Despite the prevailing assumption that narrative and scientific discourse are incompatible genres, in this article the authors show that scientific texts typically follow a narrative pattern. This simple observation that narrative and scientific texts are similar is not all that surprising when we recognize that scientific discourse, like all narratives, describes what happened and what it meant. Indeed, scientific texts are almost always accounts of scientists' experiences in reality. After developing a vocabulary of narrative, the authors analyze the works of Newton and Einstein, using narrative analysis to illuminate scientific texts as stories.

On Scientific Narrative
Stories of Light by Newton and Einstein

RICHARD JOHNSON SHEEHAN
SCOTT RODE
University of New Mexico

Two of the greatest challenges faced by rhetoricians of science are to determine whether the parallels they study between science and rhetoric are important and whether these parallels are important to the scientific community. We show in this article that narrative theory can cast an important critical light on the scientific enterprise, allowing rhetoricians and scientists to study scientific discourse and reality as narrative constructs. Narrative analysis, we believe, could help scientists identify useful theoretical themes in scientific discourse, inviting further exploration of the untapped potential in scientific theories. Moreover, scientists may also be able to use narrative analysis to recognize when a particular scientific theme has run its course and therefore needs to be replaced by a fertile new perspective. Put simply, we believe that viewing scientific texts as narratives is an invitation to creativity in scientific research. Narrative analysis can highlight new research paths in existing theories. Also, it can help scientists identify new themes that offer alternative ways to conceptualize reality.

In this article, we show that, contrary to prevailing assumptions about science and narrative, scientific discourse and narrative discourse are more alike than different. Specifically, we use narrative theory to study the works of Isaac Newton and Albert Einstein about light, demonstrating across scientific eras how scientists have used

Journal of Business and Technical Communication, Vol. 13 No. 3 July 1999 336-358

narratives to invent rational interpretations of their experiences with nature. By highlighting the parallels between narrative and historical scientific discourse, we demonstrate that narrative theory illuminates the scientific enterprise as yet another way in which humans use stories to come to terms with the strangeness of reality. Nevertheless, our intention is not to devalue science by showing that scientific texts are narratives; rather, we argue that narrative theory highlights commonalties between the sciences and humanities, potentially leading to a better understanding of both. The end result is that narrative theory opens new paths for creativity in science.

PARALLELS BETWEEN NARRATIVE AND SCIENTIFIC DISCOURSE

Our initial premise is that scientists use narratives to invent rational accounts of changing or changeable natural phenomena. Consequently, much of what we say in this article goes against widely held views of narrative in which scientific texts are often singled out as the most obvious examples of nonnarrative discourse. For example, Jerome Bruner, cited by many commentators on narrative theory, draws a sharp boundary between scientific and narrative discourse. He divides cognitive functioning into two irreducible “modes,” the narrative mode and the logico-scientific mode, and argues that narrative and scientific discourse represent two completely different ways of rationalizing experience:

> There are two modes of cognitive functioning, two modes of thought, each providing distinctive ways of ordering experience, of constructing reality. The two (though complementary) are irreducible to one another. . . . Each of the ways of knowing, moreover, has operating principles of its own and its own criteria of well formedness. They differ radically in their procedures for verification. (11)

For the most part, we agree with Bruner and those who cite him when they claim that narrative, like scientific discourse, provides a legitimate way to rationalize experience and interpret reality. However, it seems unnecessarily arbitrary to divide one from the other into “irreducible” camps merely because scientific discourse and narratives appear, at first glance, to pursue different aims. In fact, as Ben Barton and Marthalee Barton point out, academia’s habit of dividing everything into conflicting binaries might even be blinding us to the pervasiveness of narrative in professional environments (39; see also Blyler 330-31). Bruner's perceived irreducible division between narrative and scientific discourse could be primarily due to differences in content, audience, and purpose. The same differences, of course, could be highlighted between a fictional novel and a historical monograph—two very different uses of the narrative genre.

All things considered, narrative and scientific discourse may be more similar than different. For instance, consider the similar organizational patterns of narratives and scientific articles. Narratives are usually defined as texts containing a series of events ordered into a temporal succession that is familiar, or at least acceptable, to readers (see Chafe 11). The series of events in narratives, as William Labov points out, tends to follow a predictable pattern. First, narratives *orient* the readers to a particular space and time by describing a setting and supplying background information. Second, once this familiar space is created, a *complication* is introduced to disrupt the otherwise predictable evolution of the original situation. Third, presented with this disruption, the narrator or agents are then compelled to *evaluate* the complicating factors and find a resolution for the problem. Finally, the narrative *concludes* by tying up loose ends, often stressing the importance or relevance of the story. In sum, Labov argues that a typical narrative follows this pattern of orientation, complication, evaluation, resolution, and conclusion.

Some readers might be surprised to find that scientific articles generally follow the same organizational pattern. First, scientists orient their readers to current theories or beliefs about particular phenomena, usually through reviews of literature or summaries of former experiments. Second, they show how anomalous events contradict theory or resist explanation, creating a complication. Or, they show how a gap in the research leaves the theory incomplete or untested. Third, they describe a methodology used to study, or evaluate, the anomalous event or gap in the research. Finally, they resolve the complication by showing how it can be reconciled with the current theory, call for a change in the current theory, or in rare cases demand a new theory. When the traditional organizational pattern of narrative, as described by Labov, is placed side by side with the scientific article's traditional organization, the parallels between the two genres are striking (see Table 1). Of course, these genre organizational structures are not prescriptive, and certainly successful exceptions to these conventions exist. More or less, though, narratives and scientific articles

TABLE 1
Comparison of Narrative and Scientific Article Genres

Narrative Genre	*Scientific Article Genre*
Orientation	Literature review
Complication	Identification of anomaly or gap in research
Evaluation	Methodology for study
Resolution	Results
	Discussion
Coda	Conclusions

tend to fall into these patterns because they are conventions that the readers expect.

