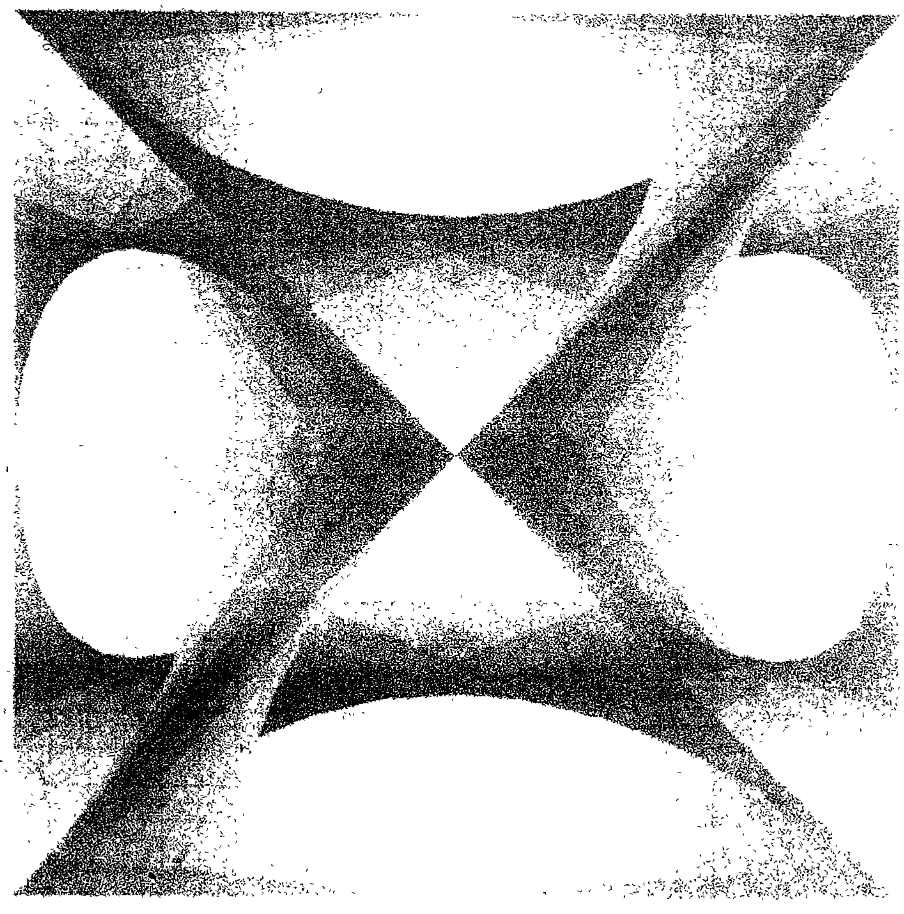
Symmetry: Culture and Science

The Quarterly of the
International Society for the
Interdisciplinary Study of Symmetry
(ISIS-Symmetry)

Volume 8, Number 3–4, 1997



Symmetry: Culture and Science
Vol. 8, Nos. 3-4, 401-408, 1997

SEEING THROUGH SYMMETRY - AS SEEN THROUGH ITS LABS

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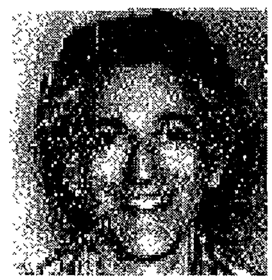

Fields of interest: Mathematical physics, science education, interdisciplinary symmetry.

Publications: (a) What Is Symmetry That Educators and Students Should Be Mindful Of It?, Chapter for the book, *Interdisciplinary General Education: Questioning Outside the Lines*, Seabury, M. B., ed., NY: College Entrance Examination Board (1999). (b) Faraday's Legacy: The Joys of Scientific Methodology, Guest Editorial for *QUANTUM* (November/December 1998), pp. 2-3. (c) Reflections of the Relevance of Nonlocality to Cognitive Science and the Philosophy of Mind, from *New Directions in Cognitive Science*, Proceedings of the International Symposium (Saariselka, 4-9 August 1995, Lapland, Finland). (d) Nonlocal Conserved Quantities, Balance Laws, and Equations of Motion, *International Journal of Theoretical Physics* 28, 335 - 363 (1989) (e) Audio-Visual Aids in Materials Science and Engineering: A Current Overview, *Journal of Materials Education* 11, 169 - 180 (1989).

