The rhetoric of Sir Isaac Newton's *Principia*: A rejection of Cartesianism

by

Charles Lee Fite

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF ARTS

Department: English
Major: English (Business and Technical Communication)

Approved:

Signature redacted for privacy

In Charge of Major Work

Signature redacted for privacy

For the Major Department

Signature redacted for privacy

For the Graduate College

Iowa State University
Ames, Iowa

1992

TABLE OF CONTENTS

ISAAC NEWTON'S RHETORIC: INFLUENCES AND DIRECTIONS

Introduction

Often when we think of scientists, we imagine observers painstakingly recording the results of experiments and the effects of natural phenomena, or we imagine theorists standing in front of dusty chalk boards working out the details of protracted mathematical expressions. Seldom do we picture scientists as writers, yet most scientists spend a substantial fraction of their time writing. Scientists, just as other scholars, must communicate with their colleagues. And although mathematics, as well as other media, plays an important role in scientific discourse, the writing of scientists remains their primary mode of communication.

Because of its vital role in scientific discovery, scientific writing and its role in scientific discourse have, in recent years, been recognized by rhetorical theorists as a legitimate avenue of study. One of the most interesting and important methods of understanding scientific discourse is to study its origins and development over the years. The first, and arguably the most, important period for the development of modern scientific discourse (particularly in English) is the second half of the seventeenth-century in England—the early days of the Royal Society and the days of Isaac Newton in his prime. The discourse that evolved in the publications of the world's first scientific journal, *Transactions of the Royal Society*, was to set the standard upon which modern scientific discourse in both the natural and the social sciences would be modeled. And not surprisingly, Isaac Newton was to help shape that discourse.

The first days of the Royal Society and the 'plain style' movement have long been recognized as an important influence on the style of scientific prose. The deliberate attempt by the hierarchy of the Royal Society to eliminate 'ornateness' in the language of its members helped to shape the prose of Enlightenment scientists and the generations who have followed them. Arguably, the Royal Society's influence affected not only scientific prose style, but modern literary prose style as well (Jones; Croll; Adolph). Isaac Newton, however, had little to do with the 'plain style' movement. He appears to have adopted the style with little or no effort, but Newton was just beginning graduate work at Cambridge when Sprat's *History* was published in 1667. And although Newton's undergraduate studies had included Aristotle and Plato, he seriously digested only the more contemporary figures, in particular Descartes. His readings also included Royal Society members (i.e., Joseph Glanville, Robert Boyle) (Westfall 87-89). Thus it seems safe to assume that Newton was aware of and quickly adopted the plain prose style.

Although Isaac Newton most likely had little or no influence upon prose style, his influence on the content and organization of the scientific article was immense. In *Shaping Written Knowledge*, Charles Bazerman studies the literary forms that emerged in the *Transactions of the Royal Society*, their influence on the discourse of the physical sciences, and their subsequent influence on the discourse of the social sciences. Bazerman argues that the deductive, closed, "Euclidean" system of argument that Newton eventually developed in Book I of the *Opticks* was to provide the model for the "communal" closed systems that scientific argument would eventually create.

In Chapter IV, "Between Books and Articles: Newton Faces Controversy," Bazerman demonstrates how Isaac Newton's strategies for presenting his optical theory changed as his conception of the rhetorical situation was altered. More specifically, Bazerman argues that Newton's attempts to answer his colleagues' critiques of his first and, with one minor exception, his only journal article, "A New Theory of Light and Colours," actually helped him to clarify and reorganize his theory into the extremely-compelling deductive argument (what Bazerman calls "the Juggernaut as Persuasion") that later appeared as Book I of the *Opticks*.

My analysis of Newton's *Philosophiæ Naturalis Principia Mathematica* will build upon Bazerman's work, confirming that much as with the optical theory, Newton's mechanical and gravitational theory were shaped by his perception of the rhetorical situation. In addition, my analysis will suggest that Newton's development of his deductive "juggernaut" was also influenced by his writing of the *Principia* and the events leading up to that writing. Bazerman doesn't analyze the writing of the *Principia* because he is more interested in influences on the mode of argument taking place in the *Transactions*, and he believes that the argument in Book I of the *Opticks* "had a more immediate and powerful impact than the abstract machine of the *Principia*" (126). Nevertheless, to fully understand the influences on Newton's creation of the deductive, closed text used by Book I of the *Opticks*, it is necessary to examine the writing of the *Principia*, an earlier work that also used the Euclidean, closed system of argument found in Book I of the *Opticks*.

Bazerman's Account of Newton's Rhetoric

A general consensus among historians is that Isaac Newton's emotional constitution prevented him from tolerating scrutiny and constructive criticism of his theories. Following the criticism of his "New Theory" article, Newton withdrew from publication and became defensive and mistrustful of sharing his ideas with others until they were fully developed and could not be questioned. While it is true that Newton's psyche would have provided interesting study for students of paranoia, Bazerman offers an alternate explanation for Newton's shock at the plethora of criticism that followed the "New Theory" article.

According to Bazerman, Newton failed to recognize the value of the newly created scientific journal as a forum for scientific argument, perceiving it rather as a forum for publishing newly discovered *facts*. Newton published the "New Theory" article to acquaint the scientific community with his theory and prepare the community for his forthcoming book. He did not expect criticism, instead expecting that the credibility as a competent observer that he established for himself would persuade his readers to accept (at least tentatively) the conclusions he drew from his experiments. Newton therefore interpreted the resulting critiques of his theory as personal attacks upon his competence, rather than as the legitimate questions and objections of his colleagues about elements of his reasoning and about details of his experimental method (89).

Although Newton misunderstood the function of the scientific journal, Bazerman argues that Newton did (perhaps intuitively) recognize the importance of an effective presentation for the "facts" he had discovered. Thus the "New Theory" article begins with an account of Newton as the competent Baconian observer who, through careful experiment, discovers some unusual phenomena and systematically goes about isolating and testing them, leading eventually to a theory to explain the phenomena. Bazerman argues that Newton intentionally chose this "discovery" mode to establish credibility for his experiments and, thereby, for himself and his argument (90-91). Articles in the *Transactions* at that time commonly used the experimental narrative, and Newton read and took notes on those articles before ever writing his own (88). Additionally, Newton's private journals indicate that the experiments were actually carried out to prove his hypotheses rather than stumbled across accidentally as the article suggests (92-93). Thus, according to Bazerman, the empirical account was Newton's solution to his rhetorical problem rather than a description of actual events.

Having established his credibility as a good Baconian observer, Newton expected his readers to quickly accept his conclusions about the phenomena. However, Bazerman argues that the highly inductive structure of the experimental narrative used by Newton, accompanied by his failure to provide procedural detail, prevented such acceptance and is thus responsible for the degree of criticism he received concerning the “New Theory” article. Newton did not link his propositions directly to his experimental results. He also assumed his readers could fill in experimental details that he left out for the sake of conciseness. Because of these flaws in his presentation, Newton’s colleagues were not satisfied with his logic (100-110).

Through answering the critiques of Robert Hooke, Christian Huygens, and others, Newton developed new strategies for leading others to his conclusions. He realized the importance of providing specific procedural details of his experimental evidence, and he discovered the value of providing a deductive structure for showing direct relationships between his theory and that evidence. Thus, Bazerman argues that through answering the critiques of his colleagues, Newton developed the more effective rhetorical strategies that would characterize his later work (100-110).

According to Bazerman, Newton's ultimate solution to his rhetorical problem (presenting his theory as fact), as it appeared in the *Opticks* decades after the "New Theory" controversy, was to develop what modern literary theory calls a "closed text" (124). "The form of compelling argument [Newton] developed," claims Bazerman, "relied on creating a closed system of experience, perception, thought, and representation that reduced opposing arguments to error" (83). Newton defined a few quantities that he perceived existing in nature. Using those definitions, he developed axioms (or laws) based upon his observation of the workings of nature that described how those defined quantities interact with each other. Using the axioms and logical (often mathematical) rigor, Newton demonstrated that his propositions led directly to the experimental results he described. Thus, once the axioms in Book I of the *Opticks* are accepted, scrupulous logic leads the reader inexorably to the propositions.

So, as Bazerman notes, a closed text does not allow for alternate interpretations. According to Bazerman, the only voice in the text is that of the author. The extremely compelling argument in Book I of the *Opticks* moves

> from definition to axiom to propositions. The propositions, supported by experimental proofs, are sequentially arranged to create an ironclad deductive argument. . . (Bazerman 119).

Books II and III, however, retain a more tentative, hypothetical tone, indicating Newton's lack of experimental evidence to support his propositions (125). Nevertheless, the deductive argument in Book I, Bazerman argues, was not only an important influence on optical theory, but was a profound influence on the format of the scientific paper in the eighteenth century and contributed to Newton's dominant presence in eighteenth-century science (127).

A More Comprehensive View of Newton's Rhetoric

That Newton misunderstood the rhetorical nature of scientific argument is well established by Bazerman (see also *The Myth of Metaphor* by Colin Murray Turbayne). Bazerman's analysis also clearly demonstrates that the "New Theory" criticism and Newton's responses to it were vital to the creation of the 'Euclidean' argument found in both the *Principia* and the *Opticks*. However, it is not clear from Bazerman's analysis that the optical criticism and its aftermath were the only influences. Indeed there is good reason to believe that Newton's writing of the *Principia* and the events leading up to it also played a vital role in the creation of his Euclidean mode of argument.

The event that suggests there could be other influences is a fire that took place in Newton's Cambridge office during the winter of 1677/1678—a fire that destroyed a nearly complete book-length manuscript of Newton's optical theory. Following the period of controversy surrounding the "New Theory" article (1672-1676), Newton, spurred on by answering his critics, had nearly completed his optical theory by late 1677. Then apparently in December 1677 or early 1678, a catastrophic fire in Newton's office destroyed the manuscript, and along with it, Newton's willingness to continue his study of optics (Bazerman 119; Westfall 276-279; see also the appendix to the present work).

After the fire, Newton abandoned optics for over a decade. During this time, he first seriously studied Greek mathematics; he developed his calculus and principles of mechanics; and he wrote and published the *Principia*—his explanation of the mechanics of our universe and his outright attack upon the mechanics of Descartes. It was not until the 1690s that Newton again took up his optical studies, and not until 1704 that he published the *Opticks*. Thus, the *Principia* may have actually been the first 'Euclidean' text produced by Newton because we simply don't know what the optical manuscript destroyed by the fire looked like.

While we don't know the exact appearance of the optical manuscript, evidence provided by Bazerman compels one to believe that Newton was beginning to recognize the value of a deductive organization and was looking to mathematics for a method of presentation in the period prior to the fire. Actually, as early as September 1672, Newton was beginning to consider reducing his argument to a mathematical form. In a letter written to Henry Oldenberg, Newton states,

> I drew up a series of such Expts on designe to reduce ye Theory of colours to Propositions & prove each Proposition from one or more of those Expts by the assistance of common notices set down in the form of Definitions & Axioms in imitation of the Method by wch Mathematicians are wont to prove their doctrines (qtd in Bazerman 113; Newton "Correspondence" 237-238).

Thus, only months after the "New Theory" article was published (after the first round of controversy, as Bazerman describes it), Newton was already looking to mathematics and its use of stated definitions and axioms to build evidence for propositions.

