Going deeper: teaching more than the mechanics

Abstract. What follows is a description of an introductory holography course titled “Lasers and Holography,” taught by the author at Columbia College Chicago since 1997. Because this is a science class at an arts college with an open admissions policy, these students have many different levels of education, dissimilar backgrounds, and varied fields of interest. There are few science majors. Therefore, specific learning objectives are developed. The author contends that for many of these students it is not enough to teach the physics of making holograms. To inspire and instill a lifelong appreciation for science and physics, one must go still deeper. Students need to be touched on more than just an intellectual level. Consequently, a broader approach is used. Ultimately, it may stir students to want to learn more, and to be confident they can. The paper addresses: 1) Becoming aware of one’s individual state of seeing 2) Perceptual illusions: their impact on the advancement of science 3) Promoting artistic applications and exposing students to fine art holography 4) Teaching holography as an information processing, as well as an image-making technology 5) Introducing and exploring philosophical implications of holographic principles.

1. Introduction

The first version of the class this author taught was for a short summer school session for high school students. Many of the students were interested in pursuing photography at Columbia, and the similarities and dissimilarities between photography and holography, along with this instructor’s background, allowed for presenting much of the course material within a context of photographic imaging.

As the course progressed to the college level the template expanded. It was clear there was fear of what physics classes were thought to be about. They were perceived to be opaque. But, it has also become clear that what inspires most of these art-oriented students, and what motivates them beyond just wanting to learn how to make holograms, is their own curiosity about the big things; their big questions, and their own grand ideas. Fortunately, the universe of physics and holography is filled with such things; things transparent and wondrously fathomless.

The philosophy for teaching is so shaped. We start with those big things. We introduce physics as thoughts: thoughts about what the universe is, about how we perceive it, about how it works, one’s self and one’s place in it. These things relate and resonate. This is a different physics. This can include philosophy, and it can include art. It is personal and it is passionate. It is meaningful and relevant.
Figure 1. This holographic image appears orthoscopic, but it is really pseudoscopic. This well known cognitive illusion is thought to arise from strongly reinforced facial feature recognition which overpowers weaker, contradictory signals. *Lost in the Green River;* 50x60cm pulsed reflection hologram. By the author, 1992.

One’s attention is caught and held, and sincere learning can begin. Individual desires and directions will guide the course. The smaller things, the details, can come later when needed; however named.

2. **Becoming aware of one’s individual state of seeing**

The ultimate learning objective is to inspire a shift in a student’s self-awareness: to be a catalyst that propels one to see more, to see differently; to expand one’s universal view, and one’s sense of place. The visual impact of holograms makes them excellent for stimulating such a shift.

To begin this process, the first class session combines lecture and demonstration to challenge students’ preconceptions. Part of the lecture proceeds:

I. When looking at holograms we may be reminded that we take our visual world, what we think of as reality, for granted. We look at the universe with preconceived ideas. We assume reality.

   A. We see as if from behind a window: a little person inside this head, passively watching a world “out there.”
      1. This outside world is separate from us “inside here.”
      2. This outside world consists of things, objects, nouns.
      3. These objects are separate, with empty space in-between.
      4. These objects are ultimately, indivisible.
      5. Reality continues, independent of us.

II. Still, some theories in physics and some philosophies hold an opposing view:

   A. There is no person “inside here.”
      1. There is no separation between the observer and the observed.
      2. The universe consists of processes and flux: not static objects.
      3. Everything is connected.
      4. We have not yet found an indivisible building block of everything.
      5. Without an observer to observe it, there is no independent reality.
The reader here may see similarities to what could be called a classical physics paradigm presented in I, and similarities to a quantum physics paradigm presented in II. But, the point is not to compare the two methods and disparage one. There is no conclusion drawn that one of these above sets of claims is superior to the other. The point though, is that there are different ways of seeing, and to bring the unaware student to such a realization. The context in which we see affects what it is we do see, and the meaning within. Here are two paradigms with which we may view the universe, reality, existence. For many, this is the first time they have encountered the idea that they see from within a context of presumptions. Many of the students in this class are in the visual arts, and not all of this is new to them. But, still they can become aware that without consciously thinking about it up to this point in their lives, they have assumed that their type of world-viewing is the only type.

![Figure 2](image_url)

Figure 2. An assumption, or preconception. As the chalk line is continuous, most viewers assume it forms an outside border and constitutes a specific object; perhaps in this instance this is a droplet of water. However, the line could just as well be an object itself, say a rubber band. Or, it separates an interior “emptiness” from an object on the outside. Perhaps now liquid surrounds a dry spot.

Later in this first class, there is a display of large-format reflection holograms (some of which are multi-channel), a transmission master is shown full aperture with a diverged laser beam, and then its real image is projected onto a classroom wall with an undiverged beam.

