The elegance of The Elegant Universe: unity, beauty, and harmony in Brian Greene's popularization of superstring theory

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Public Understanding of Science 2007; 16; 441
DOI: 10.1177/0963662505061882

Public Understand. Sci. **16** (2007) 441–454

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The emergence of string theory into popular culture can be seen in recent episodes of *Joan of Arcadia* and in the NOVA series based on Brian Greene's best-selling book, *The Elegant Universe*. Greene's book has played a significant role in string theory's emergence into popular culture. In order to persuade the general public to accept the new and controversial theory of superstrings as a revolutionary scientific theory, Greene carefully constructs his argument in *The Elegant Universe*, reinforcing the elegance and beauty of string theory. *The Elegant Universe* itself is an elegantly constructed argument, in terms of both its overall structure and its language. The threads of Greene's argument are carefully woven to create the unified textual fabric of his argument.

The mathematical structure of string theory was so beautiful and had so many miraculous properties that it had to be pointing toward something deep. (John Schwarz)

In lieu of the traditional confrontation between theory and experiment, superstring theorists pursue an inner harmony, where elegance, uniqueness and beauty define truth … Are these properties reasons to accept the reality of superstrings? Do mathematics and aesthetics supplant and transcend mere experiment? (Paul Ginsparg and Sheldon Glashow)

1. Introduction

In a recent episode of the CBS drama *Joan of Arcadia*, Joan's science-geek brother, Luke, extols the virtues of string theory to his skeptical, non-scientist father, Will Girardi.

> Luke: See, string theory provides a unified description of the universe. I mean, it's the holy grail of physics.
> Will: Yeah, like lasagna's the holy grail of Italian food.
> Luke: Not an exact analogy.
> Will: Well, maybe when I see the strings. (Garrigus et al., 2005)

When characters on a prime-time television drama crack jokes connecting string theory to lasagna, it seems safe to assume that string theory has emerged into the consciousness of

 ISSN 0963-6625 DOI: 10.1177/096366250061882

popular culture. String theory has been labeled as "the most popular approach to unification" (Battersby, 2005: 30) by many science writers and physicists and that popularity is evident in the current proliferation of magazine articles and popular science books written on the topic. Brian Greene, author of the best-selling string theory popularization, *The Elegant Universe*, has done his part to bring the new and controversial theory of superstrings to popular culture. Greene has been characterized as a new popular science icon who "can do for string theory what Stephen Gay Gould did for evolution, Stephen Hawking did for black holes, and Richard Feynman did for quantum electrodynamics: give science a friendly face, and make a chart-busting best-seller out of a rarefied subject" (Senior, 1999: 34). Since the publication of *The Elegant Universe*, Greene has become "the poster boy for theoretical physics" (Hayashi, 2000: 37), playing a small part in the movie *Frequency*, hosting a three-part NOVA series based on *The Elegant Universe* for PBS in 2003, and publishing another popular science book titled *The Fabric of the Cosmos* in 2004.

The Elegant Universe was published in 1999, four years after the beginning of the so-called second superstring revolution, in which Greene played a role. Superstring theory, or string theory for short, is one possible candidate for the theory of everything, the "holy grail" as Luke Girardi refers to it, that promises to unite modern physics' two conflicting realms of quantum mechanics and general relativity. String theory first grew out of the work of researchers at CERN, the European Organization for Nuclear Research, and has undergone two revolutions since the 1970s. Edward Witten (1997) dates the first superstring revolution from "the period around 1984–85 when the potential of string theory to give a unified description of natural law was first widely appreciated" (p. 28). By 1985, there were five different, yet equally valid, string theories. Greene initially became interested in superstring theory during the first superstring revolution while studying at Oxford in the mid-1980s, and continued his work on it at Harvard and then Cornell. While on sabbatical in 1992, Greene, along with Paul Aspinall and David Morrison, made a contribution to string theory by showing how the fabric of space can tear and re-form in a new way. In 1995, Edward Witten ignited the second superstring revolution by proposing that the five different string theories were different ways of describing one master theory called M-theory, which incorporated strings as well as multidimensional objects called membranes or branes. Most recently, string theorists have developed the "braneworld scenario," the idea that the universe exists on a three-brane structure. In the late 1990s, working within the context of the braneworld scenario, physicist Arkani-Hamed and his colleagues published calculations showing that some of the extra dimensions predicted by string theory "might be as large as a millimetre" (Brumfiel, 2005: 10). Arkani-Hamed's discovery is particularly timely in light of the anticipated completion of the Large Hadron Collider in 2007, a particle accelerator that could be powerful enough to detect these extra dimensions and "could provide significant evidence that would support string theory" (Kaku, 2005: 32).