The passage cited above and other evidence provided by Bazerman indicate that Newton was certainly beginning to consider using a 'mathematical' style of argument during his first period of optical writing (1672-1677). However, it is still unclear whether the manuscript destroyed by the fire used the same closed, step-by-step, Euclidean system used by both the *Principia* and the *Opticks*. In attempting to reconstruct steps in Newton's creative process, we cannot ignore the obvious influence that ancient Greek geometry must have had on the development of a "Euclidean" text. In the years following the fire in his office, Newton developed a great appreciation for the ancient Greeks' *geometric*, rather than (Cartesian) algebraic, method of presenting mathematical relationships (see Appendix). Thus, it seems quite likely that Newton's eventual creation of two Euclidean texts, the *Opticks* and the *Principia*, was also influenced by his growing esteem for Greek geometry. In considering this influence, we must turn our attention to the period following Newton's first optical writings (1678-1687). This period includes Newton's study of Greek mathematics, his subsequent rejection of Cartesian mathematics and mechanics, and his writing of the *Principia*. Through a study of this period, we will find that Newton's adoption of a 'Euclidean' rhetoric was part and parcel of his rejection of 'Cartesian' rhetoric.

Newton and Greek Geometry

Throughout his career, Newton studied and was fascinated by mathematics. As a student Newton, like everyone else of his day, became a devotee of the mathematics of Descartes, and it was not until much later in his career (apparently around 1678 or 1679; see Appendix) that Newton seriously studied the ancient Greeks. Following this study of Euclid, Apollonius, Pappus, and others, Newton again read and attempted to work through Descartes' *Geometry*. From this time forward, Newton came to prefer the geometry of the ancient Greeks over the algebra of Descartes. In fact, during the following years Newton rejected virtually everything Cartesian—mathematics, mechanics, metaphysics, and rhetoric.

Newton's rejection of Cartesian algebra in favor of the Greek's geometry as a method of presentation is well documented. Attesting to Newton's high regard for the Greek geometers, Henry Pemberton, who prepared the *Principia's* third edition for Newton, claimed:

> Of their taste, and form of demonstration Sir Isaac always professed himself a great admirer: I have heard him even censure himself for not following them yet more closely than he did; and speak with regret of his mistake at the beginning of his mathematical studies, in applying himself to the works of Des Cartes and other algebraic writers, before he had considered the elements of Euclide with that attention, which so excellent a writer deserves (Pemberton, Preface; See also, Westfall 378).

It is therefore clear that Newton underwent a conversion in which he discarded the algebraic representations of Descartes and other seventeenth-century mathematicians in favor of the geometry of the ancient Greeks. What is not so clear, but might also be included in Pemberton's statement, is that Newton also rejected Descartes' organization ("taste, and form of demonstration") in favor of Euclid's.

What is also unclear in Pemberton's statement is that Newton preferred the "synthetic," geometric representations only for *presenting* his results, but still retained the "analytic," algebra for discovering those results. Indeed Newton made several statements about what he believed were the proper roles of geometry and the new *Analysis* (algebra). In the introduction to his solution of a locus problem (written in the late 1670s, about the same time as the problem), Newton refers to the ancient Greeks:

> To be sure, their method is more elegant by far than the Cartesian one. For he [Descartes] achieved the result by an algebraic calculus, which when transposed into words (following the practice of the Ancients in their writings), would prove to be so tedious and entangled as to provoke nausea, nor might it be understood. But they accomplished it by simple proportions, judging that nothing written in a different style was worthy to be read, and in consequence concealing the analysis by which they found their constructions (Newton "Wastebook"; Whiteside "Papers IV" 277; see also, Westfall 379).

So Newton was concerned that his mathematics be presented as an elegant, finished product. As with his optical and mechanical theories, Newton was not content with anything less than a refined, holistic presentation, and the analytical geometry of Descartes he considered too turgid and vulgar for presentation. Readers were to be given an elegant presentation whereby they could understand the major implications of the mathematics, even if they were unable to work through the details themselves.

Working through those details was in fact impossible for most readers. Newton's demonstrations presented in their geometric forms were not nearly so conducive to understanding as the algebraic formulations. Newton was clearly aware of this fact, but was apparently willing to forego ease of understanding so that he could present his results in the more elegant, "synthetic" fashion. In relation to one of the many disputes in which he was involved (circa 1715), Newton published the following passage anonymously in the *Transactions*.

> By the help of the new *Analysis* Mr. *Newton* found out most of the Propositions in his *Principia Philosophiæ* : but because the Ancients for making things certain admitted nothing into Geometry before it was demonstrated synthetically, that the Systeme of the Heavens might be founded upon good Geometry. And this makes it now difficult for unskilful Men to see the Analysis by which those Propositions were found out (*Transactions* (29) 206; Cohen "Introduction" 295).

Newton's decision to present his calculus in geometric formulations is curious, to say the least. One of the most pronounced characteristics of the rhetoric in the *Principia* is an almost obsessive concern with providing every step, even seemingly inconsequential details, of the argument. While the details of Newton's calculus are provided by his geometrical demonstrations, they are, as Newton admits, beyond the abilities of many (actually most) readers to follow. This seeming inconsistency can perhaps be reconciled by considering that Newton was not greatly concerned about the readability of his text (the non-mathematical parts of the argument are difficult too). Instead, it seems quite likely that Newton was enamored of the ancients and their elegant method of presentation, and that he was equally disdainful of Descartes and his method. If this was the case for mathematics, it seems quite likely that it was true for the rest of Newton's rhetoric as well.

Newton's Mechanical Theory

The *Principia,* as published by Newton in 1687, is, in terms of content, a direct assault upon Cartesian mechanics. Scientists and historians agree that the crucial breakthrough that allowed Newton to go on to demonstrate that gravity controls celestial motion to the eventual satisfaction of the world was his rejection of Descartes' Theory of Vortices and the subsequent creation of his own mechanical (particularly dynamical) theory, where objects can act upon each other over a distance through forces such as gravity (Westfall 377-404; Cohen "Introduction" 47; Herivel 14-23; Brewster 291-299; see also Appendix). Newton also rejected the metaphysical justification of Cartesian mechanics as unsupported hypotheses; he relied instead on the justification that his theory simply describes what is observed, and he offered no attempts at explaining *why* the forces act as they do.

From his early days at Cambridge, Newton had been a devotee of the work of Descartes. He read Descartes' *Discourse on Method,* and he studied and became thoroughly immersed in the mathematics of the *Geometry* and the mechanics of Descartes' own *Philosophiæ Principia.* Newton was never quite comfortable with Cartesian dualism, but he did study seriously Descartes' mechanical theory, in particular his explanation of celestial mechanics, the Theory of Vortices (Westfall 98-100, 144, 301-304; Newton "Quaestions").

Descartes' theory (or hypothesis as Newton later called it) regarded matter as a continuous phenomenon permeating all space (at least within the solar system). This matter is arranged in "vortices" around massive objects such as a planet or the sun, which simply are composed of a denser matter, and a force (probably gravity) affects distant objects by displacing the continuous matter much the same way that a wave travels through water and sound travels through air. Hence, Descartes explained gravity's attraction by hypothesizing a medium, the "æther," for transmitting gravitational force.

Newton's breakthrough was his adoption of the notion that forces such as gravity can act on distant objects *without*.a medium. His entire Universal Theory of Gravitation rests on the notion that the mass of an object determines its gravitational attraction to another object—an attraction that decreases as the square of the distance between the objects. According to Newton, the motions of heavenly bodies are controlled by the mutual attractions of those bodies. Thus, Newton's *Principia* rejected not only the mathematics but also the mechanics of Descartes.[1]

In his authoritative biography of Newton, Richard Westfall argues that Newton's study of the ancient Greeks was the catalyst that caused Newton to discredit the whole of Descartes' mechanical philosophy.

> Now in the late 1670s, [Newton] stood poised to reject the fundamental tenet of Descartes' mechanical philosophy of

---

[1] In a chronological argument made in the appendix, I demonstrate that Newton appears to have completely dropped his optical theory (after the fire in 1678) before he made any breakthroughs in his mechanical theory (in 1679), and before he began seriously contemplating the motions of the solar system (in 1684). I also demonstrate that quite likely Newton's study of the ancient Greeks and his subsequent reevaluation of Cartesian mathematics occurred in 1678 or 1679 as well.

> nature, that one body can act upon another only by direct contact. Newton's mathematical papers suggest that only a wholesale repudiation of his Cartesian heritage would allow him to take that step. The repudiation determined not only the content but also the form of the *Principia* (Westfall 381).

So although Newton was clearly thinking about the use of mathematical concepts and structures in organizing his optical writing, it seems likely that his adoption of a 'Euclidean' rhetoric was also influenced by his repudiation of Cartesian mathematics and mechanics. What remains to confirm this hypothesis is a detailed analysis of both Cartesian and Euclidean rhetoric and a step-by-step comparison of Newtonian rhetoric to both. The remaining pages of this chapter will contain the former, and Chapter II will contain the latter.

Cartesian and Euclidean Rhetoric

Defining a single Euclidean rhetoric is a relatively simple task. Euclid was fairly consistent in the use of his definition-axiom-proposition-theorem format in all of his works. Additionally, hundreds, perhaps thousands, of mathematics textbooks have borrowed from Euclid for their organizations and for establishing standards of evidence. It is therefore simple enough to describe a single rhetoric that we can call Euclidean. Descartes, on the other hand, was not completely consistent in his style of presentation; neither has he been used as a model for writers of math texts (although elements of his rhetoric have found their way into them). Thus, defining a single Cartesian rhetoric is a more daunting task.

Despite Descartes' variations in style, it is possible to define a single rhetoric against which Newton was reacting. As I mentioned earlier, Newton, at the very least, read Descartes' *Discourse on Method*, his *Geometry*, and his *Principia Philosophiæ*. The *Discourse* and the *Geometry* look very similar (which is no surprise since the *Geometry* was the last of three essays appended to the *Discourse*). However, Descartes' *Principia* appears quite different, at least organizationally. Indeed, superficially, Descartes' *Principia* appears somewhat similar to the work of Euclid and to Newton's *Principia* in its use of explicitly stated propositions followed by and separated from the evidence supporting them. However, Descartes' *Principia* is similar to the *Discourse* and the *Geometry* in its emphasis on the *ethos* of the author. Descartes' strategies for building ethos, and the lapses in logic that they were used to cover, are the elements of Descartes' rhetoric that Newton quite likely reacted against most fiercely. And the book that makes most obvious use of such strategies, the *Geometry*, contains not surprisingly the first part of Descartes' 'philosophy' that Newton rejected—his mathematics.

John Fauvel's "Cartesian and Euclidean Rhetoric" clearly demonstrates this vital difference in the rhetorical strategies of the two mathematicians. The Cartesian rhetoric of the *Geometry* relies on creating an immense ethos to persuade the reader when logic fails, while Euclidean rhetoric uses careful step-by-step logic to persuade. Additionally, the rhetorics of the *Discourse* and the *Geometry* use an inductive, narrative mode very similar to that used by Newton in the

"New Theory" article, while Euclid's deductive definition-axiom-proposition organization is of course very similar to that of the *Principia*.

Cartesian Rhetoric

To begin with, Fauvel demonstrates that both the *Discourse* and the *Geometry* are first-person and, at least ostensibly, autobiographical narratives. In the *Discourse*, Descartes appears to be allowing the reader to overhear what Fauvel terms an "autobiographical rumination." According to Fauvel,

> the *Discourse* turns out to be a finely constructed story about the past persona (called "I") of a narrator (also called "I"), structured so as to bring out an imaginary intellectual journey—a fictional narrative case in the form of an autobiography (26).

Fauvel's conclusion is based largely upon the following and other similar passages in the first few pages of the *Discourse*.

> I should be glad in this discourse to describe for the benefit of others the paths I have followed, to paint a picture, as it were, of my life, of which each one may judge as he pleases; and I should be happy, too, to learn what public opinion has to say of me, and so discover a fresh mode of instruction for myself . . . (qtd in Fauvel 25).