For their first exercise then, students write observations of the holograms they have just viewed. They are discouraged from including subjective statements (opinions, aesthetic judgments), the broad description that holograms appear to have depth, or points that they have heard from the instructor (those that are learned and not their original thoughts). This exercise is designed for objective observation: non-judgmental viewing. This requires them to concentrate on and analyze their own authentic, visual experiences. It pushes them to consider what it means when something is said to have depth, to describe the sensation of depth without using the word itself, and what it is that makes holograms unique. It challenges them to be conscious of seeing, and to verbalize what it is they see.

As the semester progresses, there are more pragmatic exercises. One class is largely devoted to 3D imaging technologies that generally do not involve holography: Peppers’ Ghost, stereo photography, anaglyphs, lenticulars, polarization, the Imax system, and some hybrid systems that employ 2D image recording (photography, cinematography, videography) with holographic synthesis, for e.g. multiplexing. Each form is briefly explained and examples discussed with the emphasis on the visual
effect, and with an introduction and development of language and terms to describe the imagery. Depth cues (occlusion, parallax, etc.) are recognized along with advantages and disadvantages of these technologies. Now the fundamental point: that a hologram is not a trick. It is physics: a reconstruction of the multi-faceted and complex patterns of wavefronts emanating from something we call an object. Holograms encode patterns, and we as viewers decode those patterns.

The deep-scene transmission lab is particularly powerful for both novices and the visually astute. This is the first time a real object is used in the lab (their first hologram is a diffraction grating made only with light itself). For the deep scene though, they “light and compose” their objects. Once they have roughed-in the equipment and components, they position themselves behind a clear glass plate and look back into the scene. They are told: “Make what you see through the glass plate as you look through it as you would a window, what you hope your final holographic image will look like.” The constrictions of this geometry force them to position the object precisely and to consider lighting: what it is to have an object lighted from behind or strongly from its side; how does hard laser light affect the appearance of an object, its contours, its textures, its volume; how black will shadows be; does one type of lighting mean something different from another; and more plainly, is the object well seen? As they see the laser-illuminated object for the first time, they begin to pre-visualize. In a very real sense, they are motivated to use their imaginations. After exposure and processing they compare the final holographic image with the real object. For some, this is a moving experience: its memory resounds.

Figure 3. A visual conundrum. This pattern of dots and lines only has meaning when viewed within a context.

3. Perceptual illusions: their impact on the advancement of science
The process of perception is at least in part, a translation. But, translation however truthful, is still a form of qualification. To quote William Blake: “The eye altering, alters all.” Lens aberrations deform the photon’s path. Body chemistry transduces it, and the mind interprets its resulting signal. In this way, we see the world as right side up, even with our photon-inverting lenses; and we see straight lines, even as cascades of photons are caught upon our curved retinas, But, of course we still have blind spots (literally and metaphorically), and are often fooled. Our universe abounds in illusions. But, not all are absolutely, completely false; and in one sense an illusion might be considered a lesser truth.
The intent of science (and some say, art) is to see through to the truth. As we expand our vision and expose illusions, we can leapfrog from one level of awareness, one level of truth, to the next.

That we progress by dispelling one illusion with a higher level of truth conveniently dovetails with a short history of how our concept of light has evolved. It was Thomas Young’s double-slit experiment that evidenced interference and the wave motion of light and saw through Newton’s corpuscular theory, held for nearly a century before by most to be the ultimate truth. Works of Fresnel and Maxwell further substantiated the wave theory of light. So it was widely assumed, again for nearly a century, that in fact light is a wave. But, then Hertz perceived the photo-electric effect, and it presented inconsistencies with the light as a wave paradigm. It then took Einstein to pierce thru that veil of the time, and to reconcile the conflicting appearances with yet another paradigm: light’s wave behavior is in concert with its particle (quantum) nature: wave and particle are mutual qualities. For slightly more than a century we have balanced this duality, this perspective. Perhaps it is not because this is the final truth, but because we’ve not seen thru to a new, more complete or more subtle model.

4. Promoting artistic applications and exposing students to fine art holography
The course ardently advocates the experimental use of holography as an art form. A final project hologram which each student must conceive, design, construct, and produce, is assigned a large percentage of the total grade. Videos and slides of professional work are shown throughout the semester. Holograms are brought in for display, too. Some of these illustrate specific ideas pertaining to the final project, but still more are shown to light the imagination. The work spans the history and styles of holographic art and includes multiple artists from different regions and times. Rarely is the technical quality of the work alone discussed. Instead, the techniques are assessed as to how they contribute to the overall aesthetic of the artist and the work.

