

EXAMINE THE INDEPENDENT DISCOVERIES OF CALCULUS AND THE SUBSEQUENT RIVALRY BETWEEN ISAAC NEWTON AND GOTTFRIED WILHELM LEIBNIZ

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Abstract: The independent discovery of calculus by Isaac Newton and Gottfried Wilhelm Leibniz represents a defining milestone in the history of mathematics and science, highlighting the intellectual genius of both men and the complexity surrounding the recognition of scientific achievement in the 17th century. Newton, working in England, developed his own version of calculus, which he called the “method of fluxes,” as a way to solve fundamental problems in physics, including motion, gravitation, and rates of change. His approach was deeply rooted in physical applications and intuitive reasoning. At the same time, Leibniz, working in Germany, independently formulated calculus with a greater emphasis on mathematical rigor, formalism, and generalization. His systematic notation, including the integral (\int) and differential (dx) symbols, provided a framework that remains the standard in modern mathematics. The rivalry between Newton and Leibniz on the invention of calculus arose in a context of poor communication, nationalistic fervor and mutual distrust. Newton's major work on calculus preceded Leibniz's, as his notes and correspondence show, but the latter was the first to publish his findings in 1684 and 1686. This publication established the its notation and methods in the mathematical community. Newton, however, claimed priority based on his earlier but unpublished contributions, leading to a contentious dispute that lasted decades. National loyalties further exacerbated the conflict, with English mathematicians supporting Newton and continental mathematicians rallying behind Leibniz. This long-running controversy, known as the "Newton-Leibniz calculus controversy," had far-reaching consequences. While it created divisions within the European mathematical community, it also catalyzed rapid advances in the development and application of calculus. The controversy forced mathematicians to refine their methods, clarify concepts, and expand the theoretical foundations of the discipline. This article examines the chronology of the discoveries, the philosophical and methodological differences between Newton's and Leibniz's approaches, and the sociopolitical factors that intensified their rivalry. By examining the historical context and outcomes of this pivotal episode, the article highlights the paradox of independent discoveries: while they can lead to conflicts over priority and recognition, they often serve as catalysts for significant progress and innovation in intellectual and scientific inquiry. The Newton-Leibniz controversy not only reshaped the trajectory of mathematics, but also emphasized the interdependence of intellectual endeavors and the role of cooperation, even in the midst of rivalry.

Keywords: Discovery; Priority; Notation; Controversy; Calculus & impact

1 INTRODUCTION

The development of calculus is universally recognized as one of the most important achievements in the history of mathematics and science, providing a conceptual framework for solving problems involving change, motion, and infinity. This revolutionary mathematical tool emerged in the late 17th century, formulated independently by Isaac Newton in England and Gottfried Wilhelm Leibniz in Germany. Their discoveries, while distinct in approach and context, collectively form the basis of modern computer science. However, subsequent controversies over priority and intellectual property have not only tarnished their legacy but also affected the trajectory of mathematical progress.

Isaac Newton (1642–1727), famous for his groundbreaking contributions to physics, approached calculus primarily as a practical tool for dealing with the complexities of motion, forces, and gravitation. Rooted in his studies of celestial mechanics and the laws of motion, Newton called his system the "method of fluxes." His calculus was deeply rooted in his broader scientific investigations, including the formulation of the laws of motion and universal gravitation [1]. Newton's reluctance to publish his findings, however, meant that most of his work on calculus remained private until well after Leibniz's publication.

In contrast, Gottfried Wilhelm Leibniz (1646–1716) developed calculus from a more formal and abstract perspective. Leibniz's emphasis on notation and systematic reasoning led to the creation of the symbolic system that forms the basis of modern calculus, including the integral (\int) and differential (dx) symbols. Published in 1684 and 1686, his works on calculus were widely distributed and immediately influential, particularly among continental mathematicians [2]. Leibniz's approach emphasized generality and applicability, qualities that distinguished his work from Newton's more application-oriented framework.

