INSPIRING LEARNING ENVIRONMENT THE SCHOOL AS A THREE-DIMENSIONAL TEXTBOOK

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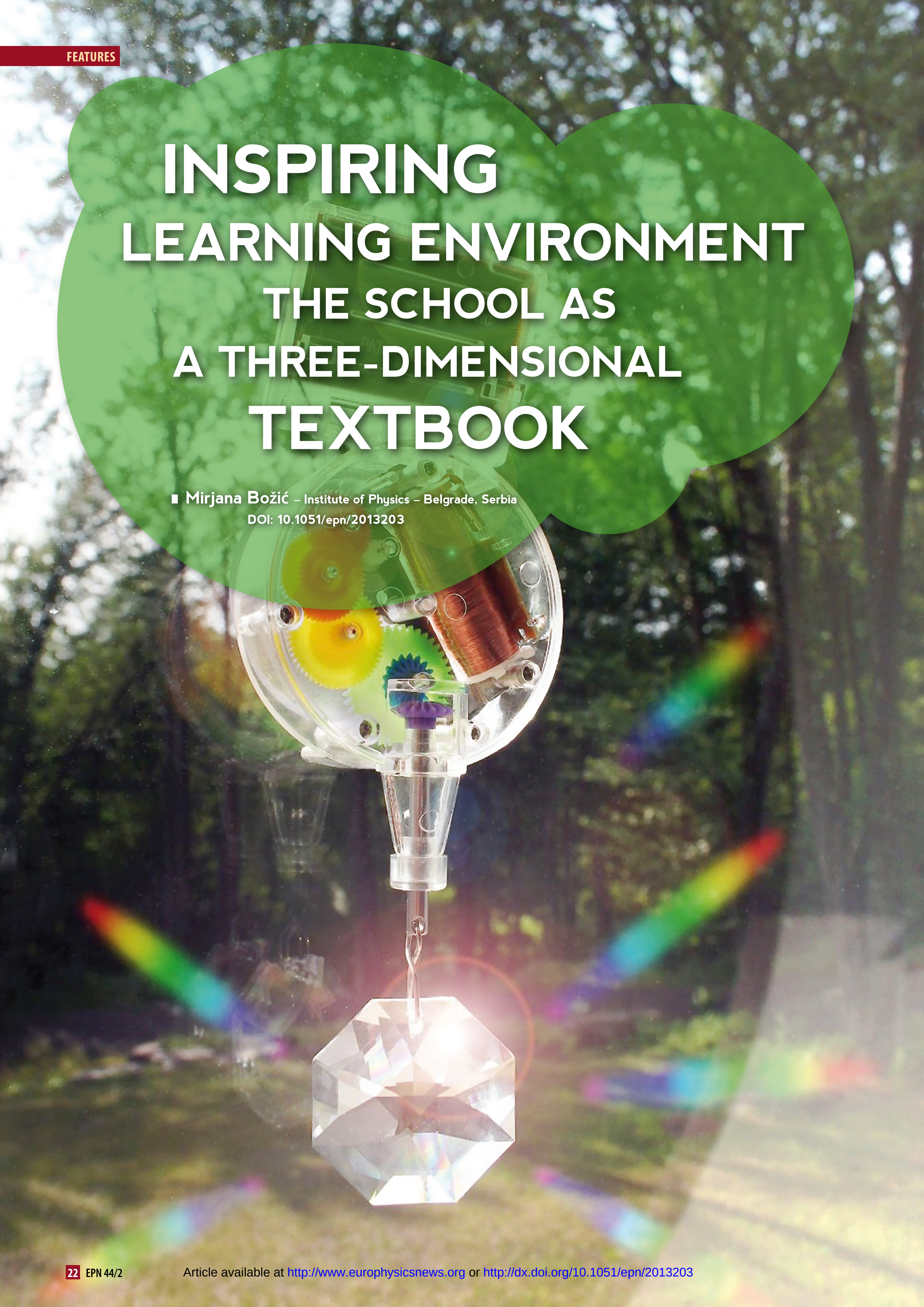

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History teaches us that knowledge about basic natural laws often began with observations of intriguing phenomena in nature. As a next step scientists started to perform measurements in the environment and later in their laboratories. Good physics teaching should provide opportunities for students to repeat the observations and reasoning of great scientists. This requires distribution of equipment over a wider space than just the classroom: think of corridors, courtyards and roofs. Consider the school building and its environment as a 3D lecture book and science lab.

