CHAPTER 1

Introduction: Relationships and Connections Between Literature and Mathematics

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"A good preface must be at once the square root and the square of its book" (Schlegel [1797] 2003, p. 239). This statement by the German poet Friedrich Schlegel (1772–1829) is an example of a literary writer drawing on mathematics to communicate the ideal aim of a written text—calling up associations of mathematics with truth, clarity, and rigidity as well as implying the impossible: the "quadrature of the circle" of simultaneously getting to the root or core of a book as well as going far beyond its range by "multiplying it with itself." Mathematically, Schlegel's condition has the number 1 as its nonzero solution: the root of 1 is 1, and the square of 1 is 1. Figuratively, Schlegel's "good preface" would thus be the book itself. We will follow this "mathematically deduced" conclusion and let the collection of essays speak for itself but also aim to use this introduction—knowing full well that we will inevitably fail to square this circle—to both address the fundamentals of relations between literature and mathematics and to give a broader context for the chapters to follow.

Literature and mathematics might seem to constitute entirely different domains of knowledge, practice, and meaning. Literature is often associated

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with subjective, individual experience, emotional depth, and the vagaries of human life, and as produced and read in particular historical, cultural, and social contexts. In contrast, mathematics is commonly seen as a system of eternal truths that are established by objective, rigorous methods employed in a steady accumulation of knowledge. Where literature is at least theoretically accessible to all literate readers and might develop its greatest power and appeal when giving rise to various interpretations, mathematics is celebrated for its certainty and precision and sometimes revered as the realm of geniuses. The chapters in this Handbook vividly demonstrate that these stereotypes and associations are at best half of the story. Neither literature nor mathematics lends itself to easy characterization, both fields experience remarkable changes, crises, and unresolved questions, and the relation between them is not one of clear-cut contrast but includes manifold connections, intricate parallels, and creative borrowings. This Handbook addresses interrelations of literature and mathematics in five categories, which work to organize and group together the chapters to follow. Like any categorization, the five groups can only delineate rough tendencies, cannot hope to cover all aspects in a broad field, and do not do justice to many of the chapters as these are wide-ranging and could be included in several or even all of the parts "Mathematics in Literature," "Mathematics and Literary Form," "Mathematics, Modernism, and Literature," "Relations between Literature and Mathematics," and "Mathematics as Literature."

Mathematics in Literature

The first part presents chapters that examine literary texts' employment of mathematics on the levels of plot and language, as topic, theme, and metaphor. This can include characters who practice mathematics as a profession, direct discussions of mathematical problems, and also the use of mathematical vocabulary and symbols. While some texts employ numbers to stand for the threat of inhuman rationalization, others introduce them in positive contexts as allowing for order or draw on the metaphorical potential of irrational numbers or imaginary numbers to suggest the "mathematically proven" existence of realms beyond reason and physical reality. Similarly, simple counting and quantification can have positive as well as negative implications: the successive reduction of King Lear's knights in Shakespeare's play suggests the unstoppable development of a mathematical series and the power that comes with commanding numbers (see Chapter 22 by Travis Williams). The protagonist in Samuel Beckett's *Molloy* experiences the sense of order and control that counting and quantification can provide when he collects sixteen stones and attempts to rotate them between his four pockets in such a way as to take them out in a specific order. At the same time, the calculation of his rate of farting as being one fart every 3.62 minutes suggests the absurdity of quantifying life (see Chapter 18 by Chris Ackerley). The lures and dangers of quantifying and calculating probabilities have a presence in literature at least since the Middle Ages (see Chapter 2 by David Baker) and show their sometimes sterile, inhuman aspects in financial speculation and profit-making projects such as those of the character Merecraft in Ben Jonson's *The Devil Is an Ass* (see Chapter 3 by Joe Jarrett).

The incorporation of mathematical symbols in literary texts showcases, in an immediately visible way, the differences between these systems of notation. Charles Bernstein's poem "Erosion Control Area 2" is creatively typeset and includes symbols from mathematics throughout:

> Clothe ≤ ma
> oμ β wolμ iε
>   WhicΦ t∩ ou ≥ (Bernstein 1996, p. 17).[1]

The focus here is on the visual impression of these mathematical symbols rather than their sound or meaning, and their strangeness draws attention to the materiality of the text and the fact that words in alphabetical letters similarly do not give immediate access to meaning but are printed symbols on paper. The Russian avant-garde writer Velimir Khlebnikov (1885–1922) employs the symbol for an imaginary number, $\sqrt{-1}$, in his short prose piece "We Climbed Aboard" (1916): "We climbed aboard our $\sqrt{-1}$ and took our places at the control panel" (Khlebnikov 1989, p. 82). The mathematical symbol stands out from ordinary printed letters and visually expresses the imaginary position above everyday reality that allows the speaker and the poem to leave reality behind and observe how "centuries of warfare passed before me" (p. 82) (see Chapter 7 by Anke Niederbudde). While $\sqrt{-1}$ is a well-known mathematical symbol and it easily lends itself to associations with imaginary and fictional domains, Thomas Pynchon's novel *Gravity's Rainbow* (1972) displays a partial differential equation that readers cannot be expected to understand but that visually communicates that complex mathematics is involved in the development of the V-2 rocket during the Second World War (see Chapter 9 by Stuart Taylor).

