The Physics Teacher

Effectively Illustrating Nature's Magic with Magic

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There is an ongoing challenge with STEM education: making physics, math, and science, in general, interesting, understandable, and retentive for college science and non-science majors, K-12 students, and the public. If not imparting detailed knowledge, at least one would like to introduce important concepts that will be remembered, appreciated, and hopefully would be pursued in more detail by audience members. One solution: as noted by Socrates, "Wisdom begins in wonder." Indeed, magic as a form of wonderment dates back to Socrates and even earlier. One of the first magic books, *The Discoverie of Witchcraft* by Reginald Scot,[1] was published in 1584, predating publication of many science texts. In this paper the author, based on recent research, advocates using *special* forms of magic to both amaze and teach, and in particular to illustrate the wonders of modern physics, i.e., Nature's magic, but with connections also to classical physics.

Past and proposed methods of incorporating magic in science presentations

Here is a summary of some past methods of incorporating magic in STEM education:

A) Use conventional magic (linking rings, cups and balls, cut and restore rope, card predictions, etc.) to first get the attention and interest of the audience. Follow this with explanations of a specific science topic, usually *unrelated* to the magic performed. This typically has been done by amateur or semi-professional magicians who also teach science courses or give science-based public talks.

Problem: Studies[2-7] have shown that magic used in this way, with the possible exception of chemical- or math-based magic, can be counterproductive. Rather than being attentive to the subsequent science being explained, many students or audience members will instead be thinking about the magic and how it was done, basically "tuning out" the remaining lecture. Thus, the science may have minimal long-term retention as, often, the magic doesn't illustrate and reinforce the science being discussed.

B) Present more or less conventional science teaching demonstrations as "magic" (bowling ball pendulum, action-reaction cannon, optical illusions with mirrors, harmonic motion, Ampere's law, hair-raising Van de Graaff demonstration, etc.). Alternately, as pioneered by Martin Gardner and others,[8-10] one can demonstrate a magic trick that utilizes some particular physics principle, using that to get the attention of the audience and introduce a specific physics phenomenon. *The Physics Teacher* has many examples of this, especially as related to optics, E&M, acoustics, and fluids, i.e., mainly classical physics.

Problem: While many of these demonstrations and revelations reinforce scientific concepts or specific phenomena presented in a conventional lecture, many are limited in scope and A/V impact. As noted, they often demonstrate simple classical physics phenomena (kinematics, optics, sound, E&M). Hence, although interesting, they often are limited in the "wonder" factor that is key to retention.[2-7] However, Prof. Clint Sprott at the University of Wisconsin and Paul Hewitt, among others, have developed physics demonstrations, some including magic, intended to invoke audience interest in physics.[11,12] Many of these demonstrations can be effective for use in classroom instruction or public lectures when, as noted, primarily illustrating classical physics.

The approach described here is a *combination* of A and B with important changes:

C) Adopt or develop special magic effects that illustrate primarily modern physics concepts, but not necessarily with the physics as the working basis for the magic. Psychological research using advanced brain imaging and other methods on the use of magic for instruction has shown that magic encourages critical thinking, problem solving, peer-to-peer interaction, and other useful learning skills.[2-7] It also can impart a sense of well-being in participants.[2-7] Also, most of the magic used in A) and B) is of human construct. Nature's magic (i.e., modern physics) is beyond human imagination and far more amazing than humans could develop, with the possible exception of Albert Einstein. As shown in the examples, the magic will not be limited to simple effects and we are not necessarily explaining how the magic works. Hence professional-level magic, including large stage magic, can be utilized for maximum impact.

