Symmetry and Asymmetry in Science and Technology

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Introduction

Symmetry and asymmetry relate to science and technology in three distinct ways: (1) science and technology possess similarities which are symmetrical and dissimilarities which are asymmetrical; (2) each entity possesses internal mathematical symmetries and asymmetries; and (3) the symmetries and asymmetries found within science and technology arise from symmetries and asymmetries found in the physical world—both natural and human-made. This paper will be divided into five parts, the first being devoted to a description of the nature of symmetry. The next three parts will discuss the three types of relations just mentioned with the final section presenting speculations about how symmetry and asymmetry arise from the operations of mind/brain and find expression in science and technology.

1. The Nature of Symmetry and Asymmetry

Among the various definitions of symmetry two find almost immediate intuitive acceptance: (1) an object possesses symmetry such that it remains the same when rotated; and (2) an object possesses symmetry when it appears exactly the same as its mirror image. These two types are called Rotational Symmetry and Reflective Symmetry. Some objects possess only rotational symmetry while others possess only reflective symmetry. The letter Z, for example, possesses rotational symmetry but not reflective symmetry while the letter A possesses reflective symmetry but not rotational symmetry. And one can classify these two types of symmetries by how many rotations are involved: two-fold, three-fold, etc.; and by how many reflective planes are involved: bilateral, trilateral, etc. There are objects that possess both types of symmetry as the Hargittais note in one of their beautiful books on symmetry (Hargittais, 1994): "Rotational symmetry, as we have seen, may appear alone, without reflection. But if an object has more than one symmetry plane, it always has rotational symmetry as well. The only case where reflection is not accompanied by rotation is when there is bilateral symmetry, with only one mirror plane" (p. 68).

Snowflakes possess both types of symmetry; each snowflake possesses hexagonal symmetry with a 6-fold rotational symmetry and six reflection planes. Interestingly, even though bound by both types of symmetry, each individual snowflake has a different shape repeated in all six directions. The physical world and the experiential world, however, rarely exhibit symmetry. Instead, we find in the physical and human worlds asymmetries large and small that arise from differences in symmetries. Chirality in chemistry presents a wonderful example of the movement from symmetry to asymmetry and back again from asymmetry to symmetry. A right-handed molecule may look like a left-handed molecule reflecting a mirror symmetry, but without rotational symmetry they are different and indeed react differently chemically. The same left-handed molecule for a drug may be completely ineffective in therapy while the right-handed version of the same molecule may be successful in performing the desired treatment.

Michael Leyton claims that the movement between symmetry and asymmetry is always bidirectional from the former to the latter and that cognition consists of the determination of past changes in shape (Leyton, 1992):

> It will be argued that an important means by which the mind recovers the past is *shape*. As

> such, shape forms a basis for memory. The mind assigns to any shape a causal history explaining how the shape was formed. It is by doing this that the mind *converts shape into memory*. Furthermore, we will reduce the study of shape to the study of *symmetry*, and thus we will show that symmetry is crucial to everyday cognitive activity: *Symmetry is the means by which shape is converted into memory* (p. 2).

Leyton goes on to assert that, "**ASYMMETRY IS THE MEMORY THAT PROCESSES LEAVE ON OBJECTS**" (p. 7). (Author's caps and boldface.)

Others have also noted that many objects in the physical world result from the movement between symmetry and asymmetry. Field and Golubitsky, in their *Symmetry in Chaos* (1992), claim an intimate relationship between symmetry and chaos and find the emergence of patterns in the movement away from perfect symmetry to asymmetry:

> Perfect symmetry and total chaos have one feature in common: both look the same at every point and from every direction. In this sense, total chaos can be thought of as perfectly symmetric. Symmetry, however, when used in art, decorative design or architecture, is usually one step down from perfect symmetry. Analogously, our pictures of symmetric chaos can be viewed as a breaking of the perfect symmetry of total chaos (p. 64).

The recognition of symmetry and asymmetry depends, therefore, upon the discernment of similarities and dissimilarities among objects. To decide that an object possesses rotational symmetry, one rotates the object and then looks and sees if the object is the same. Similarly, to determine reflectional symmetry, one places a mirror before the object, looks into the mirror and once again decides if the mirror image is the same as the object itself. To recognize asymmetry, one observes differences. In the interaction between symmetry and asymmetry one finds parallels to the use of metaphors where a metaphor contains similarities and dissimilarities between its two parts (MacCormac, 1985). Metaphors, however, are not inherently mathematical while the notions of symmetry and asymmetry inherently bring with them mathematical properties related to space and number. We shall explore the use of these properties in section II where we examine the internal workings of symmetry and asymmetry in science and technology. First, however, we shall begin describing similarities and dissimilarities of science and technology that could be construed as part of the historical macroscopic level of the interaction between symmetry and asymmetry.