The term "imaginary number," which was introduced by René Descartes in *La Géométrie*, an appendix to *Discourse on Method* (1637), implies that this mathematical entity has no correspondence in reality while other numbers have a direct relation to the physical world. The idea of mathematics as the language of the book of nature (Galileo 1960, pp. 183–84) came under increasing pressure during the nineteenth century when mathematical concepts seemed to leave reality behind, for example, by formulating a four-dimensional space that goes beyond the three dimensions that can be physically experienced. Mathematically, the fourth, fifth, or sixth dimension does not differ from the first three, but literary texts, as well as occult and spiritual movements, interpreted further dimensions in mathematics as proof of a realm beyond material existence. In Joseph Conrad and Ford Madox Ford's *The Inheritors* (1901) the fourth dimension harbors a superhuman race, and in *The Time Machine* (1895) by H. G. Wells, it is understood as time and can be manipulated to travel into the future and the past. While the mathematics of higher dimensions was taken to point to realms beyond physical existence, other developments showed long-established methods of calculation to lead to inadequate descriptions of the world: while Euclidean geometry works well to calculate triangles and spheres, "[c]louds are not spheres and mountains are not cones," as Benoît Mandelbrot (1924–2010) put it ([1977] 1982, p. 1). Mandelbrot's fractal geometry, which he developed in *The Fractal Geometry of Nature* (1977), can be used to describe more complex natural systems. As Chapter 8 by Alex Kasman demonstrates, fractal geometry and chaos theory appear in literary fiction, often, but not always, metaphorically or to take advantage of nonmathematical properties of these areas.

While Mandelbrot proposed a geometry better suited to describe the physical world than the geometry formulated by Euclid in the third century BCE, the absolute truth of Euclidean geometry had already come under attack in the nineteenth century when Nikolai Lobachevsky (1792–1856) and János Bolyai (1802–1860) described an alternative geometry which does not rest on the so-called Parallel Postulate. Euclidean geometry was mainstay in mathematics education, particularly in the nineteenth century, and literary texts refer to it across the centuries (see Chapter 5 by Alice Jenkins). In the early fourteenth century, Dante appealed to the classical problem of squaring a circle with only using "Euclidean tools," a straightedge and a compass, and its presumed impossibility, as a metaphor for humans' inability to understand the Incarnation in Christianity, and this problem reappears in later literary texts (see Chapter 10 by Robert Tubbs). In the Romantic period, Euclid's *Elements* inform William Wordsworth's "Arab Dream," (see Chapter 4 by Dan Brown), as well as Samuel Taylor Coleridge's poem "A Mathematical Problem" (1840), which begins:

> On a given finite Line
> Which must no way incline;
> To describe an equi--
> --lateral Tri--
> --A, N, G, L, E. (Coleridge 1840, p. 24)

The poem goes on with the proof of Proposition 1 of Book I of the *Elements*, which describes how to construct an equilateral triangle on a given line segment, and, considering that many men encountered Euclid as a profound presence in their mathematics education, alludes to a commonly experienced type of mathematical problem in the nineteenth century. While Euclidean geometry thus works as a "language" that connects many Victorians, access to mathematical education for girls and children from the working class was very limited—a fact that George Eliot addresses in several of her novels (see Chapter 6 by Derek Ball). Tensions between understanding mathematics as universal language and knowledge, and considering it in specific historical, cultural, and social contexts grow more acute in the twentieth century (see below).

Mathematics and Literary Forms

The chapters in the second part address ways in which literary texts engage with numbers and other mathematical constructs through their forms. Literary form can appeal to readers through its regularity but also by breaking with order and allowing for creative fluidity, and formal restraint can be limiting as well as lead to unforeseen results and inspire new structures. Poetry, which often plays with establishing and breaking regularity in rhyme, rhythm, and stanza structure, is a particularly apt genre for considering mathematics and literary form. In Chapter 11, Jason Hall shows that poets and metrical theorists across the centuries use mathematical vocabulary and paradigms to explain the organization of poems and draw on mathematics for theories of ratio, harmony, and abstraction. Mathematical structures can also play a role in the production of literature even if these are no longer visible in the end result. The Oulipo, a group of writers and mathematicians founded in 1960, aimed to "propose new 'structures' to writers, mathematical in nature, or to invent new artificial or mechanical procedures that will contribute to literary activity: props for inspiration as it were, or rather, in a way, aids for creativity" (Queneau 1986, p. 51). This included imposing constraints on literary practice, for example, in Jacques Jouet's "metro poems," composed on the Parisian metro in the time between two stops. While the structure of the metro poems is not overtly mathematical, their number and lengths depends on "chance," determined by the time between stops and the number of stops on the line. *One Hundred Thousand Billion Poems* (*Cent mille milliards de poèmes*, 1961) by Raymond Queneau consists of ten sonnets, which are written so that if the first line of any sonnet is combined with the second line of any sonnet and so forth, you will obtain a new sonnet, so that the book contains 10^{14} possible poems (see Chapter 13 by Warren Motte on Oulipian mathematics, and Chapter 12 by Alison James on relationships between chance, numbers, and literary form). The appeal of unpredictability and open-endedness that mathematical models and metaphors can provide also shows on the theater stage, even if the abstract nature of mathematics might seem to contradict the presence and immediacy of the theater (see Chapter 14 by Liliane Campos). Moreover, and connecting to the Oulipo members' interest in the role of mathematics for writing and creativity, mathematics can provide models for and help understand forms of creative practice, including relationships between nonlinearity, writing and language, and creative process (see Chapter 15 by Ira Livingston).

