School Architecture and Physics Education

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With the rise of consciousness about the importance of education, ideas, and attempts to entangle architecture with education have appeared. The new engineering building at Utah State University was designed[1] to be a learning tool for the structural engineers who will study in it. "Education by Design" and the "Use of Metaphors for Teaching" are principles advocated by Bernal in designing[2] the building for the Design and Architecture High School in Washington, D.C.

As a part of the effort to make physics more attractive to students, we proposed[3,4] to start multidisciplinary research on the implementation of physics education devices and tools into school buildings and courtyards. It turns out that this project may go hand in hand with DesignShare,[5] a program for innovative learning environments that started a few years ago. The goal of this program is to design a school as a three-dimensional textbook. A similar spirit is seen in the recent initiative to transform the approach to American public school planning and design.[6] In this paper we show how architectural intervention could improve a school's ambient conditions and reshape it into a kind of "science environment" that could help to better the understanding of some basic scientific principles and concepts. Incorporating basic physical phenomena and experiments into the school architecture would inspire and help promote active learning.

Devices to teach basic geometrical notions could be distributed all over the building and courtyard. Symmetries in nature, which determine crystal structures, may be represented on walls and on various objects.[3] The handrails of the school staircase could serve as straight inclined tracks.[3] Optics, with the Sun and artificial illumination, offers a wealth of possibilities for architectural modeling. With devices for teaching mechanics and acoustics, one may "Deck the Halls" as many authors have shown in a recent collection of *TPT* articles.[7]

The permanent presence of devices in a school permits repetitive observation of various natural phenomena. Their role is to teach through feeling, interaction, demonstration, and experimentation. Since memorizing is tightly connected with repetition as well as with associations, all this would help in the learning process.

Infusing Nature into the School Environment

An effective method of building physics into schools is to infuse sunlight into the school environment. Most of the basic laws about the properties and propagation of light were discovered using the Sun as a light source. Some examples of optical elements incorporated into school buildings include:

- ***Water wall and a fountain to observe propagation of light.*** A container with a grid of holes on the ceiling or in an external wall, coupled with a container of liquid, creates an ideal device to observe the dependence of the angle of refraction on the angle of incidence.[3,8] A fountain could be constructed to demonstrate the selective absorption of light and guiding of light by a stream of water. You may verify this by pouring water from a jug. A spot of the same color as the walls of a jug is formed at the bottom of the falling spout. This is because the walls of a jug selectively absorb light so that only one color is transmitted to the water inside it.

● ***Newton's prisms built on ceilings, roofs, and in windows.*** Windows with beveled glass may produce a spectrum during favorable conditions of light incidence. Therefore, by building prisms on the ceilings, roofs, and in windows,[3,8] students could see light spectra on the walls of their schools. They would note that the spectrum could only be seen under certain conditions and could then ask various questions about the process.

● ***RBG filters on a window to mix sunlight.*** A window consisting of three basic color filters and surrounded by two mirrors (Fig. 1) would produce a mixture of red, blue, and green light on a wall. The students could see a white area, which changes shape during the day. By changing the inclination of the mirrors, one could observe various mixtures of two colors.

● ***Thermal and UV filters.*** Modern windows use special materials to control the transparency for some spectral bands such as UV or IR. By combining those windows with conventional ones, one could directly demonstrate the invisible parts of the solar spectrum. Students could easily feel the difference in heating or see effects on fluorescent materials under such windows.

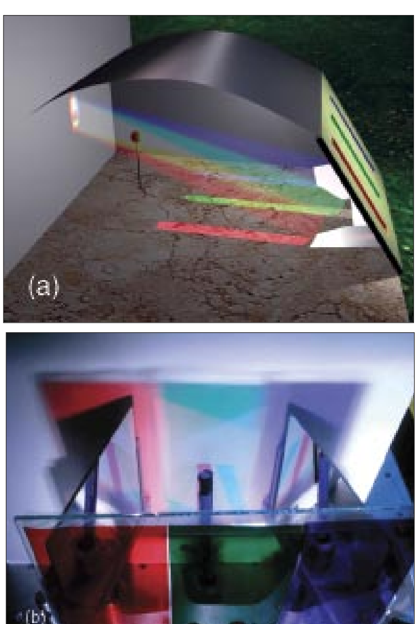

Fig 1. Filters and mirrors on a window to observe the color mixing of sunlight: (a) schematically, b) demonstration.