The primacy dispute between Newton and Leibniz has become one of the most infamous controversies in the history of science. While Newton's notes and correspondence show that he developed his version of the calculus in 1666, decades before Leibniz's publications, the lack of dissemination has led to questions of priority. The official report of the Royal Society of 1712, written by Newton's allies, accused Leibniz of plagiarism, a charge that Leibniz vehemently denied [3]. This controversy divided the mathematical community, with English mathematicians aligned with Newton and continental scholars supporting Leibniz. The nationalist backdrop of this conflict hindered cooperation and slowed the global development of computing for decades.

This article examines the independent discoveries of calculus by Newton and Leibniz, focusing on the historical and intellectual contexts of their work. It explores the methodologies and philosophies that underpinned their approaches, highlighting important differences in their motivations and techniques. It also examines the causes and consequences of their rivalry, analyzing its impact on the spread and advancement of computing. By assessing the interplay between scientific innovation, personal conflict, and sociopolitical dynamics, this study seeks to provide a comprehensive understanding of one of the most defining episodes in the history of mathematics.

2 LITERATURE REVIEW

The independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz in the late 17th century represented a milestone in the development of mathematics and modern science. These achievements highlight the intellectual energy of the Scientific Revolution, but they also highlight the complexity of scientific competition. This extensive literature review integrates scholarly arguments and scholarly citations to provide a deeper analysis of the origins, methodologies, controversies, and legacies surrounding their contributions.

2.1 The Origin of Their Discoveries

Isaac Newton (1642–1727) and Gottfried Wilhelm Leibniz (1646–1716) are credited with developing calculus independently, but their approaches, motivations, and dissemination strategies highlight profound differences in their contributions to mathematics and science. Newton's "method of fluxes," established in the 1660s, emerged from his research on rates of change and areas under curves, largely motivated by physical problems related to motion, gravitation, and mechanics. According to Westfall (1980) [4], Newton's approach to calculus was intrinsically linked to his broader scientific pursuits, including optics and mechanics. These connections emphasized the practical and interdisciplinary nature of his work, but his reluctance to publish his findings significantly delayed its dissemination. Even in *Philosophiæ Naturalis Principia Mathematica* (1687), where his methods were used implicitly, his founding meaning was accessible only to a limited group of scholars [5]. This reluctance undoubtedly prevented the immediate impact and recognition of his contributions.

In contrast, the development of Leibniz's calculus was shaped by his commitment to mathematical correspondences and his interest in geometrical problems. His approach, formalized in the 1670s and published in *Nova Methodus pro Maximis et Minimis* (1684), introduced the integral (\int) and differential (d) notations, which remain at the heart of modern calculus. Leibniz prioritized the accessibility and systematic presentation of his methods, in order to communicate widely in the academic community. As Bos (1974) notes [6], its emphasis on notation and clarity facilitated the rapid adoption and application of calculus throughout Europe, making it an essential tool for mathematical analysis. The divergent dissemination strategies of Newton and Leibniz reflect broader themes in the history of science and mathematics. Newton's cautious approach, influenced by his solitary working style and his preference for practical applications, contrasted sharply with Leibniz's cooperative and communicative tendencies. This shift not only shaped the initial reception of his work, but also contributed to the famous conflict of priorities that followed. Modern scholarship, such as Guicciardini (2003), highlights how these differences influenced the evolution of calculus as a discipline, with Leibniz's formalism and notation proving instrumental in its standardization and eventual integration into broader mathematical frameworks.

Furthermore, the Newton–Leibniz controversy highlights the role of communication in scientific progress. If Newton's calculus was based on physical applications and theoretical innovations, its potential was limited by its limited diffusion. In contrast, Leibniz's efforts to formalize and share his discoveries illustrate how effective communication can amplify the impact of scientific ideas. Recent studies indicate that the synthesis of Newtonian and Leibnizian approaches ultimately enriched the development of calculus [7], combining physical intuition and mathematical rigor to form a cornerstone of modern science and engineering. Thus, the legacy of their work lies not only in the methods they created, but also in the way they navigated the intellectual and cultural landscapes of their time.

2.2 Differences in Approach

Newton's and Leibniz's methods in the development of differential and integral calculus reflect their distinct intellectual orientations and have profoundly shaped the trajectory of mathematics and its applications. Newton's approach, deeply rooted in a geometric framework, was characterized by his concept of "fluxes," which described the instantaneous rate of

change of a variable with respect to time. Whiteside (1964) points out that Newton's reliance on geometric intuition and his use of limits made his calculus particularly well suited to solving problems in classical mechanics [8], such as motion and forces. This framework corresponds to Newton's primary interest in physical phenomena, especially the laws of motion and gravitation.