Examining mathematics and literary form in his monograph *The English Renaissance Stage: Geometry, Poetics, and the Practical Spatial Arts 1580–1630* (2006) has led Henry S. Turner to the conclusion that what literary scholars usually understand as "form" is in need of reconsideration, not least by accounting for mathematical notions of form. According to Turner, traditional concepts of form can be grouped into four categories—namely, stylistic notions of form, such as verbal patterning or metrical language; structural notions of form that include plot and stanzaic structures; material notions such as the page size and layout; and social notions of form that include class organization, economic production, and political systems (Turner 2010, pp. 580–81). Turning to mathematics and mathematical form can, so Turner argues, help rethinking these traditional concepts that are overly focused on linguistic and textualist models. In *Unified Fields: Science and Literary Form* (2014) Janine Rogers discusses various sciences, yet she also considers the specific relation of mathematics and literary form and argues for paying greater attention to the fact that form is not merely a product of knowledge, but that it is a way of knowing and source of meaning in its own right. This epistemological "*function* of form … is shared by both science and literature" (Rogers 2014, p. xvii), and mathematical form in particular shares with its literary counterpart a focus on unity and beauty (Rogers 2014, pp. 48–65). Indeed, in the early twentieth century the popular science writer J. W. N. Sullivan expressed a common idea when identifying similarities between mathematics and art in their ability to develop outside of experience and with a focus on beauty: "Although the simple, primary mathematical ideas were doubtless originally suggested by experience, the mathematician's development of them has been very largely independent of the teachings of experience. He has been guided chiefly by considerations of form—a criterion which is probably, at bottom, aesthetic" (Sullivan 1933, pp. 243–44). The idea that mathematics is focused on form, rather than deriving from experience or representing the physical world, developed rapidly in the nineteenth century. For example, Augustus De Morgan (1806–1871) explained: "no word nor sign of arithmetic or algebra has one atom of meaning throughout this chapter, the object of which is *symbols, and their laws of combination*" (1849, p. 101; original emphasis). And Henri Poincaré (1854–1912) declared in 1902: "Mathematicians study not objects, but relations between objects; the replacement of these objects by others is therefore indifferent to them, provided the relations do not change. The matter is for them unimportant, the form alone interests them" (2015, p. 44). As Andrea Henderson shows in her monograph on mathematical formalism and Victorian culture, "[n]ineteenth-century mathematicians were very aware that in distinguishing content from form and privileging the latter they were fundamentally changing their discipline and its claims upon truth" (2018, p. 30). In the early twentieth century, a number of visual artists and literary writers drew on this formalist notion of mathematics when developing and experimenting with new conceptualizations of art that similarly prioritize form over content and meaning. In this way, mathematics plays a particularly important role for literary form in modernism.

Mathematics, Modernism, and Literature

The third part focuses on developments in literature and mathematics in the first half of the twentieth century. The rise of mathematical formalism in the nineteenth century (see above), that is, the notion that mathematics is not concerned with objects and meaning but is a self-contained formal system, led to concern about its foundations: if mathematics is not grounded in a relation to nature, then the foundations that guarantee its truth and consistency have to be found elsewhere. Three main mathematical schools—logicism, formalism, and intuitionism—attempted to establish secure foundations for mathematics, and their respective prioritizing of logical, formal, and intuitive viewpoints plays out broader tensions in a period in which celebrations of rapid advancements in science and technology coexist with attempts to escape threatening rationalization in realms outside reason and calculation. None of the approaches succeeded in providing mathematics with stable foundations however, and mathematicians as well as non-professionals increasingly became aware of unresolved questions, unsolvable paradoxes, and the need to revise what had seemed to be certain knowledge. The historian of mathematics Jeremy Gray summarizes: "the mathematics of the nineteenth century is marked by a growing appreciation of error leading to a note of anxiety, hesitant at first but persistent by 1900" (Gray 2004, p. 23). The period from the 1880s to around 1930 is accordingly called the "foundational crisis" of mathematics, and the questions and anxieties surrounding mathematics also occupied non-professionals and appear in literary texts.

Chapter 17 by Howard Pollack-Milgate demonstrates that the concerns coming to the fore in the foundational crisis of mathematics are not unique to early twentieth-century modernism but have a long prehistory both in mathematics and in literature. Paradoxes of infinity crystallize the following assertions and contrasts from the fifteenth to the twentieth century: "the condition of the modern world, the utility of results versus the problems of a foundation, the notion of the mathematical as, on the one hand, certain and clear, on the other, perplexing and contradictory" (Pollack-Milgate by Chapter 17). Chapter 18 by Chris Ackerley also relates modernist concerns with earlier thinking when examining how Samuel Beckett draws on work by Gottfried Wilhelm Leibniz (1646–1716) "to gain perspective on a major concern of his times," namely, a paradox discovered by Bertrand Russell in 1901 that showed that the notion of a set motivated by trying to formalize Georg Cantor's work leads to a contradiction. If formalism is the inquiry into mathematical signs and their relations, a similar movement appeared in early twentieth-century linguistics: Ferdinand de Saussure argued that language is a self-referential system that should be examined without consideration of a sign's referent in the real world. The aim of establishing a system of signs that makes possible ordered, exact communication thus connects mathematics and language at the beginning of the twentieth century, and literary writers such as Gertrude Stein compare these projects and find in mathematics a model for the limits of representation in literary language (see Chapter 19 by Anne Brubaker).

