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Homo ludens opticus

The Magic Optical Kit

By Pal Greguss and Erno Rubik
Science education committees all around the world are involved in "kit" projects with the intention to give into the hands of children inexpensive components to explore the world of science on their own. Playing and discovering have common roots: the desire to learn about the natural world and to realize how much more there is to learn. Thus, not only children but also adults love to play, although in general they do not admit this—they call it experimenting.

A good physics teacher is playing when showing experiments, even if the children think he is doing "magic." Yet, at the same time, foundations are being laid for facts about how the laws of physics work. Since optical experiments are not only spectacular but also really have a touch of "magic," perhaps the most rewarding chapter for a teacher is optics, especially in primary and secondary schools. However, even magic cannot be performed without tools, and the "tools" in teaching optics are the optical elements such as lenses, mirrors, gratings, filters, etc.

Giving students optical elements to play around with encourages them to try to explore the world of optics on their own. This was the goal of the Education Council of the Optical Society of America at its Annual Meeting in Seattle, 1986, when they introduced the prototype of an optics kit consisting of a Fresnel lens, three different other lenses, a diffraction grating, three color filters, a flexible mirror, some optical fibers and even one embossed hologram. This inexpensive kit is suitable not only to assist primary and secondary science teachers, but also, if given to students, allows them to get acquainted with the very attractive world of optics on their own.

However, this kit has some scantiness. What happens, for example, if some of the optical elements get lost since they are only in a plastic bag? How does one ensure proper alignment of two or more elements, when the experiment in question needs a specific configuration? The latter problem is well recognized in the booklet accompanying the kit: "If you find it hard to keep the lenses steady, mount the lens in clay . . ."

This paper describes a new optical kit concept where the components can not be lost. Moreover, the concept could also be applied to explore the fundamentals of chemistry, mathematics, biology, etc., and may even provide help in teaching music and arts.

Tiles and hinges

The simplest way not to lose something is to tie it together, i.e., if one does not want to lose the optical elements, one should tie them up. The question is only to where and how. The answer sounds simple: to each other in such a way that their planar and/or spatial relations can be changed according to the configuration needed in a given experiment, e.g., when we wish to demonstrate the difference between a Galilean telescope and a Keplerian telescope.

No matter how simple this idea may sound, its technical realization needs real "magic": the hinge mechanics of Rubik's Magic, and remodelling the tiles of this puzzle so that they can perform like optical elements. As a result, if two of these optical tiles are folded together until their faces touch and then moved apart again, a hinge joint will move from one edge to another. This hinge motion is what enables the optical tiles to change their position and to

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form—through a sequence of similar individual moves—not only plane arrangements of the optical tiles but, if the geometry of the experiment in question needs it, even the most bizarre 3-D configuration. These 3-D configurations (Fig. 1) will be self-supporting structures. Thus, there is no need for any optical bench or special supporting device.

The Magic Optical Kit (MOK)

At present, two basic forms of Rubik's Magic exist: one with 8 and one with 12 tiles. We chose the hinge mechanism of the 12-tile version since we have found that with 12 properly designed optical tiles—each of which may have more than one optical function—practically all of the basic optical experiments included in the high school curriculum can be performed. The folded optical kit occupies as little space as 35 mm × 52 mm × 104 mm, as shown in the left upper part of Fig. 2.

Since all tiles are quadratic and of identical size, the optical elements are designed in such a way that the optical pathlength needed to perform a given experiment could be achieved by appropriately folding and moving these tiles. So, for example, the focal length of lenses are equal or half of the side and/or diagonal of the square-shaped tile.

In the present version of our MOK, the 12 optical tiles have the following optical element functions:

- No. 1 contains a concave lens with the same focal length as the convex lens of No. 12.
- No. 3 and No. 10 are Ronchi-rulings, but one segment of No. 10 may also be used as a blue filter, and its opposite segment as a green filter.
- No. 11 includes two color filters, too: a green and a red one, and in its diagonal segment a diffraction grating is inserted.
- No. 9 has three optical functions: a
yellow filter, holes of various diameter in its diagonal section (which may be used as aperture pinholes), and a transmission hologram that can be reconstructed by a normal flashlight.