Descartes makes it clear in this passage that the method of study he will describe in the *Discourse* is the result of his life's work; thus an autobiographical account of his life's experiences is to be used as evidence for its success. The rhetoric is openly, in fact blatantly, focused upon the author, so the author's *ethos* is of paramount importance. Descartes does concede his willingness to consider the opinions of others, but as Fauvel suggests, Descartes was not in fact desirous of criticism; he was instead trying to build his credibility by appearing extremely reasonable and open to suggestion. Similar overt attempts to build credibility are present in Newton's "New Theory" article as well (which also takes the form of an autobiographical narrative), but his strategies are of course different (more on this in Chapter II).

The extent of Descartes' efforts to build his credibility are even more apparent in the *Geometry*. In a style similar to that of the *Discourse*, the *Geometry* begins as a first-person narrative about how to apply Descartes' method to mathematics. Note Descartes' numerous references to himself and his procedures in this description of the basics of his geometry at the beginning of the book.

> I have only to join the points A and C, and draw DE parallel to CA; then BE is the product of BD and BC.
>
> If it be required to divide BE by BD, I join E and D, and draw AC parallel to DE; then BC is the result of the division.
>
> If the square root of GH is desired, I add, along the same straight line, FG equal to unity; then bisecting FH at K, I describe the circle FIH about K as a center, and draw from G a perpendicular and extend it to I, and GI is the required root. I do not speak here of cube root, or other roots, since I shall speak more conveniently of them later (5).

Such uses of the personal pronoun “I” are common throughout the *Geometry*, making it clear that the knowledge imparted is to be read as Descartes' own creation.

However the *Geometry* is not simply a narrative, as the first two pages of the book make it appear. On the surface at least, the *Geometry* is a set of instructions. Thus the reader has a more prominent position than in the *Discourse*. According to Fauvel, the *Geometry* “is the story of young René and his instruments, of a craftsman inculcating you into the skills of his trade. The author tells you how to do things, as a furniture maker might” (26). Descartes is the master, thoroughly versed in his craft and therefore beyond question, and the reader is the apprentice, struggling to develop the skill necessary to master the craft and often failing in the attempt. An examination of the *Geometry* and the context surrounding it makes it abundantly clear that Descartes was striving for this effect with all the means at his disposal, whether the readers were indeed neophytes only beginning their study of mathematics or sophisticated members of European intelligentsia. The success of the book and its subsequent influence are testament to the persuasiveness this rhetorical strategy had for Descartes' audience.

Immediately following the description of some of the basics of geometry (most of which is quoted on the previous page), Descartes explains his practice of replacing the “lines” of geometry with the “letters” of algebra—maintaining his use of the personal pronoun “I” throughout. However, following this explanation, Descartes immediately shifts to an instructional mode, marked most obviously by his use of the pronoun "we."

> If then, we wish to solve any problem, we first suppose the solution already effected, and give names to all the lines that seem needful for its construction,—to those that are unknown as well as to those that are known. Then, making no distinction between known and unknown lines, we must unravel the difficulty in any way that shows most naturally the relations between these lines, until we find it possible to express a single quantity in two ways (7, 9).

Thus on the third page of the 120-page text, Descartes first acknowledges the reader's presence. Descartes has now fully established the stance that he will maintain throughout the text: a craftsman skillfully nurturing the study of a novice in the skills of his craft. The use of the pronoun "we" rather than "you" (or the implied "you" of a command) works to persuade the reader that Descartes is nurturing rather than merely instructing and, while Descartes frequently shifts back to "I" to clearly lay claim to his creation, his pronoun choice in general helps to create a rather informal, "chatty" tone that Descartes maintains throughout the text.

Despite this informal sort of "nurturing," helpful stance that Descartes takes, his real goals are far from helping the reader to understand. Actually, what Descartes wants is for readers *not* to understand some elements of the text, yet still believe that he is doing everything he can to help them. Further into the text (but still early), Descartes makes it clear that the reader is expected to be an active participant in the learning process.

> But I shall not stop to explain this in more detail, because I should deprive you of the pleasure of mastering it yourself, as well as of the advantage of training your mind by working over it, which is in my opinion the principal benefit to be derived from this science. Because, I find nothing here so difficult that it cannot be worked out by any one at all familiar with ordinary geometry and with algebra, who will consider carefully all that is set forth in this treatise (10; see also Fauvel 27).

On the surface, Descartes' intentions seem straightforward enough. He appears to be demanding of the reader what any good teacher would demand of his or her pupils: that they take active roles in their own educations. However, the real goal of this passage is nothing less than a carefully-orchestrated act of intimidation. When readers attempt to work through the details Descartes has omitted, they find that the calculations are extremely difficult, if not impossible. Fauvel notes several similar occurrences later in the text—for example,

> I shall not give the constructions for the required tangents and normals in connection with the method just explained, since it is always easy to find them, although it often requires some ingenuity to get short and simple methods of construction (Descartes 112; *slightly* different translation qtd in Fauvel 27).

According to Fauvel, Descartes does give three examples of the constructions, but the three he chooses have reasonably simple solutions. However, the student would find that applying the method to other curves "landed them in mindboggling or impossible calculations" (Fauvel 27).

When we reexamine the *Geometry* in this light, we find that throughout the text Descartes is not actually nurturing the reader's understanding, but rather is doing everything possible to persuade readers of their own mathematical incompetence and, consequently, of his mathematical genius. Thus Descartes builds credibility for himself and for his mathematics by convincing readers that their own abilities are inadequate for working through the details that the text omits—which, of course, they are to assume Descartes has worked through himself.

The evidence that this was Descartes' strategy is strewn throughout the *Geometry*. He is constantly referring to the ease with which he, and other competent mathematicians, can carry out procedures. The word "only" in the first sentence of the passage I quoted on page 19 ("I have only to join the points . . .") indicates that Descartes considers the procedures simple to understand. And in the first sentence of the book, we are told that "any problem in geometry can easily be reduced to such terms that a knowledge of the lengths of certain straight lines is sufficient for its construction" (2). Again the words "any" and "easily" in this passage indicate the attitude of the Descartes persona toward the material. Such modifiers can be found throughout the book whenever Descartes begins to explain something new.

The two passages cited by Fauvel that I provide on page 22 give a similar impression: "I find nothing here so difficult that it cannot be worked out by any one at all familiar with ordinary geometry and with algebra . . .," and "I shall not give the constructions . . . since it is always easy to find them . . . ." Descartes clearly wants to create the impression that everything he discusses is easy—for those readers with adeptness and ingenuity.

Fauvel also notes passages where Descartes claims weariness and the short length of the book for the lack of detail.

> I will try to give the demonstrations in a few words, for I am already wearied by so much writing (Descartes 26; see also Fauvel 27).

Then later,

> but if I should stop to demonstrate every theorem I use, it would require a much larger volume than I wish to write (Descartes 111-112; *slightly* different translation qtd in Fauvel 27).

Thus, the Descartes persona unquestionably finds the material of the *Geometry* to be elementary, and as one of the wise, finds the lengthy explanations required by the young wearisome, in fact bothersome.

Despite the simplicity of the material for the Descartes persona, he warns readers in the "Advertisement" at the beginning of the *Geometry* of the difficulty of the text for the uninitiated.

> So far I have tried to make my meaning clear to everyone; but I doubt that this treatise can be read by anyone not familiar with geometry books, for I've thought it superfluous to repeat the demonstrations contained in them (qtd in Fauvel 26).

Thus, as Fauvel points out,

> "this essay was to be for initiates, in a way that the *Discourse* and the other two essays were not. The author seems to be wishing to establish that most of his readers would not be able to understand the final essay" (26).

Of course what the above analysis suggests is that what Descartes actually wanted was for no one to completely understand it.

Fauvel also suggests a few strategies outside the contents of the *Geometry* that Descartes used to build his reputation. First, the *Discourse*, along with its three appended essays, was published anonymously, but of course the authorship was not long kept secret. As Fauvel says, Descartes appeared "to prefer the pseudo-mystery of a not-well-guarded anonymity" (25). Additionally, the book was published in French (Fauvel 28). Publishing it in Latin would have made the book far more accessible to its audience of European intellectuals, but by making much of Europe await a translation, Descartes allowed the book's reputation to precede it. Thus he created a sense of anticipation to contribute to the air of mystery. Finally, Fauvel notes "a well-known story that Aubrey told," in which Descartes is visited by Europe's most eminent scholars. When they ask to see the instruments of the great Descartes, he pulls out from his drawer a compass with a broken leg and a folded piece of paper used as a straight edge (Fauvel 27). Thus the magnitude of Descartes' achievement was to be enhanced in the minds of his followers by the crudity of his instruments.

We can be left with little doubt that Descartes wished his audience to consider the *Geometry* difficult. Fauvel cites two passages written to Marin Mersenne to support this. The first was written in 1637, the year of publication.

> I do not enjoy speaking in praise of myself, but since few people can understand my geometry, and since you wish me to give you my opinion of it , I think it is well to say that it is all I could hope for . . . (qtd in Fauvel 26).

Then again in 1646, he wrote,

> I have omitted a number of things that might have made *La Géometrie* clearer, but I did this intentionally, and would not have it otherwise (qtd in Fauvel 26).

Clearly Descartes wanted readers to struggle with his book, even though he feigned a helpful, nurturing stance. By leaving out difficult or impossible steps and telling readers how simple those steps are for the adept, he persuaded his audience that they were incapable of fully understanding the logic of his argument. It seems likely that Descartes recognized weaknesses in his logic, and because logic would not suffice to completely persuade his audience, Descartes turned to another of Aristotle's elements of rhetoric. He generated an immense ethos that would cause readers to blame themselves when they didn't understand rather than blaming him. While one can certainly question Descartes' ethics in using this strategy, the strategy was, nevertheless, a resounding success—at least until half a century later when Isaac Newton encountered it.

Newton and Cartesian rhetoric

Newton's encounter with Cartesian rhetoric is not explicitly described by Newton or anyone else that I am aware of. Nevertheless, his reaction to it can perhaps be pieced together from the historical and textual evidence. Newton's rejection of Cartesian mathematics, which I described earlier in this chapter, is well documented, and many of his comments and writings suggest the tremendous contempt with which he came to view everything Cartesian.

As Westfall describes it, Newton intensely studied Descartes during his undergraduate years at Cambridge. "Notes from Descartes, whose works Newton thoroughly digested in a way that he never had Aristotle, appear throughout the 'Quaestions'" (89) (the "Quaestions is one of Newton's notebooks from his days as a student). As Westfall also notes, Newton held Cartesian mathematics in high regard until in or around the late 1670s, when he first seriously studied the ancient Greeks and then reread the *Geometry* (377-381). After this time, Newton developed an extreme revulsion for Cartesian mathematics, calling it "the Analysis of the Bunglers in Mathematics" (qtd in Westfall 380). What seems likely is that Newton, as a student still unsure of his own mathematical abilities, was persuaded during his first study by Descartes' efforts to build credibility at the expense of readers.

However, after working through the geometry of the ancients, Newton, now confident of his abilities, was no longer persuaded of his own inadequacy to handle the mathematics of Descartes. Thus the rhetoric of Descartes most likely infuriated Newton when he found himself still unable to work through some of the omitted steps.

While no direct evidence exists to substantiate this supposition, Newton did make some highly critical comments about the *Geometry* and wrote at least one manuscript pointing out "errors." According to Westfall, when Newton reread the *Geometry*,

> he went through writing in the margins comments such as "vix probo" (I hardly approve), "error," and "Non Geom." Probably in connection with this reading, he drew up a paper of "Errors in Descartes' Geometry (380).

The paper to which Westfall refers is a short critique, dated in the late 1670s, where Newton demonstrates that three claims made by Descartes in the *Geometry* are invalid (Whiteside "Papers IV" 336-345). All three claims concern Descartes' application of his method to a problem done by Pappus, and all three are made within less than two pages of text. What is of particular interest is that following the three paragraphs in which Descartes makes these claims, and before he provides demonstrations to support them, he defends his omission of steps.