These parallels are no accident and really should not be all that surprising. After all, when scientists compose scientific texts, they are describing their experiences with their surroundings and interpreting those experiences for their readers—much as journalists, historians, or essayists might describe human experiences. Narrative provides a useful organizational pattern through which scientists can recount their interactions with natural phenomena. Whether scientists are discussing results from analytical or empirical research, narrative offers a natural way to organize accounts of their experiences. Indeed, the texts of the hard sciences—often seen as terra incognito for narrative—are full of simple narratives, such as thought experiments and stories of discovery. Furthermore, a scientist's description of a research methodology is a step-by-step recounting of how that scientist went about studying the events that make up a particular phenomenon. In short, scientists' accounts of their *experiments* are narratives about how they made sense of their *experiences* with reality. The *experi*- root of both these words is not a coincidence.

Drawing parallels between narrative and scientific discourse, however, requires us to go beyond simple comparisons of organization. For this reason, let us now turn to developing a vocabulary for analyzing scientific works through narrative concepts. Later in this article, we use these concepts to study the writings of Newton and Einstein about light. Donald Polkinghorne defines narrative in the following way:

> Narrative is a meaning structure that organizes events and human actions into a whole, thereby attributing significance to individual

> actions and events according to their effects on the whole. . . . Narrative provides a symbolized account of actions that includes a temporal dimension. (18)

Polkinghorne's definition offers a concise summary of the concepts that are central to narrative theory: meaning structure (genre), actions, events, a sense of wholeness, and temporality. By meaning structure, he suggests that narrative provides a familiar pattern, or genre, through which an experience (real or imagined) can be described. Essentially, as Polkinghorne suggests, the narrative genre "organizes events and human actions"—or the sequence of "nows," as Paul Ricoeur refers to them—on which stories are plotted. The narrative genre unites these events into a living whole that would otherwise be meaningless without a sense of how the parts work together. The second sentence in Polkinghorne's definition, "Narrative provides a symbolized account of actions that includes a temporal dimension," stresses the importance of time and change in narratives. Narrative presumes, Polkinghorne claims, that the universe is more than the Enlightenment notion of "space filled with meaningless objects that moved through a time plane" (126). Instead, what determines the sense of time and place in stories are the human experiences of meaningful events. Finally, Polkinghorne's definition also implies other concepts like narrator (the speaker), agents (people or personifications who populate a narrative), and setting (the place and time where the events take place). Coupled with Labov's identification of the pattern of narrative (abstract, orientation, complication, evaluation, resolution, and conclusion), Polkinghorne's definition provides a formidable vocabulary from which to study scientific texts as narratives.

Although comprehensive, Polkinghorne's definition inexplicably lacks a concept that most narrative theorists consider essential—theme. Because theme is so important to scientific narratives, as we will soon show, we would like to make this important addition to Polkinghorne's otherwise complete definition of narrative. As Gerald Prince states simply, themes are what narratives are about (74). A narrative without themes (if such a thing were possible) would be merely a list of isolated events, names, actions, and places. Themes draw the discontinuous events of a narrative into a whole, creating an overall meaning for the narrative that is greater than the sum of its parts. Indeed, literary criticism, a specialized form of narrative analysis, is the study of cultural and historical themes—that is, what the story is about.

Similarly, in scientific discourse we can also use narrative analysis to demonstrate how scientists use cultural and social themes to give a holistic meaning to their accounts of natural events. Historian of science Gerald Holton suggests that “themata” run through scientific texts, providing consistent perspectives from which scientists conceptualize and reconceptualize their understanding of reality:

> Scanning the current scientific research literature, you will—once alerted—constantly encounter thematic elements that are basic in major areas today, and usually were also in the past—for example, the efficacy of geometry and other branches of mathematics as explanatory tools; the conscious and unconscious preoccupation with symmetries; or the use of the themata of evolution and devolution that might have been taken from the ordinary life cycle but have become, in any case, fundamental tools of scientific thought. (16)

Themata, Holton suggests, provide a motivating perspective from which a scientist or community of scientists will work. Although some themes develop slowly, Holton points out, “some thematic concepts find their place more rapidly, perhaps as a result of stunning virtuoso demonstrations (e.g., the concept of causal, mechanistic universe)” (14). To illustrate, consider the theme *mechanism*, the motivating perspective of Enlightenment science. Mechanism assumes that the natural world can be explained as a celestial machine in which matter is acted upon by forces, with God serving as the great clock maker or engineer. Interpreting all of nature in terms of machines, Enlightenment scientists reconceptualized the solar system as a clockwork (Johannes Kepler), the heart as a pump (William Harvey), and the mind as a calculating machine (Thomas Hobbes). Over time, mechanism became the dominant theme of Enlightenment science and still guides the way most people in Western culture conceptualize the universe. (Try, for example, to talk about the heart as something other than a pump that has valves and chambers.)

In addition to dominant themes like mechanism, Holton points out that in any time period opposing themes, or antithemes, offer different ways of conceptualizing natural phenomena. “For every thematically informed theory used in any science,” he writes, “there may also be found a theory using the opposite thema, or antithema” (14). For example, atomistic theories of matter have competed with continuum theories since the ancient Greeks. At various times throughout the history of science, the atomism theme and continuum theme have traded positions as the dominant way of conceptualizing reality.

