

# Optical Demonstrations through Science Fairs

G. Groot Gregory<sup>\*ad</sup>, David P. Biss<sup>bd</sup>, Barbara Darnell<sup>cd</sup>

<sup>a</sup>Optical Research Associates, 1800 West Park Drive, Westborough, MA, 01581; <sup>b</sup>Physical Sciences Inc., 20 New England Business Center, Andover, MA 01810-1077; <sup>c</sup>ScinTech, PO Box 381954, Cambridge, MA, 02238; <sup>d</sup>New England Section of the Optical Society of America, 296 Lake Ave, Newton, MA 02461

## ABSTRACT

The New England Section of the Optical Society of America (NES/OSA), founded in 1949, provides programming for the promotion of science and optics education. In recent years, the NES/OSA has combined funding to provide demonstrations during the Massachusetts Science Fairs for Middle and High School age groups and award prizes to the winners. This funding is supplied from the Section's operating budget, along with grants from the Optical Society of America (OSA). NES/OSA attends two annual science fairs comprised of the statewide finalists from 6 regional competitions. During these fairs, NES/OSA members conduct optics demonstrations using the Section's "Optics Suitcases". This talk will outline the NES/OSA's outreach program, some of the demonstrations and results.

**Keywords:** Optics Education, Outreach

## 1. INTRODUCTION

The NES/OSA was official installed<sup>1</sup> on May 5, 1949 as a local section of the Optical Society of America (OSA), operating independently of the OSA as a Massachusetts non-profit corporation. The organization provides programming for members through monthly technical meetings, job postings and networking activities. The NES/OSA also devotes funds and member time to promote science. Over the history of the NES/OSA, scholarships have been provided to area students, grants have been provided to local high school teachers for optics class room education and members have conducted demonstrations of optics and lecture programs. Each of these efforts has faced challenges to their overall sustainability.

### 1.1 Suitcase Lecture Kit

In the Early 1970's, Mark Kahan of ITEK and Stephan Benton of Polaroid led the development of a series of classroom optical demonstrations to be used by the NES/OSA membership for student outreach. Many NES/OSA members participated in the efforts, especially Bill Striker and Dick Tuft, who made significant contributions. The NES/OSA also invited local university professors and students to help create demonstrations. Some students were able to obtain course credits for their efforts. The materials used for these demonstrations are comprised of optical equipment begged, borrowed and donated to the endeavor. At its height, up to 150 lectures per year were given with the Suitcases, and the "Speakers' Bureau" had about 50 active members. These lectures continue but on a reduced basis due to restrictions on access to classrooms in these security-conscious times. Training sessions are conducted to introduce the materials to members interested in performing outreach activities.

Other programs assisting education included scholarships, grants and dinners. For several years, the NES/OSA awarded a scholarship to a local student studying optics in New England. In the late 90s, this program gave way to a grants program as the number of scholarship applicants dwindled. Grants were given to area K-12 teachers to support classroom demonstrations of optics. Over the years, several teachers received awards for programs ranging from working with color to building lasers. These awards were presented during a member/teacher dinner with a specially selected dinner speaker. With the rise of national and state standards that did not include optics, we were forced to discontinue these programs.

\* [groot@opticalres.com](mailto:groot@opticalres.com); [nesosa@nesosa.org](mailto:nesosa@nesosa.org); phone 1 508-870-6500; fax 1 508-870-6504; [www.opticalres.com](http://www.opticalres.com); [www.nesosa.org](http://www.nesosa.org)

## 1.2 Science Fairs

The NES/OSA's Scholarship chairs who oversaw the student scholarship program and then grants program quickly identified an opportunity to repurpose the Suitcases for demonstrations at Science Fairs. The contacts gained from the teacher grants program led the NES/OSA to the organizers of the Massachusetts Science Fairs. Approximately ten years ago, a small donation by the NES/OSA to the science fair overhead and prize money garnered the NES/OSA an invitation to participate in the fair with demonstration space within the building of the state-wide High School Fair which was held at MIT. In the first few years, we were often hidden from the main activities, but we were slowly moved closer to the students, parents and teachers as the popularity of the demonstrations increased. In 2003, we attended the statewide Middle School fair and became the sole sponsor for the monetary prizes. In the past few years, both events have introduced an Expo for fair sponsors to share information about their organizations and provide prime real estate for the NES/OSA to conduct its demonstrations.

The following sections will cover our basic outreach activity. "Optical Suitcases" will outline the NES/OSA's demonstration resources and "Popular Demonstrations" will describe some of the common demonstrations. "Funding" will list the sources for our monetary support for science fairs. We will describe the next steps in our program plan in the section titled "Further Outreach Efforts" and list our metrics for success. The last section will provide some concluding remarks.