The popularity of string theory is due in large part to the efforts of string theorists like Brian Greene. As one of the leading string theorists of the day and as one who is comfortable in the public spotlight, Brian Greene has helped put a "friendly face" on string theory. His task is particularly challenging because string theory is a largely abstract, mathematical theory and, as yet, has not been experimentally verified. This lack of experimental verification has led some physicists, such as Nobel Laureate Sheldon Glashow and Paul Ginsparg, to question its scientific validity. Thus, popularizing string theory involves not only explaining the theory, but also persuading the reader that it is a viable scientific theory. Alan Gross (1996) argues that "science is a rhetorical enterprise, centered on persuasion" (p. 6) and Brian Greene's string theory popularization, *The Elegant Universe*, illustrates the importance of rhetoric and persuasion in the dissemination and acceptance of popularizations of scientific theories. In order to persuade the reader to accept string theory as a scientific theory, rather than a piece of science fiction, Greene carefully constructs his argument to reinforce the elegance and beauty of string theory that John Schwarz, one of the founders of string theory, refers to above. In *The Elegant Universe*, Greene (2003a) states that "the central concern of this book is to explain the workings of the universe according to string theory" (p. 18). But, Greene writes his book not merely to explain string theory but also to promote it. John Turney (2004) argues that the string theorists' "awareness that they need to explain their thinking to lay audiences in order to justify support for their work continues to produce popular accounts of the theory" (p. 337). Greene tries to persuade the reader that string theory is not only a viable scientific theory, but that it is a revolutionary scientific theory, on the same level as the theory of general relativity and quantum mechanics. Greene positions string theory within the tradition of great scientific discoveries in the history of physics and shows that string theory is the next logical chapter in that history.

Greene's positioning of string theory as a revolutionary theory also serves to defend it against and elevate it above rival theories. In his most recent book *The Fabric of the Cosmos*, Greene states that "there is a second path [in the search for spacetime's ingredients] coming from string theory's main competitor, loop quantum gravity" (Greene, 2004: 489). Loop quantum gravity, developed in the mid-1980s by physicists like Lee Smolin, is a newer and vastly different approach to unification than string theory. Loop quantum gravity seeks to resolve the problem of gravity "by rewriting Einstein's equations within a quantum framework" (Schiermeier, 2005: 12). According to loop quantum gravity, spacetime is composed of a mathematical network of nodes and connecting links, rather than the vibrating superstrings of string theory. Although both string theory and loop quantum gravity are candidates for the theory of everything, theoretical cosmologist Sean Carroll concedes that "string theory remains the more popular theory" (Schiermeier, 2005: 12). Greene omits any mention of loop quantum gravity as a rival theory in *The Elegant Universe*. He presents string theory as the only candidate for the theory of everything and he publishes his popularization of string theory, *The Elegant Universe*, in 1999, two years before Smolin publishes his popular science book on loop quantum gravity, *Three Roads to Quantum Gravity*.

Following in the tradition of physicists writing for the masses, Greene seeks to explain string theory to the general public in simple, non-technical terminology. Like the works of other popular science cosmologists, notably those of Paul Davies and Steven Weinberg. Greene's text focuses on unity, beauty, and elegance in modern physics. As John Schwarz claims, the beauty of string theory plays a significant role in its appeal as a scientific theory. Ginsparg and Glashow (2003) accuse string theorists of pursuing this inner harmony, elegance, and beauty in place of experimental evidence. Greene's argument for the acceptance of string theory is indeed based on the principles of harmony, elegance, and beauty. *The Elegant Universe* itself is an elegantly constructed argument, in terms of both its overall structure and its language, particularly in the use of musical and linguistic analogies. The elegantly constructed form of *The Elegant Universe* reflects superstring theory's central claim of a unified, beautiful, and harmonious universe. The threads of Greene's argument are carefully woven to create the unified textual fabric of his argument, just as the fundamental superstrings are carefully woven to create the unified fabric of spacetime.

The idea of unity is particularly significant in the case of string theory because Greene presents string theory as the great unifier. This unification works on several levels. In terms of modern physics, string theory is presented as the possible unifier of the conflicting fields of quantum mechanics and general relativity. Greene also presents string theory as a unifying force in the history of science, not merely physics. He uses string theory to reconcile modern scientific theories to ancient cosmological theories, such as the Music of the Spheres. Within his own field, Greene applies the unifying potential of string theory to the internal conflict between theoretical and experimental physicists. At the heart of the conflict is the problem that there is no experimental evidence proving string theory. Greene is hopeful that physicists will experimentally verify string theory in the future, thereby healing the rift between experimentalists and theorists. The unification is significant in terms of the language Greene uses to construct his argument. String theory is the great unifier, reflecting a unified, beautiful, and harmonious picture of the universe, a picture Greene seeks to re-present through language.

2. The quest for unity

Luke Girardi sings the praises of string theory, arguing that it provides a "unified" description of the universe. The ability to unify is one of the main selling points of string theory, and Greene repeatedly glorifies string theory as the great unifier throughout *The Elegant Universe*. He argues at the beginning of his book:

> For three decades, Einstein sought a unified theory of physics, one that would interweave all of nature's forces and material constituents within a single theoretical tapestry. He failed. Now, at the dawn of the new millennium, proponents of string theory claim that the threads of this elusive unified tapestry finally have been revealed. (Greene, 2003a: 4–5)

String theory claims to have succeeded where Einstein failed in weaving together a unified "theoretical tapestry" for modern physics. String theory is presented as the fulfillment of the quest expressed by other physicists in addition to Einstein.

