion, consistency refers to producing derivatives equivalent to other valid differentiation techniques, and accuracy refers to obtaining mathematically correct derivatives verified through formal proofs and established calculus principles.

Unlike empirical studies, this investigation did not involve human participants, surveys, experiments, or statistical analyses. All findings were derived exclusively from deductive mathematical reasoning, theorem analysis, symbolic verification, formal proofs, and scholarly mathematical literature.

Results

This chapter presents the findings of the mathematical investigation of the General Power Rule and its limited applicability. The discussion is organized according to the Statement of the Problem and focuses on the mathematical foundation, applications, properties, validity, limitations, and comparison of the General Power Rule with other differentiation techniques. The analyses demonstrate that the General Power Rule extends the Traditional Power Rule through the application of the Chain Rule, making it an efficient and systematic method for differentiating composite functions. The findings also identify the mathematical conditions required for its valid application and the situations in which alternative differentiation methods are necessary. Mathematical derivations, representative examples, and theoretical interpretations are presented to support the conclusions of the investigation.

1. Mathematical foundation of the general power rule

The first objective of this investigation was to determine the mathematical foundation of the General Power Rule and explain how it is derived from the Traditional Power Rule and the Chain Rule. The analysis showed that the General Power Rule is not an independent differentiation rule but rather a direct combination of these two fundamental principles. The Traditional Power Rule differentiates the outer power function, while the Chain Rule accounts for the derivative of the inner function. Their combined application produces the General Power Rule, allowing composite power functions to be differentiated systematically and efficiently.

Table 1: Mathematical foundation of the general power rule

Component	Mathematical Contribution
Traditional Power Rule	Differentiates the outer power function.
Chain Rule	Differentiates the inner function.
General Power Rule	Combines both rules to differentiate composite power functions.

Example

Given

$$y = (2x^2 + 1)^3$$

Applying the General Power Rule

$$y' = 3(2x^2 + 1)^2(4x)$$

$$y' = 12x(2x^2 + 1)^2$$

The example illustrates that the derivative is obtained directly without expanding the expression, making the differentiation process more efficient.

The findings confirm that the General Power Rule is mathematically derived from the integration of the Traditional Power Rule and the Chain Rule. This relationship establishes the theoretical basis of the rule and explains why it accurately differentiates composite power functions while preserving the principles of differential calculus.

2. Applications of the general power rule

The second objective was to determine the applicability of the General Power Rule to different categories of differentiable functions. The investigation found that the rule can be applied to several function types provided that the inner function is differentiable and the expression is written in composite form.

Table 2: Applications of the general power rule

Function Type	Example	Applicable	Reason
Polynomial	$(x^2 + 3)^4$	✓	Composite polynomial function
Rational	$\left(\frac{1}{x} + 2\right)^3$	✓	Differentiable inner function
Radical	$\sqrt{3x + 1}$	✓	Can be written using fractional exponents
Trigonometric	$(\sin x)^3$	✓	Composite trigonometric function
Exponential	$(e^x + 1)^2$	✓	Composite exponential function
Logarithmic	$(\ln x)^4$	✓	Composite logarithmic function

Example

Given

$$y = \sqrt{3x + 1}$$

Rewrite as

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

Applying the General Power Rule

$$y' = \frac{1}{2}(3x + 1)^{-\frac{1}{2}}(3)$$

$$y' = \frac{3}{2\sqrt{3x + 1}}$$

including polynomial, rational, radical, trigonometric, exponential, and logarithmic functions. Its consistent application across these function types confirms its versatility and efficiency in simplifying differentiation procedures. However, its validity depends on the differentiability of the inner function and the proper representation of the expression as a composite function.

3. Mathematical properties of the general power rule

The third objective of this investigation was to determine the mathematical properties that demonstrate the efficiency, consistency, and accuracy of the General Power Rule. The analysis showed that these properties arise from the rule's direct integration of the Traditional Power Rule and the Chain Rule. By eliminating unnecessary algebraic expansion and simplifying the differentiation of composite power functions, the General Power Rule provides a systematic and reliable method for obtaining correct derivatives.

The findings demonstrate that the General Power Rule is applicable to various differentiable composite functions,

Table 3: Mathematical properties of the general power rule

Property	Mathematical evidence	Finding
Efficiency	Differentiates composite functions without algebraic expansion, reducing computational steps.	Simplifies the differentiation process and minimizes computation time.
Consistency	Produces derivatives equivalent to those obtained using the Traditional Power Rule and the Chain Rule when applied correctly.	Ensures mathematically equivalent results across valid differentiation methods.
Accuracy	Verified through symbolic manipulation, formal proofs, and established calculus principles.	Produces mathematically correct derivatives under appropriate conditions.