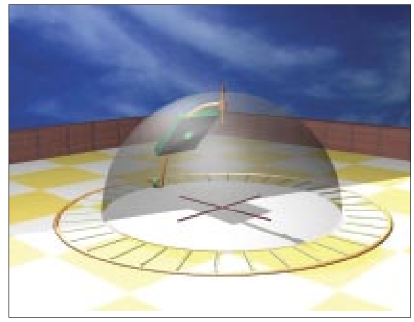

Fig. 2. Transparent dome with a diaphragm and a mechanism to record daily and annual path of the Sun.

● ***Transparent dome with a movable black sheet to observe and record path of the Sun.*** Szotak proposed[9] a very nice method to observe and record the daily and annual motion of the Sun. It is necessary to use a piece of cardboard into which one cuts a hole about 1 cm in diameter. Move this diaphragm along the internal surface of a transparent dome until the beams passing through the hole project onto the circular center of the floor (Fig. 2). Repeating the same procedure later, one finds a displaced point at the dome for the same method of projection. Performing this procedure in intervals of 5 minutes, one obtains a regular sequence of points, which depicts the motion of the Sun. The daily path of the Sun gives a circular arc. Repeating this measurement a few days later reveals that the route is displaced. In springtime the route is higher. It is evident to students that this corresponds to the approach of summer.

● ***Columns.*** A vertical column built in the school courtyard may serve as a multipurpose educational element for physical geography. It could be used to determine a geographic north-south line by observing the length of the shadow during the day. Such a column is also useful for the determination of the radius of the Earth using the method of Eratosthenes. Students collaborate with their counterparts at a distant school on the same meridian.[10]

The longitude, the latitude, the height of the place, and the value of gravitational acceleration inscribed near the bottom of the column would transmit the message to students about the importance of these quantities. A bob attached at the bottom of a cord fixed to the top of a column should be used for a pendulum experiment. Along the column one may denote the positions of a freely falling body from the top of a column at times $n\Delta t$, where Δt is the chosen time interval and n is an integer. The distances between those positions $x_{n+1} - x_n$ are proportional to consecutive odd numbers $x_{n+1} - x_n = (g/2)\Delta t^2(2n+1)$. A column with such marks corresponds to flash photography of a falling bob, but its advantage is in the permanent presence in the school environment and in its closeness to the real experiment.

● ***Mechanically drawn hologram.*** A mechanically drawn hologram could have many applications in school architecture. On a smooth, metallic, or plastic surface one can scratch a series of circles or half circles whose centers are arranged along a certain symbol, for example, along the letter F in Fig. 3. After illuminating the surface scratched with full circles, one sees two pictures of this symbol; one below, another above the surface.[11] Mechanically drawn holograms of the letters E (east), S (south), and W (west) could have an interesting application if appropriately positioned on the above-described column. E, S, and W would be seen when the Sun is on east, south, and west, respectively.

● ***Observing the day-night line on a properly oriented globe.*** A large stone globe could be placed like a sculpture in the school courtyard.[12] If properly oriented, students could observe where the day-night line on the Earth is at a particular moment of time (Fig. 4) and how it moves during the day. Students could compare the position of the day-night line, which they can see at any time on the stone globe of their school courtyard, with the position determined and presented by the U.S. Naval Observatory.[13]

Conclusion

We have enumerated many arguments for the usefulness of incorporating physics into school buildings. We support these arguments by providing examples of how this could be realized. In an analogy to the popular notion "hands-on experiments in physics," we could then have "school-on experiments in physics," which would be guided-inquiry lab assignments where students explore throughout the school building architectural arrangements related to a topic in physics.

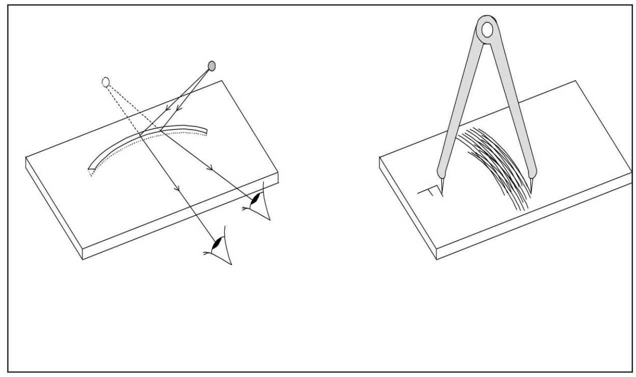

Fig. 3. By scratching a smooth surface with half circles whose centers move along a certain symbol (letter F in this case), one obtains a mechanically drawn hologram.

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Fig. 4. (a) On a globe having the same orientation as the Earth one may observe and determine the position of a day-night line and its motion over the Earth. (b) The local horizon of the observer and the tangent plane at the corresponding point of the globe have to be parallel. The north-south axis of the globe should point toward the celestial north pole.

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