Abstract: *Seeing Through Symmetry is a one-semester course that has been created for non-science majors. Here symmetry is utilized as what could be called a "hub concept". It is as if it stood for the axis of a cylinder consisting of a multidisciplinary world with ties to disciplines constituting the surface, and with the disciplines, as a consequence, tied to each other. Through this hub many aspects of the scientific and artistic worlds can be better understood and appreciated. In this paper that is explained primarily through the description of a highly graphical laboratory experience. The labs utilize computers in order to explore the many facets of symmetry (in such areas as geometry, the arts, biology, music, and physics) and enable students to create patterns through the use of hardware/software packages and elementary programming.*

1 INTRODUCTION

Seeing Through Symmetry is a one-semester course that has, on the average, run every fall and spring for the past six years. I have created this course in order to enable students explicitly to develop their quantitative abilities and analogical thinking by using concepts of symmetry both as a method within a discipline and as a bridge between disciplines. Starting with topics of symmetry in the ancient world, we then go on to broaden, refine (through a precise definition of "symmetry"), and interrelate those topics to the symmetry in areas such as art, poetry, music, mathematics, physics, chemistry, biology, and cosmology. Thus students "see through" (i.e., understand) the concept of symmetry as well as "see the world" *through* (i.e., by means of employing) the concept of symmetry. They develop interrelational and scientific abilities, in part, through the medium of a highly graphical laboratory experience; this utilizes computers in order to explore the many facets of symmetry (in such areas as geometry, the arts, biology, music, and physics) including the generation of their own patterns through the use of hardware/software packages and elementary programming. [There are, as the readers of this journal know, innumerable references for symmetry in education. A particularly good description of symmetry's value for education in general and for science education in particular is given by (Klein, 1990, p. 86).]

2 LECTURES

These are multimedia interactions: Two films are shown: One of these is an easily understood general introduction to a variety of symmetries (Robinson, 1970); the other stresses the glories of learning as seen through the mind of the prototype "Renaissance man", Leonardo da Vinci (Bobker, 1992). An audiotape is employed to demonstrate the use of the Golden Ratio in Bartok's "Divertimento for Strings". A laser is used to exhibit both the wave interference phenomenon called "diffraction" and the manner in which light waves can interfere to produce a hologram. A special feature of the course is a computer-animation-and-sound show that illustrates symmetry in art, geometry, geophysics, and both cellular and molecular biology (including the dynamically "broken" symmetry through a portion of a motion picture showing the "sickling" of a circular red blood cell into one shaped like a crescent moon, a signature of the disease called "sickle cell anemia").

Over the years the subject matter of the course has been broadened. Some of the more recent topics which Seeing Through Symmetry includes are: the structure and function of DNA, the nature of the chemical bond through explanations of electric forces, scientific bases for common uses of electricity, an introduction to the mathematical theory of groups with applications to computer algorithms, the application of waves to some aspects of the strange world of quantum physics, and the very important issue of scientific methodology (as exhibited in part through the use of Venn diagrams to illustrate class inclusions and methods of concept formation).

We were able to outfit a multimedia classroom, in part as a result of a 1993 NSF Instrument and Laboratory Improvement grant (No. DUE-9352670) for the course. The room contains 12 nodes, each with a Mac computer (plus desk lamp) in a space that easily accommodates two students, an instructor node with another Mac tied to a projection system at the front center of the classroom, and a laser printer on the opposite side of the room from this node; all are connected via an Ethernet network. There is also a VCR player connected to a large monitor at the front right side of the room, a non-chalk board (which has its own lighting) at the front center, and an overhead projector at the front left side. The instructor node permits access to each of the student nodes (e.g., for loading software or transferring files). The equipment is completed by a variety of hardware and software packages used both in teaching and in the laboratory portion of the course.

3 LABS

The laboratory experience gives the student a more complete sense of what is discussed in lecture. The labs, meeting for two hours once each week, have extensive student interactions with discussion being continually encouraged among the participants. Although students work in pairs, an individual typed report is required for each lab. Earlier labs feed into later ones as lower-level abstractions feed into higher-level ones. The labs are briefly described below in relation to the question: What is the activity and how does it connect to other areas of the course so as to convey the interdisciplinary experience? (Subjects referred to are covered earlier during lecture.)