Example

Given

$$y = (x^3 + 2)^5$$

Applying the General Power Rule

$$y' = 5(x^3 + 2)^4(3x^2)$$

$$y' = 15x^2(x^3 + 2)^4$$

The derivative is obtained directly without expanding the expression, illustrating the efficiency of the rule while maintaining consistency and accuracy with established differentiation principles.

The findings indicate that the General Power Rule possesses three essential mathematical properties: efficiency,

consistency, and accuracy. It improves computational efficiency by reducing unnecessary algebraic steps, maintains consistency by producing derivatives equivalent to other valid differentiation methods, and ensures accuracy through its foundation on established principles of differential calculus. These properties support the General Power Rule as a reliable technique for differentiating composite power functions.

4. Validity and applicability of the general power rule

The fourth objective of this investigation was to determine the mathematical conditions under which the General Power Rule is valid and applicable. The analysis revealed that the rule can be applied only when the given function is expressed as a composite power function and the inner function is differentiable. These conditions ensure that both the Traditional Power Rule and the Chain Rule can be applied correctly, resulting in mathematically valid derivatives.

Table 4: Conditions for the valid application of the general power rule

Condition	Requirement	Effect of Applicability
Composite Power Function	The function must be expressed in the form $[u(x)]^n$.	Allows direct application of the General Power Rule.
Differentiability of the Inner Function	The inner function must have a defined derivative.	Ensures that the Chain Rule can be applied correctly.
Continuity within the Domain	The function should be continuous over its domain.	Supports valid differentiation and avoids undefined results.
Defined Domain	The function must satisfy its domain restrictions.	Prevents invalid or undefined derivatives.

Example

Given

$$y = (x^2 - 4)^6$$

Applying the General Power Rule

$$y' = 6(x^2 - 4)^5(2x)$$

$$y' = 12x(x^2 - 4)^5$$

Since the function is written in the form $[u(x)]^n$ and the inner function $x^2 - 4$ is differentiable, the General Power Rule is valid and produces the correct derivative.

The findings indicate that the General Power Rule is valid only when specific mathematical conditions are satisfied. These include expressing the function as a composite power function,

ensuring the differentiability of the inner function, observing domain restrictions, and maintaining continuity where required. When these conditions are met, the rule provides an efficient and mathematically accurate method for differentiating composite functions. However, if any of these conditions are not satisfied, alternative differentiation techniques may be more appropriate.

5. Limitations of the general power rule

The fifth objective of this investigation was to identify the limitations of the General Power Rule, particularly in mathematical situations where it cannot be directly applied. The analysis showed that although the General Power Rule is effective for differentiating composite power functions, it has limitations when the required mathematical conditions are not satisfied. In such cases, other differentiation techniques are necessary to obtain the correct derivative.

Table 5: Limitations of the general power rule

Mathematical situation	Limitation	Appropriate alternative method
Implicit functions	The function is not expressed explicitly in the form $[u(x)]^n$	Implicit differentiation
Piecewise-defined functions	Different function rules require separate differentiation.	Piecewise differentiation
Non-differentiable functions	The derivative does not exist at certain points	Not applicable until differentiability is established
Fractional-order derivatives	The general power rule is limited to classical differential calculus	Fractional calculus techniques

Example

Consider the implicit function

$$x^2 + y^2 = 25$$

Since the equation is not expressed explicitly as a composite power function, the General Power Rule cannot be applied

directly. Instead, Implicit Differentiation is required to determine the derivative.

The findings indicate that the General Power Rule is not universally applicable to all mathematical functions. Its effectiveness is limited to differentiable composite power functions that satisfy the required mathematical conditions.

Functions that are implicit, piecewise-defined, non-differentiable, or involve fractional-order derivatives require alternative differentiation techniques. These limitations highlight that the General Power Rule is a specialized method within classical differential calculus rather than a universal rule for all differentiation problems.

6. Comparison of the general power rule with other differentiation techniques

The sixth objective of this investigation was to compare the

General Power Rule with other differentiation techniques in terms of their mathematical foundation, applicability, efficiency, and limitations. The analysis revealed that although all differentiation methods are mathematically valid within their respective domains, the General Power Rule provides a more direct and systematic approach for differentiating composite power functions. However, its applicability is limited to functions that satisfy the required mathematical conditions, whereas other techniques remain necessary for more specialized cases.