Greene appropriates the common motif of weaving a unified theoretical tapestry, a motif adopted by Glashow, and literalizes it with superstrings. Sheldon Glashow's 1979 Nobel Prize acceptance speech in recognition for his work with Steven Weinberg and Abdus Salam in unifying electromagnetism and the weak nuclear force into the electroweak theory was titled "Towards a Unified Theory—Threads in a Tapestry." In his speech, Glashow (1979) echoed this quest for a unified theoretical tapestry, stating "the theory we now have is an integral work of art: the patchwork quilt has become a tapestry" (p. 1). For Glashow, the integration of separate theoretical patches of electrodynamics, weak interactions, and strong interactions into one unified tapestry, a work of art, was a major achievement. Glashow defines the physicist as one who engages in an elevated search for unity. Similarly, in his book, *Superforce*, Paul Davies contends that the particle physicist is one who searches for the ultimate unity of nature. *Superforce* is an explanation of scientists' attempts to unify the four forces into one "superforce." Davies presents Weinberg, Salam, and Glashow's unification of the electromagnetic force and the weak nuclear force as an integral step in the quest for the superforce. Davies (1984) contends that "particle physics is a human adventure story without parallel" (p. 99), and he argues that "all science is a search for unity" (p. 102). Davies' dream is of that unification.

Greene appropriates this theme of unification and positions string theory as the next step in Davies' adventure story. Greene (2003a) offers string theory as the possible "Holy Grail of modern science" (p. 211) that will unite the two conflicting pillars of modern physics: general relativity and quantum mechanics. According to Greene, string theory's unifying potential works on several levels. String theory promises to unite the field of physics in two ways: by resolving the conflict between general relativity and quantum mechanics and by reconciling the conflict between theoretical and experimental physicists. Unification also plays an important role in the progress of scientific revolutions, according to Greene. He presents science as progressing through a recurrent pattern of conflict and unification:

> … progress in science proceeds in fits and starts … scientists put forward results, both theoretical and experimental. The results are debated by the community, sometimes they are discarded, sometimes they are modified, and sometimes they provide inspirational jumping-off points for new and more accurate ways of understanding the physical universe. (Greene, 2003a: 20)

Greene claims scientific progress is a process in which conflicting ideas from both theoretical and experimental scientists are debated. This communal process of debating, discarding, and modifying ideas into a more accurate way of understanding leads to scientific progress. Conflict and debate within the scientific community drive scientific progress and scientific revolutions, particularly in the major revolutions in physics.

Greene structures his argument to reflect this pattern of unifying conflict. This structuring serves a persuasive function because Greene wants to locate string theory within the history of scientific revolutions and define it as a revolutionary scientific theory. John Schwarz (2000) explains that "many string theorists … believe that string theory constitutes the third big physics revolution of the century, following relativity and quantum mechanics" (p. 199). Greene presents string theory in just this way. He does not begin his book with an explanation of string theory, but with an explanation of the conflict between the first two scientific revolutions in physics (i.e. general relativity and quantum mechanics), introducing string theory as the unifier of that conflict in Part Three of his book. In Part One, Chapter 1, titled "Tied Up with String," Greene lays out what he describes as the three conflicts in the history of physics. The first conflict he refers to is Newton's claim that a person can run fast enough to catch up with a traveling beam of light, while Maxwell's laws of electromagnetism say a person cannot. Greene claims that Einstein's theory of special relativity resolved that conflict but led the way for the second conflict (i.e. the problem that according to Einstein's theory nothing can travel faster than the speed of light but Newton's universal theory of gravitation involves influences transmitted instantaneously over large distances). Einstein stepped in again and resolved that conflict with his theory of general relativity, overturning previous conceptions of space, time, and gravity by creating the smooth "fabric of space and time" (Greene, 2003a: 6). However, the theory of general relativity at the macroscopic level led to the third conflict with the development of quantum mechanics, which described the microscopic behavior of the universe as chaotic and bumpy. Greene states that string theory resolves this conflict by challenging the standard model of physics, which traces the smallest component of matter to a particle, and claiming that all matter is composed instead of tiny, one-dimensional vibrating strings. The bumpy vibrations of point particles at the quantum level smooth out when those vibrations are extended along the length of a superstring. Greene (2003a) contends that "string theory, in a real sense, is the story of space and time since Einstein" (p. 6).

From the very beginning, Greene presents the pattern of conflict and resolution in the history of modern physics and strategically locates string theory within that history. He directly connects string theory to Einstein's theories, particularly general relativity. In Part Two of the book, Greene stresses that Einstein's theories were revolutionary and seemed radical at the time, just as string theory seems radical to many today. He contends that "most people who study general relativity are captivated by its aesthetic elegance" (Greene, 2003a: 75). Einstein succeeded in "breathing life into space and time by allowing them to curve, warp, and ripple" (Greene, 2003a: 76). Einstein, described by Greene as having the god-like attribute of "breathing life," created an aesthetically elegant and revolutionary picture of how gravity worked. According to Greene, string theory is also an aesthetically elegant theory which, if accepted, will radically change conceptions of the universe by showing that all matter is composed of tiny strings that vibrate in a world with eleven dimensions.