When in the early twentieth century, "mathematicians fashioned for themselves a new image of the subject: autonomous, abstract, largely axiomatic, and unconstrained by applications even to physics" (Gray 2008, p. 305), mathematics exhibits characteristics more commonly associated with modernist literature and art. Therefore, a number of historians of mathematics argue to view modern mathematics as part of the culture of modernism and to therefore speak of a "modernist mathematics" (Mehrtens 1990; Gray 2008). Chapters 20 and 21 by Arkady Plotnitsky examine relationships between modernist literature and modernist mathematics. Chapter 20 focuses on the movement toward independence and self-determination that characterizes both modernist literature and mathematics; Chapter 21 brings into view the question of mathematics and ontology. Even if ontological questions are more evident in the postmodernist literature of the second half of the twentieth century, modernist texts engaging with mathematics are both concerned with epistemological questions about the possibility and certainty of mathematical knowledge and with ontological considerations regarding the structures and "worlds" that mathematics creates and the ways in which these can be compared to literary fiction (see Chapter 16 by Nina Engelhardt).

Relations Between Literature and Mathematics

Part four collects chapters that directly address the question of how literature and mathematics connect to each other as areas of knowledge, education, and practice. While, as detailed above, literature and mathematics can be seen as opposites in a number of ways—regarding universality and individuality of knowledge, certainty and vagueness, accessibility, and so on—they also share characteristics that suggest a surprisingly close relationship between them, closer than between literature and science. Indeed, although mathematics and the natural sciences are often thought of together—for example, in discussions about the "STEM" subjects (science, technology, engineering, mathematics)—mathematics is not implicit in the S for science: it is not based on empirical research. Rather, it shares characteristics with the humanities when it "can be considered a creative cultural achievement since it is only accountable to human thinking" (Mühlhölzer et al. 2008). But counting mathematics as a discipline of the humanities is problematic too since it is not concerned with human beings or their cultural achievements (Mühlhölzer et al. 2008). The German physicist and philosopher Carl Friedrich von Weizsäcker held that asking whether mathematics is part of the natural sciences or the humanities is based on an incomplete classification, and that it belongs to a third category, namely, that of structural science (Weizsäcker [1971] 1980). Bernd-Olaf Küppers, like Weizsäcker a physicist and philosopher, explains:

> The distinguishing feature of this type of science is that—unlike the natural sciences and the humanities—it deals with the over-arching structures of reality, independent of the question of where these structures actually occur, whether they are found in natural or artificial, living or non-living systems. Owing to their high degree of abstraction, the structural sciences include a priori the entire realm of reality as the area of their applicability. (Küppers 2018, p. 176)

And since the structural sciences, for which mathematics is the "archetype," is abstract and has an "integrative function," it can, so Küppers argues, serve as a link between the natural sciences and the humanities (Küppers 2018, pp. 176, 178).

Chapter 26 by Imogen Forbes-Macphail locates mathematics in reference to the Huxley-Arnold-debate in the 1880s, a well-known negotiation of the respective educational, social, and cultural value of literary and scientific knowledge between Thomas Henry Huxley and Matthew Arnold. Shifting the focus to mathematics, Forbes-Macphail notes that both literature and mathematics had to defend themselves against the growing importance of science education. She demonstrates how the poet Matthew Arnold and mathematicians James Joseph Sylvester and William Spottiswoode characterized their fields in similar ways, as not immediately lending themselves to application but being pursued for the sake of knowledge and beauty. Moreover, this nineteenth-century discussion values mathematics, like literature, for its ability to connect ideas within mathematics and between disciplines—a characteristics of the structural sciences that Küppers similarly notes today: "They already link up large areas of natural science, economics and the humanities" (Küppers 2018, p. 178).

The then following chapters examine further concepts of the relation between literature and mathematics. For example, the idea of consilience, formulated by E. O. Wilson in 1998, describes the convergence between different areas of knowledge, particularly of the humanities and the sciences. Chapter 23 by Matthew Wickman examines the prehistory of consilience in Newton's fluxional calculus and discusses a consilient logic of figure in reference to Newton's formulation of the calculus and a poem by Robert Burns. Chapter 28 by Steven Connor notes the self-referentiality of both mathematics and language and argues that this constitutes not equality or identity but a convergence of congruences. The foreignness of actual dates in literary fiction, for example, in novels by Charles Dickens, shows that words and numbers might share similar structures but that ultimately, they remain external to each other. Chapter 29 by Jocelyn Rodal puts into focus the notion of equality itself, demonstrating how Ezra Pound takes equation to describe things that are different yet also show sameness and how this notion informs his use of metaphor, comparison, and juxtaposition. Again, a concept in mathematics—here an equivalence relation—offers abstract understanding and illuminates the way in which mathematics as a structural science can work to describe relationships and link different fields of knowledge.