## 2. OPTICAL SUITCASES

The NES/OSA Suitcases form the core of our exhibit. The contents have not changed in several years but have been augmented with additional demonstrations provided by members. Four cases of approximately 50 cubic feet hold the bulk of the equipment. Each is lined with foam so the cases can be shipped; they are also used for an SPIE Short Course taught by Mark Kahan entitled "Introduction to Optics for Non-Optical Engineers".

### 2.1 Historic Suitcase Contents

Contents of Case 1 include:

- A chess-set transmission hologram
- Two bottles of water, each containing diatomaceous earth (to scatter a laser beam when transmitted through)
- Lenticular displays
- Flashlight
- Instructional materials on demo's that can be run using various pieces of equipment (e.g. via overhead projector, etc.)
- Overheads displaying real-world cases where the effects of refraction & diffraction can be readily observed
- Moiré pattern demonstration materials
- Photonics demonstrations: demonstration of room-light blinking due to A/C current, rewired TV remote controllers to allow viewing 24 bit/sec signals sent to TV, a PC-fan rigged through a rheostat used to chop a laser beam and hear changes in pitch, an amplified speaker with both sound & LED output
- Misc. laser pointers, spare LEDs, salt/pepper
- Polaroid/overhead pieces (1" squares to hand out)

Case 2 includes:

- Broken HeNe laser with a removable cover which allows the pumping cavity to be seen
- Large magnifier
- Light table
- Reflected light "trap" (1/4-wave plate/linear analyzer sandwich)

- Overheads displaying birefringence via scotch tape montages
- Polarizer sheets and analyzer sheets
- Vectograph of moon-rocks and viewer (seen as 3-D via parallax & polarization)
- Plastic squeeze-bar which can be used to show isoclines & isochromatics
- Stereograms and a stereogram viewer
- Fiber-optic cable (thin, long)
- Half-wave plate
- Glass ruled-grating
- CD disk
- Optical bench for a laser
- American Optical demo case containing a beam multiplier, pinholes, mounts, front surface mirrors, a "water bath" (small aquarium with black-back), plastic positive and negative lenses, and photodetector

Case 3 includes:

- Laser with rail mount
- Power supply for the laser
- Spare laser

Case 4 includes:

- Fiber bundles (horse-hair, fiberoptic card reader head, pig-tails, etc.)
- Long-filament ( $\approx 6''$ ) Tungsten bulb
- Corner-cube
- 20X beam expander
- Fiber-optic faceplate

## 2.2 Recent Additions to Demonstrations Materials

- Hands on Optics Mini Kit supporting Magnification and Ultraviolet light modules
- Hands on Optics "*Hit the Target*" Laser Kit
- Various laser levels and pointers
- "Jello Optics" templates
- Diffractive Optics<sup>2</sup> Samples
- Mirascope
- LED based laser communications demonstration<sup>3</sup>

## 3. POPULAR DEMONSTRATIONS

We have found that we need to have a diverse set of demonstrations to attract and capture the attention of the diverse audience. In most cases, we provide an optical concept and then provide a context that is familiar to the individuals participating in the demonstration.

### 3.1 Corner Cube

A simple demonstration uses a corner cube retroreflector. A palm-sized corner cube is held at eye level facing a group of students who have not decided that they want to engage in the demonstrations. The students are asked, “Whose eye do you see and how do I know it is an eye?” This works best with 3 – 5 students so each one can easily see the input face of the corner cube. Their initial guess may include the eye of the friend next to them, with further observations beginning to identify the frame of their own glasses or lack thereof. The demonstrator may suggest covering one eye and evaluate what they see. Quickly the students will realize that they are viewing their own eye. The demonstrator will explain that the corner cube will always cause an incoming ray to be reflected 3 times and back in the direction from which it came. At the end of the demonstration, students are asked where this device is used and it is explained that this phenomena occurs often in everyday life such as with bike reflectors and roadway markers. This completes the demonstration’s goal of relating the concept to a known context.

### 3.2 Giant Kaleidoscope

Kaleidoscopes are well known to many students and parents, but we were inspired by Doug Goodman to build a big one. Doug has built large kaleidoscopes from dressing mirrors obtained from home stores that can be quickly taped together. The NES/OSA added a marketing flair by enclosing the mirrors in a jeweled tube, thus creating a bedazzled kaleidoscope, which attracts a lot of attention from young children.