However, this geometric basis was less adaptable to abstract or generalized mathematical contexts, limiting the flexibility of Newton's methods beyond specific applications in physics. In contrast, Leibniz developed a symbolic and systematic calculus that revolutionized mathematical abstraction. His notation, which includes symbols such as \int and $\frac{d}{dx}$, remains fundamental to modern mathematics and has proven to be a versatile tool across disciplines. As Kline (1972) has noted [9], Leibniz's symbolic approach allowed for a level of generalization and abstraction that was not possible with Newton's geometric framework. Leibniz explicitly codified the rules of differentiation and integration, which allowed for the systematic exploration of mathematical problems. These rules provided a clear and universal structure that facilitated the widespread adoption of his methods, particularly in fields such as engineering, economics, and the natural sciences.

The philosophical divergence between Newton and Leibniz also played an important role in determining their methodologies. Newton saw mathematics as a way to describe and understand the natural world. His work was therefore heavily influenced by empirical observations and physical reasoning. Rather, Leibniz approached mathematics as a universal language of reasoning, capable of encompassing both physical and metaphysical domains. Breger (1994) points out that this broader perspective led Leibniz to favor formalism and systematic structure in his mathematical work [10], reflecting his belief in the universal applicability of logical principles. This philosophical divergence not only influenced their approaches to calculus, but also fueled the infamous controversy between Newton and Leibniz over the invention of calculus. Newton's calculus was initially limited to his personal research and communicated mainly through private correspondence and unpublished manuscripts, while Leibniz published his findings systematically and openly. This change in dissemination further exacerbated the conflict, as the symbolic calculus developed by Leibniz was soon accepted throughout Europe, eclipsing Newton's developments.

Looking back, the methodologies of both mathematicians have left lasting legacies. Newton's emphasis on geometry and physics laid the foundation for classical physics, while Leibniz's symbolic system became the foundation of modern mathematical analysis. The historical interaction between these approaches highlights the richness of computer science as a discipline and highlights the influence of philosophical orientations on scientific innovation. Recent research continues to explore this dynamic, highlighting how the methodological and philosophical choices of these pioneers shaped the evolution of mathematics [5, 11].

2.3 Conflict of Priority

The debate over the priority of the discovery of calculus remains one of the most controversial episodes in the history of mathematics, characterized by a complex interplay between personal rivalries, nationalist fervor, and the broader intellectual culture of the 17th and early 18th centuries. The controversy officially erupted in 1699 when English mathematicians accused Leibniz of plagiarizing Newton's unpublished work on flows. This accusation gained momentum, culminating in the Royal Society's inquiry in 1712, which produced the famous *Commercium Epistolicum*.

This document, heavily influenced by Newton - who was then president of the Royal Society - claimed that Leibniz's calculus was derived from Newton's earlier manuscripts [2]. However, the impartiality of this report has been widely questioned, as Newton's dominant role in the proceedings introduced considerable bias. Modern scholars, however, tend to favor the view that Newton and Leibniz developed their ideas independently. Stedall (2012) points out that the mathematical culture of the 17th century [12], marked by advances in algebra, geometry, and infinitesimal techniques, created a fertile intellectual environment for the emergence of calculus. Both Newton and Leibniz built on the foundations laid by predecessors such as Descartes, Fermat, and Barrow, who had explored the relationships between tangents, areas, and infinite processes.

Although Leibniz had access to some of Newton's early manuscripts, there is no convincing evidence that he directly borrowed or copied Newton's ideas. Rather, Leibniz's symbolic calculus represents a distinct and innovative formulation that evolved from his own intellectual investigations and philosophical inclinations. The rivalry between Newton and Leibniz was also fueled by nationalist tensions, particularly between England and continental Europe. As Feingold (1990) notes [12], the calculus controversy became emblematic of a wider cultural and intellectual competition, with Newton's English supporters and Leibniz's continental allies framing the debate as a struggle for intellectual supremacy. This polarization obscured the true intellectual achievements of both men and delayed the wider acceptance and synthesis of their ideas. The ambiguous nature of the conflict also prevented the development of a unified mathematical framework, with English mathematicians largely adhering to Newton's geometric methods, while the continental tradition adopted Leibniz's symbolic approach.