Chapter 25 by Margaret Kolb and Chapter 27 by Andrea Henderson are not directly concerned with the relationship between literature and mathematics but examine both as engaging with and contributing to wider developments, in different yet comparable ways. In the nineteenth century, newly accessible data, for example collected during a census in Britain in 1801, opened up questions that, so Kolb asserts, reverberate in both mathematics and literature: "How should numbers be aggregated, arranged, and read? What are the limits of numerical representation? Can a part—what we now call a sample—explain a larger whole?" (Kolb, Chapter 25). Henderson argues that the logic of late-Victorian capitalism, placing value not in individuals but in their links to others, shows in late-Victorian characterization that privileges characters' relations to each other, and is epitomized in the mathematical field of combinatorics. Chapter 24 by Aaron Ottinger identifies similarities between geometry and propositional logic and between probability and associationist logic and examines how Laurence Sterne's *Tristram Shandy* (1759–1767) combines these to challenge readers' accidental associations and elicit moral feelings. Also examining mathematical thinking and reading response, Chapter 22 by Travis Williams begins by analyzing explicit references to number and calculation in William Shakespeare's *King Lear* to then develop a way of "reading mathematically" that is independent of such direct engagement with mathematics. He argues that imaginary numbers—which in Shakespeare's time were seen as purely mental creations that enjoyed a liminal, "imaginary" existence but served a practical purpose in calculation—depend on a similar logic as reading or viewing *King Lear* where the audience is led to imagine what is later exposed as a pretense and this process serves a function. In these chapters, engaging with reality by taking into account "merely" probable or imagined states emerges as a strategy that links mathematics and literature.

Mathematics as Literature

Chapters in the last part address ways in which mathematical writing—in research, education, and popularization—exhibits literary qualities and can usefully be examined with the tools of literary analysis. Chapter 30 by Benjamin Wardhaugh shows that a distinctive early modern culture of mathematical reading and activity can be traced in the marginal annotations of printed texts, on waste paper, and slates: learning mathematics involved manually doing mathematics, using blank spaces to copy diagrams, supplement proofs, and correct printing errors. Chapter 31 by Marcus Tomalin argues that mathematical texts possess literary qualities and examines the relationship between mathematics, narrative, and temporality in classical proofs by Leonhard Euler, Carl Friedrich Gauss, and a late twentieth century proof of a lemma that appeared in Andrew Wiles's paper establishing Fermat's Last Theorem. Next to mathematical practice in research and education, literary texts and devices also play an important role in the communication of mathematical knowledge to non-professionals. Tom Stoppard's play *Arcadia* (1993) is a prime example of the way in which metaphors, dialogue, and performance on stage can convey complex mathematical ideas such as chaos theory, fractal geometry, and Fermat's Last Theorem (see Chapter 14 by Liliane Campos). The successful way in which *Arcadia* makes mathematical intricacies understandable, fun, and relevant to everyday life was acknowledged by the Royal Institution of Great Britain when it short-listed the play for an award in the category "best science book ever written." Chapter 32 by Marc Alexander examines Marcus du Sautoy's *The Music of the Primes* (2003) as a popular science book that communicates complex mathematical concepts, in particular regarding its use of analogy as a way to give non-experts a sense of understanding. Alexander's chapter also is an example of taking a mathematical approach to literature when it employs a quantitative methodology to analyze texts. As he argues, "[q]uantitative approaches cannot and should not replace an analyst's reading of a text, but they can supplement our existing methods for finding areas worth studying" (Alexander, Chapter 32). The chapters in this part demonstrate the fruitfulness both of taking a quantitative, mathematical approach to literature and of examining mathematical writing with the tools of literary analysis.

Literature and Mathematics Studies

The remainder of this introductory chapter charts the development of the study of literature and mathematics, with reference to the broader field of literature and science studies. Literature and mathematics is commonly understood as a subfield of literature and science, and while it shares key questions, concerns, and developments with the larger field, mathematics differs from the natural sciences in several important aspects. While the natural sciences rely heavily on observation and experiment, much of mathematics is done without specialized instruments or reference to nature. While this is far less the case today, as computers are indispensable parts of mathematical research and applications, historically and for many non-professionals who primarily encounter mathematics while in school, mathematics retains a stronger image of abstract, theoretical knowledge. At the same time, of course, mathematics plays a crucial role in the natural sciences, in scientific practice, and in gaining knowledge about the world. Indeed, a key development toward modern science was its mathematization: Isaac Newton (1643–1727) put natural philosophy—the precursor of modern science—on mathematical foundations in his *Philosophiae Naturalis Principia Mathematica* (1687). One consequence of Newton's immensely influential approach was to replace Cartesian vortex theory, an alternative, earlier seventeenth-century theory to explain planetary motion and gravitation that used verbal formulations and could not compete with the comprehensiveness and predictive power of Newton's explanations in mathematical form. The increasingly close connection between mathematics and natural philosophy implied a correspondingly larger distance to literature and the humanities, particularly with the professionalization and further mathematization of scientific disciplines in the nineteenth century: "In the mid-nineteenth century, scientists still shared a common language with other educated readers and writers of their time…. [Scientific writers] shared a literary, non-mathematical discourse which was readily available to readers without a scientific training" (Beer [1983] 2000, p. 4). While Gillian Beer here presents mathematization as an obstacle to shared discourse, mathematics itself served as a common language in the nineteenth century: mathematical education focused on studying geometry, in particular Euclid's *Elements*, and this ensured an educational experience shared by mathematicians and non-mathematicians alike: "mathematics … was a shared experience and a 'common knowledge' for nineteenth-century readers and writers, and its impact on society and culture was immense" (see Jenkins 2017, p. 217). However, the mathematization of the sciences led to a growing distance between professionals and the larger public: by and large, as Beer points out in the 1980s, "[n]on-scientists do not expect to be able to follow the mathematical condensation of meaning in scientific journals, and major theories are more often presented as theorems than as discourse" (Beer [1983] 2000, p. 4). Since the mathematization of the sciences is a decisive factor in the historical development of the sciences and in the changing relations between literature and science, any study of literature and mathematics or literature and science necessitates reflection about the other.