Holton's concept of themes and antithemes, in contrast to Thomas Kuhn's notion of paradigms, is more evolutionary than revolutionary because it recognizes that there are always competing thematic movements in science. Over time, competing antithemes rise, fall, and in some cases overcome the dominant perspective for interpreting natural phenomena.

Holton does not speak of scientific texts as narratives, but his claims for themata in the texts and history of science are almost identical to discussions of theme in narrative theory. He writes that scientific themes are the essence of what the scientific discourse is about, and he claims that themes help scientists shape descriptions of natural events into whole accounts that are familiar to the scientific community. Nevertheless, Holton seems to hint at parallels with narrative theory:

> For my part the most fruitful stance to take now is akin to that of a folklorist or anthropologist, namely, to look for and identify recurring general themata in the preoccupation of individual scientists and the profession as a whole, and to identify their role in the development of science. (17)

In looking for themes in scientific discourse, we are much like the folklorist or anthropologist teasing out cultural themes that are woven through scientific texts. We are, to modify Prince's definition of theme, articulating what scientific narratives are about.

NEWTON'S AND EINSTEIN'S STORIES OF LIGHT

With this understanding of narrative tentatively established, let us now turn to our analyses of the works of Newton and Einstein about light. For two reasons, we have chosen to analyze Isaac Newton's *Opticks* and Albert Einstein's Nobel Prize winning work, "Concerning a Heuristic Point of View about the Creation and Transformation of Light." First, they represent the dominant theories of light from two different eras in science. Newton's *Opticks* became the preeminent text about light through the eighteenth century, and Einstein's quantum theory of light is still the basis for modern theories about light. Second, they illustrate two very different ways of narrating scientific experiences. Most of Newton's *Opticks*, as we show, is unmistakably narrative. Throughout the *Opticks*, Newton writes discovery narratives in which he, as an agent, experiences phenomena and interprets those experiences for his readers. Einstein's article also uses narrative techniques although it is written in the modern objective scientific style that conceals the agent.

Newton's *Opticks*

The *Opticks*, first published in 1672, was Newton's definitive work during his lifetime. Whereas Newton's masterwork *Principia* was an extremely complex mathematical text in which he employed his newly invented calculus and Euclidean geometrical proofs to prove mechanistic theories of motion, the *Opticks* was (and still is) highly accessible to both novice and scientist. Newton presented his arguments in a plain, Baconian way, allowing the simple facts and lucidity of his observations to persuade his audience. He begins the text with a disclaimer, "My design in this Book is not to explain the properties of Light by hypotheses, but to propose and prove them by Reason and Experiments" (1). Later in the text, he reaffirms his commitment to experiment over hypothesis:

> This Analysis consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, admitting of no objections against the conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in experimental philosophy. (404)

Newton's intention in disclaiming hypotheses in the *Opticks* was to forego epistemological arguments over his premise that light is a particle. Instead, he claims that his intent is to demonstrate through inductive experimentation that a particle theory of light is "stronger" than other theories (404). However, arguments through experiments, Newton realized, required observable accounts rather than deductive or geometrical proofs. For Newton, narrative offered a viable way to demonstrate his conclusions through completely empirical means that even novices could repeat. Using narrative rather than logical deduction was a powerful rhetorical move.

The *Opticks* is divided into three books. In the introduction to the first book, Newton defines the terms and axioms he uses to discuss his experiments with light-related phenomena. While doing so, he introduces his particle theory of light by familiarizing the audience with two related themes that were gaining strength in seventeenth-century natural philosophy: atomism and mechanism. He defines light in atomic terms: "Definition I. By Rays of Light I understand its least Parts, and those as well Successive in the same lines, as Contemporary in several Lines. For it is manifest that Light consists of Parts" (1).

The mechanism theme is more subtle at the beginning of the *Opticks*, especially to present-day readers who still mostly think in mechanistic terms. Nevertheless, Newton's mechanistic assumptions are apparent in definition 2 of "refrangibility" (refraction) and definition 3 of "reflexion" (reflection) of the *Opticks*. In these definitions, Newton speaks of streams of particles being refracted (bent) or reflected by their interaction with surfaces. Later in the first book, Newton's terminology becomes more obviously mechanistic as he argues that light rays are bent due to their "attraction" to surfaces (like gravity or a magnet) and that they are reflected by "force." Moreover, the conceptual basis for his eight definitions and eight axioms are purely mechanistic in that they assume that the universe is orderly and predictable.

After defining his atomistic / mechanistic vocabulary in the definitions and axioms, Newton then begins describing a long series of experiments with light (more than 300 pages in the text we used). For each set of experiments, he first establishes a "proposition" and then offers a series of experiments to prove that proposition. To demonstrate, here is a quote from his account of the famous first experiment in which he shines a stream of light into a prism, creating the colors of the light spectrum (i.e., the colors of a rainbow) on a piece of paper:

Proposition I. Theorem I.

Lights which differ in Colour, differ also in Degrees of Refrangibility.