Recent studies have sought to move beyond the polemics of the controversy to better appreciate the independent contributions of the two figures. Guicciardini (2011) argues that Newton's and Leibniz's methods were shaped not only by their respective intellectual contexts, but also by their divergent philosophical orientations: Newton's emphasis on physical applications, while Leibniz's on mathematical formalism and abstraction. This divergence, although initially a source of

conflict, ultimately enriched the development of calculus as a discipline, leading to its adoption in diverse fields, from mechanics to economics.

The conflict over the priority of computation also highlights broader issues in the historiography of mathematics, particularly the role of intellectual networks, national identity, and the transmission of knowledge. Gray (2021) points out that the controversy highlights the importance of recognizing mathematics as a cumulative and collaborative enterprise, where independent discoveries often emerge from shared cultural and intellectual currents. Far from being a zero-sum contest, the contributions of Newton and Leibniz collectively laid the foundations of modern mathematical analysis, demonstrating the interplay of individual genius and collective progress in the history of science. In retrospect, the calculus controversy serves as a case study in the complexity of intellectual primacy and the sociopolitical dimensions of scientific discovery. Its determination in favor of mutual recognition of independent achievements not only honors the legacies of Newton and Leibniz, but also illustrates the broader processes by which scientific knowledge evolves and is contested.

2.4 Influence in Mathematics and Inheritance

The contributions of Isaac Newton and Gottfried Wilhelm Leibniz to the development of calculus fundamentally reshaped the trajectory of mathematics and science, influencing subsequent generations of mathematicians, scientists, and engineers. While the rivalry between these two figures has often overshadowed the specifics of their individual contributions, it is essential to appreciate the long-term impact of their work on various scientific fields, especially classical mechanics and mathematical analysis.

Newton's development of calculus, often called the "method of flows," was closely linked to his revolutionary laws of motion and his law of universal gravitation. These laws provided a comprehensive mathematical framework for understanding physical phenomena, laying the foundation for classical mechanics. Newton's calculus, with its emphasis on rates of change and relationships between variables, was central to formulating the laws of motion that govern the behavior of objects under force. As Guicciardini (2003) points out, Newton's work enabled practical applications such as the prediction of planetary orbits and the analysis of fluid dynamics. His methods helped solve real-world problems by providing precise mathematical tools for modeling the natural world, bridging the gap between abstract theory and empirical observation.

Leibniz, on the other hand, developed a more systematic and formalized approach to calculus, which is the foundation of the modern notation used today. His notation, introduced in the late 17th century, revolutionized the way mathematicians conceptualized and communicated mathematical relationships. The Leibnizian notation system, with its clear and concise symbols for differentiation and integration, made calculus more accessible and flexible for further development [6]. In contrast to Newton's emphasis on physical intuition and geometric principles, Leibniz's approach was rooted in symbolic logic, which facilitated the extension of calculus into broader areas of mathematical analysis. This shift allowed Leibniz's ideas to be more readily adopted and adapted by later mathematicians, notably Johann Bernoulli and Leonhard Euler, who used his notation to expand the field of calculus into the fields of differential equations and mathematical physics.

Leibniz's systematic rules of differentiation and integration provided the language needed to articulate the fundamental principles of mathematical analysis. His approach laid the foundation for the development of key concepts in differential equations and mathematical physics, which became fundamental to the study of dynamical systems, heat flow, and wave propagation. As such, Leibniz's symbolic contributions were integral to the development of a new mathematical framework capable of dealing with more complex and abstract problems in science and engineering. Today, historians and mathematicians largely recognize the independence of Newton and Leibniz's discoveries, although it is clear that they worked in parallel to address similar mathematical challenges. Despite their different methodologies—Newton's more geometric and philosophical, Leibniz's more algebraic and formal—their work advanced the field of mathematics in profound ways. Both men encountered similar problems related to the concept of the derivative and integral, and despite their different approaches, they arrived at essentially the same basic principles of calculus. This highlights not only their individual genius but also the universality of the mathematical truths they discovered.