It has been verified that audience members will better retain scientific material if the magic is embedded as part of the magic presented.[2,3] Hence, the material should illustrate specific and interesting science concepts integrated with the magic presented. Especially, as noted, such a presentation can serve to introduce many aspects of modern physics, "Nature's magic,"[13,14] that may otherwise seem difficult to present. This can generate wonder and appreciation of modern science, but, as will be shown, in many cases important connections to classical physics can also be included. This approach has been used by the author and others[9,10,15] with good success. This includes college lectures to both science and non-science majors, public lectures, and specialized talks, e.g., banquet talks and AAPT presentations. At the University of Michigan-Ann Arbor, magic also is used as part of a highly successful high school summer camp program developed by the author and colleagues.[16] This session typically is fully enrolled, usually has a wait list, and often also attracts teachers to sit in. Likewise, college classes at other schools employing magic effec-

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tively are usually in high demand, especially among non-science majors.[15]

Once students are motivated, they often will read assigned material not covered in detail in lectures more readily, so that the lecture time needed for the magic can be accommodated. Some students may then often be interested in learning magic and, as noted, that can be beneficial in developing good learning skills and a sense of well-being. Likewise, successful teaching often involves an instructor who is interested in the course material and in preparing good lectures. Incorporating magic in lectures can help with that goal.

Some examples of appropriate science-related magic

Background information

As noted, to be most effective the magic performed should have some direct link to the science being presented and illustrate the science in a memorable fashion. This often can be done by adopting or modifying well-known magic routines to introduce specific science topics or by using standard magic techniques to develop new science-related effects. This includes the use of "forcing" techniques (e.g., employing a forcing card deck, gimmicked dice, Svengali deck or pad, special book tests, magic squares, etc.), use of magician's choice and multiple outs, levitation techniques, vanish and production methods, optical illusions, sleight of hand, handcuff and other escapes, mentalism techniques, and other well-known methods.[9,10,17-22] Many of these are based on stage magic used by famous vaudeville magicians.[23,24] Again, the object is to use special magic illustrating science concepts to generate wonder, produce long-term retention, and inspire audience members to pursue the topics introduced in more detail, including, if students, more detailed course material, homework problems, etc.

As indicated, the method proposed here is different than revelation methods that explain the physics behind a particular trick or demonstration.[8-12] Instead, we generally don't explain the methods employed but instead leave that as a challenge for the audience. As noted, using magic in lectures can make these fun and interesting for the instructor, especially if some of the magic is changed from year to year, so new effects are learned and added as appropriate.

Some examples of the magic the author has adopted or developed are demonstrated in a public-lecture video as part of the highly successful *Saturday Morning Physics* public lecture series for the public at the University of Michigan-Ann Arbor.[13] This YouTube series includes lectures on a wide range of topics in modern physics and science.

In many cases minor but important changes in a standard magic routine can be made to introduce a specific physics topic. In other cases, well-known techniques, as noted for example forcing a specific card or number, levitation using magnets or thread and other methods, use of optical illusions, and employing gimmicked apparatus (handcuffs, liquid pitcher, vanish box, magic slate, marked or "forcing" cards, gimmicked dice, etc.), are utilized. These and other basic methods can usually be adopted to develop new, science-related magic routines.[13,14]

As a member of a magic society, the author has taken a pledge not to reveal in detail the magic techniques employed, especially if using commercial magic, to non-magicians. But most of the techniques, methods, routines, and apparatus discussed here are described in standard reference books,[17-24] DVDs, online sources, or are otherwise available commercially. The latter include instructional videos that can be purchased from various magic suppliers[25-34] or are available online for purchase and download. Another useful resource includes members of local chapters of national magic societies (below), who usually will be quite willing to share information. In addition, they often have swap meets where gently used magic apparatus, DVDs, and books can be purchased at modest cost. A local magic store of

Table I. Examples of physics topics and related magic physics topic-related magic.

Gravity and the forces of Nature	Levitation effects; happy/sad ball drop; Van de Graaff levitation; magnetic globe levitation; floating ball (Fig.1); eddy current magic (drop tube)
Quarks and the Standard Model	Six card prediction matrix; gimmicked dice; magic slate prediction effect (Fig.3); math magic (e.g., magic squares)
Particle-wave duality and QM	Needle through balloon (Fig. 4); card frame penetration; selected card transpositions; handcuff and other escapes; gimmicked guillotine
Nuclear reactions and transmutations	Clock and color-changing chemical magic; color-changing silks; index of refraction matching and vanish
Nuclear decay	Chemical clock reactions (various lifetimes); math-based magic; barrier penetration effects
Handiness, chirality, and stereo isomers	Polarized light magic; twisted arm illusion; related optical illusions
$E=mc^2$; matter-antimatter	Vanish box and flash paper; other vanishing effects
Time dilation and the twin paradox	Time predictions and magic (gimmicked watches and clocks; chemical clock reactions)
Equivalence principle, bending of light, and gravitational lensing	Limp/stiff rope; optical magic (modified lenses or mirrors)
E&M waves; electricity in brain and body	Mind reading and mentalism; electronics-based magic; book tests; remote vision effects
Phase transitions	Gimmicked liquid pitcher; chemical clock and color-changing reactions or effects
Scientific observations	Optical illusions; floating head illusion
Most topics	Book tests with relevant books; modified card magic; mentalism; and ... ??