The kaleidoscope was constructed from a 9 inch diameter, 4 foot long cardboard tube with three mirrors cut to length and width. The width(W) of the mirrors is calculated from the Law of Sines knowing the inner tube diameter (2R) and the angle (A) between each mirror such that

$$2R = \frac{W}{\sin(A)} \quad (1)$$

An eyepiece was made from a spring form cake pan with a hole in the base and another cake pan is used to hold colored beads/foils as target for the kaleidoscope image. Painting the tube and gluing plastic jewels complete the presentation. The tube can be mounted in a stand made of polyvinyl chloride (PVC) plumbing pipe.



Figure 1 Kaleidoscope used at both ends.

We allow the kaleidoscope to violate the Concept/Context rule since it is just plain fun for parents and kids. We also will remove the eyepiece and target (Figure 1) to allow folks to look at each other from both ends. Removing the target and replacing it with a parent's face frequently results in gasps and is entertaining to both ends. We also encourage parents to take photos of their multi-faced (Figure 2) children so the participants have something to remember the experience.



Figure 2 Kadeiscope image of one of the co-authors

### 3.3 Gelatin (Jello™) Optics

Optical components are useful to illustrate basic optical concepts, and with ‘Jello Optics’ we generate a method to demonstrate basic concepts of refraction with a medium that is very engaging to young students. Lenses, lightpipes, and prisms can be easily cut from a sheet of Gelatin. The Gelatin also scatters light so a laser beam is visible as it passes through the material allowing students to see the path that theoretical (or in this case very real) rays would take through an optic. We use a double concentration of Knox which holds up well at room temperature. Gelatin is fun to handle by the audience so making extra is recommended as the optical components do not last long under probing, poking and bending, even at double strength. It is also useful to point out that the Gelatin does not contain any sugar, so it won’t taste very good.

The refractive index can be measured with a laser line and a template. Refractive angles for a given input angle, optical shape and index values are pre-calculated and printed onto a template. The lens is cut from a block of gelatin with a sharp knife for the plano side and a piece of sharpened aluminum roof flashing bent to match the radius of the convex side. The index can be read off the scale on the right side. Two or more batches of gelatin can be prepared with and without sugar to adjust the refractive index so different measurements can be made. Figure 3 shows the set up for this demonstration. The measurement and concept of index of refraction can then be related to the concept of eye-glasses, microscopes, telescopes and camera lenses, although fewer students are familiar with cameras not enclosed in their cell phone.

Light pipes and prisms can also be cut from gelatin to show Total Internal Reflection (TIR). A laser beam can be directed toward a prism so the beam passes through the material and then tilted to achieve the critical angle causing the beam to be captured by TIR. This makes a fun hands-on activity. Similar demonstrations can be made with long strips of gelatin as shown in Figure 4. Fiber optics and modern telecommunications are good context for these illustrations.

With additional preparation (a few days before the demonstration), a high sugar concentration of gelatin can be prepared and molded in a cylindrical tube to demonstrate an index gradient material. After the gelatin rod is formed, the rod is submerged in a bath of water to leech out the sugar near the surface of the rod giving a radial index gradient. Laser light will then be seen to bend within the gradient rod similar to rod lens used in photocopy machines. This is another good addition to the TIR demonstration.

We recently added gelatin to our polarization demonstration as gelatin easily exhibits form and stress birefringence.