> I believe that I have in this way completely accomplished what Pappus tells us the ancients sought to do, and I will try to give the demonstrations in a few words, for I am already wearied by so much writing (26).

Clearly, Newton was not satisfied with Descartes' demonstrations, and quite likely, he was angered by Descartes' excuse for not providing more detail. Imagine how Newton must have felt (especially considering his emotional constitution). He had recently endured a period where his own credibility (in optical studies) had been questioned, and now he was discovering that the acknowledged master in mathematics, to whom he and the rest of Europe had long been devoted, had been less than forthright about the claims he made. Even more, he concealed flaws in his logic in a high-handed rhetoric. Surely, Descartes must have seemed exceedingly pompous and arrogant to Newton considering the rhetorical stance of the *Geometry*.

Newton's only other surviving (specific) critique of the *Geometry* further demonstrates the contempt he eventually felt for Descartes and the concurrent feelings of respect that he came to have for the ancients. According to the editor of Newton's mathematical papers,

> Never one to stomach an overreacher and increasingly in a mood to be sharply critical of all things Cartesian, Newton soon concluded that in supposing the Greeks not to have solved the problem of the 3/4-line locus in all its generality Descartes had gone badly wrong (Whiteside, "Papers" 222).

Later mathematicians conceded the novelty of Descartes' solution (Whiteside, "Papers" 221). However, Newton, who was quite likely reacting to the arrogance of Cartesian rhetoric, was now becoming unwilling to concede to Descartes even his considerable achievements.

Euclidean Rhetoric

Textual evidence clearly indicates that Newton found the mathematical presentations of Euclid and the other ancients preferable to those of Descartes. Indeed it is becoming increasingly clear that he found Euclidean rhetoric in general, mathematical and verbal, preferable to the rhetoric of Descartes. Unlike Descartes' rhetoric in the *Geometry*, which regards the mathematics as an invention of the author understandable to only the most proficient readers, Euclid's rhetoric claims to *reveal* absolute, Platonic truths with little or no explicit acknowledgement of the reader's presence. Even more importantly, Euclidean rhetoric provides specific step-by-step details that lead readers through a thorough, logical progression from definitions to axioms to propositions. So although Euclidean rhetoric doesn't address readers directly as Cartesian rhetoric does, it is in fact much more reader-friendly because it endeavors to clarify rather than to confuse.

Fauvel describes Euclid's rhetoric as "perfectly straightforward: there is no sign that he notices the existence of readers at all. Rather, he seems engaged in laying down inexorable eternal truths" (25). This rhetoric stands in contrast to that of Descartes in the *Geometry* where "the mathematics described is clearly created, not unveiled, in rhetoric which veers from grabbing the reader by the lapels to treating you (sic) with utter disdain (Fauvel 25). Unlike the rhetoric of Descartes, Euclidean rhetoric focuses solely on the text, excluding, as much as possible, the presence of both reader and writer. Depending on the translation, the personal pronouns "I" and "we" are occasionally used (see Archibald "Euclid's Division of Figures"), and as Fauvel notes, the implied "you" of a command is often present: "the nearest Euclid seems to get to recognising the existence of readers is in his 'let such-and-such be done' mode. . ." (25). However, the axiomatic presentation of Euclid is concerned primarily with the system being described. We don't see the long digressions as in the *Geometry* where Descartes takes time to 'chat' with the reader. Euclid has no need to justify his *exclusion* of steps because he doesn't exclude any.

The fact that Euclid provides each step that one must go through in order to follow the logic of his geometry is the vital difference between his rhetoric and that of Descartes. Euclid begins by defining the basics of geometry (e.g., points, lines, angles). He then takes care to postulate a few 'self-evident' assumptions about the manipulation of those defined quantities, or axioms (e.g., if two things are both equal to a third, they are also equal to each other.) Then using only these most basic assumptions, Euclid presents his propositions and proceeds logically to demonstrate their validity with detailed step-by-step 'proofs.'

Euclid's rhetoric differs substantially from Descartes' in several respects. Cartesian rhetoric overtly addresses the audience over and over again, while Euclidean rhetoric avoids such references as much as possible. Cartesian rhetoric is primarily organized as a narrative, whereas Euclidean rhetoric uses formal, numbered propositions followed by proofs. But the crucial difference that was likely the most important difference for Newton is that Cartesian rhetoric leaves out demonstrations of many of its claims, substituting instead the word of the author that they can be easily accomplished by the reader. It was this final element of Cartesian rhetoric that it seems Newton was reacting most virulently against. However, apparently as a result of this reaction (and quite likely other elements as well), Newton rejected the whole of Cartesian rhetoric and much of Cartesian philosophy.

To further substantiate this claim, Chapter II of this thesis will take up an analysis of Newtonian rhetoric. Although this analysis will focus on the *Principia* as an example of Euclidean rhetoric, it will also examine Newton's "New Theory" article, drawing comparisons between Newton's earlier rhetoric and that of Descartes in the *Geometry*.

AN ANALYSIS OF NEWTON'S RHETORIC

In *Shaping Written Knowledge*, Bazerman argues that the process of answering criticism to the "New Theory" article contributed to Newton's development of the Euclidean framework used by both the *Principia* and the *Opticks*. Newton's writing process therefore contributed significantly to the organization and content of his optical theory. Although I am arguing that Newton's rejection of Cartesian mathematics, mechanics, and rhetoric also contributed to the development of this Euclidean organization, I am doubting neither the rhetorical character of Newton's process of discovery nor the vital role of the optical criticism in that process.

Analysis in this chapter will demonstrate that the mechanical and gravitational theory in the *Principia* was also largely a product of Newton's writing process and his perception of the rhetorical situation. The scenario I would paint is that answering the optical criticism played a part in Newton's decision to look to mathematics for a system of argument, but that his later rejection of Cartesian mathematics was important for his decision to develop a Euclidean system. Thus, my work fills in the gap, both chronologically and rhetorically, between the period of optical criticism (1672-1676) described by Bazerman and the writing of the *Opticks* in the 1690s.

The "New Theory" Article and Cartesian Rhetoric

The content and structure of Newton's article, "A New Theory of Light and Colours," clearly appears to be the result of Newton's perception of the rhetorical situation. The similarity that Bazerman demonstrates between Newton's "discovery narrative" and other articles in the *Transactions* during the period and the evidence that he provides that Newton reshaped his presentation to conform to that style are compelling evidence supporting this assertion. However, the discovery narrative is only the first of three distinguishable sections to the "New Theory" article. And while the second section is arguably in the *Transactions* style, the third definitely is not. Bazerman suggests no model that influenced the content and structure of this third section. My analysis, however, will demonstrate that Cartesian rhetoric was quite likely an influence on this section, and indeed on the entire article.

Following the discovery narrative, Newton's article had two other distinguishable sections: "an account of the invention of the reflecting telescope and a general exposition of the doctrine of colors . . . " (Bazerman 95). The description of the reflecting telescope and its invention conform closely to the narrative style used by *Transactions* articles; however, the last section is quite different. It is instead an expository list of claims with only occasional references to experimental evidence. According to Bazerman, "this last section seems in direct contrast with the stated principles and general practice of the journal" (96).

Bazerman argues, quite convincingly, that Newton was summarizing his theory in this third section, omitting much of the empirical evidence on which it was based for the sake of conciseness. The article was meant to acquaint the scientific community with Newton's theory and prepare readers for his forthcoming book. So rather than providing all the experimental details, which Newton had in fact worked through, the article relied on the experiments it did describe as examples of his procedures and on the credibility Newton established as a competent observer in the discovery narrative. The question Bazerman does not answer is why Newton believed this strategy would be successful even though *Transactions* articles did not generally have anything like this third section. The answer to the question may be that Descartes had used this same strategy to great success, and Newton, at this stage in his career, still retained a great deal of respect for Descartes.

The discovery narrative

While the *Transactions* articles of the period were clearly an important influence on the composition of Newton's discovery narrative, it also seems likely that the first-person narratives used by Descartes in *Discourse on Method* and the Geometry were influences on the rhetoric of this section as well. The discovery narrative is a first-person, autobiographical narrative in the Cartesian tradition. Take for example, the opening paragraph of the "New Theory" article (as published, it is a letter addressed to Oldenberg).

> To perform my late promise to you, I shall without further ceremony acquaint you, that in the beginning of the Year 1666 (at which time I applyed my self to the grinding of Optick glasses of other figures than *Spherical*,) I procured me a Triangular glass-Prisme, to try therewith the celebrated *Phænomena* of *Colours*. And in order thereto having darkened my chamber, and made a small hole in my window-shuts, to let in a convenient quantity of the Suns light, I placed my Prisme at his entrance, that it might be thereby refracted to the opposite wall. It was at first a very pleasing divertisement, to view the vivid and intense colours produced thereby; but after a while applying my self to consider them more circumspectly, I became surprised to see them in an *oblong* form; which, according to the received laws of Refraction, I expected should have been circular (3075-3076).

The numerous personal references and the autobiographical scenario created by Newton bear a striking resemblance to the narrative of Descartes in *Discourse on Method.* A description of past experience by Descartes, very similar in form to the one used by Newton, is provided as an example.

> I was then in *Germany*, whither the occasion of the Wars (which are not yet finished) call'd me; and as I return'd from the Emperors Coronation on towards the Army, the beginning of Winter stopt me in a place, where finding no conversation to divert me and on the other sides having by good fortune no cares nor passions which troubled me, I stayd alone the whole day, shut up in my Stove, where I had leisure enough to entertain myself with my thoughts. Among which one of the first was that I betook myself to consider, That oft times there is not so much perfection in works compos'd of divers peeces, and made by the hands of several masters, as in those that were wrought by one only: ("Discourse" 17-18)

The similarities between these passages are impossible to ignore. Beyond the more superficial similarities in narrative style, both writers still have similar strategies—they are each endeavoring to build credibility. Newton is trying to establish that he is a competent Baconian observer, untainted by the bias of a theoretical disposition; and Descartes is attempting to establish himself as well-traveled, well-connected, and contemplative. Clearly, numerous differences do exist; however, these differences are largely the result of the differing goals of each discourse and of what each writer perceives as important for building credibility. The discovery narrative of Newton is even more similar to the *Transactions* articles of the period, but the similarity with the narrative of Descartes' *Discourse* certainly suggests the possible influence of Cartesian rhetoric as well. In fact, it raises the question of what influence Cartesian rhetoric had on all of the *Transactions* articles of the late-seventeenth century.

The doctrine of colours

While Descartes' influence on Newton's discovery narrative is debatable, the influence of Cartesian rhetoric on the last section of the "New Theory" article is more easily defended—if for no other reason than that no other model exists. As noted before, Bazerman states that Newton's exposition of his doctrine is written contrary to the practices of other *Transactions* articles of the period. However, that exposition does resemble to a remarkable extent the rhetoric of Descartes in the *Geometry*.

The most important similarities between Cartesian rhetoric and the Newtonian rhetoric of the "New Theory" article are deletion of evidence and accompanying attempts to build credibility which persuade readers that the evidence exists. The most important differences are (1) Newton's evidence really existed as he claimed, whereas Descartes' occasionally did not, and (2) Newton's attempts to build credibility were directed only at establishing his own competence, whereas Descartes' were directed at establishing his own superiority and the reader's incompetence. Despite the honesty in Newton's claims and the subterfuge in those of Descartes, Newton did borrow a great deal from Cartesian rhetoric. Of course, at this time Newton was unaware of Descartes' dishonesty.

Newton's shift from the second to the third section of his article is marked most notably by a shift from a narrative to an instructional mode, much the same as Descartes' shift in the *Geometry*.

