Art-science, beauty-reason and holography

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Abstract. Display holography holds a distinction that makes it appealing to a wide audience. It can be appreciated at a deep level by people of all ages and in all fields of endeavor. It provides a unique opportunity for us to gather in an intimate location to learn, enjoy, and enlighten one another. This paper offers demonstrations to explore the relationships between art and science, esthetics and mathematics, and the dualities that exist in nature. On the practical level, a visual model for deep understanding of holography and a proposal for “making holograms that sell” will be presented. In writing this article, the author acknowledges the fact that for this symposium, a Proceeding will be published as well as a set of audio-visual recordings. With that in mind, this article represents largely the printable contents, leaving the audio-visual part as “performance” to be electronically recorded.

1. Introduction
It is my honor and privilege to give the “welcome” paper to the participants of the Ninth International Symposium on Display Holography (ISDH). Three years ago, this symposium took place in Shenzhen, China, where I delivered the opening paper entitled “Teaching Advanced Physical Concepts Using Display Holograms [1].” Today, I wish to continue on that theme but broaden it to include some relevant personal histories along with a “geometric model [9]” that is used to explain holography to a general audience. The “live” oral presentation will include material not possible to replicate here in print.

The most noticeable difference between this gathering with other symposia and conferences is the broad inclusion of artists, scientist, entrepreneurs, and other people with diverse educational backgrounds, personalities, and philosophies. I wish to stress the similarities amid this diversity, between art and science, and between beauty and reason.

For those interested in the business of display holography, it is disheartening to realize that in spite of the years of attempts and expectations, the market has not really caught on. I wish to offer my opinion on this subject and a possible solution.

Note that I have avoided the use of the word “truth” in the title. The meaning of the word has lately been contaminated by the media and we have developed doubts about its “truthiness.” On the other hand, 2+2=4 is still accepted universally. It is “reasonable.”

2. Why I am a teacher and who taught me how to teach
Three weeks before this symposium, my Yale University class of 1957 held its 55th reunion with a special theme. We were requested to voluntarily submit a “Life Report” that defines us as to who we are. A panel of distinguished writers held a forum to publically discuss this collection and possibly assemble it into a book form.

My own “Life Report” relates not only to “Why I am a Teacher”, but in particular, a teacher of holography. I therefore include an expanded version of this report.

2.1. Why I am a teacher – a Life Report
Back in 1947, I was one of about 20 children from ages 6 to 12 and older, fortunate enough to attend school in a village near Guangzhou (Canton), China. Because of droughts, floods, plagues, war, and revolution, we never
had a single year of uninterrupted attendance. In one room, we had one teacher who taught the equivalence of first to eighth grades all at once. I never learned his name because everyone just called him “Teacher.”

He was a poet and the most respected person in the village. We relied on him to help resolve all conflicts, public and personal. He even dictated that the pronunciation of certain words be changed so that they rhyme in Tang poetry. Most of the lessons consisted of reciting poems in unison in a sing-song manner. For art, we had calligraphy, and for math, we learned the use of the abacus.

One day, he fell ill and asked me to take over the class. I remember it well. We were studying an epic poem about an emperor and his favorite concubine and had a great deal of subtlety. I had to go over it word by word and found that there were many parts I could not understand. We agreed to ask Teacher the next day.

We did so. Teacher told us that it was fine not to understand. But if we memorized the poem and recite it to ourselves when we become older, we would come to understand it eventually. That weekend, I encountered a group of my classmates in the market place. They stopped, bowed to me in unison, and addressed me as “Little Teacher.”

I was deeply moved. It was at that moment I made a life-long decision to become a teacher.

An earlier event was responsible for my interest in science in general and nuclear physics in particular. It was the ending of the Japanese occupation of our village in 1945 by two “atomic” bombs.

The choice to accept the first and only job in 1963 at Lake Forest College was based on its village-like location and the broad educational experience it offered to a relatively small number of students.

It was immediately apparent to me that nuclear physics was not a suitable subject for teaching undergraduates. Research had to be performed at an up-to-date accelerator, which was the isochronous cyclotron at the Oak Ridge National Laboratory 500 miles away. I tried to convince my wife that we could treat the summer trips as vacations near the Smoky Mountains. The commuting during the academic year was extremely difficult, however, especially after our first child was born in 1964.