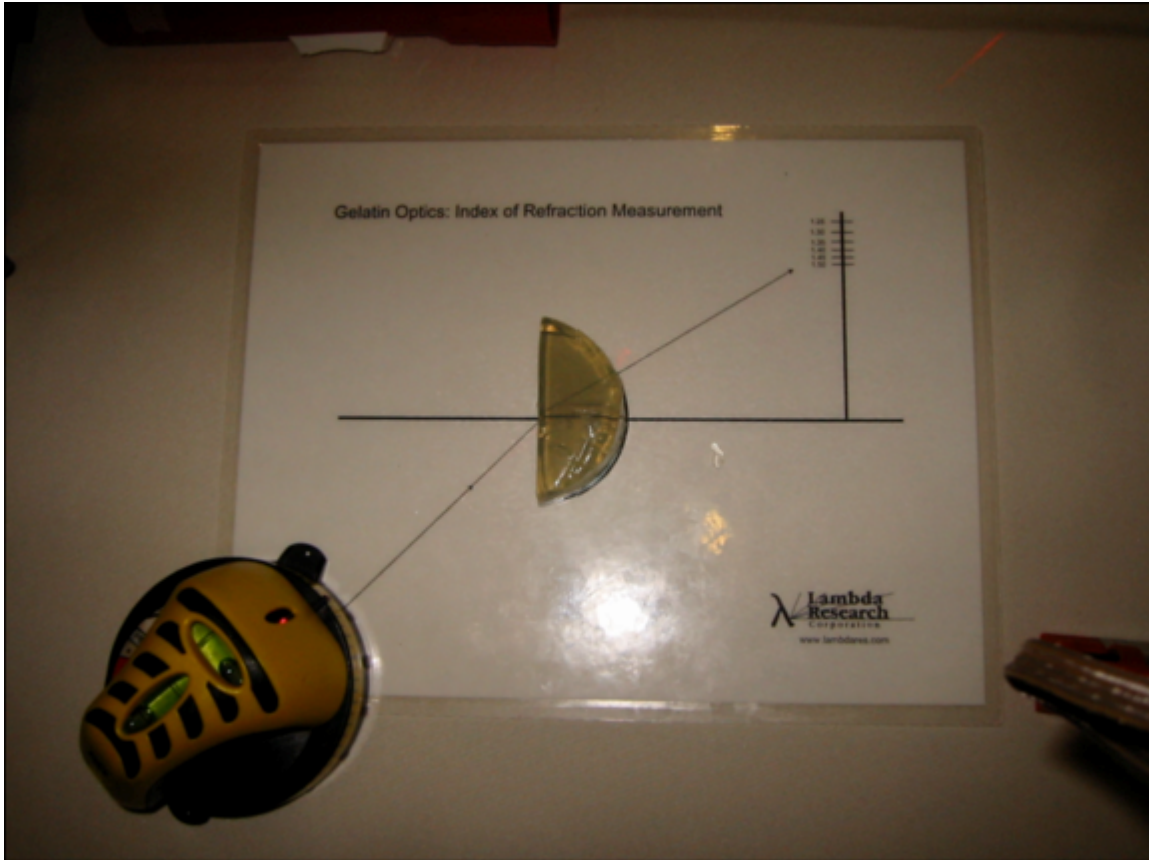


Figure 3 Refractive index template with Gelatin Lens

### 3.4 Polarization on a Light table

Polarization is a difficult concept to understand, but there are many common applications that allow us to affectively include this into our common suite of demonstrations. In general we will setup either a light table or overhead projector with two crossed polarizers. A demonstration may begin showing that light passes through an individual polarizer and then show the extinction as a second polarizer is turned to be crossed with the first. Rotating a polarizer over a laptop or cell phone screen also shows extinction to provide the initial context for the demonstration. Once the polarizers are crossed on the light table, a plastic squeeze bar can be inserted between the two and stressed. With no stress the plastic has no optical activity and the light is blocked when passing through the crossed polarizers. When stressed the plastic becomes birefringent and a varying polarization retardance will allow light to escape through the crossed polarizers. This action can be equated to the behavior of Liquid Crystals (LC) in a liquid crystal display (LCD). The backlight and LCD pixels are described and the student is introduced to the technology behind the common devices to many phones, computers and televisions.

Plastic tape is another material exhibiting birefringence. Figure 5 shows various layers of tape on viewgraph sheets where color can be used to show how birefringence is wavelength dependent. As an observer moves their head to different viewing heights and angles the color will change improving the demonstration. Often students will recall seeing odd patterns in window glass while wearing polarizing sunglasses, causing an exciting “Aha” moment.



Figure 4 Co-author demonstrating Total Internal Reflection in Gelatin Lightpipe

As mentioned before, we now place gelatin between the polarizers. Placing a rubber band around a block of gelatin provides the stress needed to show the birefringence. The gelatin and also be pushed and squeezed showing the birefringence affects.

### 3.5 American Optical Demonstration Kit

One of our older components is a demonstration kit from American Optical (AO). Although AO is no longer around it was one of the founding optical companies in the US originally incorporated in Southbridge MA in 1869<sup>4</sup>. The AO kit includes a water tank, lenses, microscope objectives, pinholes and optical rails with a mounted HeNe laser with beam divider. A typical setup will place the water tank on the rails with 5 laser beams passing along the length of the rails. Water with diatomaceous earth is poured into the tank. The diatomaceous earth will cause light passing through the tank to scatter toward the viewer. Milk can also be used but will sour if not cleaned from the tank. Two plastic lenses, one concave and one convex, are placed in the tank causing the laser beams to diverge or converge. These lenses are made of plastic sheets with two curves cut to form the powered element. The lenses look like lens profiles with some thickness similar to the lens shapes cut from gelatin forming a transition to/from the gelatin optics demonstrations.