The rivalry between Newton and Leibniz, while unfortunate, serves as a historical reminder of the competitive nature of scientific progress. It emphasizes the importance of intellectual exchanges and the need for cooperation and communication in the advancement of knowledge. Their disagreements, although bitter, eventually led to a deeper understanding of the importance of rigor, coherence, and clarity in the formulation of scientific ideas. The development of calculus as a discipline flourished precisely because of the tensions and debates that arose between the two thinkers, demonstrating the dynamic interplay between competition and cooperation in the scientific process. The legacies of Newton and Leibniz thus show how such intellectual rivalries can drive innovation and shape the future of scientific thought.

The independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz are a perfect example of the intellectual complexity that reigned during the Scientific Revolution. These two scholars, working separately and almost simultaneously in the late 17th century, reached similar conclusions about the mathematical principles that form the basis of calculus, albeit with differences in notation and methodology. Their achievements, while revolutionary in themselves, were also marred by intense rivalry, especially when conflicts arose over priority and recognition. This rivalry illustrates the

competitive nature of intellectual progress, where the interaction between individual genius and the broader intellectual currents of the time played an important role in shaping the development of new ideas.

Studies such as Hall (1980) and Guicciardini (2003) have shed light on how these parallel developments, despite their controversial context, have enriched the mathematical tradition. Newton and Leibniz's work in calculus paved the way for advances in physics, engineering, and other sciences, creating a lasting legacy that continues to influence modern science and technology. Understanding their contributions in their historical context not only sheds light on the personalities involved but also provides valuable insights into the dynamics of scientific discovery. Their work shows how scientific innovation often emerges from collaboration and competition within a larger intellectual environment, highlighting the evolution of knowledge in the context of personal rivalry and collective progress.

An examination of their contributions shows that their discoveries were not isolated or accidental, but emerged from a broader movement of scientific thought and research. Newton's work in physics, particularly his laws of motion and gravitation, was closely linked to his development of calculus, which he used as a tool for understanding the natural world. Leibniz, for his part, developed his approach to calculus from a more abstract perspective, focusing on its application to mathematical theory. The two approaches, while different, demonstrated the power of computation to explain and predict phenomena in nature, ultimately influencing the trajectory of modern mathematics and physics.

The rivalry between Newton and Leibniz, although initially destructive, eventually led to the wider dissemination of their ideas and the eventual standardization of calculus, securing its place in the scientific canon. The discovery of computation, in this sense, highlights the tension between individual cognition and the collective advancement of knowledge, providing a valuable lens through which to examine the nature of scientific discovery. His work continues to shape the fields of mathematics, science, and engineering, reinforcing the idea that intellectual progress is often the product of competition and collaboration within a dynamic historical context.

3 RESEARCH METHODOLOGY

The methodology used in this research includes a detailed historical and comparative analysis of the independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz, as well as an exploration of their rivalry. The research followed a multi-step approach, beginning with a review of primary and secondary sources, including historical documents, letters, and publications by both scientists. These sources were analyzed to trace the development of each individual's calculus, focusing on their respective methods, concepts, and mathematical innovations.

A comparative analysis was conducted to highlight the similarities and differences in Newton's and Leibniz's approaches to calculus. This involved examining their published works, such as Newton's *Philosophiæ Naturalis Principia Mathematica* and Leibniz's papers on differential and integral calculus, to understand their distinct systems, techniques, and philosophical implications. The study also considered the broader historical context in which these discoveries were made, such as the scientific environment of the 17th century, the political and intellectual climate, and the influence of early mathematicians on their work.

The study also explored the rivalry between Newton and Leibniz, focusing on the conflicts of priority and the controversies that followed between their followers. The methodology involved examining letters, official documents, and reports from both sides to assess how the conflict escalated, affected the scientific community, and shaped the development of mathematics. The analysis also included an exploration of the long-term impact of this rivalry on the institutionalization of computing and its eventual acceptance in the scientific community. By synthesizing historical accounts, biographical details, and scholarly analysis, this research aims to provide a balanced understanding of the contributions of the two mathematicians and the intellectual and personal tensions that accompanied their rivalry.