Oak Ridge was a center for refining uranium for the “bomb”. Because I was not a US citizen at that time (my legal status was Displaced Person), I was prevented from access to most areas outside of academic research at the cyclotron. It helped that George W. Clement, then Governor, signed a statement declaring me an Honorary Citizen of Tennessee. I was permitted to visit laser researchers at Oak Ridge and subsequently learned to build helium-neon lasers at Lake Forest College. That turned out to be a critically important experience.

Lake Forest College had a national reputation in developing new physics experiments for undergraduates. It received a government grant to host a summer conference on this subject in 1965. In searching for new topics, I discovered the publications on holography by Emmett Leith and Juris Upatnieks [2,3]. I wrote to Leith and asked for a loan of an example to be shown at our conference.

To my surprise, he not only sent me a 4x5 inch hologram of chess pieces, he asked me to keep it. His generosity literally changed my life.

Immediately after I learned how to view the hologram and studied the basic theory involved, I realized that this subject could be applied to a wide spectrum of topics from technology to art. Being visually appealing, it would be possible to teach the subject at any level to a broad audience, including artists.

I also questioned the format of the 4x5 inch hologram: If this is a 3-D medium, why are we stuck with a 2-D flat format like paintings and photographs? I immediately worked with two first-year students and published a paper entitled “360° Holography [4]” in 1966 followed by another paper called “Cylindrical Holography [5]” in 1967. This opened to me the flood gate of interests from the commercial world. I started to get grants [6], made two educational films [7,8], and later received a generous donation of an entire professional laboratory on holography and fiber optics from the Newport Research Company then led by Milton Chang. My dream of switching from nuclear physics to holography was finally realized!

During my first sabbatical leave in 1969-70, I was appointed by the NSF supported program, the Chautauqua Lectures, to tour the US on twelve university campuses, coast to coast, from Stanford to Maryland. The objective was to teach the new subject of holography to other physics professors and have them spread the new frontier. Each university had a center to recruit twenty-five other professors from nearby colleges and universities to gather for a two-day session in the fall, and another two-day session in the spring for feedback. To my knowledge, it is a broad program that is continued today, and includes many areas of new developments in science and technology.

On my second sabbatical leave in 1976-7, I was appointed Adjunct Lecturer by the School of the Art Institute of Chicago. I created a geometric model [9] for teaching holography to artists through visualization and without mathematics. During this same sabbatical, the Chinese government invited me, my entire family of five, and my wife’s parents, to a month-long lecture tour in Shanghai, Beijing, and Guangzhou.
In recent years, I have become increasingly interested in reaching out to a younger audience. My latest "gig" was accepting an invitation from the Lake Forest Country Day School to be their inaugural Scientist in Residence program on April 27, 2011. After giving lectures with demonstrations to all the first to eighth graders in the morning, I taught a kindergarten class of about 40 children in the afternoon.

This *déjà vu* moment reminded me of the time sixty-four years ago when I took over a class under one roof to teach children of all ages in a village in China, and how I was inspired to become a teacher for life. On that revelation, I decided to retire completely from paid teaching appointments.

I cannot end this life-report without mentioning an incident involving an interaction with my grandchildren. Three summers ago when little Anna was three and Ian was six, I thought the time was right to take them to my lab and show them holograms.

At the entrance to the science building at Lake Forest College, they suddenly became really excited and yelled, “Rocks!” What they saw were garden variety pebbles of difference sizes and colors around the bushes and trees. They were jumping around, picking, inspecting, and could not stop playing with them. I had to pull them into my lab and finally showed them the holograms.

But it was clear that the highlight of their visit were the rocks.

Now, every time I go to my lab, I have to pass by these damned rocks. They remind me of the lesson I learned from the children, which has helped me to keep my feet firmly to the ground.

If only I were a poet, I would have written an “Ode to the Rocks.”

2.2. My secret physics teacher – Richard P. Feynman

By sheer luck, my employment at Lake Forest College in 1963 coincided with the publication of the three-volume Lectures on Physics by Richard P. Feynman [10]. In fact, I was able to obtain mimeographed copies as early as 1961 from friends in Caltech. I was completely overwhelmed by the clarity and elegance of his expositions on every topic that I was to teach. But they did not include any homework problems, thus could not be used as textbooks. Therefore, I chose an existing well known standard textbook for students, and used the Feynman treatments for preparing my lectures and demonstrations. I kept this fact a secret from students otherwise they would anticipate my presentations and encouraged to skip classes.