course is another good resource. In some cases, special apparatus can be custom built by commercial vendors.[25-28] This is especially useful if non-gimmicked, duplicate apparatus is also used (see below). A college, high school, DIY public, or home workshop can often be utilized to build apparatus from plans readily available from various books and other sources.[25]

Some specific examples

The introductory material

When the author introduces himself for the first time to an audience (students or public), it is stated that the author may at times assume the role of a magician, "The Great Frederico," and as a magician may lie, cheat, deceive, and for example use secret collaborators in the audience. Alternately, the author may at other times be presenting material as a well-respected physics professor, hence will tell the truth, never deceive, and always acknowledge any collaborators. The audience is then challenged to decide which persona is appropriate at a given time during the presentation.[13]

Likewise, the primary difference between magicians and scientists is noted before a public lecture: magicians know what they are doing, i.e., the outcome of a magic effect is known, for example appearing to saw an assistant in half. In contrast, scientists do experiments with often unknown or surprising outcomes, the latter often welcomed as they can represent new discoveries.

Table I lists a few examples of the physics topics and related magic one can use in a lecture. Several of the examples are demonstrated in one of the author's talks for the general public.[13] Suitable video clips from that presentation are used in several of the figures shown here. Table I includes only a small selection of various science-related magic that has been developed (or adopted) and used by the author and colleagues in various presentations. More examples are discussed in the extended version of the paper and other material posted as a supplement online.[14]

Once the basic premise is accepted, i.e., that the magic should illustrate the science to be presented, it usually is obvious if a particular magic effect or technique can be adopted for this purpose.

Levitation and the basic forces of Nature

In Fig. 1 we show a standard levitation effect, a floating ball that can be manipulated to do some amazing movements. In any case there are many levitation effects that can be done. All can be used to introduce the forces of Nature and the fact that gravity is by far the weakest of these, hence it's easy to levitate objects. This can then lead to a discussion of Galileo's free-fall experiments and the strange nature of gravity, i.e., acceleration of an object independent of its mass. What is limit as mass goes to zero,[13] i.e., does light fall due to gravity?? So, is gravity a conventional force??

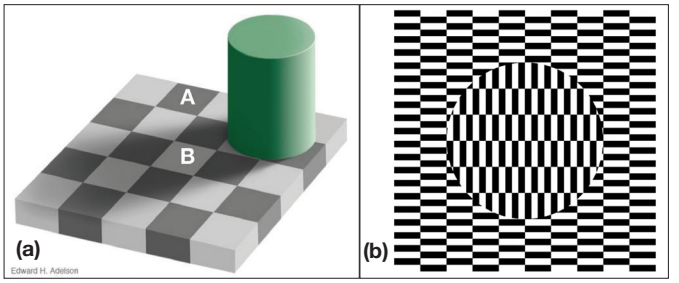

Fig. 2. (a) Adelson's checker illusion and (b) the Ochi illusion. Squares A and B in (a) are the same shade of grey, and nothing of course is actually moving in the Ochi illusion. CAUTION: Don't look at these if such illusions cause vision and other problems.

Seeing is believing??