3.1 Computer Drawing: Reflections, Rotations, and Designs

The object of this lab is to: (a) introduce students to the computer, and (b) enable participants to create and understand designs that have reflectional or rotational symmetry. Students can test for those symmetries by using the software package to compare an "image" of the design with the design itself. They can also do a comparison by getting a printout of their design on which can be laid a transparency for tracing the design and then folding or rotating that tracing. In addition they can create their own colored designs using a variety of reflectional and rotational symmetries. In this way the student sees a relation between symmetry and art.

3.2 Learning Algorithms through the Language of Logo

The object of this lab is to enable students to learn about a computer algorithm. What they see is how a repetitive command, or "algorithm", can be used to create certain simple figures. Hence they experience "time-translational" symmetry which they can, for example, interrelate to rhyme schemes of poetry.

3.3 Drawing and Hearing Patterns: Polygonal Symmetry and Fibonnacci Tones

In this lab (a continuation of 3.2) the student: (a) employs algorithms (via Logo) to simplify the creation of regular polygons that have both reflectional and rotational symmetry, and (b) uses the Fibonnacci sequence, an example of an algorithm discussed in lectures, to hear tones and thus learn more about the musical scale. Hence students can see connections between music, design, and computers; for example, by using the concept of an algorithm one may create certain musical patterns.

3.4 Intricacies of Coloration: Coordinates, Translations, Groups and Tessellations

In this lab (a continuation of 3.3) the student sees: (a) how coordinates of points can be represented by the computer, a prelude to (b) how different colors are determining factors for the nature of translationally symmetric designs, (c) an instance from the mathematical theory of groups, and (d) how algorithms can be created to tessellate the screen. Hence students learn (or re-learn) the analytical-geometry basics of locating objects in space; see how this is related to design, to poetry, and to music through the creation of symmetries and "broken" symmetries; understand how art can be a manifestation of group theory in mathematics and how the latter can be used to create art; and glimpse "infinity" through symmetries that can go on and on through time and space.

3.5 Patterns in Music: Sound and Sight

This lab takes place at our School of Music (each pair of students is in a small room containing a piano). Its purpose is to serve as a literal "hands-on" introduction to elementary ideas in music and music symmetry through exploration of the visual and aural aspects of the keyboard. It does this by: (a) asking students to learn about symmetrical patterns that can be associated with the keyboard, both visual and (what I would call) "aural temporal"; (b) teaching them to relate the psychophysical concepts of pitch and frequency to each other and to the Fibonnacci sequence; and (c) giving them the experience of performing the broken symmetry of musical "rounds". As a result of this lab students can interrelate music, mathematics, art, and physics, with even a little psychoacoustics!

3.6 Experiencing Motion in Space and Time

The purpose of this lab, and the ones that follow, is to see the value of technology for investigating aspects of certain natural phenomena including those, which exist beyond the range of human vision and hearing. The computer with auxiliary devices attached to it is used to "extend" our visual and auditory senses. This in turn makes it possible for us to understand the manner in which symmetric aspects of nature contribute to our sense of the world of motion, sound, and light. In this lab students build on their experience of graphical representations (as introduced in Lab 4) through the visualization of scientific data obtained via the simultaneous monitoring and display of different phenomena by computer equipment. This enables them to: (a) see the value of technology's omnipresent concept of *voltage* through the display of battery outputs as a function of time; (b) understand aspects of *motion* through experiencing the movement of their hand, using an ultrasonic motion detector; (c) conceptualize some details of a periodic phenomenon that has time-translational invariance, called "simple harmonic motion", using a mass-on-a-spring connected to a force probe. By means of this lab students can see the obvious tie to mathematics, as well as to epistemology (i.e., how we acquire knowledge about the world; in this case, scientific knowledge). They can also see connections to art, music, and poetry. For example, the stressed-and-unstressed pattern in poetry's sonorous iambic pentameter may be represented through the use of visual voltage steps exhibiting a similar periodicity in time.