The early academic study of relations between literature and science stresses the role of literary texts in interpreting science and its implications. For example, Marjorie Hope Nicolson gives her 1950 *The Breaking of the Circle* the subtitle: *Studies in the Effect of the "New Science" Upon Seventeenth-Century Poetry*. As Martin Willis summarizes in his overview of early literature and science criticism: "Such a one-way model of influence has fallen out of favor—in both literature and science and history of science scholarship—and is one of the key beliefs that the contemporary criticism has worked to overturn" (Willis 2015, p. 42; for the overview see pp. 32–51). Scholarship in the 1980s made a decisive development away from researching influence in favor of considering mutual interrelations and shared discourses, with pioneers Gillian Beer and George Levine both focusing on the work of Charles Darwin in particular. As Levine and Beer examine the narrative, metaphorical, and creative qualities of Darwin's writing, mathematics does not play a large role in their works. Levine even stresses the absence of mathematical thinking and notation that brings to the fore the more literary character of Darwin's writing: "Darwin demonstrates the regularity and comprehensibility of phenomena without reducing them to the strict form of logic and mathematics" (Levine [1988] 1991, p. 19). Alice Jenkins summarizes for scholarship on science in nineteenth-century Britain: "historicist studies in the tradition of Beer (1983), Levine (1988), Shuttleworth (1984), Dawson (2007), and O'Connor (2007) have given comparatively little attention to the mathematical sciences, and especially to mathematics itself" (Jenkins 2017, p. 219).

While mathematics plays only a very limited role in the quickly growing field of literature and science studies in the 1980s, Linda Dalrymple Henderson's (1983) *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* has its main focus on mathematics, albeit primarily in its relation to the visual arts. Henderson explores ways in which modern art engages with and contributed to the new understanding of space that developed from non-Euclidean geometry and the mathematics of higher dimensions. The mathematical expansion of familiar notions of space feeds into modern movements' departures from representing visual reality and exploring possibilities of perception outside the restrictions of visible, three-dimensional reality, for example, in Cubism, Dadaism, or Surrealism. Henderson's research has been immensely influential, yet, its relevance for literature and mathematics studies long remained untapped. As recently as 2018, Mark Blacklock developed the implications for literary studies that Henderson's (1983) monograph touched upon: "Henderson's work demonstrates that the geometries developed in the nineteenth century and their popular and occultist elaborations informed Modernist production in the visual arts and outlines potential lines of inquiry in the literary arts. I have followed these leads" (Blacklock 2018, p. 6).

Yet, mathematics is not completely ignored even in the first decade of research on the "two-way traffic" between literature and science that Beer advocates in the 1980s ([1983] 2000, p. 5). Indeed, Beer employs mathematics as an extreme example to illustrate the fruitfulness of understanding literature and science as mutually affecting each other rather than only taking science to influence the literary. In her 1990 lecture "Translation or Transformation? The Relations of Literature and Science" at the Royal Society, she points out that mathematicians are no strangers to creative and figurative language. When Mandelbrot terms structures in his fractal geometry "Cross Lumped Curdling Monsters" and "Knotted Peano Monsters, Tamed," he allows nonmathematical readers to "glimpse the implications of the theorems that are interspersed between the sentences": "A verbal mimesis of his [Mandelbrot's] own theoretical work is implied, in which the random, the inordinate, the non-Euclidean is granted an appropriate language that bulges, miniaturizes and grows gargantuan, constantly shifting across registers of scale and distance to achieve its imaginative effects" (Beer 1990, p. 90). Thus, while mathematical symbols and formulas can result in excluding non-professionals, Beer highlights that literary scholars' examination of metaphors and language can illuminate even the field often seen as furthest removed from everyday language.

The notion that science is not an objective accumulation of truths about reality but subject to the possibilities of language, historical circumstances, and social conditions and participates in constructing reality is central to research in science studies, beginning in the 1960s and intersecting with the field of literature and science. Milestones in work on the historical, social, and cultural dimensions of science include *The Structure of Scientific Revolutions* (1962) in which Thomas Kuhn argues that science is not a linear accumulation of truths but characterized by paradigm shifts, sociologists Bruno Latour and Steve Woolgar's *Laboratory Life: The Construction of Scientific Facts* (1979) introducing the important role of writing and text in scientific practice, and *The Manufacture of Knowledge* (1981) by Karin Knorr-Cetina which advances the thesis that products of science are not disinterested uncoverings of truth but constructions dependent on the social and historical context in which they are produced. Many more names and works could be added here, but as a comprehensive survey cannot be our aim here, we focus on highlighting the role of mathematics in the surge of interest in the sociology and history of science from the 1960s onwards.