The Proof by Experiments

> Experiment 1. I took a black oblong stiff Paper terminated by Parallel Sides, and with a Perpendicular right Line drawn across from one Side to the other, distinguished it into two equal parts. One of these parts I painted with a red colour and the other with a blue. The Paper was very black, and the Colours intense and thickly laid on, that the Phaenomenon might be more conspicuous. This Paper I view'd through a Prism of solid Glass, whose two sides through which the Light passed to the Eye were plane and well polished, and contained an Angle of about sixty degrees; which Angle I call the refracting Angle of the prism. And whilst I view'd it, I held it and the prism before a Window in such manner that the Sides of the Paper were parallel to the prism, and both those

> Sides and the prism were parallel to the Horizon, and the cross Line was also parallel to it: and that the Light which fell from the Window upon the paper made an Angle with the paper, equal to that Angle which was made with the same Paper by the Light reflected from it to the Eye. Beyond the Prism was the Wall of the Chamber under the Window covered over with black Cloth, and the Cloth was involved in Darkness that no Light might be reflected from thence, which in passing by the Edges of the Paper to the Eye, might mingle itself with Light of the Paper, and obscure the phaenomenon thereof. These things thus being ordered, I found that if the refracting Angle of the Prism be turned upwards, so that the paper may seem to be lifted higher by the Refraction, its blue half will be lifted higher by the Refraction than its red half. (20-21)

Newton follows this account with a graphic illustration and a related second experiment. Afterward, in the form of a scholium, he reconstructs the experiments for the readers, employing his previously defined atomistic / mechanical vocabulary to explain the events observed:

> Now from these Experiments, it follows not, that all the Light of the blue is more refrangible than the Light of the red: For both Lights are mixed of Rays differently refrangible, so that in the red there are some Rays not less refrangible than those of the blue, and in the blue there are some Rays not more refrangible than those of the red: But these rays in proportion to the whole Light are but a few. (25-26)

In other words, Newton claims that streams of blue light particles are bent more by the prism than streams of red light particles (thus explaining why the color red is on one side of all rainbows, whereas blue is on the other side). Or, to rephrase his original proposition, light rays of different colors refract (bend) differently through a prism, proving that sunlight, or white light, is made up of rays of different colored light particles. Shining sunlight into a prism, therefore, sorts out these colors into a spectrum because each color bends more or less than the other colors, creating the colors of the rainbow.

That Newton is using narrative to illustrate his experiments should be apparent. In each account, he depicts a series of actions and events that take place within a temporal time frame. As narrator, he begins each account by describing a setting for the experiment, carefully identifying a place (the chamber) and a set of objects in that place (the wall, the window, the cloth, the prism, and the paper). He shows how his step-by-step interaction with a prism and a stream of light led to events in which a color spectrum appears on the paper, and he describes the logical steps that brought him from a defined starting point to a final end point. As he does so, he fuses the events of the experiment into a whole, drawing causal relationships between his acts, as agent, and the events he observes. In sum, all the elements of narrative are to be found in Newton's accounts of his experiments, including events, actions, agent, narrator, setting, wholeness, and temporality.

Newton concludes the *Opticks* at the end of the third book with the now famous list of queries in which he highlights his themes for his readers. In the three books of the *Opticks*, from definitions to scholia, Newton faithfully casts his accounts of light into the vocabulary of atomism and mechanism. Consequently, as his readers follow these narratives of his experiences with light, they grow increasingly familiar with his atomistic / mechanistic vocabulary. In other words, they begin to adopt the perspective from which he is interpreting these events. Like Newton, they begin to see his experiments in terms of particles and their mechanical interactions with surfaces like the prism, water, and walls. So when Newton uses the queries to interpret the meaning of his own narratives, his claims that light *must* be a particle and that it *must* follow mechanical laws seem logical conclusions that need to be drawn. Within the queries, the implicit themes of atomism and mechanism that had been shaping the discovery narratives in the body of the *Opticks* are made explicit.

Newton writes in query 29, "Are not Rays of Light very small bodies emitted from shining Substances?" (369-70). He asks in query 26, "Have not the Rays of Light several sides, endued with several original Properties?" (358). And, refuting wave theories of light (and thus his critics), Newton begins query 28, "Are not all Hypotheses erroneous, in which Light is supposed to consist in Pression or Motion, propagated through a fluid Medium?" (362). Clearly, Newton contends that particles, including light particles, are the building blocks of the universe. Emboldened by the success of his discovery narratives, Newton states, "Now by the help of these Principles, all material Things seem to have been composed of the hard and solid particles above mention'd" (402). In making this claim, Newton concludes that atomism is the strongest possible explanation for his exhaustive narratives of experimentation. All through the *Opticks*, atomism had been the guiding perspective he brought to his project and the lens through which he reaches his final interpretations and conclusions.

Similar to his use of atomism, Newton's reliance on mechanism as a guiding theme also comes out strongest in the queries. Newton writes that the physical world is

> very simple, performing all the great Motions of the heavenly Bodies by the Attraction of gravity . . . which bodies persist in their motion or Rest, receive Motion in proportion to the Force impressing it, and resist as much as they are resisted. (397)

With his "Laws of Motion . . . as general laws of Nature" firmly in place (401), Newton feels free to construct a "synthesis [that] consists in assuming the Causes discover'd, and establish'd as Principles, and by them explaining the Phaenomena proceeding from them, and proving the Explanations" (405). Before the queries, Newton had used the mechanism theme as a guiding premise in his discovery narratives rather than as a scientific explanation; but in the queries, he solidifies his mechanistic views by suggesting that "the main Business of natural philosophy is to argue from Phaenomena without feigning Hypotheses, and to deduce Causes from Effects, till we come to the very first Cause [God], which is not mechanical." Overall, his experiments, he claims, are designed "to unfold the Mechanism of the World," discovering the mechanical laws on which God built the universe and set it into motion (369). Finally, in query 31, Newton asks a straightforward mechanistic question that captures the essence of his studies on light:

> Have not the small Particles of Bodies certain Powers, Virtues, or Forces, by which they act at a distance, not only upon the Rays of Light for reflecting, refracting, and inflecting them, but also upon one another for producing a great Part of the Phaenomena of Nature? For it is well known that Bodies act upon another by the Attractions of Gravity, Magnetism, and Electricity. (375-76)

To sum up at this point, we find in Newton's *Opticks* that each of his discovery narratives, or experiments, is designed to advance the two scientific themes, atomism and mechanism. To reinforce these themes, Newton offers account after account, experiment after experiment, story after story, to gradually shape the way his readers conceptualize light (see also Gross 122). As a result, his discovery narratives create the overwhelming sense that his empirical methods—based on observable and repeatable proof that even a novice can understand—are leading him to discover truths about light. To prove that his particle theory of light is stronger than wave theories, he uses narrative elements like agent, narrator, setting, actions, events, and temporality to create a consistent perspective that proves his guiding themes.