3.7 Symmetry of Oscillations: Sine Waves and Sound

This lab, drawing from concepts learned in the previous one, serves as an introduction to some elementary properties of sound by using the computer to measure periods that are thousands of times shorter than one second. The student learns: (a) how to measure the frequency and amplitude of periodic sinusoidal signals produced by tuning forks and then apply that knowledge to the observation of periodic *non*-sinusoidal signals; (b) what gives rise to the remarkable symmetrical patterns, called "Lissajous figures", that result from combining 2 sinusoidal signals whose frequencies stand in a simple numerical relation to each other. Ties to epistemology are seen through consistency arguments: the participant must compare the measured value of frequency with the "standard" value stamped on the tuning fork (is the standard value the "correct" one? what do we mean by "correct"? do we use similar methods to acquire knowledge in the arts?) Through the use of (b) can be seen obvious ties to mathematics as well as feedback to the visual arts; and with a little more imagination one can see how both music and poetry can benefit from such insights. An example is the tuning of a piano string via visual comparisons between a given input frequency and that from the string.

3.8 Building Symmetry from Symmetry: The Fourier Spectrum

This lab serves as an introduction to the addition of symmetrical wave patterns. The student learns about: (a) "Fourier synthesis", as manifested in complex periodic sounds, with their corresponding shapes, occurring when two or more simple periodic sounds with their corresponding shapes, resembling "sine wave" shapes, are combined, or "synthesized" (although true sine-wave shapes are referred to as "Fourier components", our simple approximate shapes will also be so referred to); (b) "Fourier decomposition", a method showing how complex periodic shapes can be broken down (or "decomposed") into their Fourier components, enabling students to look at the "shape" of their voice and of their heartbeat; and (c) how to synthesize their voice and heartbeat from the Fourier components. There are a variety of interconnections gleaned from this lab. Ties to mathematics are obvious. But in addition, connections can be made to the technology of "electronic" music and voice production, the visual arts, biology (e.g., how does the structure and function of the vocal chords and heart relate to the nature of the waves they produce?), and, most remarkably, to the limitations of a certain type of knowledge through the Heisenberg Uncertainty Relation in quantum physics (e.g., why is it that to be able to precisely locate a particle's position is to be unable to precisely locate its velocity?).

3.9 Waviness: In Water and Light

This lab serves as an introduction to the addition of wave patterns — a far-ranging investigation, as it applies to almost all waves in the universe. Here the focus is on the visual as students learn about: (a) brightness and light waves through the experience and measurement of the intensity of light as well as through the observation of a spatial and temporal invariance (each a symmetry property) of that intensity under certain conditions. By modeling light as a transverse wave and using polarizers they are also able to demonstrate and explain how such polarizers work in altering the intensity of light; and (b) waviness in water by the computer simulation of waves, through which students can observe the wavelength of waves, measure their speed, see how waves interfere with each other, and observe the effects of their interference. The connections are of course to mathematics (and once more emphasize an important epistemological point about methodology in the physical sciences), but also to the visual arts, to music (with the phenomenon of "intensity of light" being analogous to the "loudness of sound"), and to cosmology (e.g., how do we know the distance to stars and what they are made of?!).

Other labs in the planning stage are titled: "Slipping" Symmetry: Crystals, Fractals, and Chaos; Bounced, Flipped, Rotated, and Decomposed Light: From Mirrors to Spectra; and On Balls and Bombs: The Geometry of Projectile Motion.

4 OTHER ASPECTS OF THE COURSE

These are: (a) 2 closed-book exams; (b) a visit to a science museum: students submit a paper describing their observations and making remarks critiquing (pro or con) exhibits they found notable; (c) a term project: the capstone experience of the course, this consists, in order, of a report on their preliminary idea, a progress report, a class presentation, and the final report; (d) two types of (anonymous) course evaluations: my own mid-semester evaluation is designed to let me take steps to immediately modify aspects of the course; another, end-of-term All University Curriculum questionnaire has questions related to the ones given at mid-semester. Although we are using supplementary materials plus portions of one text (O'Daffer and Clemens, 1992) I am currently writing a book, instructor's manual, computer demonstration files, and updated laboratory manual.

5. CONCLUDING REMARKS

I hope that students carry away from the course the lesson that science *begins* from an individual's observations of the world as a highly imaginative probing into the workings of nature (not just a rigid compilation of facts and formulas). Seeing Through Symmetry is designed to help show students that the world is of a piece. It is to convey the sense that where the human mind journeys there are no barriers.

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