The sociologist David Bloor pointed out in 1973: “One of the central problems of the sociology of knowledge is that status of logic and mathematics. These branches of knowledge are so impersonal and objective that a sociological analysis scarcely seems applicable” (Bloor 1973, p. 173). Bloor argues that, while Karl Mannheim (1893–1947) “could not see how to think sociologically about how twice two equals four” (1973, p. 173), Ludwig Wittgenstein’s (1889–1951) *Remarks on the Foundations of Mathematics* demonstrates the possibility and value of a sociology of mathematics. Bloor’s *Knowledge and Social Imagery* (1976) develops at greater length that mathematics can be part of a so-called strong program in the sociology of scientific knowledge that sees scientific knowledge and epistemic standards as context-dependent, social phenomena. Bloor admits “that these ‘constructive proofs’ cannot be offered in abundance” (Bloor [1976] 1991, p. 84) since a long tradition has established mathematics as the epitome of objective and true knowledge. The development of quaternions, formulated by William Rowan Hamilton in 1843 as an extension of complex numbers to applications in three-dimensional space, is a main example in Bloor’s project of showing “that there is nothing obvious, natural or compelling about seeing mathematics as a special case which will forever defy the scrutiny of the social scientist” (p. 84) and that an alternative mathematics is imaginable (see Bloor [1976] 1991, chapter six, “What Would an Alternative Mathematics Look Like?”). In the 1990s, Andrew Pickering also drew on Hamilton’s work on quaternions to illustrate that mathematical concepts are not found in nature or a pre-existing Platonic realm but are “constructed” in specific historical and cultural circumstances (Pickering 1995, chapter 4 “Concepts: Constructing Quaternions,” and Pickering and Stephanides 1992). More generally, Pickering used examples from mathematics to analyze how knowledge is produced not only in the better-explored experimental sciences but also in theoretical practice (Pickering 1995).

In a 2010 essay on the cultural strategies, resources, and conjunctures of mathematical practices, Moritz Epple concludes: “Detailed historical analyses of the practices of mathematisation and mathematical argument in science as *cultural* practices are still rare compared to the recent history of experiment” (Epple 2010, p. 219). The editors of *Perspectives on Mathematical Practice: Bringing Together Philosophy of Philosophy of Mathematics, Sociology of Mathematics, and Mathematics Education* (2007), Bart Van Kerkhove and Jean Paul Van Bendegem, arrive at a similar answer to the question:

> Is mathematics finally going through the Kuhnian revolution that the sciences or, more precisely, the philosophers, historians, sociologists, economists,

> psychologists of science, … have been able to deal with ever since the magical year of 1962? … [O]ne cannot easily identify a book that has played the part that *The Structure* has played – of course, Lakatos' *Proofs and Refutations* comes pretty close, but it does not possess the generality of Kuhn's work. (Van Kerkhove and Van Bendegem 2007, p. vii)

This summarizing assessment in 2007 highlights, firstly, that mathematics still occupies a special position in the history, philosophy, and sociology of science in the twenty-first century, and, secondly, the exceptional role of Imre Lakatos's *Proofs and Refutations.* Published in 1976, *Proofs and Refutations*—an allusion to the famous paper "Conjectures and Refutations" by Karl Popper—argues that the development of mathematics is not a steady accumulation of truths but a dialectical process and that mathematics is fallible, for example, in the sense that theorems can be refuted by finding counterexamples that require adjusting the theorem. Lakatos's *Proofs and Refutations* marks an important development in the philosophy of mathematics, and it is also remarkable in the way in which its literary form—it is written as a fictional dialogue between teacher and students—is part of the argument. Lakatos explains that "[t]he dialogue form should reflect the dialectic of the story," namely, the story of the development of mathematics as the community decides which proofs are valid (Lakatos [1976] 2015, p. 5). As the dialogic form in *Proofs and Refutations* suggests, it is worth paying attention to the ways in which mathematics is practiced, negotiated, and communicated among scholars, learners, and non-professionals, and literary scholars are well-positioned to explore this aspect.