4 THEORETICAL FRAMEWORK

The study of the independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz, and their subsequent rivalry, is framed by several important theories. These theories provide a basis for understanding the mathematical and philosophical dimensions of their discoveries, as well as the intellectual conflict that followed.

4.1 Theory of Limits and Continuity

The development of calculus by Newton and Leibniz is based on the theory of limits and continuity, a fundamental concept in the study of functions. This theory allows for the exact determination of rates of change and the accumulation of quantities, which are at the heart of differential and integral calculus. Both mathematicians used the idea of limits, although they took slightly different approaches. Newton's method focused on instantaneous rates of change, which he used to analyze motion, while Leibniz's notation emphasized the sum of infinitesimal differences. Limit theory serves as the backbone for understanding the mathematical innovation of calculus.

4.2 Mathematical formalism vs. Intuitionism

The rivalry between Newton and Leibniz can also be analyzed through the prism of mathematical formalism and intuitionism. Newton's approach to calculus was more intuitive and related to physical phenomena such as motion and change. He saw calculus as a way to solve physical problems. In contrast, Leibniz's approach was more formal and abstract, emphasizing symbolic manipulation and the development of a coherent mathematical language. The difference between their approaches highlights the tension between formalism, which emphasizes rigor and structure, and intuitionism, which emphasizes the role of the human mind in understanding mathematical truths.

4.3 Theory of Invention vs. Discovery

A philosophical debate surrounding the development of computing involves whether it is an invention or a discovery. In this context, the theory of invention vs. discovery assumes importance. Newton and Leibniz claimed to have independently "discovered" the principles of calculus, but the question remains whether these principles were already inherent in the structure of mathematics or whether they were created by intellectual genius. This theory is essential to understanding the intellectual legitimacy of their claims and the implications for the history of mathematics.

4.4 Theory of Intellectual Property and Priority Conflicts

The rivalry between Newton and Leibniz was not only a mathematical conflict, but also a conflict over intellectual property and academic priority. This theory examines the question of who is given credit for inventing calculus. Newton, who had developed his ideas earlier but had not published them immediately, and Leibniz, who had published his work earlier, both sought recognition for their contributions. This conflict led to accusations of plagiarism and had a lasting impact on how intellectual property rights and academic recognition are understood.

4.5 Theory of Mathematical Universality

Another important theory in this context is the idea of mathematical universality, the idea that some mathematical truths exist regardless of human invention and can be discovered by different people at different times. This theory is particularly important for the independent discoveries of calculus by Newton and Leibniz, who reached similar conclusions without collaborating or even being aware of the work of the other. The theory of mathematical universality suggests that the laws of mathematics are universal and can be discovered through various paths, leading to a better understanding of the nature of mathematical truths.

Distinct theory guiding the research: The research is primarily guided by the theory of intellectual property and priority conflicts, as it examines the profound impact of the rivalry between Newton and Leibniz on the development of calculus and on the broader history of scientific discovery. This theory provides a framework for understanding the social and intellectual dynamics that shaped the outcome of the conflict, influencing how mathematical discoveries are valued and how the scientific community deals with issues of priority and intellectual property. It also highlights the broader implications of the relationship between individual contributions and collective knowledge in the history of science.

5 DISCUSSION

The independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz in the late 17th century represented a turning point in the history of mathematics. The two men, working separately and without knowledge of each other's work, developed the basic principles of calculus, but their approaches and notes were markedly different. This led to a bitter and protracted conflict over priority, the results of which continue to shape the legacy of computing today.

6.1 Isaac Newton's Approach to Calculus

Newton's development of calculus, which he called the "method of fluxes," was largely motivated by his work in physics. Beginning in the mid-1660s, Newton sought a mathematical framework to describe the dynamic nature of the physical world. He focused on understanding motion and change, especially the instantaneous rates at which quantities change, which would be essential for his later formulation of the laws of motion and universal gravitation. Newton's approach was closely integrated with his physical theories, and he used calculus primarily as a tool for solving real-world problems, such as calculating the orbits of celestial bodies and understanding the dynamics of forces.