II. Cultural Symmetries and Asymmetries between Science and Technology

Our discussion of symmetries and asymmetries in science and technology begins with an exploration of similarities and dissimilarities between the two enterprises. Until recently many in the United States have believed that technology exists as a stepchild of science in the form of applied science. Technological projects depended upon principles discovered by scientists engaged in basic research. After the Second World War, Vannevar Bush, a scientific advisor to President Harry Truman, espoused this view in a report which led to the establishment of the National Science Foundation:

> Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science.

> Today it is truer than ever that basic research is the pacemaker of technological progress. In the nineteenth century, Yankee mechanical ingenuity building largely upon the basic discoveries of European scientists could greatly advance the technical arts (Billington, 1983, p. 8).

Yet if one looks at the technological developments of the nineteenth century and earlier, one usually finds that they developed independently and often without scientific understanding preceding them. The steam engine, automobile, and airplane all were developed before the fundamental physical principles expressed in the mathematics of thermodynamics and aerodynamics were understood. For centuries bridges and buildings had been constructed without mathematical knowledge of statics. Thomas Telford constructed some of the most famous and successful British bridges in the early nineteenth century. David Billington, in his *The Tower and the Bridge* (1983), describes Telford's lack of scientific knowledge as follows:

> Telford had little use for the science of his day, was untrained in mathematical formulations, and made few if any calculations for his designs. He was reputed to have no knowledge even of geometry, let alone the calculus invented in the seventeenth century by Newton and Leibnitz. It seems incredible today that without any mathematical analysis someone would seriously guarantee a 600-foot-span arch, over two and one-half times the span of any previous European bridge. Even more remarkable is the fine performance of his numerous extant iron bridges whose forms did not come from mathematical analysis. When saying that science had little influence on Telford, I mean two distinct ideas, first, that discoveries of nature's laws by people like Galileo and Newton did not play any role in Telford's designing, and, second, that Telford did not use in his design work the mathematical formulations devised by such researchers. Thus, science here means new discoveries and new methodologies *developed independently of design imperatives*. On the other hand, Telford directed innumerable tests on structural elements which he designed, and he also carefully observed the behavior of structures in service (p. 42)

The phrase, "developed independently of design imperatives," gives the basic differentiation between science and technology. While science seeks to understand the nature of the physical universe, technology or engineering (I am using these two terms as synonymous) seeks to construct artifacts to modify the world. Engineers design structures and machines for human purposes, often largely independent of scientific theories.

Vannevar Bush's wartime experience grew in part out of the successful development of the atomic bomb (the Manhattan Project), a dramatic example of technology which emerged from scientific theory—nuclear physics. Many technologies do depend upon scientific theories developed by basic research but not all technologies do so depend. Some technologies have a life of their own, others emerge from science as applied science, and most often science and technology interact. Modern science can hardly exist without technology in the form of instrumentation and most recently in computer simulations and modelling.

Understanding, therefore, that science and technology sometimes exist independently of each other, let us first examine the similarities and dissimilarities of each before dealing with their interaction (MacCormac, 1986). These similarities and dissimilarities underlie the symmetries and asymmetries which we shall discuss in section II.

One way of discovering similarities and differences between the two is to examine the values held by each and observe where they do and do not overlap. Scientists often distinguish between the internal values which scientists assume and the external values which society imposes upon science. Scientists, for example, pursue knowledge about the physical world for its own sake regardless of the consequences of that knowledge. This dedication to "knowledge for its own sake" is an internal value. The consequences of that knowledge is an external value. Chemists who synthesize a new compound are delighted with that scientific result and may deny any responsibility for the fact that this very same synthesized product may be used for chemical warfare. The defense of knowledge for its own sake as an internal value of science finds support in the contention that if research were restrained because unintended consequences might result in harm, then almost no scientific investigations could be undertaken. No one can tell in advance how the results of scientific knowledge will be used. Yet, on the other hand, in justifying appropriations for scientific research, possible positive consequences lure lawmakers into making such commitments.