After publication of the *Opticks*, Newton's particle theory of light quickly dominated the scientific community. The queries, meanwhile, served as the eighteenth century's research program into studies of light. However, like any good antitheme, the wave theme was not completely vanquished. A century later, Thomas Young revived the wave theory of light, recasting this old theme into mechanistic terms. Young employed words like *wavelength*, *amplification*, *interference*, and *frequency*, using the wave theme to resolve anomalies in Newton's particle theory. Later in the nineteenth century, the success of James Clerk Maxwell's theory of electromagnetic waves solidified the wave theme as the dominant perspective from which to discourse about light-related phenomena—until Einstein proposed his quantum theory of light.

Einstein's 1905 Light Quanta Article

Einstein's 1905 light quanta article, "Concerning a Heuristic Point of View about the Creation and Transformation of Light," is well-known for two reasons. First, it introduced the concept of *light quanta*, which later became known as *photons*. The concept of *energy quanta* had been developed 5 years earlier by Max Planck, but Einstein was the first to recognize that Planck's quanta could be used to explain other natural phenomena. The second reason this light quanta article is remembered is for its explanation of the photoelectric effect, which eventually earned Einstein his Nobel Prize. (Einstein did not win the Nobel Prize for his theory of relativity, as is widely assumed.) Einstein's light quanta article is very different from Newton's *Opticks*, offering an interesting challenge to our discussion of scientific narrative. Perhaps the most significant difference is that Einstein's article, like most modern scientific articles, lacks an agent. Nevertheless, it follows the narrative pattern, using an implied agent who is active behind the scenes.

Much like a writer of any narrative, Einstein begins his 1905 light quanta article by orienting his readers to a context and calling his readers' attention to a conflict or incongruity in that context. In Einstein's narrative, the conflict is set within the context of the body of scientific beliefs. He writes, “There is a profound formal difference between the theoretical representations of gases and other ponderable bodies which physicists have constructed and Maxwell’s theory of electromagnetic processes in so-called empty space” (544). The incongruity Einstein identifies is the difference between the discontinuous theories of particles (gas molecules, atoms, electrons) and the continuous theories of waves (light, electromagnetism, force, electricity, X rays, ether). In other words, Einstein points out that particle descriptions of matter are fundamentally incompatible with Maxwell’s nineteenth-century electromagnetic wave descriptions of light. In making this seemingly plain distinction for his readers, Einstein identifies two competing themes that provide foundations for two incompatible descriptions of nature: particle and wave.

Essentially, by identifying these themes and their fundamental incompatibility, Einstein puts his finger on one of the most basic conflicts in the history of science. For at least 2,500 years, continuous (wave) and discontinuous (atomic) theories of nature have taken their respective turns as dominant theoretical narratives in physics. Having identified these paradoxical “heuristic points of view” in physics, Einstein identifies the problem he addresses in the rest of the article:

> In spite of the complete experimental verification of the theory of diffraction, reflection, refraction, dispersion, and so on, the theory of light that operates with continuous spatial functions may lead to contradictions with observations if we apply it to the phenomena of the generation and transformation of light. (544)

In other words, Einstein suggests to his readers that, despite the success of the wave theory of light, in some cases it contradicts experimental observations. He shows that there is a complication in current theories of light that needs to be resolved. To address this problem, Einstein suggests that a new “heuristic point of view” (i.e., a different theme) resolves the contradictions between theory and experiment:

> It appears to me, in fact, that the observations on “black-body radiation,” photoluminescence, the generation of cathode rays with ultraviolet radiation [i.e., the photoelectric effect], and other groups of phenomena related to the generation and transformation of light can be understood better on *the assumption that energy in light is distributed discontinuously in space* [i.e., quanta]. According to the presently proposed assumption the energy in a beam of light emanating from a point source is not distributed continuously over larger and larger volumes

> of space, which move without subdividing and which are absorbed and emitted only as units. (545, emphasis added)

Thus, at the end of the introduction to the article, Einstein clearly states for his readers the basis of his new heuristic point of view concerning light. He suggests that he employs Planck's concept of energy quanta, to reconceptualize light into discontinuous terms. Indeed, with little hesitation, Einstein posits that if we accept Planck's argument that energy is quantized, then we are further obligated to accept the notion that light is discontinuous, or quantized.

In the body of the article, Einstein then works toward evaluating and resolving the conflict in theories of physics. In the methodology section, he begins by evaluating current beliefs about light and proving that Planck's notion of energy quanta can be applied to theories of light. If energy is quantized, Einstein argues in the body of the article, then the energy in light is distributed discontinuously in space, much as energy is distributed discontinuously in particles of gases. If so, Einstein points out, light should carry energy discontinuously also. He concludes the body of his article by writing that

> if . . . monochromatic radiation (of sufficient small density) behaves like a discontinuous medium consisting of energy-quanta . . . , it is reasonable to inquire if the laws of emission and transformation of light are so constituted as though light were composed of these same energy quanta. (552)

In other words, Einstein suggests that if energy is quantized, light must be quantized also.