The necessity to extend physics and science teaching beyond the space of the classroom has been identified during the last decades by many educators. For example, the authors of articles in Deck the Halls column in Physics Teacher, published from 1972 to 2001 and collected by Pizzo, proposed many devices for demonstrations along the hallway. The European Physical Society published posters with biographies of famous European physicists to be used in primary and secondary schools throughout Europe. In *Ellinogermaniki agogi* in Athens, installations for science teaching have been distributed all over the building. In 2003 in Graz, at the First Preparatory Conference for the World Year of Physics 2005, the activity "Physics in school architecture" was initiated as a WYP2005-Europe project. Since then, many cognitive installations and didactic patterns for an extended school space have been proposed in the literature and implemented in schools [1-3]. These devices should stimulate observations, induce associations, inspire and support learning of physics, mathematics and natural sciences, and help active teaching.

Let learning environment teach

In parallel to the efforts of the physics community to intertwine physics education and school architecture, the drive to innovate school design to improve the learning environment as a whole, has been developing in many countries. School architects have been arguing that a good learning environment facilitates, enriches and refines learning and creative thinking [4]. In addition, the design of a modern school should meet the requirements in terms of utilization, energy, comfort and sustainability. Such views and goals support the programme promoted by UNICEF to create "Child-friendly schools" all over the world.

In 2004, the UK government initiated the most ambitious programme of school construction since Victorian times - *Building Schools for the Future* (BSF). The goal was that "by 2020, every child in secondary education will be in a fully refurbished or completely rebuilt learning environment, designed to the highest quality, with integrated ICT — the best possible learning environment." This programme turned out to be very complex and expensive, and was interrupted in 2010. Nevertheless, several dozens of new schools were built. Through the Faraday project *Exemplar designs for science* areas in schools were made available to local authorities, building professionals and schools.

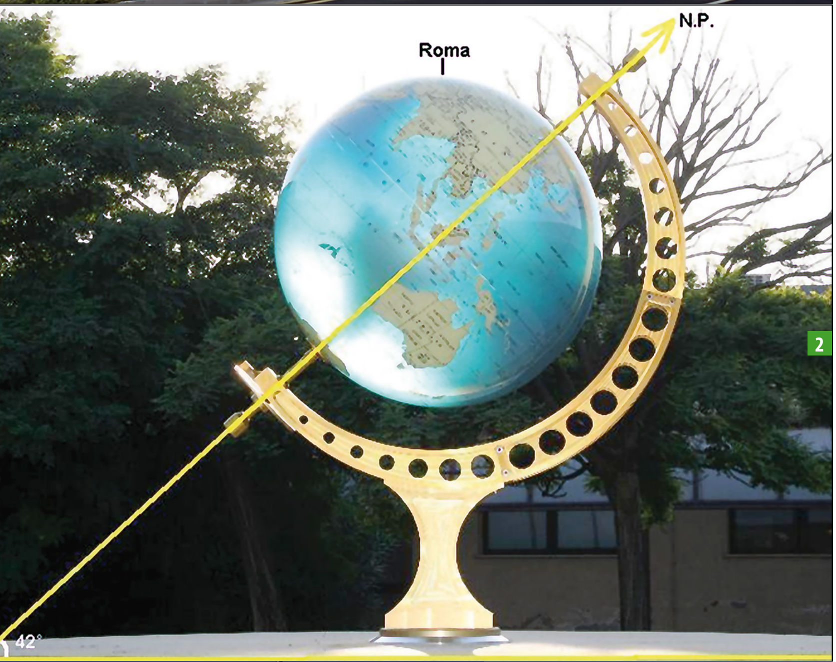
Seeking to improve the quality of America's schools and the communities they serve, the American Architectural Foundation (AAF) has engaged, since 2005, hundreds of superintendents, local government officials and design professionals, as well as parents, teachers, students, and other stakeholders in the programme *Great Schools by Design*.