Greene draws another parallel between general relativity and string theory by highlighting past conflicts between theoretical and experimental physics. Greene (2003a) claims that "the search for a new theory of gravity was initiated, not by experimental refutation of Newton's theory, but rather by conflict of Newtonian gravity with another *theory* … [T]hus, internal theoretical inconsistencies can play as pivotal a role in driving progress as do experimental data" (p. 84, emphasis in original). Greene wants to show that internal theoretical inconsistencies are just as valuable as experimental data in driving scientific progress. He is challenging the criticism that theoretical physicists play a lesser role in the progression of science, relying on data from experimentalists and offering little in return. Greene is also addressing the criticism articulated by Glashow and Ginsparg that string theory is not a scientific theory because it has not been proved experimentally. In an interview for the NOVA series based on *The Elegant Universe*, Glashow (2003: 10) asks "is that [string theory] a theory of physics or a philosophy?" Greene uses Einstein to defend the validity of string theory against Glashow's criticisms. Einstein's theories of gravity emerged because of theoretical inconsistencies, just as string theory has emerged because of theoretical inconsistencies. The conflict between theorists and experimentalists, Greene contends, is part of the normal process of scientific progress, as seen in the historical example of Einstein's theories of gravity.

In the chapter that follows, Greene tackles general relativity's conflicting theory, quantum mechanics, and compares the radical nature of quantum mechanics to that of string theory. Greene presents quantum mechanics as leading to weird and bizarre ideas, paving the way for the weirdness of string theory. Greene (2003a) states that "by 1927 … classical innocence had been lost" (p. 107). Quantum mechanics introduced new and bizarre ideas, such as Heisenberg's uncertainty principle, Feynman's "sum-over-paths" approach, and Schrödinger's wave function, shattering the innocent classical idea that everything could be neatly explained and accounted for. The loss of classical innocence is not lamentable to Greene. Rather, it was a necessary step in the history of modern physics. Greene implies that it is again time to modify conceptions of the universe. The old conception of the universe operating on two conflicting sets of laws (i.e. general relativity and quantum mechanics) should be replaced by a new conception (i.e. string theory) that will surpass the old conception by unifying past conflicts. By presenting quantum mechanics as a weird scientific theory that has been accepted and embraced by the scientific community, Greene intimates that while string theory may seem radical right now, it may still be accepted by the scientific community in the future. Also, by associating aspects of string theory with both general relativity and quantum mechanics, Greene offers string theory as the logical unifier of both theories. If string theory shares similarities with both general relativity and quantum mechanics, it would be the ideal candidate for the unifying theory of everything.

3. Aesthetics and modern physics

The string theory's new view of the universe is based on ideas of unity, harmony, beauty, and elegance. In *The Elegant Universe*, Greene (2003a) argues for "the profoundly felt view that the universe, if understood at its deepest and most elementary level, can be described by a logically sound theory whose parts are harmoniously united" (p. 130). Greene makes a larger claim about the beauty and unity of the cosmos as a whole. The parts of a theory that accurately describe the workings of the universe must be harmoniously united in order to be accurate. Greene places the blame for the discord in modern physics between quantum mechanics and general relativity on the scientists. Scientists just haven't correctly figured out the laws of nature. Nature is not contradictory rather, "the central conflict of contemporary theoretical physics has been a problem of our own making" (Greene, 2003a: 157). Scientific theories and scientific language try to reflect the beauty and harmony of nature. Consequently, a theory that describes the harmony and beauty of nature should also be harmonious and beautiful. String theory promises to harmoniously unite quantum mechanics and general relativity.

By relying on aesthetic concepts of beauty, harmony, and elegance to justify the revolutionary potential of string theory, Greene positions himself within a tradition of the physicist as the seeker of ultimate beauty of the universe. However, the physicist's conception of beauty is different from the artist's conception of beauty, as Greene and other popularizers before him are quick to point out. Recent popular science works by Steven Weinberg and Paul Davies illustrate the significance of aesthetics as defined by physicists. In 1992, Steven Weinberg published *Dreams of a Final Theory*, in which he speculated about the prospects of a unified theory of everything. Weinberg's book is essentially a defense of experimental particle physics against its enemies, which he identifies as philosophy, sociology, and religion. In the book, Weinberg "resurrect[s] the traditional, apolitical, high-culture rhetoric for basic science … [and] portray[s] the high-energy physicist as the last hero of Western civilization and the divinely inspired bearer of high culture who pursues humanity's search for transcendent truth and beauty" (Degen, 1994: 738). Weinberg presents the scientist as one who engages in the elevated quest for truth and beauty. The scientist's quest for truth and beauty differs from the artist's quest because it is a scientific quest that searches for a deeper beauty that is not readily apparent to non-scientists.