The conclusion of Einstein's 1905 light quanta article resolves the theoretical conflict by offering three demonstrations that show how the concept of light quanta can be used to reconceptualize the paradoxical behavior of light. Historians consider all three demonstrations revolutionary, but the most significant is Einstein's discussion of the photoelectric effect, for which he won the Nobel Prize. Until Einstein, scientists studying the photoelectric effect could not determine why frequency (color) rather than intensity (amount) of light is related to the velocity of an electron emitted from a metal when light is shown on the metal surface. It would be like asking why the color rather than the amount of the water in a wave determines whether pieces will be chipped away from a wall's surface. Einstein's reinvention of light into quantum terms, however, described this phenomenon easily: "The simplest explanation is that a quantum transfers all its energy to a single electron" (555). In other words, Einstein reasoned, light quanta strike the metallic surface in particle-like energy bundles, either knocking the electron out of the metal or reflecting harmlessly away. Light quanta of low frequency, therefore, would not have enough energy to knock out an electron and thus would bounce off the metal ($e = h\surd$).

Much as Newton used the particle theme to narrate his experiences with light through a prism, Einstein uses the quantum theme in a narrative to redescribe experiences with the photoelectric effect:

> Quanta of energy penetrate into the surface layer of the body and their energy, at least in part, is transformed into kinetic energy of electrons. The simplest explanation is that a quantum transfers all of its energy to a single electron; we shall assume that this occurs. We shall however, not exclude the possibility that electrons can absorb only parts of the energy of light quanta. An interior electron with kinetic energy will have lost some of this kinetic energy by the time it reaches the surface. Besides this, we must assume that each electron will have to do some work (an amount characteristic of the body) when it leaves the body. The electrons lying right at the surface of the body will leave the body with the greatest velocity normal to the surface. (555)

After a few calculations, Einstein then concludes:

> If each quantum of energy of the exciting light gives up its energy to an electron independently of all other quanta, then the velocity of distribution of the electrons, that is, the characteristic of the produced cathode ray, is independent of the intensity of the exciting radiation; on the other hand the number of electrons leaving the body, all other conditions being the same, will depend on the intensity of the exciting radiation. (556)

In sum, Einstein's article closely follows the narrative pattern, leading his readers from orientation to complication, through evaluation to resolution, and finally from resolution to a conclusion. In the introduction to the article, Einstein begins by orienting the readers to the current research on light and showing that these accounts have fundamental theoretical complications. In the body of the article, he establishes and defines a scientific theme (quanta) that he claims can resolve these complications. Then, the body of Einstein's article reconceptualizes the phenomenon of light from a new "heuristic point of view," using quanta as a guiding theme. Finally, in the latter part of the article, he resolves the theoretical complications mentioned in the introduction of the article by using narrative to reconceptualize scientists' unexplained experiences with three different light-related phenomena: the photoelectric effect, Stoke's rule, and the ionization of gases with ultraviolet light. Einstein organizes his article into three parts that reflect the narrative genre: first, an introduction that identifies complications / paradoxes in the current wave theory of light while orienting the readers to those theories; second, an evaluation of possible alternatives and the relevance of Planck's energy quanta to theories of light; and third, a resolution of the conflict in theories of light by retelling three experiments through the quantum theme, or perspective.

To this point, we have argued that Newton's and Einstein's works are narratives that orient readers to a situation and then lead them from a complication to a resolution. These two texts offer very different kinds of narratives. In his *Opticks*, Newton uses himself as an agent who is manipulating his physical environment in ways that lead to discoveries. Einstein's narrative, reflecting the modern assumption that objective science needs to be impersonal, does not include himself as an agent; rather, Einstein serves as a dispassionate narrator who leads the audience from complication to resolution. The agent in Einstein's narrative is a hidden puppeteer, putting physical events into motion and interpreting the resultant experiences for the readers.

SCIENTIFIC THEMES AND NARRATIVES

Francis Bacon, while laying the foundation for modern empirical science, warned scientists that the act of simply cataloging observations and facts is not adequate in scientific research:

> But this kind of experience is . . . a mere groping, as of men in the dark, that feel all round them for the chance of finding their way; when they had much better wait for daylight, or light a candle, and then go. But the true method of experience, on the contrary, first lights the candle, and then by means of the candle shows the way; commencing as it does with experience duly ordered and digested, not bungling and erratic. (115)

Bacon's candle signifies the relationship that exists between themes and narratives in scientific discourse. Certainly, scientists can catalog the physical events, or the ever-occurring "nows," that are all around them. They can also use logical and mathematical means to manipulate the data they have collected. But only when they use a theme (i.e., "light a candle") to fashion their observations into comprehensive narratives can they make meaning out of physical events for their readers. Themes hold scientific movements together, and they provide the guiding perspective from which scientists invent and shape their theories, or narratives, of nature. Once made aware of the themes that guide larger movements in science, as Holton points out, you will constantly discover these themes in scientific literature. Expanding on Holton's understanding of themes in science, we have argued that scientists use narratives to introduce, to expand, and to reinforce their conceptions of reality. Indeed, the genius of Newton and Einstein may be in their identification and application of fertile themes toward the invention in their descriptions of phenomena, not in their discovery of truths.

The scientific community, much like any community, is held together by the themes and narratives it holds in common. The stories a community tells are essentially smaller parts of the larger cultural narratives that offer its members an identity and provide them with a perspective for interpreting and discoursing about reality. Similarly, in scientific communities, the articles and books that scientists write are essentially smaller parts of the larger theoretical narratives that hold scientific communities together. To identify the themes at the heart of those narratives / theories is to identify the perspective from which scientists conceptualize, reconceptualize, and recontextualize reality. Themes are the heart of scientific invention.