In April 2006, the Finnish National Board of Education organized the international conference "The school of tomorrow – learning environment, pedagogy and architecture", seeking to answer the question: "How can we create innovative and inspiring learning environments now and in the future, what are the criteria for evaluating school buildings, and what kinds of demands does the fast-developing information technology pose?"

In the answer to the above questions, the emphasis is on flexible, multi-use buildings that combine ecological ideas and sustainability in their energy use. One of the cornerstones is the prioritizing of state-of-the-art information and communications technology (ICT), which is to become an integral part of school environments. Schools should provide the foundation for students to interact, solve problems together and work with teachers. School should also be a place for social interactions, both for children and adults.

In the annual DesignShare Awards programme [4b], conducted since 2000, applicants were asked to follow principles consistent with the requirements described above. This awards programme has attracted designers from all over the world. In 2004 the author of this article wrote to the founder of DesignShare, Randal Fielding, to attract his interest to the idea that building components take the role of teaching tools in physics education. In his answer Fielding coined the term "school building as a three-dimensional textbook of physics". "Sustainable Elements and Building as 3-D Textbook" is one of the design patterns generated later by Fielding and Nair:

◂ Rainbow-maker designed by David Dear exclusively for Kikkerland Design Inc. ©www.kikkerland.com



"In a school setting, sustainable design becomes an excellent teaching tool. It can become a dynamic model to teach architecture, engineering, construction, and environmental science in harmony with nature" [4a].

Designers of the NUS School for Mathematics and Sciences in Singapore, who received the Honor Award in 2006, whole-heartedly accepted the concept of a school as a 3D learning tool. They explored the innovative use of elements abstracted from scientific and mathematical concepts, which are then integrated into the total building form (Fig.1).

At the national summit on Science, Technology, Engineering and Mathematics (STEM) education, organized in 2010 by AAF and the Bill & Melinda Gates Foundation in Washington DC, participants explored how the design process can contribute to the creation of innovative models for STEM school development. *Let the learning environment teach*, was one of the messages from this summit: "In addition to learning from their teachers, parents, other adults, and peers, students learn by interacting with their environment. A thoughtfully designed learning environment—with such design elements as exposed structural components and mechanical systems, meaningful artifacts, preserved ecosystems, and rich landscapes—inspires STEM students and provides vital opportunities for investigation." [5]

From science museum to schools space

In science museums and educational journals one finds many examples that can be used as hands-on experiments at schools and universities, both indoor and outdoor. They allow personal scientific exploration, and transform the school to a 3D lecture book. Here are a few examples.

Day Night Year Globe – DING

The Day Night Globe, designed and created by R. Anati in the Clore Garden of Science [6] in Israel, is the paradigmatic example of a cognitive setup in school yards [1, 3a]. It was devised in 2009 at *Roma Tre* University [3a] (Fig. 2) and named Oriented World Globe (or Parallel Globe). A similar one constructed from concrete at the Center for professional advancement of educators (CSU) in Šabac, Serbia (Fig. 3) was named DING (*Dan I Noć i Godina*

FIG. 1: School for Mathematics and Sciences in Singapore [4a].

FIG. 2: World Globe at *Roma Tre* University. The Globe axis is parallel to Earth's axis and the Globe location (Rome) is at its top.

FIG. 3: DING in Šabac, Serbia. The day-night line lies along the meridian **(left)** during equinox, and makes an angle of 23.5° with the meridian **(right)** during solstice.

FIG. 4: **(left)** The inclined-plane apparatus with bells and pendulum in the Galileo museum in Florence, http://catalogue.museogalileo.it/multimedia/InclinedPlane.html; **(right)** A version of this apparatus with bells along two tracks at an exhibition in the courtyard of the Historical museum of Bern, in 2005/06.