- No. 5 and No. 8 are polarizers, but No. 5 has a liquid crystal coated segment for some IR experiments.
- No. 4 is a mirror, the backside of which is a diffusing screen for projection.
- No. 6 is a second convex lens, but its focal length is different from that of the convex lens in No. 12.
- No. 7 is in general a Fresnel-lens, but in the MOK shown here, it is a mosaic of small lenses of identical focal lengths (fly's eye lens).
- No. 2 has a hologram on both sides: a Denisyuk-type white light (reflection) hologram and an embossed hologram.

**Experimenting with MOK**

In reporting on this new optical kit, the elements of which cannot get lost, there is no attempt to show and explain all the optical experiments that can be performed with the MOK. Rather some of the possibilities inherent in this concept for both teachers and students are shown.

The first step in starting an experiment is to unfold the MOK. Depending upon the moves during unfolding, the result will be either a planar or a 3-D configuration that can be considered to be rectangular or ringshaped, depending upon the relative position of the optical tiles to each other, as shown in the lower row of Fig. 2.

To achieve a self-supporting configuration for an optical pathlength needed, several tile-moving strategies can be considered, sometimes resulting in bizarre, unexpected shapes. One challenging feature of MOK is just to find out which is the best moving strategy for the given task. This, however, does not mean that there is only one self-supporting configuration for a specific optical pathlength.

Figure 3 shows the first steps of one of the possible optical tile moving strategies leading, e.g., to the self-supporting configuration of Fig. 4. These configurations are suitable to study the behavior of lenses, mirrors, the laws of image formation, and the functioning of Keplerian and Galilean telescopes, to measure the magnification of magnifiers, to understand the principle of microscopy, etc.

But in several cases, there is no need at all for a 3-D configuration; the planar formation is even more adequate. If, for example, the MOK is folded in such a way that optical tile No. 12 covers No. 1—as shown in Fig. 5—one can learn that if the focal length of a convex and a concave lens is equal, the resulting optical power will be zero. However, the same planar configuration can be used to study moiré effects if No. 10 covers No. 3.

Planar configurations may also be suitable to learn about the laws of color mixing. If No. 9 is folded over No. 10, the blue filter covers the yellow, and this segment of the composite tile becomes green, the same color as its opposite corner shows. While folding No. 10 on No. 11, the blue filter will cover green filter, the red filter covers the green filter, and the experimenter can learn what additive and subtractive color mixing means.

Sometimes both planar and 3-D configurations are needed, as in experiments with polarizers. Folding MOK in such a way that No. 5 covers No. 8 and placing a plastic film between them, the basics of stress analy-
sis can be understood when stretching the plastic film. However, using a ringshaped configuration—similar to that shown in Fig. 2—in which No. 5 and No. 8 are facing each other but with a space between them, and putting glass tubes of various lengths filled with sugar solutions of various concentrations, the basic laws of polarography can be studied.

These few examples demonstrate the many-sided possibilities inherent in MOK. A final example describes an optical experiment the interpretation of which, however, leads to understanding of vision processes. Optical tile No. 9 has pinholes in one of its segments. If one holds this tile as close as possible to one eye so as to be able to look through two of these pinholes, holding a pin at a distance of about 20–30 cm from the tile, one may see two pins instead of one because two retinal images are formed.

**Space in plane**

There are several definitions of a hologram, and one of these is "space in plane," indicating that optical three-dimensionality is coded into a plane surface in such a way that when it is decoded, the original three-dimensionality is reconstructed.

Since some of the tiles of MOK are holograms, we got the idea to create a Magic Holographic Toy (MHT), where the individual tiles are holograms or segments of holograms. The reconstructed image, depending upon the hologram type and reconstruction geometry, may appear to be behind the tile, embedded in its plane, or even in front of it. The hinge mechanism allows the formation of bizarre self-supporting 3-D structures. Thus, games can be designed that, when a given shape is correctly formed, the player will see non-existing objects meeting each other somewhere in space.

A further step in developing this idea led to the creation of a Magic Psychophysical Kit allowing experiments related to stereoscopy, anaglyphs, cyclopean vision,\(^2\) inverted perspective, etc. A detailed description of MHT and MPK will be given later elsewhere. The authors would very much appreciate receiving comments on how to improve MOK, whether 12 tiles are enough or too many, whether some other optical elements should be included or some perhaps omitted or changed, etc., so when making it available to the public (as we hope to in the very near future), it could really help to disseminate optic culture, to educate Homo ludens opticus.

**REFERENCES**