I was so obsessed with Feynman’s charm and wisdom on every topic that I not only read all books I could find written by and on him, but also watched the 16mm films of his lectures produced at Cornell University before he joined California Institute of Technology. I imitated his lecture style - roaming the floor with chalk in hand, and even the way he told jokes.

The ultimate example of his pedagogic genius is the 152-page book on quantum electrodynamics, entitled QED [11]. Without a single equation, he clearly explained this advanced subject in graduate level physics using the now universally accepted “Feynman diagrams.” It was this *tour de force* that continued to inspire me.

At Lake Forest College, as far back as I can recall, the Physics Department has made it a tradition to give each physics major at commencement a complete set of the Feynman Lectures - a hefty gift both in bulk and in cost. This year, we had ten recipients. Thank goodness, the set is now available in DVD format.

I surmise that countless physics professors share my secret. We all appear smarter in doing so, thanks to Richard P. Feynman.

2.3. My not-so-secret teacher on holography – Joseph W. Goodman

As I have written in Section 2 above, I was appointed to teach a Chautauqua Program on holography during my 1969-1970 sabbatical leave. It was the most daunting experience of my teaching career, knowing that I was to teach colleagues most of whom are older and probably smarter than me. I was frantic in making preparations, and soon realized that serious readings of the Gabor and Leith-Upatnieks publications were not enough.

Then I found Prof. Joseph W. Goodman’s book Introduction to Fourier Optics, now in its 3rd edition [12]. That gave me all the “ammunition” I needed, never mind that Stanford was one of the twelve universities in my program.

During the following sabbatical leave in 1976-7, the Chinese government invited me to a lecture tour that included Beijing, Shanghai, and Guangzhou (Canton). I knew only Cantonese and had to lecture in English, leading to great problems during my first program in Beijing. The interpreter appointed to translate for me had great difficulty with the technical vocabulary and phrases. In the audience was Prof. Hsu Da-Xiong from the Beijing University of Post and Telecommunication, who understood everything I was saying and volunteered to take over as translator.

It was surprising to me that Prof. Hsu’s conversational English was quite poor at that time, but he was fluent in technical English, especially on the subject of Fourier optics. He later told me that he had been
teaching from Goodman’s textbook for years, solved every problem in it, and practically memorize much of the book. That’s how he had learned English! Goodman was to him was like Feynman was to me!

Professor Hsu, who soon taught holography to students who later became the founders of many of the holographic label companies in China, is often honored as the “father of holography” in China.

2.4. The Geometric Model for Holography.
As I had mentioned in Section 2.1, during the 1976-7 sabbatical, I was appointed as Adjunct Lecturer at the School of the Art Institute of Chicago.

Here I had the opposite problem encounter with the Chautauqua program – I was to teach artists, most of whom did not have technical training in holography, and some of them downright abhorred technology and mathematics.

At that time, long before the publication of the book QED, the Feynman diagram was already famous. I thought: if Feynman can come up with simple diagrams to explain this difficult subject in physics, I should be able to do something similar on the particular subject of holography. The result was my publication of the article “Geometric Model for Holography. [9]” The reader is respectfully asked to consult the publication directly.

3. Why Big Display Holograms Don’t Sell
3.1. The business of holography
My first and last interest in holography has always been its beautiful concepts. In addition, because of its visual appeal, it lends itself to become an instrument for scientific education to a broad spectrum of students. That is not to say that I have no interest in making a business of selling holograms for profit. Even in doing so, I sold holograms and the material for making them strictly for educational purposes [14].

From the moment Leith and Upatnieks published their work along with Denisyuk’s discovery of Lippmann holograms [17], countless entrepreneurs have set up businesses to market them as novelties, advertising, and of course, fine art. Very few were able to make it a successful enterprise, with only one exception. Stephen A. Benton’s invention [15] of “rainbow” holography drastically reduced the band-width and allowed holograms to be mass produced by embossing. This opened up a multi-billion dollar business around the world. Let us thank him and all those who have kept holography alive.

3.2. Why deep-scene holograms don’t sell
In my opinion, there is a very simple reason why people don’t buy beautiful, big, deep scene transmission or reflection holograms, even with full color: It is too cumbersome and expensive to illuminate them.

Large holograms need large space to display them. For a transmission hologram, much space is needed behind the piece. If it requires laser illumination, safety rules forbid outputs over 5 milliwatts. For a reflection holograms, a viewer trying to get a close look will be burned between the lamp and the hologram. Placing a hot lamp next to the hologram is not a solution.