▲ **FIG. 5:** Brachistochrone fall apparatus. The shortest possible travel time is along a cycloid.

Globus - Day Night Year Globe). DING has attracted a lot of interest among students, teachers, citizens and media.

Outdoor and indoor local meridian

Gnomon, with associated local meridian line and other elements, is a multipurpose educational tool for physical geography, astronomy and measurement science [3b, 7]. It was built in the courtyard of the Grammar school in Pančevo, Serbia, by Cucić and his students. The successor of Gnomon, a small hole (the "eye") in the wall or roof and the associated internal local meridian line, like the Great Meridian Line in the *Basilica San Petronio* in Bologna, is a more precise instrument for studying Sun's motion [8]. This instrument yielded the most accurate possible definition of the duration of the tropical year for establishing the Gregorian calendar.

By measuring the diameter of Sun's image projected onto the church floor along the local meridian line, Cassini demonstrated that the Sun's apparent diameter decreases as its distance from Earth increases. This showed that the apparent uniformity of the solar motion is not uniform at all. It represents the first observational confirmation of Kepler's Second Law [8].

In Serbia we are looking for an appropriate school building in which the internal meridian would be devised. This important astronomical instrument would ease the teaching of Kepler's laws by providing appropriate observations. In traditional courses, these laws are just formulated without giving students any idea about how the laws were established and verified.

Inclined plane

The inclined-plane apparatus in the Galileo museum in Florence (Fig. 4), devised to provide an experimental demonstration of the Galilean law of falling bodies, is very suitable for implementation along school staircases. Small bells are placed along the plane at increasing distances, arranged in the sequence of odd numbers. The underlying physics is that, for motion with constant acceleration, the distances covered during consecutive equal time intervals ($(n\text{-}1)\Delta t$, $n\ \Delta t$) are proportional to $2n\text{-}1$. A pendulum is attached to the top of the plane. When releasing a small ball from the top of the plane while swinging the pendulum one observes and hears that at each successive half oscillation of the pendulum, the ball strikes one of the small bells.

Brachistochrone fall apparatus

Inspired by the brachistochrone (from Greek βραχιστος, shortest, and χρονος, time) fall apparatus in the Galileo museum in Florence, the student Zindović in the Mathematical grammar school in Belgrade constructed a similar one for his baccalaureate exam (Fig. 5). The device consists of a wooden frame with a cycloidal channel and a straight channel. When releasing two balls simultaneously down the two channels, one observes that the ball falling down the arc of the cycloid reaches the bottom first, despite the fact that its path is longer.

Educational fountain

The fountain erected recently at the CSU in Šabac (Serbia) shows a pattern of jets flowing from holes in a vertical tube with a constant water level H (Fig. 6). The fountain is very useful for active teaching of many topics: projectile motion, the law of hydrostatic pressure, Bernoulli's equation, the equation of a parabola, the maximum of the quadratic polynomial function, the roots of quadratic equation, history of physics…

This pattern was first found theoretically by Torricelli around 1640. The horizontal distance reached by such a water jet depends on the exit velocity *and* on the time of flight. It follows that the range is maximum (equal to H) for a water jet emerging from a hole at half the height of the water column. Jets from two holes at the same distance from the middle hole are found to have the same range. At the beginning of XX century an erroneous pattern started to appear in physics and science textbooks, persisting even in some XXI-century textbooks, as described and commented by Slisko [9]. This erroneous pattern is based on the intuitive argument "bigger spouting speed – longer horizontal range".

▼ **FIG. 6:** Torricelli's tube as an educational fountain in Šabac, Serbia. Note that the water jet emerging from a hole at half the height of the water column reaches the maximum range (see text). Dozens of new installations are currently under construction in the courtyard of CSU Šabac, thanks to the eagerness of its director G. Stojićević and physics teacher T.M. Topalović, and a grant of the Swiss agency for cooperation and development.