Weinberg (1992) claims that "progress in physics is often guided by judgments that can only be called aesthetic" (p. 17), but he goes on to clarify what he means by physicists' aesthetic judgments. In his chapter titled "Beautiful Theories," he lays out specific criteria for beautiful theories, including simplicity, inevitability, symmetry of laws, and rigidity. Attempting to explain his conception of beauty as a physicist, Weinberg distinguishes between the types of beauty associated with art, mathematics, and physics:

> A physicist who says that a theory is beautiful does not mean quite the same thing that would be meant in saying that a particular painting or a piece of music or poetry is beautiful. It is not merely a personal expression of aesthetic pleasure; it is much closer to what a horse trainer means when he looks at a racehorse and says that it is a beautiful horse. The horse trainer is of course expressing a personal opinion, but it is an opinion about an objective fact … (Weinberg, 1992: 133)

The beauty Weinberg refers to is not like that associated with art, music, or poetry. It is not based merely on subjective aesthetic pleasure; his type of beauty is more objective. It is a personal opinion, but it is also based on objective facts about the usefulness of the theory. Weinberg also argues that his conception of beauty is not the same as mathematical elegance. He contends that:

> I should also distinguish the sort of beauty I am talking about here from the quality that mathematicians and physicists sometimes call elegance. An elegant proof or calculation is one that achieves a powerful result with a minimum of irrelevant complication. It is not important for the beauty of a theory that its equations should have elegant solutions. (Weinberg, 1992: 134)

A mathematically elegant theory then is not necessarily a beautiful theory.

In *Superforce*, Paul Davies shares Weinberg's preoccupation with beauty, but his conception of beauty is closer to that of mathematical beauty. In the chapter entitled "Symmetry and Beauty," Davies argues that the physicist is in a unique position to understand and appreciate the beauty of the universe: "nature *is* beautiful … Successful theories are always beautiful theories … Beauty in physics is a value judgement involving professional intuition and cannot be readily communicated to the layman, because it is expressed in a language that the layman has not learned, the language of mathematics" (Davies, 1984: 68, emphasis in original). Ironically, Davies writes that physicists cannot communicate their appreciation of the mathematical beauty of scientific theories to the layman in a book specifically intended for the layman. Davies articulates a similar position to Greene regarding the beauty of the universe and the need for theories to reflect the beauty of the universe. Like Weinberg, Davies argues that the physicist's conception of beauty is different from the layman's; it involves professional intuition that the non-physicist lacks. Weinberg and Davies distance themselves and their notions of beauty from artistic notions of beauty and aesthetics. They place themselves outside of traditional notions of beauty by arguing that physicists are in a unique position to appreciate this beauty. Davies contends that physicists and laymen speak different languages, and the physicist is closer to understanding the language of nature. Davies (1984) argues that "mathematics is a language, the language of nature" (p. 69), and he compares mathematics to music, explaining that "for someone who had heard only single musical notes, the beauty of the symphony would be impossible to explain" (p. 69). Mathematics is a language like music, and one must be conversant in that language to comprehend the beauty of nature.

The beauty of nature is connected with the beauty of string theory in Greene's text, but what is the scientific relevance of that beauty? Philosopher James McAllister analyzed the role aesthetics and beauty play in formulating and accepting scientific theories and whether beauty is a criterion of truth. McAllister (1991) concludes that "scientific theories are subjected to assessment on two separate evaluative canons, one concerned with the empirical worth of the theory as evinced by its application in prediction, and the other concerned in an aesthetically disinterested fashion with the purely perceptual qualities of the theory" (p. 338). A theory's aesthetic virtues are separate from its empirical validity; aesthetic judgments are disinterested, but that does not mean that they are unimportant. Even though many scientists express the view that beautiful scientific theories are more likely to be true, McAllister argues that, for scientists, beauty in and of itself is not a sign of truth. However, there are some cases in which scientists need non-empirical criteria. McAllister (1998) claims that "in fields such as string theory, where there are few opportunities to test theories against empirical data, such a decision [to remove all weight from aesthetic preferences] would deprive scientists of the sole effective basis for choosing among competing theories" (p. 184).

Greene seems to agree with McAllister's assessment that aesthetic judgments are separate from empirical judgments. He claims:

> Aesthetic judgments do not arbitrate scientific discourse, however. Ultimately, theories are judged by how they fare when faced with cold, hard, experimental facts. But this last remark is subject to an immensely important qualification … it is certainly the case that some decisions made by theoretical physicists are founded upon an aesthetic sense—a sense of which theories have an elegance and beauty of structure on par with what we experience. Of course, nothing ensures that this strategy leads to truth. (Greene, 2003a: 166–7)

According to Greene, empirical criteria are still the most important criteria for judging the truth and validity of scientific theories, but there are some cases in which physicists rely on aesthetic judgments, as McAllister claims. Aesthetic judgments do play a role in some cases, but not a major role. What role, then, do aesthetic criteria play in *The Elegant Universe*, and how does Greene define aesthetics and beauty in his book?