3.3. Possible solutions
In 2001, I presented a paper [16] proposing a scheme that can universalize display holograms into one single modular design that can meet the following goals:

- Safety from heat and radiation
- Bright enough for outdoors
- Thin, independent of hologram size
- Fixed alignment
- Free form – display in any shape
- No size limit

The basic concept of the Pixelated Holographic Display (PHD) system is to illuminate the hologram from behind with a panel of small lasers or light from the tips of fiber optics. Figure 1(a) shows a basic tile of a transmission hologram setup. It is a 30x30 cm section being illuminated 2 cm behind by an array of small diode lasers each without a collimating lens. Each individual spreading beam is directed upward at 45° at a 1 cm² area of a corresponding HOE in contact with the hologram. The HOE converts the spreading beam to a collimated beam going through the hologram downwards at 45°. As a whole, the entire hologram is illuminated by the equivalent of one single collimated reference beam.

Figure 1(b) depicts a similar concept for a tile-sized reflection hologram with a sheet of HOE on the left (viewer) side. The light from the single-mode fiber optics tips, fed into the fiber bundle by a single white-light or laser source far away, passes through the transparent hologram at the “wrong” angle, thereby suffering no diffraction. It then encounters the HOE that is designed to convert the spreading incident light into a reflected collimated beam going downward at 45° back through the hologram. Together, all the light from the fiber tips go through the hologram and is transformed into a single collimated light directed at the hologram from the viewer’s side. In this fashion, a viewer can touch the hologram without blocking the reconstruction light.

The collective result satisfies all the bulleted points listed above. In addition, we have avoided the classical Rayleigh resolution criterion because it does not apply to Gaussian beams or any beam that fades out at the edge of an aperture.

Thus far, we have assumed fixed holograms made on “classical” materials like silver-halide or photopolymers by currently existing methods. However, PHD will apply to future “live” holograms that are composed in situ, and in real time. When that day comes, a PHD-tiled wall can serve as a living room “window” conveying 3-D motion pictures captured by an array of micro-cameras broadcasting from a submarine moving through an ocean or set up on top of a beautiful mountain.

Note that nothing above violates any fundamental physical laws. Therefore, this proposed scheme is “possible”. Let us hope that with the rapid development of nano-technology, the dream of achieving this feat might be realized in one or two decades.

4. Abstract Symmetry and Equations as Poetry

4.1. An example of abstract symmetry
Observe the two figures above:

What is so “symmetrical” about them? Holographers will recognize that Figure 2b shows components of a spatial filter. There is a microscope objective, a pinhole and the adjustment screws to direct a laser beam and focus it through the pinhole.

What is in Figure 2a? It is an “inductor” made of a coil of wire, which is electrically connected to an adjustable “capacitor” made of a stack of parallel aluminum plates. The knob on the latter allows one to “dial” one row of plates into the other, varying the parallel area between the two stacks, and controlling the capacitance. This “resonant circuit” allowed us to “tune” to a radio station of our choice in the vacuum tube days.

Now imagine that the spatial filter had not been invented. How would you have come up with the idea? Here’s one way we could think of it, the explanation of which will illuminate the beauty and value of “symmetry” in science. If you expose a ring of wire to the broadcast radio waves, it will respond to all electromagnetic disturbances including thunders, spark plugs firing in car engines, and other “noise” and “cross talk” from all radio stations. To obtain good reception, one needs to invent high quality components to provide a “narrow bandpass” filter so that you can fine-tune to a desired channel and block out all of the “noise”.

When a laser beam is directed by mirrors and then spread out onto your holographic plate by a lens, all of which have dirt on them, the resultant light has many distracting patterns on it. We holographers call that “noise”. Using the same concept of providing a “narrow bandpass” filter in radio, we focus the beam through the pinhole so that only the original parallel beam from the laser can pass. Light that scattered off dirt does not focus through the pinhole and is blocked. That is how we “clean-up” the beam. Thus, it is a spatial filter.

Therefore, the invention of a spatial filter is accomplished by recognizing the “symmetry” between an event in the time domain and translating it into an equivalent event in the space domain. It is a beautiful symmetry between space and time.

All physical laws are fundamental; and they manifest their consequences in subtle ways when applied to different situations. Knowing this abstract “connection” is the reward of studying science.