In their own ways, Newton's and Einstein's works about light illustrate how narratives and themes play four important roles in scientific discourse. First, scientific narratives are the individual texts through which scientists resolve conflicts in the scientific community by interpreting their experiences with natural phenomena. In Newton's case, the conflict was between particle and wave theories of light. Seeking to resolve this conflict, his narrative accounts of his experiments with light described how he used meticulous empirical methods, or contrived experiences, to demonstrate how a mechanistic-particle theory of light offered the strongest explanation for light-related phenomena. Similarly, Einstein's article was designed to resolve specific light-related anomalies that Maxwell's wave theory could not explain. Using the concept of energy quanta as a theme, Einstein demonstrated that reconceptualizing light as a quantum phenomenon offered a more comprehensive explanation of the paradoxical behavior of light. In both these cases, Newton and Einstein used themes to invent or reconstruct theories of light, resolving conflicts between observations and theory.

Second, scientists use narrative to describe their methods of study or the observed series of events. By describing their step-by-step methods, scientists recount the temporal succession of actions and events that led them to their results and conclusions. In essence, experiments are contrived experiences in which scientists, as agents, initiate a series of natural events that are observed and described for the readers. The methodology sections in scientific texts, therefore, are intended to recount the actions of the scientist, describing how specific actions led to a series of observed events. Later, in the discussion section, scientists typically reconstruct the sequence of events, using themes to interpret or reinterpret the events in a way that resolves the research question. In the texts we analyzed above, both Newton and Einstein used narrative techniques to describe their methods of study and offer their interpretation of the events. Their texts show that scientists use narratives to retell the experiment for the readers and thus demonstrate how their new or modified theory better explains the succession of events that they observed.

Third, scientific narratives can be found in the broader theories and methods that are accepted as valid by the scientific community. Narrative theorist Joseph Rouse suggests that "both the practices of scientific research and the knowledge which results from them acquire their intelligibility and significance from their being situated within a narrative" (181). In making this point, Rouse suggests that scientific communities, like all communities, are defined by their shared metanarratives:

> In the narratives of science . . . there is no unitary authorial point of view from which an entire course of events can be surveyed, for there are multiple authors engaged in an ongoing struggle to determine the configuration of the narrative within which they are all situated. (181)

In other words, the individual texts of science shape and reinforce broader narratives that bind the scientific community together. If Rouse is correct, the works of Newton and Einstein, as much as we want to identify them as revolutionary, are primarily contributors to larger movements in the scientific community. The narrative accounts of light offered by Newton and Einstein were informed by broader social narratives, such as mechanistic, atomistic, or quantum interpretations of reality. And, since their inception, Newton's and Einstein's accounts of light have been retold by various narrators (e.g., textbooks, teachers, historians, theorists), becoming part of the ongoing accounts of reality that bind together members of the scientific community. Like all scientific theories, the individual narratives of Newton and Einstein are situated responses to the tradition of accomplishments and reversals that went before them. From the Astronomy 101 instructor explaining how the moon orbits the earth, to the Nobel laureate recounting the discovery of the double-helix structure of DNA, narratives are the means through which members of the scientific community invent, shape, and advance their interpretations and explanations of reality.

Finally, the fourth role of scientific narrative is to enforce the values, methods, and traditions of the scientific community. Whereas narratives validate theories by actualizing scientific methods and beliefs, they also help restrict divergent versions of the community's metanarratives. The works of Newton and Einstein may be revolutionary; however, both authors make a concerted effort to reflect the conventions of the scientific community and to demonstrate how their conclusions are aligned with the community's metanarratives. Few scientific texts, even the most revolutionary, stray far outside the metanarratives that inform the scientific community. In other words, as Dennis Mumby points out, "organizational narratives of any kind often articulate an organizational reality that is accepted as 'the natural order of things'" (114). Indeed, the importance and validation of scientists' works, including those of Newton and Einstein, are reliant on their ability to demonstrate allegiance to the continuously reconstructed theories in the scientific community.

NARRATIVES AND SCIENTISTS

Let us conclude with the issue that introduced this article: Do these parallels between science and narrative matter? We believe analyzing scientific texts as narratives opens paths for scientific creativity. An ability to identify themes in scientific discourse might help scientists explore untapped potential for further research by recognizing new ways to apply useful themes. Furthermore, narrative analysis might help scientists recognize when a particular theme has run its course and therefore needs to be replaced by a promising countertheme.

An acknowledged problem in much of scientific research is that successful theories, or narratives, have a tendency to crystallize into dogma. Or, as Earl MacCormac suggests, the original stories of science have a tendency to solidify into "myths" whose origins in metaphor and narrative are soon forgotten. With each successive retelling, the author's original uncertainties and reservations fall away, leaving the harder edges and straighter lines of unchallenged truths. Also addressing the relationship between science and narrative, Jean-Francois Lyotard suggests that this problem is one of legitimization. Scientific narratives, he writes, are initially legitimized through a statement like "As long as I can produce proof, it is permissible to think that reality is the way I say it is." Only later is a scientific theory legitimized by a statement like "I can prove something because reality *is* the way I say it is" (24). The first statement requires the speaker to tentatively provide the proof, keeping open a door for modification of the theory. The second statement, however, presumes that the proof has already been provided, allowing the theory to stand on its own without additional proof. Over time, like any cultural story, a scientific narrative is told so often that it becomes the unquestioned touchstone against which future generations measure the truth of other beliefs. The narrative becomes what is true and the way things are done around here. Those who do not accept the prevailing narratives need not apply.