Figure 5 Birefringence of tape shown between two crossed polarizers on a light table

Optical power is based on a refractive index difference, higher power with a larger difference. The water tank readily shows this concept by measuring the focal length of the beams as they converge from the positive lens in water and then in air. The four times index difference increase causes a similar four times increase in optical power when the focal point goes from 12 inches to 3. This can lead to discussions on underwater goggles and thickness of one's eyeglasses.

#### 4. FUNDING

Educational initiatives use funding from grants and operating surpluses of the NES/OSA. For the past several years, the NES/OSA has matched funds from OSA Local Section Activity Grants up to \$1500. More recently, grants have been obtained from the OSA Foundation and from the SPIE. The SPIE grants have been used to purchase new and updated equipment for the optical suitcase.

As an independent entity, NES/OSA operations rely on member dues from individuals and corporations, along with surpluses from regional technical conferences organized by the NES/OSA. Individual member dues cover most activities of the organization including informing members of activities, mailing and internet costs and corporate filings. Dues from local optics-related businesses provide funds for outreach efforts. Addition support has come from the estate of one member whose wish was to continue the active support of students.

As a section of the OSA, the NES/OSA is eligible to apply for annual Local Section Activity Grants. These grants can be used for various activities, which we typically direct toward outreach. These grants are competitive among all of the sections and are awarded on merit. Each grant application requires that the NES/OSA file an annual report of the

section's activities with the OSA and a report on all past grants received. With the creation of the OSA Foundation, additional funds are available for educational outreach efforts with similar requirements as the Activity grants.

This past year NES/OSA was successful in winning a SPIE Educational Outreach Grant. This grant will be used to update and improve our demonstration materials as well as supporting activities beyond the science fair venues.

## **5. FURTHER OUTREACH EFFORTS**

The NES/OSA continues to improve and increase educational outreach opportunities. Our focus is on slow and sustainable growth that matches the time and interests of our members. In 2009 and 2010, the NES/OSA participated in the Cambridge Science Festival<sup>5</sup> offering optical demonstrations. Both years brought thousands of students and parents to our tables with lines of students waiting to see what we had to offer. We are also working to collaborate with the local universities to include college students in to our efforts; Tufts University students from the OSA student chapter joined us in 2009 at the Cambridge Science Festival. Additional efforts are under way at Boston University.

Suitcase updates are a priority. We have benefited from the legacy of the early work done to produce the Lecture kit, but some equipment is dated and needs replacement. New areas of optical technology also need to be included in our demonstrations.

We also need to improve our own internal promotion of the outreach activities to bring more members into the program. This may be the biggest challenge due to existing time commitments already on our members although we believe there is interest. Further expansion will be limited without new hands to do the demos.

## **6. SUCCESS MEASUREMENTS**

We do not have any formal metrics to measure our successes in these efforts. We have success in winning grants and generating surplus funds to support our outreach efforts. We receive invitations from science fair organizers and festivals to come back to future events. We receive letters from students thanking us for a prize. But we do not know if we have helped produce a new scientist or engineer. Although we have seen anecdotal successes when a student hears about some technology and will explain what they recently learned to a sibling, friend or parent. One example of this is captured in Figure 6. The student pictured had learned about refraction and TIR from one of our members and returned 30 minutes later with his mother and sister to teach them what he had learned.



Figure 6 Student explaining refraction to parent

## 7. CONCLUSIONS

The transition of the section's outreach efforts to science fair demonstrations has reached a sustainable program with an increasing number of members trained and experienced in offering demonstrations. While our focus is on students we believe that we need to include all visitors so we provide the same attention to teachers and parents as supporting actors in the student's life. We try to learn from our own past to manage our goals to slowly increase our outreach efforts. We believe that the program is now ready for some expansion into regional science fairs which we understand and perhaps ready to venture back into the classroom. With the current educational focus on standards, the classroom may mean targeting informal education through science clubs and other after school activities.

## REFERENCES

- <sup>1</sup> "Installation of the New England Section of the Optical Society of America," J. Opt. Soc. Am. **39**, 566-566 (1949)
- <sup>2</sup> <http://www.tessera.com>
- <sup>3</sup> Similar to <http://sci-toys.com/scitoys/scitoys/light/light.html> with LED used in place of laser
- <sup>4</sup> [http://www.antiquespectacles.com/american\\_optical/american\\_optical.htm](http://www.antiquespectacles.com/american_optical/american_optical.htm)
- <sup>5</sup> <http://cambridgesciencefestival.org>