In his discussion of beauty and elegance, Greene focuses mainly on the concept of symmetry in addressing notions of mathematical beauty and elegance. Greene describes mathematical beauty as the reflection of the symmetries in nature:

> … much in the same manner that they [symmetries in nature] affect art and music, such symmetries are deeply satisfying; they highlight an order and a coherence in the workings of nature. The elegance of rich, complex, and diverse phenomena emerging from a simple set of universal laws is at least part of what physicists mean when they invoke the term "beautiful." (Greene, 2003a: 169)

Symmetry is beauty for the physicist. The beauty of mathematical symmetry highlights an order and coherence in nature, a coherence and unity that Greene often refers to. Elegance comes from the ability of a few simple laws to explain diverse phenomena. Even though mathematical beauty differs from beauty in art and music, it is still deeply satisfying and "aesthetically" pleasing in its own way. Like Weinberg and Davies, Greene has a difficult time communicating to the layman what a physicist means by the term beautiful. He states that this is "part" of what a physicist means, but cannot entirely explain what he means. In an interview for the NOVA series based on his book, Greene (2003b: para 21) elaborates on his definition of elegance stating, "when we talk about theories of physics being elegant, what we often mean is that a theory is able to explain a wide range of phenomena using a very small number of powerful ideas." According to Greene, the elegance of a theory resides in its ability to explain and unify a wide range of phenomena in a few simple ideas. This is the concept of mathematical elegance that Weinberg refers to and distinguishes from his notion of beauty in *Dreams of a Final Theory*.

Even though Greene argues that aesthetic judgments do play a part in the formulation of scientific theories, the concepts of beauty and elegance play a major role in the formulation of Greene's argument for the acceptance of string theory, and not merely the mathematical definition of beauty and elegance pushed by Greene. The book is titled *The Elegant Universe*. Greene describes the universe itself as elegant, elegant in an artistic sense and not necessarily a mathematical sense. Several reviewers have referred to Greene's account as elegant and eloquent. Reviewer Chris Quigg (1999) states that "string theory is a beautiful dream, beautifully told in *The Elegant Universe*" (p. 127). Laurie Brown (2004) claims "his writing is clear, entertaining, sometimes humorous or poetic—in a word, elegant" (p. 327). Greene presents string theory as an elegant and beautiful theory, and he uses elegant, metaphorical language to explain string theory. Beauty, harmony, and elegance are important thematic as well as stylistic elements in Greene's text. Greene relies on elegant musical metaphors and linguistic analogies to explain what fundamental strings are. Greene repeats the metaphorical connection between superstrings and strings on a violin and strings of cloth throughout his text. Greene's text itself is harmoniously woven together; he constructs a unified tapestry through his repeated allusions illustrating the connection between superstrings, music, and language.

4. Harmony and the Music of the Spheres

Greene compares the new theory of superstrings to the ancient concept of the Music of the Spheres, suggesting that string theory is a more accurate and scientific theory of the musical nature of the cosmos. He begins his explanation of string theory in Part Three of *The Elegant Universe* with an allusion to the ancient Pythagoreans:

> … music has long provided the metaphors of choice for those puzzling over questions of cosmic concern. From the ancient Pythagorean "music of the spheres" to the "harmonies of nature" that have guided inquiry through the ages, we have collectively sought the song of nature … With the discovery of superstring theory, musical metaphors take on a startling reality, for the theory suggests that the microscopic landscape is suffused with tiny strings whose vibrational patterns orchestrate the evolution of the cosmos. (Greene, 2003a: 135)

Greene acknowledges the long tradition of using musical metaphors to explain the workings of the cosmos. He connects himself with scientists and thinkers of the past, saying "we" have "collectively" sought the song of nature. He refers to the ancient Pythagorean idea of the Music of the Spheres, an idea based on the connection between music, mathematics, and cosmology. According to the Pythagoreans, planets and stars were attached to rotating crystal spheres that produced actual sounds; the cosmos itself was conceived of as "a vast lyre, with crystal spheres in the place of strings" (James, 1993: 38). Pythagoras is also a significant figure because he supposedly discovered "that consonant sounds and simple number ratios are correlated—that ultimately music and mathematics share the same fundamental basics" (Biddy, 2003: 14). Pythagoras was one of the first philosophers to show the direct correlation between music and mathematics; he united the two fields.

Although the idea of the Music of the Spheres may seem more like fantasy than science in today's world, this "connection of music with the origin and structure of the cosmos has a much greater historical credibility … [I]n Ancient, medieval, and Renaissance times, to claim that the order of the universe was 'musical' was to claim that it was expressible in terms of mathematics" (Field, 2003: 30). Musical and mathematical theories of the cosmos were closely intertwined in the past. Historian Bruce Stephenson (1994) contends "the sciences of astronomy and harmonics are related in their very foundations. Each attempts to systematize information received from one of the senses capable of perceiving beauty" (p. 35). Astronomy is associated with the visual act of observation, harmonics with the act of hearing. There is an aesthetic connection between the ability to observe and hear beauty in the study of astronomy and harmonics. Ptolemy modified the original Pythagorean conception of the Music of the Spheres in his treatise on *Harmonics*, associating the Music of the Spheres less with the physical act of observing and more with a mathematical theory to strengthen the mathematical basis for his work. In the *Harmonice Mundi*, Kepler continued to propose the Pythagorean idea of a musical cosmos based on harmonic mathematical ratios, but unlike Pythagoras, Kepler did not believe that the heavens literally made real, audible sounds. After Kepler, though, the Music of the Spheres moved out of the realm of science into mysticism and art.