Honesty (a commitment to the truth) exists as the most sacred internal scientific value. The ethical value of honesty occupies central stage in the drama of science, for without trust the experimental performance of the individual researcher cannot be accepted. If the results of one experimenter are tested by another and found wanting, then the second investigator seeking replication usually assumes that flaws exist either in the attempted replication or in the original results. Rarely do scientists assume that their colleagues have committed fraud even when large discrepancies take place.

Personal honesty may be presumed but the scientific community offers the social safeguards of peer review of funding proposals, the refereeing of scientific papers, and, most importantly, confirmation or disconfirmation through attempts to replicate. With these institutional protections, scientists assume that although occasional cases of fraud do arise, they will be isolated instances and eventually uncovered and the culprits exposed.

Beauty also permeates science as an internal value with several forms of expression. Scientists claim beauty in the fit of their theories to the physical world as confirmed by experiments. Theories are called beautiful in terms of their internal organization: how the concepts interact with each other and how the concepts find expression in equations and algorithms. And the very mathematical parts of the theory possess beauty in their order and elegance.

Technology possesses the same internal values of a commitment to truth and an expression of beauty. But technology does not pursue truth for its own sake because the very nature of technology depends upon a teleology which blurs the distinction between internal and external values. Engineers strive to construct artifacts designed to be efficient, economical, and elegant. Each of these goals can express both an internal and an external value. Machines which are efficient in design often also consume fewer resources, thus expressing the external value of conservation. A device economical to construct and/or economical to operate similarly affects the external productivity of the structure or machine. Elegance can have both an internal and an external expression; in the case of structures like bridges, the elegance of the design (internal) affects the perceived elegance or beauty of appearance (external).

Teleology in technology also affects the nature of knowledge as a value and the ethical impact of technology. Since the major purpose of science is the pursuit of knowledge for its own sake, except, perhaps where intentional harm could be foreseen, the ethical impact of science is not a major issue. But in technology, engineers create artifacts to improve human life and thereby directly affect humans and the environment. Since technology cannot produce structures and machines without concurrently producing waste and pollution, an important ethical question becomes the tradeoff between the benefits and harms of technology. Rarely does technological knowledge take the form of pure investigation. Instead, technological knowledge exists as pragmatic knowledge providing insight into how to construct things, and knowledge of how those things will carry out their purposes. For example, engineering knowledge about computers includes architectural design of hardware along with knowledge of the possibilities of developing software to execute various functions like the solution of equations, word processing packages, statistical packages, and so on.

We found that science expresses both internal and external values but usually not in a direction explicitly shaped by its goals (its primary goal being the pursuit of knowledge for its own sake). Technology, however, possesses two additional values: a symbolic value intentionally designed to be expressed culturally in its artifacts; and a synergistic value expressed in the interaction between humans and machines and humans and structures. These values are both internal and external at the same time since artifacts symbolize both the internal conceptual world of engineering design and the external cultural life of technology.

Basically science and technology have different fundamental commitments: science to pursue knowledge alone and technology to pursue knowledge for the purpose of improving human life and culture. Scientists try to live within the world of internal values while engineers eagerly express their internal values of honesty and design in structures and machines that express external values. But scientists necessarily test their theories in the physical world and this forces them to break outside the limits of internal values. If we look for symmetry in the values of science and technology we will find symmetry in several places. First we will find symmetry in the internal values of mathematics used in both enterprises. Then we shall find symmetry in the designs of technology expressed in artifacts which exist in the physical world. We shall find, however, a major asymmetry in the commitment of science to internal values and of technology to a commitment to a fusion of internal and external values. But this asymmetry is not as stark as at first it might seem because scientists sometimes unexpectedly find symmetries of the physical world in their experiments. We shall now investigate these symmetries and asymmetries in more detail in the following section.

III. Formal Symmetries and Asymmetries

We noted in section I that geometrical objects may possess Rotational Symmetry and Reflective Symmetry. Symmetries also occur in algebra as well as geometry.

> The equation X + 1 = 0 has two solutions, *I* and *-I*, in the Gaussian integers. These solutions are different, but all their properties are the same. The permutation of the Gaussian integers that takes a + b*i* to a - b*i* preserves all the structure of the Gaussian integers—addition and multiplication—and takes *I* to *-I*. Just like a symmetry of the equilateral triangle takes one vertex to another and preserves the structure of the triangle.
>
> For any polynomial equation we can look at the group of symmetries of its solutions. Evariste Galois showed that this group determines to what extent it is possible to solve the equation with a formula like the quadratic formula. The group of symmetries of the roots of a polynomial is now called the *Galois group* (Johnston and Richman, 1997, p. 104).