School development plan

The staff of the primary school "Djordje Krstić" in Belgrade accepted a proposal of their physics teacher Lj. Ivančević to base the new four-year school development plan on the concept of a school as a 3D textbook. Teachers, students, their parents, school and local authorities have been involved. As an illustration of students' involvement, on a wall showing EPS posters with biographies of famous European physics, students drew charged clouds and lightnings as a symbol of "thought flashes". The uranium decay series is shown on the wall along a staircase. Wire models of a square meter, a square decimeter and a square centimeter in the corridor should help students to more easily memorize these units. Four *matryoschka* dolls on the wall along the staircase, sized as 8:4:2:1, should familiarize students with concepts like similarity of geometrical bodies, scaling and proportions.

In the library, students can observe a LED color mixer through holographic glasses (Fig. 7). This color mixer was inspired by Planinšić's ping pong color mixer, in which a ping pong ball encloses three light emitting diodes.

A set of devices for observing optical phenomena using sunlight were displayed at the window. Examples include a moving rainbow maker, a water tank with a stick to observe refraction of light, a piece of dark paper with a hole to observe Sun's daily motion on the celestial sphere, two dark paper sheets forming a slit to observe diffraction, *etc.*

Conclusion

The concept of a school as a 3D text book of physics has attracted educators, students, architects, school authorities and funding agencies from many countries. We hope that the experience acquired will be useful for further implementation of this concept in existing schools as well as in designing new schools. ■

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About the Author

Mirjana Božić is research professor in the Institute of Physics in Belgrade, full professor in quantum optics at the Physics Faculty, University of Belgrade and visiting professor at the Old Dominion University in Norfolk, USA. Her research has been in the foundations of quantum mechanics, particularly on the interpretation of quantum interference experiments and physical nature of spin. In the field of physics education she has been developing and implementing, with physics teachers and architects, the concept of school as a 3D lecture book.

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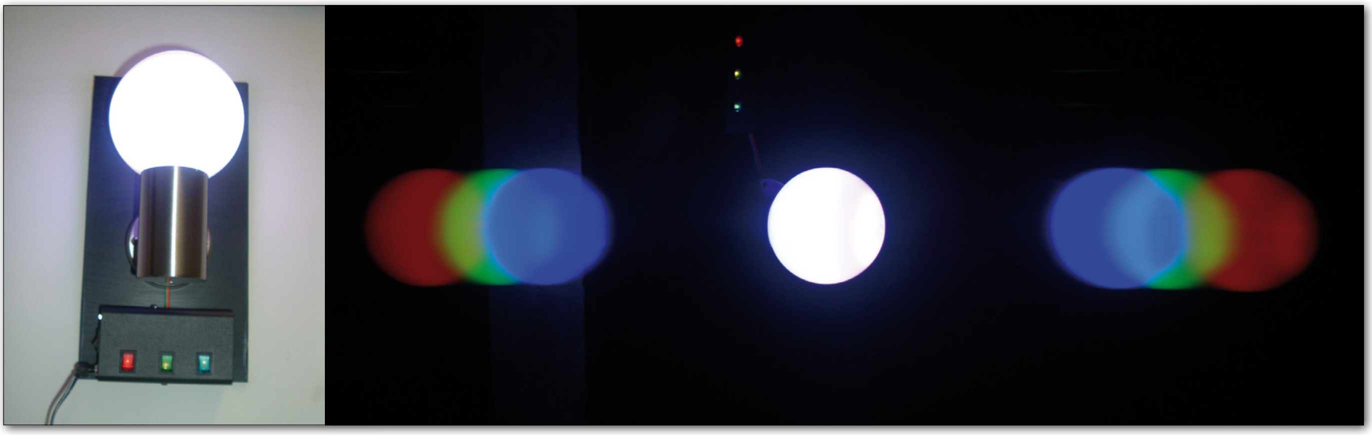

▾ **FIG. 7:** **(left)** Color mixer with a red, a green and a blue LED. **(right)** When looking at the mixer through holographic eye-glasses, one sees both the effect of diffraction and the effect of mixing neighboring colors.