> I shall now proceed to acquaint you with another more notable difformity in [the reflecting telescope's] Rays, wherein the *Origin of Colours* is unfolded: Concerning which I shall lay down the *Doctrine* first, and then, for its examination, give you an instance or two of the *Experiments*, as a specimen of the rest (Newton 3081).

For one of the first times in the article, Newton is using the pronoun "you." Prior to this section, "I" has been the only pronoun used almost without exception, whereas in the third section, "you" is much more common [although, as Bazerman notes, the shift is primarily from "first person active to third object existential" (96)]. In this passage, Newton is also warning readers that the evidence he will provide for his "doctrine" is to be taken as illustratory only, and not as the sum-total of evidence for his theory.

Later in the section, Newton again refers to the omission of experimental evidence. More than any other passage in the article, this statement shows the influence of Cartesian rhetoric on Newton.

> Reviewing what I have written, I see the discourse it self will lead to divers Experiments sufficient for its examination: And therefore I shall not trouble you further, than to describe one of those, which I have already insinuated (Newton 3085).

The influence of Descartes' statements that encourage readers to work through omitted demonstrations for their own benefits and that claim a desire for conciseness as reasons for his omissions can clearly be seen in this passage. Newton is not lecturing to pupils as did the Descartes persona, but rather he is enjoining equals to make the discoveries for themselves, so his statement reflects this difference in the relationship between writer and audience. However, in a fashion very similar to Descartes, Newton doesn't want to burden his text with thorough demonstrations of all his claims.

Finally, near the end of the article, Newton makes a statement very similar to the disclaimer of Descartes where he welcomes criticism of his work.

> This, I conceive, is enough for an Introduction to Experiments of this kind; which if any of the *R. Society* shall be so curious as to prosecute, I should be very glad to be informed with what success: That if any thing seem to be defective, or to thwart this relation, I may have an opportunity of giving further direction about it, or of acknowledging my errors, if I have committed any.

Considering Newton's reaction to the criticism he did receive, it seems that like Descartes his desire for criticism was perhaps not genuine, but was instead intended to demonstrate his reasonableness. But of course Newton regarded the criticism he did receive as unfounded and due to the inability of his critics to experiment carefully, rather being due to errors on his part.

It seems likely that Newton was led to believe that his doctrine would be accepted because of the acceptance, and indeed the tremendous stature, of Descartes in Europe during the seventeenth century. Certainly the discovery narrative was patterned after the *Transactions* articles of the period in an attempt to build credibility for the doctrine of colours. But it seems likely that the factor that caused Newton to believe such a strategy would be persuasive was the success of that strategy for Descartes.

It is not necessary to assume that Newton *consciously* modeled his rhetoric after that of Descartes. Bazerman notes that "since Newton had taken notes on and summarized a number of [*Transactions*] articles, imitating that model need not have been a highly reflective act" (91). Similarly, the rhetoric of Descartes could have made its impact on

Newton due simply to his close study of and great respect for the mathematician during this period of his career.

The *Principia* and Newton's New Rhetorical Strategy

As a result of the period of criticism following the "New Theory" article and as a result of the subsequent contempt he developed for Cartesian rhetoric, and Descartes in general, Newton radically altered his rhetorical strategies. By the time he completed the *Principia* in 1687, Newton had created a radically new rhetoric based on the Euclidean system of mathematical argumentation, for which he had by now developed an immense amount of respect. This new rhetorical strategy would characterize Newton's work for the rest of his life and would make a major contribution to his contemporary success and his historical legacy.

The *Principia* is divided into three volumes. The first two, "De Motu Corporum" ("On the Motion of Bodies") are a series of mathematical propositions and demonstrations where Newton uses his newly developed calculus to demonstrate the mechanical principles of a hypothetical universe where forces can operate upon objects at a distance—in cases where there is no resisting medium ("Liber Primus") and in cases where there is one ("Liber Secundus"). He then uses Book III to argue that our universe obeys those principles. Book III, "De Munde Systemate" ("System of the World") is thus the heart of Newton's 'natural philosophy,' where he uses observed "phenomena" to demonstrate that the motions of bodies in our world are described by the mechanical principles of books I and II.

It should be no surprise by now that the organizational framework of the *Principia* resembles that of Euclid's *Elements of Geometry* (as well as those of his other works). Just as does Euclid, Newton starts by defining a few quantities he recognizes as existing in the universe. From these definitions, Newton proposes three axioms, or laws of nature, that describe the interaction of the defined quantities. Following the definitions and axioms (and some corollaries and scholia used to illustrate them), are Newton's two books (368 pages) of mathematical propositions along with their accompanying geometrical theorems. Using these definitions, axioms, and mathematical results, Newton creates, in Book III, an argument for the validity of his propositions that he believes cannot be questioned. Unlike in the "New Theory" article, Newton now provides every detail of experimental evidence. And he organizes his claims and evidence (propositions and theorems) so that each claim can be justified with evidence as it is encountered. Thus, once the definitions and axioms are accepted as factual, the logical progression of steps is designed to lead one inevitably to each succeeding proposition. As Bazerman notes for the *Opticks*, this closed, logical system leaves no room for interpretation. Once the system is accepted, logical rigor reduces to error any conclusions contrary to those of Newton.

Euclid was working in the abstract realm of mathematics; thus not surprisingly, Newton's first two books are nearly identical (in form, if not in content) to the *Elements*. However, where physics departs from mathematics, Newton departs from Euclid. The third book of the *Principia*, although still very similar in form to the *Elements*, adds an additional element—empirical evidence. Before Newton states a single proposition, he lists a series of six observed "Phenomena," the goal of which is to demonstrate experimentally that the orbits of the various planets and their satellites are elliptical. In addition, the axioms of Newton are also based on his observation of nature and justified by appealing to readers' experiences within the physical world, whereas Euclid regarded his axioms as "self-evident" to any logical, thinking person.

After demonstrating empirically that the known planetary objects revolve in elliptical orbits (Phenomena I-VI), Newton demonstrates mathematically that an inverse-square force—one which decreases as the square of distance—directed at the center of those objects results in elliptical orbits for their satellites (Propositions I-III); he then claims that gravity is in fact that same inverse-square force. Propositions IV and V make this claim for the earth-moon system, for the other planetary systems, and for the sun-planets system. Proposition VI claims that gravity is a property of planets in general and that its magnitude depends on a given planet's mass. Finally, Proposition VII states that gravity is a property of objects in general and dependent on their masses:

> *That there is a property of gravity pertaining to all bodies, proportional to the several quantities of matter which they contain* (414).

This 'Universal Law of Gravitation' is essentially the thesis of Newton's argument. The only further evidence Newton requires to demonstrate it is the already well-known empirical result that gravity is an inverse-square force and the (also previously known) magnitude of that force at a given distance from the earth's center. Thus seventeen pages into Book III, Newton explicitly states the thesis of the entire work. The rest of the book (another 133 pages) is devoted to further illustrating the validity of that thesis—for example, showing how gravity controls the motions of comets and the ocean's tides.

Deductive and inductive structure in the *Principia*

The primarily deductive organization that Bazerman describes for the *Opticks* is clearly apparent in the *Principia* as well; however, the step-by-step basing of propositions on previously stated results in the *Principia* (and in the *Opticks*) also takes advantage of what is best about an inductive organization—namely, it doesn't ask readers to make logical leaps of faith. The most important deductive characteristic of the *Principia* is the early statement of its thesis. As I noted above, the thesis of the *Principia* is stated early in the third book. Although it is over four hundred pages into the work as a whole, the thesis is very early in the text as Newton intended it to be read. Newton makes it clear in his introduction to Book III that the first two books are not to be read thoroughly, but rather, are to be used as references when needed.

> . . . I chose to reduce the substance of this Book into the form of Propositions (in the mathematical way), which should be read by those only who had first made themselves masters of the principles established in the preceding Books: not that I would advise anyone to the previous study of every Proposition of those Books; for they abound with such as might cost too much time, even to readers of good mathematical learning. It is enough if one carefully reads the Definitions, the Laws of Motion [the axioms], and the first three sections of the first Book. He may then pass on to this Book, and consult such of the remaining Propositions of the first two Books, as the references in this, and his occasions, shall require (397).

So as the text is meant to be read, we first learn what Newton is up to less than twenty pages into his argument since most of the first two books are for reference only and the "first three sections of the first Book" are basically a mathematics lesson in Newton's calculus and some of the mechanical principles derived therefrom.

Interestingly enough, however, the organization does have many inductive characteristics. As Bazerman notes (and as I will discuss shortly), Newton became obsessed with pinning down every detail of his argument, apparently out of an intense desire to avoid criticism (and as I have argued, out of his desire to avoid the rhetorical practices of Descartes). Thus Newton was unwilling to make any claims for which he had not already provided evidence—evidence to which he would refer in the proposition's theorem. Thus definitions, axioms, mathematical results, empirical results, and any propositions on which a given proposition depends come before the proposition. Newton did take advantage of the deductive (claims preceding evidence) structure for each individual proposition, but the Euclidean format alerts readers to expect evidence for a given proposition to immediately follow in the theorem.

Still with the thesis stated so early in the book (as it is meant to be read), the overall organization appears to retain a largely deductive character. But with further analysis, we find that Newton has already made the bulk of his argument in the six propositions preceding the thesis (Proposition VII)—an argument that incidentally relies heavily on *inductive* reasoning. As I described it above on pages 42 and 43, Newton's argument is essentially made by demonstrating that gravity controls all the planetary motions, and by asking readers to extend what he has shown them about planets to objects in general. He even provides instruction for those who don't concede the validity of inductive reasoning at the third book's beginning (see "Rules for Reasoning in Philosophy" (398)). So Newton has it both ways. He is able to state his central claim early in the text, yet he has already blunted most criticism by providing very persuasive evidence before its statement. The rest of the text provides further evidence for the universality of gravity, but few would doubt the claim after working through Theorem VII.

Thus it appears that Newton learned valuable lessons from answering his critics and from his rejection of Descartes. He learned the value of stating one's most important claims early in a discourse to allow readers to better understand the relevance of the evidence that follows. And perhaps even more importantly, he learned the importance of providing detailed evidence to support each claim. Even more than this though, adapting the structure created by Euclid to his own needs, Newton proceeded from a few assumptions about the mechanical operation of the universe ("Definitions" and "Axioms"), some observational evidence ("Phenomena"), and some assumptions about how science should be conducted ("Rules for Reasoning in Philosophy") to create a logically interconnected, "closed" system of claims that cannot be questioned from within the system. After readers accept Newton's assumptions and empirical evidence, they are logically compelled to accept his propositions. Interestingly, Newton seems to have recognized the weakest points in his theory. In the first edition of the *Principia*, he termed the "Rules for Reasoning in Philosophy" and the "Phenomena" as "Hypotheses" instead. However, in later editions he altered the titles, recognizing the persuasive value of the more concrete, factual names and quite likely the more accurate descriptions that the later titles provided.

Analytic argument and its accompanying scholia

The step-by-step, closed (what I will call 'analytic') argument used by Newton in the *Principia* and the *Opticks* stands in direct contrast to the rhetoric of Descartes in the *Geometry* and to the rhetoric of the "New Theory" article. To my knowledge, no one but Newton has ever used Euclid's system of definitions, axioms, and propositions as an organizational scheme for anything but mathematics. Quite likely this is due to the nearly unreadable result that system produces. The multitude of references in Book III of the *Principia* to the mathematical demonstrations of (primarily) the first book, to the "Phenomena," and to previous "Propositions" make the text unbearably tedious and difficult to follow. It is only when one considers Newton's extreme concern about criticism, his revulsion for Cartesian rhetoric, and the magnitude of what Newton accomplished that the difficulty of his text becomes more understandable.