One can sketch algebraic symmetry further into trigonomic forms like sine and cosine waves, classical Fourier analysis and matrices. Lattices, frieze patterns and space groups also exhibit forms of symmetry. But these formal descriptions of symmetry found in the equations are not nearly as interesting and fruitful as the transitions between symmetry and asymmetry found in both science and technology.

The development of contemporary chaos theory has often seized upon the logistic map as an example of unexpected abrupt transitions from stable regular forms to unstable chaotic forms. Here is the algorithm for the logistic map:

$$x=ax\,(1-x)$$

When a=3, the iterated values of x double and then at a= 3.56994456... the values of x become chaotic. The ratio of distances between values of a that lead to successive doubling of periods is the Feigenbaum constant, 4.6692. . . . The logistic map finds application as a model of the spread of an epidemic or population growth. In chaos theory a transition takes place from chaotic forms to stable attractors and from stable attractors to chaos, and until one has carried out iterations with various values starting from different initial values, one cannot predict where one will find stability and where one will find instability. The stable attractors of chaotic systems are fractals (Mandelbrot, 1983). But not all of these fractals are symmetric; indeed most of them are not but many are similar to symmetrical geometrical structures. Those that are similar are usually affine. Many fractals are slightly asymmetric and these may be the most interesting, especially when they are the strange attractors of chaotic systems. Similarly, the fractal-like geometrical forms found in nature and elsewhere may either be symmetric or only slightly asymmetric.

The "edge of chaos" where these abrupt transitions take place from chaos to stability in mathematical expression probably describe the most creative movements in nature and experience. The fractal strange attractors not only may possess fractal dimensions that are not necessarily integers, they also manifest self-similarity repeating the same geometrical patterns at different degrees of dimensionality. When these patterns are symmetric, the same symmetry will appear at the macroscopic as well as microscopic levels.

IV. Empirical Symmetry and Asymmetry in Science and Technology

Among human-made objects symmetry often appears as in the design of bridges, buildings, and automobiles and in the artistic patterns of quilts, wallpaper, and even sidewalks. And scientists have discovered symmetry in representations of molecules and in theories about atomic and subatomic particles. Botany exhibits fractal symmetry in plants, trees and bushes while biology exhibits fractal symmetry in animals. Marine organisms produce shapes easily mirrored by fractal forms. Symmetry abounds in nature but not everywhere. The most interesting phenomena seem to arise from the movement from symmetry to asymmetry (and the reverse) as stability becomes chaotic or chaos becomes stable in fractal forms.

The very process of discovery manifests an interaction between chaos and stability reflected in the parallel movement between asymmetry and symmetry. The development of Magnetic Resonance Imaging in medicine illustrates this process. In 1946, two scientists, independently of each other, found that certain nuclei in the periodic system when placed in a magnetic field absorbed energy in the radiofrequency range and re-emitted this energy as the nuclei relaxed to their original orientation.

> Because the strength of the magnetic field and the radiofrequency must match each other, the phenomenon was called *nuclear magnetic resonance: nuclear* because it is only the nuclei of the atoms that react; *magnetic* because it happens in a magnetic field; and *resonance* because of the direct dependence of field strength and frequency (Keen and Smith, 1986, p. 2).

The symmetry of stability of the spin of the nuclei of atoms was perturbed by a large magnetic field tuned to a radiofrequency range moving the nuclei into instability (asymmetric to their normal movement).

P. C. Lauterbur (1973) suggested the use of this phenomenon for medical imaging by adding a second, weaker magnetic field, the gradient field, to pick up the re-emitted signal.

> Because the strength of the magnetic field is proportional to the radiofrequency, the frequency of, for instance, a hydrogen nucleus at one end of a water molecule differs from the signal of another hydrogen nucleus at the other end of the sample. Thus, the location of these nuclei can be calculated. Once their location is known, an image can be created of a slice through a human body, for example. Basically, therefore, MRI requires a strong static magnetic field produced by a large magnet, a second weaker magnetic field that varies across the sample, a radio transmitter and receiver, and a powerful computer to calculate an image (Keen and Smith, 1986, p. 3).

Earlier than Lauterbur, Damadian (1971) had shown that tumor detection by MRI was possible.