For their final project holograms, students are challenged to do more than Denisyuk arrangements with objects they have found. If they absolutely desire a found object, they need to somehow expand the project. (It is interesting that many students, especially those with backgrounds and interests from far afield, choose objects of sentimental value.) They can choose to do a transmission or reflection piece; and manipulate the color (within limits, of course) if it is in reflection mode. They can construct, combine, sculpt. They can practice with multiple exposures and reference angles, masking,
pseudoscopic imagery using molds, incorporate other media, make mosaics, and use light itself as the subject. They can do anything they can imagine within the lab’s capabilities.

The projects are evaluated with several criteria. The whole process is graded, from the conception, to the production in the lab, to final viewing. They are asked the rationale for their project: why this subject, why this geometry? The emphasis is on the quality of their comprehension displayed throughout, and on the intellectual and creative effort. This prevents the technical features from outweighing all others. Brightness is not the almighty arbiter; so the lucky and lazy who just happen upon bright images don’t get to outshine those who have understood and worked hard but, because of the fickle finger of holography fate, or because their aesthetic doesn’t demand it, don’t have as bright a result.

![Image](image.png)

**Figure 6.** Real image information is downloaded with an undiverged beam

5. **Teaching holography as an information processing, as well as an image-making technology**

Those of us in the field are accustomed to think of holography as a medium for recording and playing back information. But, this is a different way for students to think about “3D” pictures. Though the immediate, visceral impact of holograms may be a prime motivator for learning in this class, it is at least as important, as intimated earlier, that holography be understood and appreciated for the even larger contributions and ideas it offers. Information processing is specifically important.

So early on, it is made clear that holograms use waves as handles for carrying information. That in fact, visible light waves are not necessary to produce holograms. A definition has been carefully
devised to encompass this quality: A hologram is the recorded interference pattern of a pure, coherent wave and a deformed portion of itself.

Additional points:

1. Holography is essentially an information processing technology: it records and retrieves information.
2. “Pure” holography (as distinguished from computer generated or digital hybrids) does not produce or manufacture new information; and in this sense it does not ‘create’ it.
3. The information is not stored locally: there is no point-to-point relationship.
4. Information can be stored throughout a volume, not just on a surface.
5. Information may even be stored inside of information.
6. This information can be accessed at the speed of light.
7. Different information is accessible from different perspectives.
8. Holographic storage volumes exceed other technologies.

“Seeing” is visual information processing: the eye gathers and transmits light information to regions of the brain which then decode and interpret it. Because of this process, there is the thought that technically we do not see objects. Instead, we recognize patterns and give them object names. In this way then, we are not just passive observers of a world ‘out there’, but are very active in the making of our reality.

6. Introducing and exploring philosophical implications of holography principles

Students have now moved from the introductory theories to learn the underpinnings of the physics in holography: interference, diffraction, stimulated emission. They have also made several different holograms. With added insight they are now prepared to look again at the big things. They are assigned reading on the holographic paradigm, a discussion of Alain Aspect’s work on Belle’s theorem, David Bohm’s implicate and explicate order, and Karl Pribram’s holonomic model. Some of the ideas presented:

I. A new paradox in physics has theorists suggesting a holographic model of the universe. Some say the universe actually is a hologram.

II. Researchers claim our brains may process information similarly to holographic information processing. Memory specifically may rely on interwoven neural networks like holographic interference patterns for non-local storage and rapid recall. Some say our brains actually are holograms.

III. The theories intertwine and conclude: consciousness itself might produce the appearance of reality.

These claims entice and incite strong reactions. The idea that objective reality does not exist is powerfully polarizing, with some students deeply inspired and others deeply offended (though most are inspired). Some mistake it to imply ‘reality’ does not exist at all, and this makes them more fervent still. Questions stream: What would the reference beam be? Where would it come from? Where is the real reality? Would there be a God? There are affirmations: It makes so much sense. Finally, there is a scientific explanation for the interconnectedness of everything. There are accusations: That is absurd: I know I exist. That does not let me control my own destiny. This is impossible to prove.
7. Conclusion

With the culminating reading, students have become fully involved; thinking and talking about the big things. Perhaps, they have seen through their earlier assumptions, and without even knowing what to call it, they now think and talk about classical physics, quantum physics, and the new physics. Then, for the last lecture, this offering:

To understand, means literally to stand under, as we might stand under the stars. Just as we need light to enter our eyes in order to perceive it, we need to stand in reconstructing wavefronts to perceive the hologram’s message. Now we have insight. As we move we gain intelligence. There are more ways to see: more to see. If we can learn to shift our perspective, our angle of view, we may learn that which we have yet to understand. Information is ubiquitous. Intelligence surrounds. Intelligence embodies.

![Figure 7. The diverged beam projects the virtual image of a transmission master. Mo’s Ladder, by the author.](image)