The exceeding tediousness of Newton's analytic argument can be seen in Proposition III and its accompanying theorem. The phenomena that Newton refers to are the five empirical results concerning the planets and their moons that immediately precede the propositions of Book III, and the propositions and corollaries referred to are mathematical results from Book I.

> *That the force by which the moon is retained in its orbit tends to the earth; and is inversely as the square of the distance of its place from the earth's centre.*
>
> The former part of the Proposition is evident from Phen. VI, and Prop. II or III, Book I; the latter from the very slow motion of the moon's apogee; which in every single revolution amounting but to 3° 3′ forwards, may be neglected. For (by Cor. I, Prop. XLV, Book I) it appears, that, if the distance of the moon from the earth's centre is to the semidiameter of the earth as D to I, the force, from which such a motion will result, is inversely as $D^{2\ 4/243}$. . .

The labor involved in following long tracts of such prose, replete with references to previous results that force the reader to flip through previous pages of the book to understand the argument, is too much for most readers. Not all of Newton's propositions were so dependent on previous results; still few readers have had the patience, the fortitude, or the ability (remember his *geometric* demonstrations are nearly impossible to follow as well) to understand his analytic argument. Nevertheless, the direct relationships Newton meticulously established between propositions and evidence made it possible for him to accuse any who accepted his basic assumptions and yet not his propositions as either an uncareful reader or as mathematically incompetent.

Newton was, in fact, well aware of the unreadability of his closed, analytic text and therefore illustrated his propositions with abundant scholia in order to make his propositions more easily understandable to readers and in order to further elaborate on issues that the analytical argument does not directly address. In the introduction to Book III, Newton explains the relationship of the scholia to the "principles" expounded upon in his analytic text.

> . . . These principles are the laws and conditions of certain motions, and powers or forces, which chiefly have respect to philosophy; but, lest they should have appeared of themselves dry and barren, I have illustrated them here and there with some philosophical scholiums, giving an account of such things as are of more general nature, and which philosophy seems chiefly founded on; such as the density and resistance of bodies, spaces void of all bodies, and the motion of light and sounds.

So although Newton regarded the step-by-step, analytical argument to be the significant breakthrough and the real substance of his argument, he also recognized the value of explaining the implications of his analysis using tangible examples that make those implications more easily understood.

A good example of Newton's use of his scholia to illustrate his analytical argument follows Proposition and Theorem IV. The proposition and my condensed version of the theorem are shown on the following page. Although even my condensed version of the theorem is rather lengthy, it is important to gain some understanding of Newton's argument in order to contrast it with his illustration in the scholium.

> *That the moon gravitates toward the earth, and by the force of gravity is continually drawn off from a rectilinear motion, and retained in its orbit*
>
> The mean distance of the moon from the earth . . . [is] 123249600 *Paris* feet, as the French have found by mensuration. And now if we imagine the moon, deprived of all motion, to be let go, so as to descend towards the earth with the impulse of all that force by which (by Cor., Prop. III) it is retained in its orb, it will in the space of one minute of time, describe its fall 15 1/12 *Paris* feet. This we gather by a calculus, founded either upon Prop. XXXVI, Book I, or (which comes to the same thing upon Cor. IX, Prop. IV, of the same Book . . . Wherefore, since that force, in approaching to the earth, increases in the proportion of the inverse square of the distance, and, upon that account, at the surface of the earth, is 60 · 60 times greater than at the moon, a body in our regions, falling with that force ought to describe 60 · 60 · 15 1/12 *Paris* feet; and in the space of one second of time, to describe 15 1/12 of those feet. . . .[We also find from a pendulum experiment performed by Huygens that bodies on earth fall at 15 1/12 *Paris* feet per second;] . . . therefore the force by which the moon is retained in its orbit becomes, at the very surface of the earth, equal to the force of gravity which we observe in heavy bodies there. And therefore (by Rule I and 2) the force by which the moon is retained in its

> orbit is that very same force which we commonly call gravity; for, were gravity another force different from that, then bodies descending to the earth with the joint impulse of both forces would fall with a double velocity, and in the space of one second of time would describe 30 1/6 *Paris* feet; altogether against experience (407-408).

Newton's argument then is: since the force controlling celestial motion and gravity have the same magnitude at the earth's surface (facts that he demonstrates empirically and mathematically), and since only one force is observed, then the two forces must in fact be the same one.

This argument seems straightforward enough to the modern mind, even though following the direction of Newton's analytical argument is somewhat difficult. But Newton was faced with an audience who questioned whether physical principles valid on Earth could be extended to the heavens. Thus he needed a tangible example that would make that extension easier for his readers to accept. What he used in the scholium to accomplish this goal is what modern science would call a 'thought experiment.'

> The demonstration of this Proposition may be more diffusely explained after the following manner. Suppose several moons to revolve about the earth, as in the system of Jupiter or Saturn . . . . Now if the lowest of these were very small, and were so near the earth as almost to touch the top of the highest mountains, the centripetal force thereof, retaining it in its orbit, would be nearly equal to the weights of any terrestrial bodies that should be found upon the tops of those mountains . . . . Therefore if the same little moon should be deserted by its centrifugal force that carries it through the orbit, and be disabled from going onward therein, it would descend to the earth; and that with the same velocity, with which heavy bodies actually fall upon

> the tops of those very mountains, because of the equality of the forces that oblige them both to descend. [And if the centripetal force were different from gravity, the moon would fall at twice the rate we observe because of the influence of both forces.]. . . And therefore the force which retains the moon in it orbit is that very force which we commonly call gravity . . . (409).

The rhetorical value of this 'thought experiment' is that it creates a plausible, easily-comprehended scenario that helps readers to overcome their prejudices about the difference between the heavens and the earth. The scenario helps readers to extend what they already intuitively understand about the motions of objects on the earth to the motions of objects in space. It makes the logic of Newton's argument easily understandable. If readers want the details of the evidence Newton uses to support his conclusion, they can refer to the theorem, but to get the 'big picture' of his argument in a form they can easily understand, readers need only refer to the scholium. Considering the rhetorical effect of the titles he used (theorem versus scholium) and the concern he had for providing every detail, Newton obviously considered the analytical arguments in the theorems to be the vital elements of his theory. However, considering the difficulty of those analytical arguments, contemporary readers were probably often content with reading the scholia.

Although Newton primarily uses the scholia to clarify and simplify, he also uses them to anticipate (and answer) potential objections readers might have to any of his assumptions. The scholium following the "Definitions" at the beginning of the work is one such example. Newton's definitions all assume an absolute space, time, and motion—notions which seventeenth-century thought had yet to completely accept. Thus Newton apparently felt it important to define and justify his assumptions philosophically.

> Hitherto I have laid down the definitions of such words as are less known, and explained the sense in which I would have them understood in the following discourse. I do not define time, space, place, and motion, as being well known to all. Only I must observe, that the common people conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common. . . (6).

Newton then follows with seven pages that define and argue for the existence of these absolute concepts. It is clear from the above passage and from the placement of these definitions and justifications in the scholium that Newton regarded the concepts of absolute time, space, and motion as obvious assumptions. However, it is also clear that he recognized that those assumptions might be questioned. Thus, the rhetorical strategy behind the scholium is similar to that of the others. It solidifies and clarifies Newton's position. Again, as with the rest of the theory, Newton is trying to account for every detail, every possible objection to his claims.

Euclidean format and the "System of the World"

Newton's motivation for looking to mathematics, in particular Greek mathematics, for a system of argument is not completely certain; however, several possibilities do exist. Quite likely Newton's motivation was some combination of all of them. First of all, Bazerman argues for the *Opticks*, and I agree for the *Principia*, that Newton wanted a system that would present his theories as he perceived them—as concrete *fact*. Thus in looking to mathematical forms of argument, in particular Euclidean argument, Newton avoided as much as possible the 'slippery' nature of words. Although Newton had no hope of actually reducing his theories to purely mathematical relationships, his use of the mathematical designations: "definition," "axiom," "proposition," "theorem," "lemma," "corollary," and "problem" to organize even the primarily non-mathematical parts of his theories had the rhetorical effect of creating a mathematical precision and certainty of which words are incapable.

In addition, the *Principia* was primarily an achievement in mathematics and mathematical physics. The notion that gravity controls the motions of the planets was not a new idea; it was only the mathematics of Books I and II that allowed Newton to be the first to demonstrate it to the world. Thus Newton, in his introduction to Book III, makes it quite clear that the chief value of the work is mathematical.

> In the preceding books I have laid down the principles of philosophy; principles not philosophical but mathematical:

> such, namely, as we may build our reasonings upon in philosophical inquiries. . . ("Principles" 397).

Without the mathematical demonstrations of the first two books, the propositions of Book III about the mechanics of our solar system are, for Newton, "hypotheses." And remember that Newton, unlike Descartes, wanted every detail of his argument pinned down. He wanted a 'synthetic' meshing of the various elements of his theory like those of the ancient Greeks. Thus it was vitally important that the relationships between the 'natural philosophy' of Book III and mathematical principles of the first two books be made as explicit as possible.

The decision to make the ties between Book III and Books I and II explicit by extending the mathematical format to Book III was in fact a conscious decision on the part of Newton. In an early draft, the *Principia* was envisioned as two books: "De Motu Corporum" and "De Munde Systemate." The first book was composed of the mathematical treatises of what eventually would be Books I and II. As it grew in length, Newton divided this original "De Motu" into two books along what he eventually saw as a natural division (motion without a resistant medium and motion with one). However, the original Book II, "De Munde Systemate," was written as an essay, rather than in the Euclidean style (Westfall 420-434). And while the justification for Newton's "System" was always "De Motu," the relationships between the original two books were not made explicitly, as they were in the

Principia. Continuing in the introduction to Book III of the *Principia*, Newton states:

> . . . I now demonstrate the frame of the System of the World. Upon this subject I had, indeed, composed the third Book in a popular method, that it might be read by many; but afterwards, considering that such as had not sufficiently entered into the principles could not easily discern the strength of the consequences, nor lay aside the prejudices to which they had been many years accustomed, therefore, to prevent the disputes which might be raised upon such accounts, I chose to reduce the substance of this Book into the form of Propositions (in the mathematical way), which should be read by those only who had first made themselves masters of the principles established in the preceding Books . . . ("Principles" 397).

Clearly, Newton was not satisfied with the essay form of his "System." As Newton stated, he realized that just as with the "New Theory" article, readers would not be able to see the implications of his mathematical demonstrations for celestial mechanics unless he made the logical connections for them. So what Newton wanted for his mathematics (a 'synthetic' formulation), he also wanted for his entire theory. He wanted a closed, interwoven, mutually-supporting network of propositions and demonstrations—a synthetic genre.

What Newton was really talking about was his new standard for evidence. The original "System" relied not so much on the mechanical principles demonstrated mathematically by Newton for evidence, but rather on creating plausible scenarios based on the common experience of readers and writer. While the actual justification was, to Newton's mind, the mathematics of "De Motu," the original "System" persuaded by generalizing from experiences that readers were commonly familiar with rather than explicitly referring to mechanical principles established in "De Motu." Thus, the original "System" was very similar to the scholia of the *Principia*.

Actually, the arguments of the original "System," are more than similar to those in the scholia. It appears that the arguments made in the scholia are at times revised versions of those made in the "System." Fortunately, we can compare the two because copies of the original "De Motu" and "De Munde Systemate" were deposited by Newton in Cambridge library. As an obligation of his chair as Lucasian Professor of Mathematics at Cambridge, Newton was required to deposit with the University Library revised and polished versions of his lectures. However, the two texts Newton deposited are regarded by historians as the early drafts of the *Principia*, rather than actual records of his lectures (Cohen "System" vii; Westfall 423).