The central idea of Newton's method was the notion of "flux" (quantity in motion) and "flux" (rate of change of a quantity), which can be seen as an early formulation of the derivative. Newton developed the concept of the limit, which allowed for understanding instantaneous rates of change, although he did not explicitly define it in the modern sense. His work in calculus was used primarily in his study of physics as an abstract mathematical theory. However, Newton did not publish his work until later in his life, and even then he kept many of the methods he used secret. This would have led to a conflict with Leibniz over priority of discovery. Newton's emphasis on the physical applications of calculus, rather than the formalization of the method itself, was another distinguishing feature of his approach compared to Leibniz.

6.2 Gottfried Wilhelm Leibniz's Approach to Calculus

Leibniz, working independently of Newton, developed his own version of calculus in the late 1670s and early 1680s. Leibniz's approach to calculus was more abstract and formal than Newton's, emphasizing the manipulation of symbols and the development of mathematical operations. Unlike Newton, who used calculus primarily as a tool for solving physical problems, Leibniz treated it as a mathematical theory in its own right, emphasizing the general principles governing rates of change and accumulation.

Leibniz introduced the notation that remains the standard in calculus today. His integral sign (\int) symbolized the concept of summation, derived from the Latin word "summa", while his notation for differentiation, using "d" as the symbol for differentials (e.g., d/dx), provided a more direct and systematic way to express the process of differentiation. These notes were a significant advance over Newton, as they made the concepts of calculus more accessible and usable for future generations of mathematicians.

Leibniz's work was published in 1684 in *Acta Eruditorum*, a leading academic journal of the time, where he presented his findings in a formal and systematic manner. He envisioned calculus as a tool for solving problems in a wide range of scientific fields, not just physics, making it an important mathematical development in its own right. His approach was closer to modern mathematics, emphasizing rigor and precision in symbolic manipulation.

6.3 Rivalry and Conflict

The rivalry between Newton and Leibniz began to intensify around 1699 when the question of priority over the invention of calculus became a point of contention. A letter to the Royal Society from a Newton supporter accused Leibniz of plagiarizing Newton's unpublished work. Newton, who had not yet published his work, claimed that Leibniz had seen his private manuscripts and copied his methods. The Royal Society, under Newton's influence, investigated the matter and eventually sided with Newton, claiming that he had been the first to discover calculus.

However, this decision was not accepted by everyone. Leibniz's supporters in Europe strongly disagreed, and the issue became a source of strong national pride. English mathematicians supported Newton, while those on the continent rallied around Leibniz. The conflict escalated, with both sides accusing each other of dishonesty and intellectual theft. The rivalry between the two men, as well as their supporters, led to a period of division in the mathematical community.

The matter was further complicated by the fact that both men had independently developed similar ideas at the same time. Newton had developed his method of fluxions in the 1660s, but did not publish it until much later, while Leibniz's work had been published many years earlier. Despite the obvious similarities between their work, the dispute has centered on priority, with Newton's lack of official publication becoming a key point of contention.

6.4 Resolution and Legacy

Although the dispute over the discovery of calculus was never fully resolved during their lifetimes, modern scholars tend to agree that Newton and Leibniz independently arrived at the same basic principles of calculus. Over time, mathematicians have come to appreciate the contributions of both men, with Newton's work recognized for its fundamental role in physics and Leibniz's contributions seen as crucial to the formalization and spread of calculus as a theory.

Leibniz's notation, more systematic and flexible, became the standard and is still used today, helping to shape the development of modern calculus. Furthermore, Leibniz's approach, which emphasized symbolic manipulation and abstraction, provided the basis for the formal mathematical structures that dominated 18th and 19th century mathematics. In turn, Newton's contributions to physics, particularly his laws of motion and universal gravitation, formed the basis of classical mechanics and continued to influence scientific thought for centuries.

The rivalry between Newton and Leibniz, while unfortunate, had a lasting impact on the development of mathematics and science. It highlights the complexity of intellectual history and underscores the importance of rapid publication in the scientific process. Ultimately, both men made monumental contributions to the understanding of computation, and their work continues to shape mathematics and physics to this day.

This dispute also serves as a warning about the dangers of intellectual isolation and the importance of collaboration and communication in the scientific community. Despite their personal enemies, the independent works of Newton and Leibniz helped advance humanity's understanding of the world and laid the foundation for the future of mathematics.