Narrative analysis might allow scientists to overcome dogma and myth. By training, or perhaps by default, scientists often shy away from the indeterminacy of narrative. They adopt what Nobel laureate physicist Steven Weinberg calls a "rough-and-ready realism, a belief in the objective reality of the ingredients of our scientific theories" (167). Realists measure their beliefs against reality—or at least what they perceive to be reality—and are no longer interested in proving (or disproving) the proof. But when we study scientific texts as narratives, we pry open the door of creativity by reconsidering the uncertainties and reservations that were once an important part of the original text. Moreover, we see the scientific discourse not as an expression of eternal truth but as a story about what the scientist observed and what that scientist thought it should mean.

In contrast to realism, viewing scientific discourse in terms of narrative urges a critical approach to scientific theories that highlights the importance of discourse toward the invention and articulation of scientific beliefs. This critical approach invites scientists to pay greater attention to the way they discourse about reality, to look for places where themes in their texts can be further explored or challenged. Often, if we consider the history of science, the great scientists have been as likely to find the origins of their revolutionary scientific beliefs in close readings of the works of others as they have been to find them in a laboratory. If so, a critical approach to scientific discourse invites scientists to use narrative analysis to identify the guiding themes that underlie their research and theories. Scientific narratives, like all narratives, reveal a community's perspectives on the world, so analyzing scientific texts as narratives should allow scientists to acknowledge the perspectives with which they approach their research in the physical world.

Narrative analysis urges scientists and rhetoricians of science back into the text. It urges them to analyze scientific narratives to help them uncover the untapped potential or the limitations of their underlying themes. Once identified, these themes can serve as loci for inventing new scientific beliefs and theories. Indeed, the great scientists have often been highly aware of the language of science, teasing out the subtle assumptions in theoretical texts and challenging them. Newton and Einstein, as many historians have pointed out, were masters at identifying the essential ideology of a theory (e.g., mechanism, gravity, quanta, relativity). Then they would expand on those ideologies to invent a new theory. The genius of great scientists is often found in their ability to challenge worn-out themes or exploit potential themes into novel theoretical positions. Our hunch is that a purposeful, critical approach to identifying themes—including a study of their potentials and limitations—in scientific discourse would allow other scientists to do the same. Moreover, recognizing that science is essentially a continual process of constructing and reconstructing the community's stories about reality, as Rouse points out, might urge scientists to reconceive their theories to create new understandings of reality.

Viewing scientific texts as narratives is an invitation to creativity. The primary drawback to naive realism is that it assumes that scientific discourse somehow gets beyond a society's narratives. It assumes that when scientists describe their theories or their experiences/ experiments, they are somehow doing something different than narrating a history. But if scientists were aware of the themes on which their theories rely, they might be able to explore their theories and look for new avenues of research.

REFERENCES

Bacon, Francis. *Novum Organum*. Vol. 8 of *The Works of Francis Bacon*. Ed. J. Spedding, R. Ellis, and D. Heath. Boston: Taggert and Thompson, 1863.

Barton, Ben F., and Marthalee Barton. "Narration in Technical Communication." *JBTC* 2.1 (1988): 36-48.

Blyler, Nancy Roundy. "Narrative and Research in Professional Communication." *JBTC* 10 (1996): 330-51.

Bruner, Jerome. *Actual Minds, Possible Worlds*. Cambridge, MA: Harvard University Press, 1986.

Chafe, Wallace, ed. *The Pear Stories: Cognitive, Cultural, and Linguistic Aspects of Narrative Production*. Norwood, NJ: Ablex, 1980.

Einstein, Albert. "Concerning a Heuristic Point of View about the Creation and Transformation of Light," *Annalen der Physik* 17 (1905): 132-48. Trans. Ed. H. A. Boorse and L. Motz. *The World of the Atom*. New York: Basic Books, 1966: 544-57.

Gross, Alan. *The Rhetoric of Science*. Cambridge, MA: Harvard University Press, 1996.

Holton, Gerald. *Thematic Origins of Scientific Thought*. Cambridge, MA: Harvard University Press, 1988.

Kuhn, Thomas. *Black-Body Theory and the Quantum Discontinuity, 1894-1912*. New York: Oxford University Press, 1978.

Labov, William. *Language in the Inner City*. Philadelphia: University of Pennsylvania Press, 1972.

Lyotard, Jean-Francois. *The Postmodern Condition*. Trans. Geoff Bennington and Brian Massumi. Minneapolis: University of Minnesota Press, 1993.

MacCormac, Earl. *Metaphor and Myth in Science and Religion*. Durham, NC: Duke University Press, 1976.

Mumby, Dennis. "The Political Function of Narrative in Organizations." *Communication Monographs* 54 (1987): 113-27.

Newton, Isaac. *Opticks*. 1730. 4th ed. New York: Dover, 1952.

———. *Principia*. 1729. Trans. Andrew Motte. London: Dawson, 1968.

Polkinghorne, Donald. *Narrative Knowing and the Human Sciences*. Albany: State University of New York Press, 1988.

Prince, Gerald. *Narratology: The Form and Functioning of Narrative*. New York: Mouton, 1982.

Ricoeur, Paul. "The Narrative Function." *Hermeneutics and the Human Sciences*. Ed. and Trans. J. Thompson. Cambridge, Eng.: Cambridge University Press, 1981. 289-96.

Rouse, Joseph. "The Narrative Reconstruction of Science." *Inquiry* 33 (1990): 179-96.

Weinberg, Steven. *Dreams of a Final Theory*. New York: Vintage, 1992.

Richard Johnson Sheehan is an assistant professor of language and rhetoric at the University of New Mexico. At New Mexico, he researches rhetoric of science, specifically modern physics, and teaches courses in rhetoric, rhetoric of science, and professional writing.

Scott Rode is a doctoral candidate at the University of New Mexico. His research interests are narrative theory, language and rhetoric, and Victorian studies.