By examining the text of the original "System" and comparing it to the text of the *Principia*, we can see that some of Newton's scholia are in fact revisions of the original essay. For instance, Newton's scholium explaining the effect of gravity on the motion of the moon uses not only a similar rhetorical strategy (a thought experiment), but a very similar argument as the following passage from the original "System."

> That by the means of centripetal forces, the Planets may be retained in certain orbits, we may easily understand, if we consider the motions of projectiles. . . .
>
> Let AFB represent the surface of the Earth, [see Newton's diagram (my Figure 1) on the following page] C its center, VD, VE, VF, the curve lines which a body [he mentions a

> stone in the previous paragraph] would describe, if projected in an horizontal direction from the top of a high mountain, successively with more and more velocity . . . . And for the same reason that the body projected with a less velocity, describes the lesser arc VD, and with a greater velocity, the greater arc VE, and augmenting the velocity, it goes farther and farther to F and G; if the velocity was still more and more augmented, it would reach at last quite beyond the circumference of the Earth, and return to the mountain from which it was projected. . . .
>
> But if we now imagine bodies to be projected in the directions of lines parallel to the horizon from greater heights, as of 5, 10, 100, 1000 or more miles, or rather as many semi-diameters of the Earth; those bodies according to their different velocity, and the different force of gravity at different heights, will describe arcs either concentric with the Earth, or variously eccentric, and go on revolving through the heavens in those trajectories, just as the Planets do in their orbs (5-7).

Newton noted in my deletions that the velocity would remain constant due to Kepler' second law and the fact that he (Newton) was assuming no air resistance.

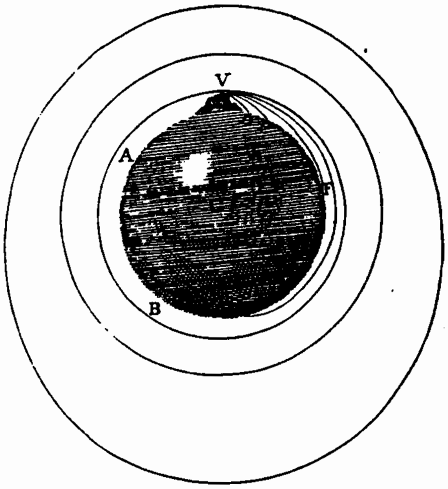

Figure 1. Newton's figure illustrating a projectile thrown from a mountain top ("System" 6)

Note in this passage how Newton apparently revised it to create the argument in the scholium that I cited on pages 51 and 52. Newton retained the idea of an object orbiting at the mountain tops and how that could be extended to satellites orbiting in space. This was apparently, as I noted earlier, because Newton wanted readers to accept that the mechanics of terrestrial objects are the same as the mechanics of those in space. Interestingly, however, Newton discarded the notion of a stone thrown from a mountain top, preferring instead to use a "very small" moon. He probably decided his readers understood that the force controlling a planet's satellites emanated from the planet's center; and thus, they did not need the analogy between projectiles and satellites. But it seems to me that retaining the analogy would have been a very effective tool for persuading readers that mechanics, celestial and terrestrial, are the same. Perhaps this is yet more evidence that Newton expected the reader to be persuaded by the analytical argument and that the scholium was primarily for clarification.

This thought experiment used by Newton in the original "System" and then revised and used as one of his scholia is clearly different from the analytic text of the *Principia*. Actually, it resembles in at least two respects the texts of the *Geometry* and the "New Theory" article. First, the thought experiment, in both cases, is a narrative. Newton asks the reader to imagine; he tells a story about what would happen if certain events were to occur. Second, Newton uses one, or only a few, examples to illustrate a general law, much the same as did both the *Geometry* and the "New Theory" article. Thus it seems clear that in rejecting this format for his "System," Newton was again demonstrating his dissatisfaction with Cartesian organization and standards for evidence. But while he clearly rejected the Cartesian style for proving his conclusions, Newton still found it useful for making the logic of those conclusions easily understood. In this way, Newton anticipated (and perhaps created a model for) the practices of future scientists. Today, just as did Newton, scientists rely on thought experiments to illustrate their conclusions, not to prove them.

Conclusions

The preceding analysis clearly demonstrates that Newton considered his Euclidean, analytic, closed system (or mode) of argument to be the primary persuasive force in the *Principia*. While the scholia occasionally explained some of his assumptions and often clarified and illustrated the analytic argument, they were, as their name implies, inessential to the chain of reasoning. Newton developed this Euclidean, analytic mode as a response to both the inadequacy he perceived in the "New Theory" article and the contempt he developed for the Cartesian mode found in the *Geometry*.

Newton chose Euclidean mathematical argument as a model for primarily three reasons. (1) The tone of the Euclidean presentation matched Newton's epistemological view of his theory; it regarded the theory as concrete fact. (2) The Euclidean step-by-step system of directly, and explicitly, connecting every claim to supporting evidence was a much more persuasive mode of argument for Newton's audience than the practice of providing only examples of the evidence and relying on writer credibility to persuade where evidence was missing. And (3) the great respect Newton developed for the mathematics of the ancients as a mode of presentation (and the concurrent revulsion he developed for the mathematics of Descartes) led him to model the ancients wherever possible. The last two of these reasons are of course mutually supporting; in fact it makes even more sense that Newton's revulsion for Cartesian rhetoric (and preference for Euclidean) is what caused his preference for the geometrical representations of the ancients.

To what relative degrees each of these factors were influences on Newton's rhetoric is only marginally important; they were in fact all influences. What is important is that the resulting mode of argument was exceedingly persuasive and was an important influence on following generations because of the closed framework that linked mutually-supporting propositions and evidence, and because even within this framework, Newton was still able to maintain a primarily deductive organization. As Bazerman notes, science would eventually develop communal closed systems through such practices as the citation of other people's contributions. Also, scientists would eventually learn to combine rigorous logical and mathematical demonstrations with explanatory material such as that found in Newton's scholia (largely because they don't attempt such monumental works). Thus many of the difficulties in Newton's presentation were overcome. Nevertheless, the essential elements of content and organization that Newton established in the *Principia*, and continued in the *Opticks*, have remained with scientific writing to the present day.

ACKNOWLEDGEMENTS

I would like to thank all of my thesis-committee members, Professors John Hagge, David Russell, and Curt Struck-Marcell, for their efforts in reading and critiquing this work, particularly considering the short space of time I gave them to do so. Special thanks also to Professors Hagge and Russell for their tireless assistance in helping me to define, shape, and complete the project. Finally, I would like to thank my wife, Pami, for tolerating lonely nights, financial hardship, and considerable clutter while the work was in progress.

WORKS CITED

Bazerman, Charles. *Shaping Written Knowledge.* Madison, Wi.: University of Wisconsin Press, 1988.

Brewster, Sir David K. H. *Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton.* 2 vols. Edinburgh: Constable, 1855.

Cohen, I Bernard. Introduction. *A Treatise of the System of the World.* 2nd ed. By Isaac Newton. 1731. Facsimile reprint London: Dawsons of Pall Mall, 1969. vii-xxii.

______. *Introduction to Newton's 'Principia.'* Cambridge Mass.: Harvard University Press, 1971.

Descartes, René. *The Geometry of René Descartes* with a facsimile of the 1st ed. 1637. Trans. David Eugene Smith and Marcia L. Latham. Chicago: Open Court Publishing, 1925.

______. *A Discourse of a Method.* 1649. Trans. John Newton. Facsimile reprint London: Dawsons of Pall Mall, 1966.

Fauvel, John. "Cartesian and Euclidean Rhetoric." *For the Learning of Mathematics*, 8:1 (1988): 25-29.

Heath, Sir Thomas. *A History of Greek Mathematics.* 2 vols. New York: Oxford University Press, 1921.

Herivel, John. *The Background to Newton's Principia.* New York: Oxford University Press, 1965.

Newton, Isaac. "A New Theory of Light and Colours." *Philosophical Transactions of the Royal Society*, 7:80 (1672): 3075-3087.

______. *Mathematical Principles of Natural Philosophy.* Trans. Andrew Motte. 1729. Revised. Florian Cajori. Berkeley, California: University of California Press, 1934.

______. *A Treatise of the System of the World.* 2nd ed. Trans. Unknown. 1731. Facsimile reprint London: Dawsons of Pall Mall, 1969.

______. *Correspondence.* Ed. H.W. Turnbull, J, F, Scott, A. R. Hall, and L. Tilling. 7 v. Cambridge: Cambridge University Press, 1959-1977.

Pemberton, Henry. Preface. *A View of Sir Isaac Newton's Philosophy.* Dublin: Hyde, Smith, & Bruce, 1728.

Turbayne, Colin Murray. *The Myth of Metaphor.* Rev ed. Columbia, S. C.: University of South Carolina Press, 1970.

Westfall, Richard. *Never at Rest: A Biography of Isaac Newton.* New York: Cambridge University Press, 1981.

Whiteside, D. T. Introduction. *The Preliminary Manuscripts for Isaac Newton's 1687 Principia 1684-1685.* By Isaac Newton. New York: Cambridge University Press, 1989. ix-xxi.

______. *The Mathematical Papers of Isaac Newton* 12 v. New York: Cambridge University Press, 1971.

APPENDIX: CREATIVE PERIODS IN THE LIFE OF NEWTON

For better understanding the relationship between Newton's optical writing and his writing on celestial mechanics and gravity in the *Principia*, it is useful to examine chronological stages in his thinking process. Keeping track of the large number of dates involved in this task and understanding their relevance can be a daunting task. I have therefore provided a time line on the next page (Figure 2) to facilitate the following discussion. The goal of the discussion is to establish that Newton had temporarily abandoned his work on optics before taking up serious study of celestial mechanics, and that it was only after the publication of the *Principia* that Newton returned to the writing of the *Opticks*. Such evidence lends support to my assertion that Newton's final decision to use a Euclidean organization was closely associated with the writing of the *Principia*.

The influence of the *Principia* on the *Opticks* is far from simple to establish; much easier to establish, considering Bazerman's work, is that the early optical writings influenced the *Principia*. And because of a tragic event in the life of Newton, a destructive fire in his Cambridge office, we will probably never be able to trace exactly the trail of the influences these two texts had upon each other. However, it is also because of this fire, and maybe Newton's generally reclusive attitude during this period, that the *Opticks* was not Newton's first published book. Thus, the fire is also the event that made it possible for the *Principia* to influence the *Opticks*, and it is possible that Book I of the