There are many interesting optical illusions[35-37] that can be linked to science. In particular, how reliable are human observations? As seen in the illusions shown in Fig. 2 and Refs.13 and 14, one cannot always trust what one "sees" or is reported seen by others. There are many examples of false discoveries in science, including the infamous case of N-rays.[38] The debunking of that discovery, although it had been supposedly verified by others, led to the disgrace and eventual suicide of the scientist who had first claimed the discovery. The lesson: scientists must use instruments for observations, and these

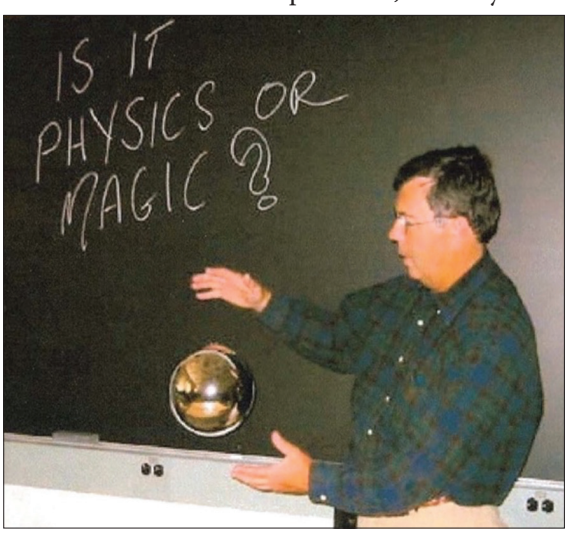

Fig. 1. Author demonstrates floating ball illusion illustrating the weak nature of gravity.

Fig. 3. Audience or student selected quark combinations and author's Σ+ prediction (uus=usu= Σ+; Table II).

Table II. Some elementary particles and their 3-quark constituents

Particle	Quarks [a]	Charge (e)
Neutron	udd	0
Proton	uud	+1
Σ^-	dds	-1
Ξ^-	dss	-1
Ξ^0	uss	0
Σ^+	uus	+1

a) u=up quark (charge +2/3 e); d= down quark (charge= -1/3 e); s= strange quark (charge = -1/3 e)

must be carefully calibrated to produce objective, reproducible data independent of a particular human operator.

Quarks and the particle zoo

In Fig. 3 we illustrate a mentalism effect using a gimmicked pad, a variation of Corinda's "slate test"[18] as performed by Max Maven and other contemporary magicians. Spectators select an unseen set of three cards each with a quark marked on the card (up, down, strange, charmed, bottom, top). Magically the chosen cards have been predicted (usu) together with the particle they make, in this case,[13] Σ+. As example, Table II shows some simple three-quark systems suitable for this effect. This is highly effective magic and illustrates the use of professional-level magic without the constraint that the method employed must be based on a specific physics phenomenon. The magic effect serves to illustrate a physics concept, in this case that just a few quarks (and their antiquarks) can make a whole "zoo" of elementary subatomic particles. Amazingly, however, one needs to introduce fractional charges and, even stranger, these have never been observed alone. Another effect, among many possible illustrating this and the Standard Model, utilizes a six-card special matrix (representing the six basic quarks) with a special key embedded in the cards.[13,14]

Particle-wave duality

Particle-wave duality is another aspect of Nature's magic with important practical applications. At the atomic and nuclear level, particles such as electrons, protons, neutrons, alpha particles, etc. can act either as classical particles or as waves with wave-like properties. Just as a beam of laser light will create a diffraction pattern passing through fine powder (e.g., lycopodium), a beam of electrons passing through a thin foil of atoms will create a similar diffraction pattern, thus acting as a wave, as can readily be demonstrated in a lecture with an electron diffraction apparatus. The electron microscope, key in the study of viruses, is another important manifestation of electrons acting as waves. Likewise, subatomic particles acting as waves can penetrate a classically forbidden potential energy barrier, as happens in nuclear decay, e.g., alpha decay.[39,40] Long-lived nuclear decays are one of the main tools for determining the age of objects, such as Earth (4.5 billion years old[39,40]).