6 RESEARCH GAPS

Future research on the independent discoveries of calculus and the rivalry between Isaac Newton and Gottfried Wilhelm Leibniz could uncover several key gaps:

- (1) External influences: examining how sociopolitical, cultural, and philosophical contexts influenced their work.
- (2) Collaborative ideas: The study of indirect intellectual exchanges and wider influences from the scientific community.
- (3) Long-term mathematical impact: Learn how his work shaped the development of later mathematical fields.

- (4) The effect of rivalry on science: Evaluate how rivalry influenced acceptance and cooperation in the early development of computer science.
- (5) Philosophical and ethical issues: Investigate ethical issues related to intellectual property and scientific priority.
6. Gender and Nationalism: Studying how national pride and gender factors have influenced scientific rivalry and discourse.
- (6) Interdisciplinary Impact: The study of how computing has affected fields beyond mathematics, such as economics and biology.
- (7) Modern reappraisal: using digital tools to reassess the nature and impact of rivalry.
- (8) Cross-cultural perspective: studying the impact of non-Western mathematical traditions on the development of calculus.
- (9) Correspondence and rivalry: analyzing how letters and rhetoric shape public opinion and scholarly communication.
- These research gaps offer opportunities to better understand the impact of rivalry in the history of science and the evolution of mathematical thought.

7 CONCLUSION

The independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz marked one of the most important and controversial moments in the history of mathematics. Their work laid the foundation for modern calculus, revolutionizing the study of change, motion, and the area of applied mathematics still used today in physics, engineering, economics, and beyond.

Isaac Newton, known primarily for his contributions to physics, developed the principles of calculus in the late 17th century as a tool for solving problems related to motion and rates of change, particularly in his study of planetary motion and the laws of motion. Newton called his version the "method of fluxes," emphasizing the concept of change over time. His work was closely linked to his physical theories, such as gravity, and was largely a byproduct of his efforts in theoretical physics. In contrast, Gottfried Wilhelm Leibniz, a German mathematician, independently developed his own version of calculus at the same time. Leibniz's approach focused on formalizing the process of differentiation and integration, developing a notation system that was widely adopted. His notation, particularly the use of the integral (\int) and differential (d) symbols, remains the standard for modern calculus. Unlike Newton, Leibniz approached calculus from a more formal and abstract perspective, seeking to understand the mathematical foundations of change itself.

The rivalry between Newton and Leibniz, which developed into one of the most famous intellectual conflicts in history, arose from claims of priority over the invention of calculus. The results of both men were remarkable, but the case became entangled in national pride, academic politics, and personal animosity. Newton's supporters, especially in England, claimed that Newton had discovered calculus first, while Leibniz's supporters in Europe argued that Leibniz's work was independent and more refined. The Royal Society, which Newton led at the time, sided with Newton, condemning Leibniz for plagiarism, although there is no convincing evidence that Leibniz had seen Newton's unpublished manuscripts. Leibniz, in turn, accused Newton's disciples of stealing his work.

This bitter conflict had lasting effects on the development of mathematics. Although Newton and Leibniz both contributed to the foundation of calculus, the rivalry delayed the widespread acceptance and spread of calculus in Europe, with English mathematicians largely adhering to Newtonian methods and continental scholars favoring Leibniz's approach. The debate over priority continued for years, damaging the reputations of both.

Ultimately, the contributions of both men were recognized as essential to the development of calculus. Modern historians of mathematics agree that, while Newton's work on calculus was closely linked to his physical theories and empirical methods, Leibniz's approach was more systematic and laid the foundation for much of the later formalization of calculus. Today, Newton and Leibniz are credited with the independent discovery of calculus, and their notes are used interchangeably, recognizing the importance of their parallel work. In conclusion, the independent discoveries of calculus by Isaac Newton and Gottfried Wilhelm Leibniz represent a pivotal moment in the history of mathematics, marked by innovation, rivalry, and reconciliation. The legacy of their work shaped the course of mathematics and science, and their contributions remain central to many fields of study. Despite the severity of their disagreement, their intellectual achievements transcended the conflict, with both men known as the co-founders of calculus.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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