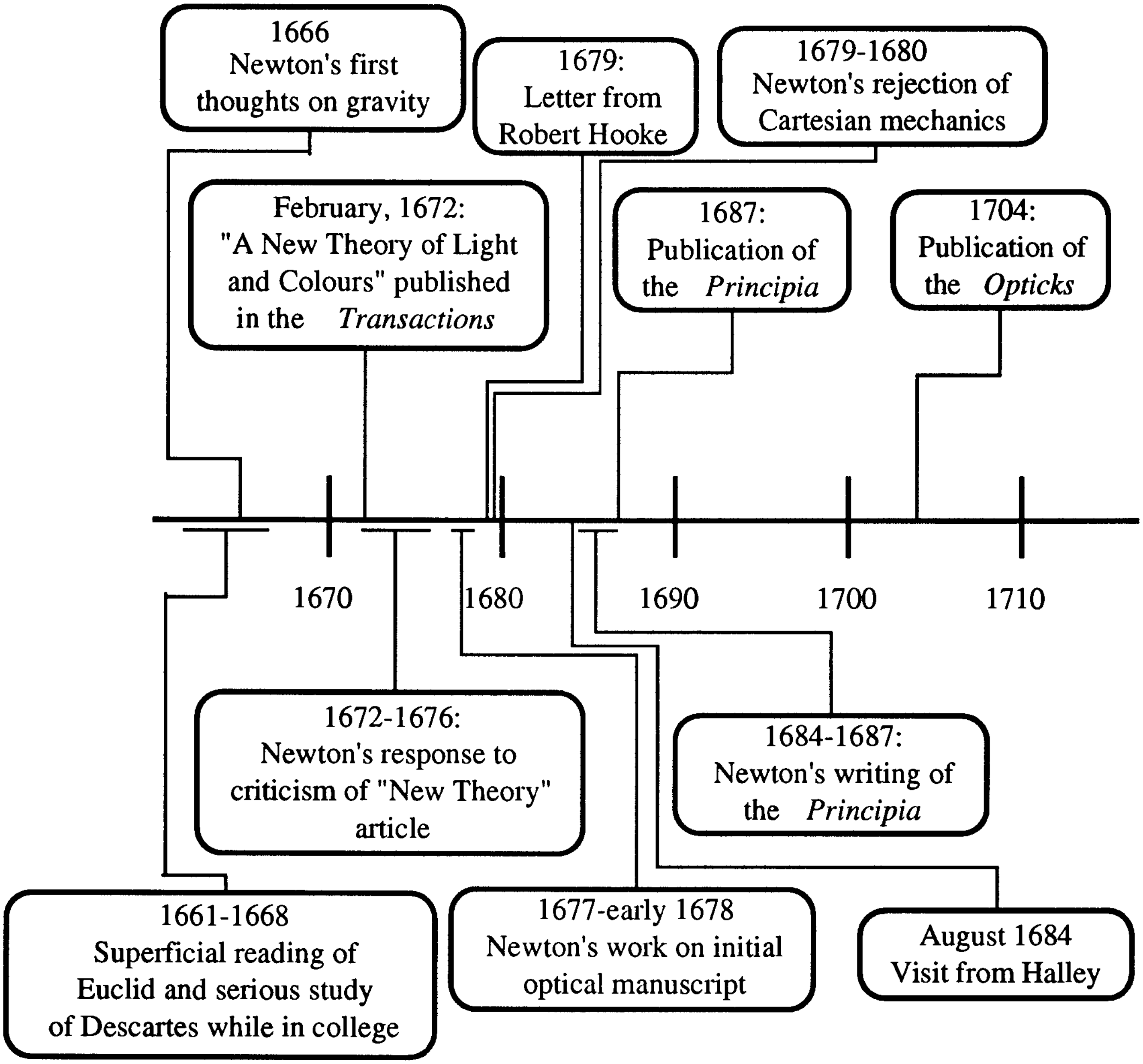

Figure 2. Important Events in Newton's Life

Opticks would not have been the “logical and empirical juggernaut” that Bazerman describes had the manuscript not been destroyed (121).

Optics

The fire to which I have been referring apparently occurred during the winter of 1677/1678, and it destroyed a nearly complete book-length manuscript of Newton’s optical theory. Following the period of controversy surrounding the “New Theory” article (ending in 1676), Newton, spurred on by answering his critics, nearly completed his optical theory by late 1677. Then apparently in December 1677 or early 1678 a catastrophic fire in Newton’s office destroyed the manuscript, and along with it, Newton’s motivation to continue his study of optics (Bazerman 119; Westfall 276-279).

Richard Westfall, in his authoritative biography of Newton, confirms that most of the work on the optical manuscript occurred during 1677. Newton’s correspondence about optics continued into mid-1678, but most of it appears to have been futile attempts to recover some of his lost work from his correspondents (Westfall 276-280). Westfall also notes “a hiatus in Newton’s correspondence from 18 December to February . . .” (278) that might indicate a period of depression following the monumental loss. Thus, Newton’s initial period of optical writing was clearly over by early 1678. Newton did not produce another draft of his optical theory until circa 1690, and he didn’t publish the Opticks until 1704 (Bazerman 84).

Celestial Mechanics

Although Newton abandoned his optical theory for over a decade following the fire in his office, within the next few years, he began a correspondence about celestial mechanics with Robert Hooke, Edmund Halley, Christian Huygens, and others that would lead eventually to the *Principia*. Newton had long had an interest in planetary motion and, along with his correspondents, had long suspected that gravity controlled that motion. In fact, his first thoughts on the role of gravity in planetary motion apparently occurred in 1666 (Westfall 143). However, he soon put aside his thoughts on the subject and concentrated on optics, mathematics, and other interests. One theory advanced is that he did so because an inaccurate figure for the earth's radius caused him to believe his ideas were misguided (Brewster 290; Whiteside, "Manuscripts"). Another suggestion is that it was simply because of an overriding interest in optics (Herivel 14). However, Westfall believes that Newton lost interest because he had not yet worked out his mechanics (laboring still under Descartes' 'Theory of Vortices') and thus could not explain the effect of gravity to his own satisfaction (155). Whatever the reason, scholars agree that Newton didn't regain his interest in celestial mechanics until the early 1670s, when he published a few minor results in the *Transactions*, and that no serious breakthroughs occurred until 1679. (Brewster 291-292; Herivel 14; Westfall 377).

The series of events that is generally thought to have rekindled Newton's interest in celestial mechanics is Robert Hooke's attempts in late 1679 to open a correspondence with Newton concerning the forces causing planetary motion (Brewster 291-292; Westfall 382; Herivel 14). However, Newton did not himself perhaps realize his interest until much later (around 1684). Hooke was clearly beginning to discard the accepted notion that each planet has its own unique force controlling its motion; he also introduced an understanding of circular motion that up to then Newton had demonstrated no evidence of understanding. Despite the value these ideas would eventually have for Newton (the reason why Hooke would eventually raise a charge of "plagiary" against him), Newton claimed in 1679-1680 to have no time for "philosophy," being absorbed in alchemical studies and personal affairs (Westfall 382-383).

Thus, even in 1679, Newton claimed to have little interest in what would eventually be his greatest work. Nevertheless, Westfall contends that in 1679, Newton "stood poised to reject the fundamental tenet of Descartes' mechanical philosophy of nature, that one body can act on another only by direct contact" (381). Newton's experiments with a pendulum and even more importantly, according to Westfall, experimental evidence Newton encountered in his alchemical studies led him to question the "aether," or medium, that Descartes had postulated for transmitting forces between objects not in contact with each other (Westfall 377). D. T. Whiteside, in his introduction to a publication of early manuscripts of the *Principia* concurs with Westfall that Newton's breakthrough came during the winter of 1679-1680, because his correspondence stops discussing the Theory of Vortices at that time. So although Newton would not take up serious study of celestial mechanics until 1684, he was making the fundamental breakthrough that would permit his success in 1679.

After Hooke's attempts in 1679, Newton did show some interest in celestial mechanics. He carried on a short correspondence with John Flamsteed concerning cometary motion. And some brief correspondence took place with Hooke, Edmund Halley, and Christopher Wren as well. However, the event that would spark Newton's serious study of celestial mechanics and would lead directly to his publication of the *Principia* in July of 1687 is well known and the story has been told often. The event is a visit to Cambridge in August of 1684 by Halley, where he asked Newton, who was already known for his mathematical prowess, what the orbit of a planet around the sun would be, supposing that the force of attraction was the reciprocal of the square of the distance between the two objects. Newton promptly answered that it was an ellipse, and upon Halley's surprised reaction and query as to how he knew, Newton said he had calculated it. After a search of his office, Newton claimed to have misplaced the calculation (although Westfall suggests that Newton wanted to recheck it), but he promised to send it to Halley at his earliest convenience. This occurrence set off a chain of events that, largely through the encouragement of Halley, led to Newton's almost complete absorption in the mechanics of the solar system for the next two and one-half years, and to his publication in 1687 of the *Principia* (Westfall 402-404; Cohen "Introduction" 47; Herivel 23; Brewster 296-299).

Greek Mathematics

An even more important, but closely related, question for understanding Newton's motivations is when did he reject Cartesian algebra for presenting his mathematical results, choosing instead Euclidean geometry. The evidence surrounding this question is somewhat conflicting, and thus it seems likely that setting a definite date is impossible unless new evidence should be forthcoming in the future. What seems most likely is that Newton's conversion from both Cartesian mathematics and mechanics is a process that took place over a period of years. Thus, exactly when he decided to adopt geometry as a method of presentation will most likely remain, at least to some degree, a mystery. Nevertheless, some useful benchmarks can be set.

The following passage in Sir Thomas Heath's *History of Greek Mathematics* indicates that while Newton was aware of the ancient Greeks' geometry early in his career, his respect for it did not come about until much later:

> We are told that Newton, when he first bought a Euclid in 1662 or 1663, thought it a 'trifling book', as the propositions seemed to him obvious; afterwards, however, on Barrow's advice, he studied the *Elements* carefully and derived, as he himself stated, much benefit therefrom (370).

Heath does not make clear the source of this passage. However, if it can be trusted, then Newton apparently bought his first volume of Euclid only a year or two after arriving at Cambridge, though he clearly did not study Euclid seriously until later, when his colleague and predecessor as Lucasian Professor of Mathematics (also translator and promoter of the *Elements*), Isaac Barrow, persuaded him of its value.

Both Westfall and D.T. Whiteside, the editor of Newton's mathematical papers, marshall evidence to suggest that it was during 1678-1680 that Newton first studied the ancient Greek loci problems seriously, but Whiteside also makes clear the limitations of methods for dating the manuscripts (Westfall 377-378; Whiteside "Papers IV" 217-229). According to Whiteside,

> From identifying quirks in the handwriting style of the original autograph manuscripts we may, it is true, locate their date of composition in a fairly narrow interval of time, probably during 1678-9 and certainly not much after 1680, but for all other illumination we must necessarily have recourse to essentially unprovable conjecture, relying extensively on personal prejudices which can be controlled only by the internal evidence of the texts themselves ("Papers IV" 217).

Both Westfall and Whiteside suggest that two books published in France in 1679 (one was Fermat's reconstruction of Apollonius' treatise on *Plane Loci* and of five of the propositions in Euclid's *Porisms*) may have helped to develop Newton's interest in the ancient Greeks (Westfall 378; Whiteside "Papers" 224-225). But Whiteside also demonstrates that Newton was studying the ancient Greeks earlier because of a mathematical computation on a letter dated about June 1678 ("Papers IV" 217). Thus, Newton's first serious study of Greek geometry apparently came almost immediately after the 1677-1678 fire in his office, and considering the imprecision in the dating, could have even begun somewhat before it.

In fact, considering the proximity of the dates, and considering the evidence presented by Bazerman that Newton had thought of basing his argument in definitions and axioms as early as 1672 (113), it is not implausible that Newton might have used a Euclidean organization for his first optical manuscript. However, one last piece of evidence suggests that Newton's study of geometry belongs with the 'mechanics' period following the fire. After his study of the classic loci problems, Newton again studied Descartes' *Geometry*. Almost immediately, Newton began an outright attack upon it.

This was the first salvo in a long and continuous attack upon both Descartes' mathematics and his entire mechanical philosophy (culminating in the *Principia*). Westfall argues, therefore, that Newton's study of the ancient Greeks was the catalyst that caused Newton to discredit the whole of Descartes' mechanical philosophy.

> Now in the late 1670s, [Newton] stood poised to reject the fundamental tenet of Descartes' mechanical philosophy of nature, that one body can act upon another only by direct contact. Newton's mathematical papers suggests that only a wholesale repudiation of his Cartesian heritage would allow him to take that step. The repudiation determined not only the content but also the form of the *Principia* (Westfall 381).

So although Newton was clearly thinking about the use of mathematical structures in organizing his optical writing, it seems more likely that his adoption of a Euclidean organization was a part of his repudiation of everything Cartesian. And if that is the case, then Newton's idea for developing his closed text must also be associated with the *Principia*, his wholesale rejection of Descartes' philosophy.