In the development of MRI we see the interaction of symmetry and asymmetry in science and technology on two levels: (1) the perturbation of symmetry into asymmetry in the nucleus; and (2) the employment of (1) by technology to produce an MRI machine that can now be used to image the symmetries and asymmetries of the human body. This second interaction between science and technology occurs at the macroscopic, cultural level. Without the existence of powerful magnets, the disturbance of the nuclei could never have been discovered; yet, without the theory of how a strong magnetic field affects nuclei in the radiofrequency range, the device could never have been built. Similarly, radio transmitters and receivers had to be in existence. Scientists pursuing knowledge for its own sake depended upon the technology of engineers who had built devices to improve communications. These different goals are part of the asymmetry between science and technology. We find the symmetry in both enterprises utilizing the same theory with the same mathematics (largely the domain of science) and both enterprises utilizing the same machine, the MRI (largely the domain of technology).

V. Symmetry and Asymmetry in the Mind and Brain

If one looks at the resting state positron emission tomography (PET) scan or a resting state MRI scan of the brain, at almost every level, the brain seems to possess a left-right dihedral reflective symmetry. Organs on the left are matched by the same organs on the right. And some regions like the hippocampus exist in a horseshoe-like ring symmetrically divided in the middle with half on the left and the other half on the right. From this structural symmetry one might infer that the symmetry which we see in the external physical world arises from the symmetrical functions occurring in the symmetrical structure of the brain. But an investigation of cognitive functions demonstrates a number of asymmetries in the regions of the brain where these functions seem to originate. Careful examinations of brains have only revealed slight asymmetries between the two hemispheres in the differing sizes of regions on each side. Galaburda (1996) comments:

> By and large, however, we have only found slight differences in the amount of brain substrate devoted to the particular architectonic area or a particular gross anatomic landmark. In other words, despite the fact that the left hemisphere is significantly different from the right, there appears to be no structure or chemical constituent that is present in one hemisphere but not in the other. . . . This leaves quantitative differences as the only difference between areas present in both hemispheres. The message here is not that quantitative differences are not important and might not even be the whole explanation of

> cerebral dominance, but it is also likely that quantitative differences lead to qualitative differences by permitting the arrival at thresholds and emergent properties (p. 52).

And this asymmetry is more than just a left-handed/right-handed asymmetry. Sight by the left eye does activate the right occipital cortex and sight by the right eye does activate the left occipital cortex, but the viewing of words by men activates only a region in the left hemisphere while the viewing of words by women activates both left and right hemispheres (Shaywitz, 1995). Similarly, viewing circles and squares activates asymmetrical regions in both men and women with the regions activated between the two sexes themselves asymmetrical (MacCormac, 1997).

Just why the operation of mind arising from the symmetrical structure of the brain produces an asymmetry remains largely a mystery. One might speculate that the development of a phenotype as the infant matures through interaction with the world generates this asymmetry. The argument might be that the world is not fundamentally symmetrical and that the individual learns asymmetry through experience. In cognitive perceptual activations these external world asymmetries are transmitted to neuronal connections that become asymmetrical. This explanation seems much too simple, however, when one observes the vastly complicated network of neural connections in the human brain that remain plastic until death. Individuals with lesions in particular regions can often learn to perform in other regions the functions normally associated with that region. One might also note that memory for various functions seems spread all over the brain rather than in any one location.

We have already seen that in nonlinear systems creativity often takes place in the transitions from symmetry to asymmetry and vice versa. Neuronal functions in the brain also function in a nonlinear, chaotic fashion with transitions from instability to stability and from stability to instability. These transitions may produce the human creativity which allows us to survive and grow in the world. Humans continue to evolve in both biological evolution through minor mutations and cultural evolution through new adaptations to society. These two forms of evolution operate according to different theories but they do interact as changes in the environment affect biological evolution and biological evolution affects how we interact with the physical world.

Conclusion

We have discovered an interaction of symmetry and asymmetry between science and technology on three levels: (1) the mental world in which science and technology exist in theories and designs; (2) the physical and social world; and (3) the mind and brain.

We will leave open the issue of whether symmetry is discovered in the empirical world or imposed on the physical world by the mind. We will also leave open how the mind introduces asymmetries into cognition. We can claim, however, that in the interface between symmetry and asymmetry (paralleled by the interface between chaos and stability) creativity arises. We further claim that mathematical instruments like chaos theory can best represent the emergence of creativity from the interaction between symmetry and asymmetry.

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