The needle through balloon effect is a good illustration of this (Fig. 4), by claiming that the needle represents a subatomic particle that can be either a classical particle or a wave, and if a wave, it can penetrate the balloon material (the barrier analog) without breaking it as is demonstrated. But surprisingly, it then acts as a classical particle and bursts the balloon with good A/V impact when an audience member tries it. (The balloon is secretly turned to a thinner section on the side of the balloon.) Penetration effects using a card in a frame, sword through neck apparatus, rope through body, and similar magic can also be adapted for this. This can lead to a discussion of electrons moving in solids as waves, the advent of solid-state electronics, and all the practical applications (computers, cell phones, GPS, etc.). Likewise, penetration effects as noted can serve to illustrate long-lived nuclear decay and the use of such decay to determine the age of geological and archaeological formations, human and animal remains (e.g., dinosaurs), dating the time scale and forms of human evolution, the path of human migrations, and dating other important, interesting events.[39,40]

Fig. 4. Needle through balloon effect illustrating particle-wave duality and quantum barrier penetration as a wave, e.g., alpha decay and solid-state electronics. Needle magically then becomes a "particle" (solid needle) when a spectator tries the effect (on sides) and bursts the balloon.

Enhancing the magic for wonder and retention

The above are only a few illustrative examples employing magic to effectively illustrate Nature's magic, with a few additional examples given in Table I, in the related video,[13] and in the supplementary material.[14]

Most effects are more effective if a "swap out" method is used to reinforce the magic, making the magic even more puzzling.[14] This hopefully keeps the audience engaged well *after* the presentation ("How did he/she do that?"), thus increasing the "wonder" factor. This is done by using duplicate props, one gimmicked, one not. It can include some custom props made by magic equipment suppliers,[25-28] or modifications

made to a standard gimmicked prop, by removing or making inoperable the gimmick portion of the prop. As example, one can alter a gimmicked pitcher so it's an identical appearing but now normal pitcher that can be used and then swapped out to be later casually left out for inspection. Likewise, one can have two sets of books for book tests, one gimmicked with an answer key, another normal, and similarly for gimmicked card decks, modified Rubik's cubes, and other props.[17-22] Students and audience members, many at times in groups of several people, will often come up after a lecture to inspect any props casually left out. But of course, the props left out will appear to be normal, which they are, making the previous magic even more amazing and memorable.

Science of Magic Association (SoMA)[41]

Related to the topic of this paper, a special magic society has been created (SoMA) consisting of magicians, neurologists, psychologists, and other scientists dedicated to studying how magicians (and Nature) deceive human observers. In the case of magicians, what are the most effective moves to divert the attention of the audience, e.g., as measured by eye-tracking studies.[4] A classic example of this is the gorilla in the room[42] and related tests, where most observers will not report seeing a "gorilla" come and go into a room of people![4,42] Likewise, how reliable then are eyewitnesses, for example at a crime scene where eyewitness identification can be a matter of life or death (and has been) for those accused of a serious crime?

Other magic societies and resources

In addition to SoMA, there are two major magic societies that can provide many resources needed for incorporating magic in instructional material. The primary U.S.-based group is the Society of American Magicians (SAM),[43] whose first president was Houdini. The other major group, which is a large worldwide association, is the International Brotherhood of Magicians (IBM).[44] SAM in particular has many local chapters, and members of those chapters can provide resources and advice as needed to develop and critique science-related magic developed.

As noted, additional material from the author can be found in the online supplementary material for this paper.[14] Likewise, there are many online websites that offer discussion groups related to magic. A public encyclopedic website devoted to magic with extensive historical and other information, MagicPedia (http://geniimagazine.com/wiki/index.php/Main_Page), is a good resource for magic-related material.[45] Most magic effects and science topics mentioned in this paper are described in more detail on the internet and in particular in Wikipedia and MagicPedia,[45] and an extensive compendium of "book test" methods used for mentalism and remote vision effects has recently been published.[46] Fortunately, some brick-and-mortar magic shops still exist and are usually run by magicians anxious to help others. Finally, the author may be contacted to provide more details and other information about specific magic effects.

Conclusions

Modern psychological research supporting the author's and others' anecdotal evidence suggests that employing specially developed or modified science-related magic to introduce an audience to modern science, i.e., Nature's magic, can be very effective. In addition, it can make teaching science more engaging and interesting for instructors, an important factor for effective teaching. Nature is magical, but like all magic once the secrets are revealed, it may no longer be as magical but still very amazing and a source of wonder.

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