By using this musical analogy and referring to the Music of the Spheres, Greene situates himself within the history of cosmology as told by Pythagoras, Ptolemy, and Kepler, and he reclaims the tradition of the Music of the Spheres for the realm of modern science. He states that with string theory, musical metaphors "take on startling reality"; they become more than just metaphors the ancients used to understand the cosmos. String theory succeeds where the musical theories of the cosmos put forward by Pythagoras, Ptolemy, and Kepler failed. String theory's music of the spheres is not literally music composed of audible sounds that can be heard by the average person. The music of string theory is a deeper and more scientific music created by the subatomic vibrations of superstrings. Rather than producing distinct musical notes, the music of string theory produces the unique properties of the various particles. The harmony of string theory is also a deeper kind of harmony than musical harmony; it is the harmonious unification of the laws of physics. Greene (2003a) argues the "nature of the string is the crucial element allowing for a single harmonious framework incorporating both theories" (p. 136). The harmony of string theory comes from its ability to unify quantum mechanics and general relativity.

5. Weaving the tapestry: language and strings

String theory's promise to harmoniously unite quantum mechanics and general relativity into a unified theoretical tapestry takes on added significance in Greene's text because of his reliance on metaphors connecting the fabric of spacetime to the textual fabric of his argument. He makes analogies between superstrings and language. In Chapter 6, Greene states:

> … using our linguistic analogy, paragraphs are made of sentences, sentences are made of words, and words are made of letters. What makes up a letter? … Letters are letters—they are the fundamental building blocks of written language … Similarly, a string is simply a string, as there is nothing more fundamental, it can't be described as being composed of any other substance. (Greene, 2003a: 141–2)

Strings are like letters; they are the fundamental building blocks of matter. Greene reinforces the idea that strings are not composed of any other substance with the comparison to letters. A letter is a letter and a string is a string; one cannot break them down further. He argues that "strings are truly fundamental—they are 'atoms,' *uncuttable constituents*, in the truest sense of ancient Greek" (p. 141, emphasis in original). Greene goes back to the etymology of the original Greek word to explain what strings are. Strings are atoms: one-dimensional strings that cannot be divided further. Atoms have commonly been conceived of as particles in the old language of classical particle physics, not as strings. A superstring is actually closer and *truer* to the original Greek word, Greene argues, than a typical particle atom composed of subatomic particles. In this passage, Greene is not only comparing superstrings to language he is also attempting to create a new language for string theory by modifying the meanings of words and concepts from the old language of particle physics. Greene (2003a) contends "we must significantly modify both our language and our reasoning when attempting to understand and explain the universe on atomic and subatomic scales" (p. 88). He has to modify how people understand the idea of strings by expanding the meaning of the word string. The strings in string theory are not like ordinary strings; they are not strings on a violin or strings from a piece of cloth, even though these are two metaphors that Greene uses repeatedly throughout his book.

By employing the linguistic analogy, Greene successfully illustrates the fundamental nature of superstrings, but he does not really create a mental picture of what a one-dimensional superstring is. According to several critics, representing and explaining string theory through language becomes a serious problem for Greene. Jeffrey Winters (1999) argues that Greene "skirts the issue, presenting the underlying concepts metaphorically" (p. 95). Bert States (2003) similarly contends that Greene "is forced to use the language of our simple three-dimensional world to explain the nature of a world containing at least eight more dimensions … [I]t doesn't mean string theory is wrong; it means only that what makes it tick is … lost in the translation out of the original language of mathematics" (pp. 16–17). States claims that the original language of string theory is mathematics and that Greene's difficulty arises from trying to "translate" string theory from one language (i.e. mathematics) to another language (i.e. ordinary language). Greene doesn't really address the problem of the different languages of string theory and does not explain what the language of string theory is. If the original language of string theory is mathematics, how then can Greene explain the theory in language intended for the non-scientist?

The popular culture example from *Joan of Arcadia* illustrates the scientist's (i.e. Luke Girardi's) problem of explaining string theory to the non-scientist (i.e. his father). Greene (2003a) contends in the preface of *The Elegant Universe* that he wrote the book to make "physics research accessible to a broad spectrum of readers, especially those with no training in mathematics and physics" (p. xiv). Greene uses simple language to describe string theory to both scientists and non-scientists. He includes more technical sections for the scientists, but he always begins those sections with comments directed to the non-scientists like "you can go to the next section without losing the logical flow" (p. 158). Greene relegates the lengthy technical notes for the scientists to the back of the book. However, the inclusion of the instructions for the non-scientists reinforces rather than bridges the gap between scientists and non-scientists. There is still a language barrier in Greene's book, a barrier acknowledged by Davies. In *Superforce*, Davies argued that the beauty of nature is expressed through a mathematical language that only scientists could understand and appreciate. Greene relies on elegant analogies and metaphors to represent string theory through language, but he cannot completely explain the mathematical properties of string theory to the general reader who has little or no knowledge of mathematics or physics. Instead, Greene pushes the elegance, harmony, and unity of string theory rather than its mathematical properties through elegant metaphors and analogies, such as the analogy between superstrings and letters and the analogy between the fabric of spacetime and the fabric of Greene's text.