The 1953 Nobel Prize was awarded to Fritz Zernicke for inventing the phase contrast microscope, thereby revolutionizing biology. He used the opposite concept to the spatial filter when he placed a black dot where our pinhole is, thereby blocking the original light that illuminates transparent specimens, allowing only light that is affected by the specimen to come through. In the history of science and technology, many such beautiful ideas were discovered by recognizing the reason in symmetry.

4.2. First: A confession

It is a common notion that artists in general, are “afraid” of mathematics. In fact, many artists admit this characterization themselves. I wish to recount a humbling personal experience which offers a counterpoint to this conception.

At the beginning of my tenure as an Adjunct Lecturer for the School of the Art Institute of Chicago during my sabbatical year in 1976, I was offered a guided tour of the masterpieces in the world-famous collection. I mentioned to the appointed guide that my family and I had visited the museum several times and had “seen” the most famous works, and that I really want to learn more about “modern” art.

She led me into a large room with building material and equipment spread around the floor, apparently in the process of remodeling. We stood there for what seemed to be a very long time. I finally reminded her that I was ready for the tour.

She politely pointed out to me: “Sir, we are standing in a new “installation” by (name I have forgotten)”. She then showed me work by others (names I have also forgotten), and finally the large works by Jackson Pollock. Ah-ha!! I showed-off by mentioning that I have seen a movie about him.

To artists: we are even! I am just as befuddled about modern art as you might be about the theory of holography.

4.3. Equations as poetry written in an international language

We all know that many great poems don’t need to rhyme. And of course, most poems are written in languages we don’t know. Therefore, we should acknowledge that mathematical equations that induce awe, wonder, and inspiration can be written in the truly international language of mathematics. Let us take some examples.

First:

\[ E = mc^2 \]
To me, this equation brings joy, excitement, pain, relief, and grief all at once. It recalls the moment when my adopted mother and I were hiding in caves during the Japanese occupation of our village. The sudden ending of the war gave us a new life. Then I learned it was the two “atomic” bombs dropped by the United States that ended our miseries, along with the massive death and destruction in Japan.

I was greatly mystified by the awesome power of these bombs. I tried to read about it from every source I could find, and learned that our sun uses this method to create the energy that makes life on earth possible. I was so impressed with this process that it later lead me to the study nuclear physics for my Ph.D.

Second:

\[ F = ma \]

This is Newton’s Second Law of Motion. It reads: “the total force \( F \) acting on a body of mass \( m \) causes it to accelerate at the rate of \( a \) along the direction of the force. This equation “explains” everything from electrons going around the nuclei to planets going around the sun and the motion of every mass that is subjected to a force.

It has a particular meaning to me: it gives me euphoria!

When I think of this equation, I think of windsurfing! Did you know that with a steady wind speed of 12 mph, I can be sailing at 15 mph? Seems impossible? Not so, says Newton.

If I sail in a direction perpendicular to the wind, the component of the wind force along the direction of motion will be constant regardless of my speed. Thus, if this were the only force, I would accelerate toward the speed of light. However, \( F \) means the “total force”, and it includes the “frictional force” that is always exactly in the opposite direction of the motion. The frictional force increases with the speed of the mass. Therefore, the total forces will decrease with the net speed of the mass, until it reaches a “terminal speed” when the frictional force is exactly equal and opposite to the component of the wind force in the direction of motion. The concept is exactly analogous to any mass in a free fall in the atmosphere– it accelerates until the frictional force equals (and is opposite) to the gravitational force.

Thus, my terminal speed in windsurfing is completely dependent on my skill and the design of the equipment, as long as there is a steady wind at any speed. To experience the wind at my back while appreciating the laws of nature at work adds to the awe and thrill of the whole experience. It is poetry in motion!

I can go on and apply this Newton’s second law of motion to skiing! Skiing is the art of falling down a beautiful mountain----------. Well, I can go on and on, but have to stop myself here due to space limitation!

There are several ways we can write down mathematically the relationship between the creation of a hologram and the reconstruction of its image. To me, the most “beautiful” way is to express them is as a “Fourier transform pair”. I am writing them in one dimension, \( x \), for simplicity.

\[
\begin{align*}
  g(x) &= \int_{-\infty}^{\infty} G(u) e^{i2\pi xu} du \\
  G(u) &= \int_{-\infty}^{\infty} g(x) e^{-i2\pi xu} dx
\end{align*}
\]

Here, \( g(x) \) stands for the hologram; \( x \) locates a point on the hologram, \( G(u) \) stands for the image of the object; and \( x \) stands for the spatial frequency of the interference pattern formed between the reference beam and light from a point on the object. Thus a hologram is created by adding up all the interference patterns caused by the interference of a reference beam with every object beam; and the image of a hologram is formed in your eye by adding up all the beams diffracted by each interference pattern recorded. In short, one is the summary of the other. Each is complimentary to the other. If one is real, so is the other.