Work in the history, philosophy, and sociology of science that stresses the constructed and context-dependent nature of scientific knowledge initiated intense debate that culminated in the so-called Science Wars of the 1990s. On one side, scientists and scholars in the humanities insisted that scientific knowledge be valued as an objective description of reality and criticized what they denounced as relativist views of social constructivism and arbitrary postmodernist positions. The other side emphasized the need to recognize the role of historical, social, and cultural conditions on what is perceived as scientifically valid and true, and the fact that these agreements and the realities they construct undergo change. *Mathematics, Science, and Postclassical Theory* (1997), edited by Barbara Herrnstein Smith and Arkady Plotnitsky, participates in the Science Wars by giving exceptional prominence to mathematics and with an unusual calming note in the sometimes heated discussion of the 1990s. As the editors explain in their introduction, what they call "postclassical" theory—involving critical analyzes of concepts such as knowledge, objectivity, truth, and proof—also has implications for mathematics, yet, the chapters in the collection "dealing with mathematics suggest that the relations—both historical and conceptual—between mathematics and postclassical theory are on the whole quite cordial and that, even where those relations are complex, they do not involve any wholesale refutations or underminings in either direction" (Smith and Plotnitsky 1997, p. 3). In contrast, at the height of the Science Wars in 1996, in what has become known as the Sokal Hoax, physicist Alan Sokal published a fabricated paper in the journal *Social Text*: it argued that quantum gravity is a linguistic and social construct, and was aimed at exposing the lack of intellectual rigor in postmodern critical theory and, ultimately, the unfoundedness of constructivist arguments. The Sokal Hoax serves as a concrete, if maybe overly discussed, moment in the relations between the humanities and the sciences, and it has a lesser-known companion piece in mathematics: in 2012, a paper apparently authored by Marcie Rathke but in fact created by using Mathgen, an online random generator of mathematical papers, was accepted in the journal *Advances in Pure Mathematics* (Eldredge 2012). While mathematicians were quick to point out that this is not a top-tier journal, this "landmark event in the history of academic publishing" shows that determining intellectual rigor in mathematics may be more difficult than scientific realists in the Science Wars implied and the broader public may expect (Taylor 2012).

The twenty-first century sees further explorations of the historical, social, and cultural conditions of mathematics that question traditional assumptions of its objectivity, transcendence, and unchanging truth. *Where Mathematics Comes From: How the Embodied Mind Brings Mathematics into Being* (2000) by George Lakoff and Rafael Núñez presents mathematics as, like everyday language, "grounded in sensory-motor experience. Abstract human ideas make use of precisely formulated cognitive mechanisms such as conceptual metaphors that import modes of reasoning from sensory-motor experience" (Lakoff and Núñez 2000, p. xii). Using cognitive science to investigate mathematical thinking, Lakoff and Núñez conclude that what they call the "romance" of mathematics (p. xv)—namely, its image as a disembodied, transcendent, true language of nature—is wrong and that mathematics originates in embodied experience and "a great many of the most fundamental mathematical ideas are inherently metaphorical in nature" (p. xvi). Where this cognitive approach to mathematics advances a project also pursued by Brian Rotman in Ad Infinitum*; The Ghost in Turing's Machine; Taking God Out of Mathematics and Putting the Body Back In* (1993) and stresses mathematics' connections to language, and metaphor in particular, a 2009 special issue of the journal *Configurations* is dedicated to the imagination as a realm in which mathematics and the arts meet. The contributions to the special issue *Mathematics and the Imagination* bring together scholarship from different disciplines to examine "how/what mathematicians imagine when they do math, and how mathematics is imagined by mathematicians and nonmathematicians alike" (Saiber and Turner 2009, pp. 12–13). Similarly, the collection of essays *Circles Disturbed: The Interplay of Mathematics and Narrative* (2012), edited by Apostolos Doxiadis and Barry Mazur, is consciously designed as "a two-way interaction between mathematics and narrative"

(Doxiadis and Mazur 2012, p. xvi) and adds a focus on narrative to the earlier work on metaphor and imagination.

Less focused on theoretical examination, *Mathematics in Popular Culture: Essays on Appearances in Film, Fiction, Games, Television and Other Media* (2012), edited by Jessica K. Sklar and Elizabeth S. Sklar, takes account of the growing presence of mathematics in popular culture—a trend that is still ongoing with recent cinema films including *The Imitation Game* (2014), *The Man Who Knew Infinity* (2015), and *Hidden Figures* (2016). Recent developments in research on interactions between mathematics, language, literature, and art have seen Lynn Gamwell's monumental *Mathematics+Art; A Cultural History* (2016) that discusses examples from the Stone Age to the present day, and an emerging focus area on mathematics and modernism (Hickman 2005; Cliver 2008; Tubbs 2014; Brits 2017; Engelhardt 2018). The digital humanities constitute another area of interest in twenty-first-century literature and mathematics studies. Computing technologies, based on mathematical processes, allow for quantitative analyzes and considering big data sets and are used to increase the reach and relevance of research in the humanities. At the same time, this initiates renewed discussion of the relations between literature and mathematics and of the value of mathematics and mathematization for the humanities. Matthew Handelman's (2019) *The Mathematical Imagination: On the Origins and Promise of Critical Theory* presents an alternative strand to the well-known position in critical theory that originated with Theodor Adorno and Max Horkheimer who "steadfastly opposed the mathematization and quantification of thought. For them, the equation of mathematics with thinking … provided the epistemological conditions leading reason back into the barbarism and violence that culminated in World War II and the Holocaust" (Handelman 2019, p. 2). Fears that too great a reliance on mathematics could compromise the humanities, for example, by prioritizing quantitative over qualitative interpretations, have reappeared in the twenty-first century and make worthwhile Handelman's project of exploring the more positive role of mathematics in other twentieth-century thinkers' cultural and aesthetic theories (2019, p. 19). At the same time, as this introductory chapter has begun to argue and the following chapters illustrate in much greater detail, mathematics is not a monolithic system of thought and, though lending itself to repressive and reductive thinking, holds surprising potential for paradox, imagination, creativity, and freedom.

Note

1. The mathematical symbol ∩ is like the plus sign, +; it is a binary operation that acts on sets—given two sets A and B, the A ∩ B is the set containing the elements that are contained in both A and B. It is called the intersection of A and B.

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