Table 6: Comparison of the general power rule with other differentiation techniques

Differentiation technique	Primary application	Strength	Limitation
Traditional power rule	Simple power functions	Simple and straightforward	Limited to functions of the form x^2
Chain rule	General composite functions	Applicable to various composite functions	Requires identifying the inner and outer functions separately
General power rule	Composite power functions	Efficient, systematic, and reduces unnecessary algebraic expansion	Applicable only to composite power functions with differentiable inner functions
Implicit differentiation	Implicitly defined functions	Suitable for equations not expressed explicitly	Cannot be replaced by the General Power Rule
Fractional calculus methods	Fractional-order derivatives	Applicable to non-integer order differentiation	Uses different mathematical principles from classical calculus

The comparison demonstrates that each differentiation technique has a specific scope of application. The Traditional Power Rule is most appropriate for simple power functions, while the Chain Rule provides the general framework for differentiating composite functions. The General Power Rule extends these principles by offering a more efficient method for composite power functions. However, implicit differentiation and fractional calculus remain essential for mathematical problems beyond the scope of the General Power Rule.

The findings indicate that the General Power Rule complements rather than replaces other differentiation techniques. Its primary advantage lies in simplifying the differentiation of composite power functions through the combined application of the Traditional Power Rule and the Chain Rule. Nevertheless, its effectiveness depends on the mathematical structure of the function being differentiated. Consequently, selecting the appropriate differentiation technique remains essential for obtaining valid and accurate mathematical results.

Discussion

The findings confirm that the General Power Rule is derived from the combined application of the Traditional Power Rule and the Chain Rule. The Traditional Power Rule differentiates the outer power function, while the Chain Rule differentiates the inner function, allowing composite power functions to be differentiated accurately and systematically.

The verification examples involving polynomial, rational, radical, and composite polynomial functions consistently produced correct derivatives, demonstrating that the General Power Rule is applicable to different classes of differentiable composite functions. These results also show that the rule

simplifies differentiation by eliminating unnecessary algebraic expansion, reducing computational steps and minimizing possible errors.

The investigation further established that the General Power Rule is valid only when the inner function is differentiable. When this condition is not satisfied, alternative differentiation techniques must be applied.

Overall, the findings demonstrate that the General Power Rule is a valid, accurate, and efficient differentiation technique for composite functions. These results address the first research question and provide the foundation for understanding the rule's applications, mathematical properties, validity, and limitations.

Conclusion

This mathematical investigation examined the General Power Rule by establishing its mathematical foundation, applications, properties, conditions for validity, limitations, and relationship with other differentiation techniques.

The findings confirm that the General Power Rule is a logical extension of the Traditional Power Rule and the Chain Rule. It was successfully applied to polynomial, rational, radical, and composite functions, consistently producing correct derivatives while simplifying the differentiation process.

The investigation also found that the rule is efficient, accurate, and reliable when the inner function is differentiable. However, it cannot be directly applied to non-differentiable, implicit, or piecewise-defined functions, where other differentiation techniques are required.

Overall, the study concludes that the General Power Rule is a valid and systematic differentiation technique for composite functions and successfully achieved the objectives of the investigation.

Recommendations

Based on the findings and conclusions of this mathematical investigation, the following recommendations are proposed to enhance the teaching and learning of differential calculus and to provide directions for future mathematical investigations on the General Power Rule and related differentiation techniques.

- Mathematics instructors may emphasize the relationship between the Traditional Power Rule, the Chain Rule, and the General Power Rule to help students develop a deeper conceptual understanding of differentiation and its applications to composite functions.
- Students studying differential calculus are encouraged to practice applying the General Power Rule to different classes of differentiable functions, particularly polynomial, rational, radical, exponential, logarithmic, and composite functions, to strengthen their analytical and problem-solving skills.
- Future researchers may extend this investigation by examining the application of the General Power Rule to multivariable calculus, implicit differentiation, and higher-order derivatives to further explore its mathematical significance.
- Further studies may investigate the relationship between the General Power Rule and advanced topics in calculus, including fractional calculus and numerical differentiation, to determine possible extensions of the rule beyond the scope of classical differential calculus.
- Future mathematical investigations may compare the computational efficiency of the General Power Rule with other symbolic and numerical differentiation techniques using more complex mathematical models to further evaluate its effectiveness in advanced mathematical problem-solving.

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