On one level, superstrings are like letters; they are the fundamental building blocks of matter and words respectively. On another level, superstrings are like language, in that both are woven to create fabrics. The fabric of spacetime is composed of superstrings, as the fabric of Greene's text is composed of language. String theory's elegant, harmonious, unified fabric of spacetime is re-presented in the elegant language composing the textual fabric of Greene's argument. Greene cleverly plays with the connection between language, strings, and texts. He argues that "seemingly disconnected threads of research in string theory have now been woven together into a single tapestry" (Greene, 2003a: 287). Greene's book can be seen as that tapestry, in which he seeks to explain and unify string theory through language. String theory is the great unifier, so the language that represents string theory must also function as a unifier. Greene uses the metaphor that the fundamental strings are like the strings of thread in a tapestry. Superstring theory is literally composed of threads and strings; it is a *textus*. Greene describes his arguments as if they were composed of threads and strings. In the passage immediately preceding his discussion of relativity and quantum mechanics, Greene (2003a) claims "a central thread in what follows will be those developments that carry forward the revolution in our understanding of space and time …" (p. 20). His argument for the acceptance of string theory is itself composed of strings and threads which are woven together to create a unified whole.

Taking the string analogy one step further, superstrings have been woven together to create the "fabric" of spacetime, as language has been woven together to create Greene's text. At the end of the book, Greene (2003a) claims that "an ordinary piece of fabric is the end product of someone having carefully woven together individual threads, the raw material of common textiles. Similarly, we can ask ourselves whether there is a raw precursor to the fabric of spacetime—a configuration of the strings of the cosmic fabric" (p. 378). Greene plays up this connection between the superstring fabric of spacetime and the fabric of his argument. He repeatedly uses the terms fabric of spacetime and fabric of the universe in connection with threads and strings, but the strings and threads are literal as well as metaphorical. All of these descriptions echo the idea of bringing together, weaving, and unifying separate threads and ideas into a coherent, harmonious whole. The act of bringing together and unifying disconnected threads into one elegant work of art functions on several levels.

In weaving together his argument for the acceptance of string theory in *The Elegant Universe*, Greene incorporates notions of unity and aesthetics as voiced by other popularizers, ancient theories of cosmology like the Music of the Spheres, and common string motifs of unified tapestries and fabrics of spacetime. According to Greene, string theory is the great unifier of quantum mechanics and general relativity, of theoretical and experimental physicists, and of ancient cosmologies and radical new theories. String theory is a great unifier in terms of the history of physics; it is the next chapter in the story of physics, following general relativity and quantum mechanics. Yet, Greene presents string theory as more than just the next unifying chapter in physics; he presents string theory as a theory that surpasses previous theories. String theory succeeds where the Pythagoreans, Einstein, and countless other particle physicists failed. String theory incorporates ideas that before seemed disconnected and shows that the ideas can be woven into an elegant, unified tapestry. Switching metaphors, Greene (2003a) makes the bold claim that "string theory thereby unravels the central Gordian knot of contemporary theoretical physics" (p. 14). The central Gordian knot Greene refers to is the conflict between general relativity and quantum mechanics, but there are many knots in Greene's text, including the conflicts between theorists and experimentalists, and the way science progresses through a pattern of conflict and unification. Even with this allusion, Greene intimates that string theory can solve the unsolvable problem. When faced with the hopelessly complex Gordian knot, Alexander the Great simply cut the knot with his sword, rather than unravel it. Alexander took the short cut and won the throne, but string theory, according to Greene, is not going to take the short cut; it will unravel the Gordian knot. This is a bold claim made in a very ambitious book that attempts to unravel knots and re-incorporate the loose threads into an elegantly unified whole. *The Elegant Universe* successfully presents elegant analogies and metaphors as representations of the elegance of string theory, but fails in unraveling the Gordian knot explaining string theory itself. The Gordian knot left unsolved at the end of *The Elegant Universe* is the same knot left unsolved at the end of the scene from *Joan of Arcadia*. As a scientist, Luke Girardi shares Greene's problem of conveying the greatness of string theory to non-scientists. In an attempt to understand string theory, Luke's policeman father makes an analogy between string theory and lasagna, but Luke argues that it's not an exact analogy. Will Girardi replies that maybe he will understand when he *sees* the strings. However, as the scientist knows, Will Girardi will never be able to physically see the superstrings of superstring theory. At the end, Will is left with a vague analogy between string theory and lasagna and an incomplete understanding of this possible holy grail of modern physics.

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