Without any regard to the mechanism of mathematics, just look at the equations! There is perfect symmetry. The hologram and its image are made of each other, and in the same way.

If the earth were visited by beings from a faraway galaxy that were far more advanced than we, who no longer require eyes or ears for making observations, then they would “see” our holograms and the objects recorded in them as one and the same thing.

Finally, in university bookstores as well as in technical expositions, you may often find printed on T-shirts and shopping bags the following “message”: 
In the beginning, God said:

\[
\begin{align*}
\nabla \cdot \mathbf{E} &= \frac{\rho}{\varepsilon_0} & \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\
\nabla \cdot \mathbf{B} &= 0 & \nabla \times \mathbf{B} &= \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}
\end{align*}
\]

And there was light.

There is no better way to describe “everything” about light than these four Maxwell’s Equations on electromagnetism.

(At this point, let me remind my readers who are artists that I am not taking revenge for having suffered the humility of being in the middle of a “performance” art piece and not knowing it.)

In the way in which a graphic artist can perform outstanding feats on a computer without knowing the details of how each electronic component works, we can “read” these equations and get to understand their meanings without doing calculations. Michael Faraday and Thomas Edison had something in common - neither of them had training in mathematics. They were able to “visualize” concepts that led to great inventions.

Let us just “look” at these equations. There is something ugly about them! Compared to the beautiful symmetry of the Fourier transform pair for holography, these are full of asymmetries.

I have already discussed the asymmetry between the two equations on the left side in a previous paper(1). The equation on top left reads: “the divergence of the electric field at a point is proportional to the total “electric charge density at that point.” The equation below it reads: “the divergence of the magnetic field at a point is equal to zero.” We can understand this based on our current knowledge: If there is a net electric charge at a point, we can visualize electric field lines going into or out of the point. We accept for a fact that for each magnet, large or small, there is always a north-pole and a south-pole. Thus, every magnetic field-line we can imagine must be a continuous loop, never beginning or ending at a point.

But nature must not favor \( \mathbf{E} \) over \( \mathbf{B} \)! We demand that the divergence of \( \mathbf{B} \) MUST NOT BE ZERO. Therefore, we conclude that there must exist magnetic monopoles, i.e., north and south poles of magnets must exist alone just like positive and negative electric charges! We just have not found them yet.

It is through this kind of symmetry arguments many now known particles were discovered. The anti-particle is a prime example.

Now onto the pair of equations at the right: they are even uglier! The top-right equation reads: The curl of the electric field at a point is equal to the negative of the rate in which the magnetic field is changing at a point. The bottom equation reads: “The curl of the magnetic field is proportional to the electric current density \( \mathbf{J} \) at the point plus the rate at which the electric field is changing at the point! Why the extra term with \( \mathbf{J} \) in it? This discrepancy can be remedied using what we did with the divergence equations: if we allow the existence of magnetic monopoles, then there would be a magnetic current density; and both equations would each have two terms on the right side. Now we have perfect symmetry for both the divergence and curl equations.

In free space, there are no net electric or magnetic charges. Thus all four equations will have only one term on each side of the equal, in perfect symmetry.

Michael Faraday, through this kind of “thought experiments” and without mathematical calculations, invented the motor and the electric generator!

It gets better: we now can state the following absolutely astonishing facts: In free space where there are no electric or magnetic charges, any change in the electric field around an area of space generates a magnetic field through it; and any change in the magnetic field through an area of space generates an electric field through it. In this way, the electric and magnetic fields resurrect each other through free space until they encounter a flower. There, they transfer their energy to make it bloom.

Next time you see a sunset, know that somewhere on the sun an electron changed its orbit causing a shift in its electric field, which generated a magnetic field, which created what we call “light,” and began a long journey through space until it reaches your consciousness.

If only I were a choreographer, I would compose a ballet with a magnificent \textit{pas de deux} between \( \mathbf{E} \) and \( \mathbf{B} \) across the celestial stage of life.

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