Potential Value of Toys in Engineering Education

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Introduction

Classroom demonstrations add to students' interest and their understanding of the subject matter. Many references are available that deal with demonstrations, for example in physics courses[1-4] and engineering[5-6]. A wide variety of apparatuses and processes have been developed or adapted for demonstrations; these range from simple to complex, inexpensive and homemade devices to elaborate, expensive and commercially available units. Children's toys and the so called "executive toys" or novelties have also been employed as demonstration tools[7-10]. Properly selected toys offer at least three advantages: (1) they are relatively inexpensive and readily available for immediate use; (2) there is a good chance that students are familiar with them from their own experiences; and (3) they exhibit a wide variety of scientific concepts. In addition to their utility for classroom demonstrations, toys can be used for other educational purposes such as informal science education and inspiring ideas for student projects.

The literature on toys in education is indeed rich, especially in publications such as *American Journal of Physics*, *The Physics Teacher*, and the European journal *Physics Education*. Since engineering fundamentals are extensions of those of physics, the paper on toys written by colleagues in physics could well be relevant and applicable to our profession. Most of the toys discussed in the literature are related to aspects of solid mechanics, popular and well know toys like the top, yo-yo, gyroscope, slinky, balancing toy, buzzing magnets, rattle disk, Euler's disk, etc. An online search for physics of toys will reveal adequate number of links to get an interested reader on a journey to learn more, however, two excellent papers are included here for completeness[11-12].

Some of the toys discussed in the literature are related to fluid mechanics. Probably the oldest one and the most frequently written about "fluids toy" is the Cartesian diver, a floating object in a bottle of water that can be moved up or down based on the force exerted on the bottle, that demonstrates hydrostatic pressure and buoyancy. Its use has been documented as early as the 17th century[13], but interestingly it has continued to the present day in several forms and modifications[14-17]. Another popular toy is the drinking bird, an oscillating bird that seems to take small sips of water by tilting down to make a contact between its felt-covered beak and water in a glass and up, and repeating this cycle for quite a long time, demonstrating evaporation and center of gravity[18-19]. A wonderful old toy is the putt-putt boat which demonstrates the third law of Newton among other phenomena it exhibits[20-22]. Slime and silly putty are also child's toys that have remained popular for several decades as gooey and deformable substances with strange rheological behavior[23]. One can think of the lava lamp as an example of a novelty item that shows strange fluid properties in an artful and pleasing way. Other fluids related toys are soap bubble generators, smoke ring and air vortex generators (known as blasters), balsa wood or paper model airplanes, rockets, and balloon helicopters among others. It is interesting to note that Ludwig Prandtl, a giant figure in Fluid Mechanics, was fascinated by toys as observed by Theodore von Karman, one of his most famous students[24]. The late Professor Julius Sumner Miller found toys "enchanting." He hosted many TV shows on physics demonstrations with simple devices and toys in the 1960s and 70s. Video clips of several of his shows are available on YouTube[25].

The purpose of this paper is to introduce three fluids toys that, although available for quite sometime, have not been documented in the literature. Indeed the author was surprised that his search did not result in any relevant references, as he had assumed for sure someone had seen the educational value of these toys and had written about them. Thus, he decided to write this paper to share his findings about these toys and their potential in education.

Fluids Toys

Three inexpensive novelty toys that display an array of fluid mechanics phenomena are shown in Figure 1. They cost $7 to $11 each, and are available through online stores specializing with science and educational kits and at science museum gift shops[26]. The common tread among these toys is that the fluid motions they display are driven by density difference between the fluids (or other substance) contained in them. The toys could be used in a variety of educational settings, including class demonstrations to enhance lectures and student understanding, design projects in independent studies or undergraduate research, and informal science education for general public and younger students through school visitation programs. Later in the paper, several homework assignments based on these toys are also suggested as challenges for students.

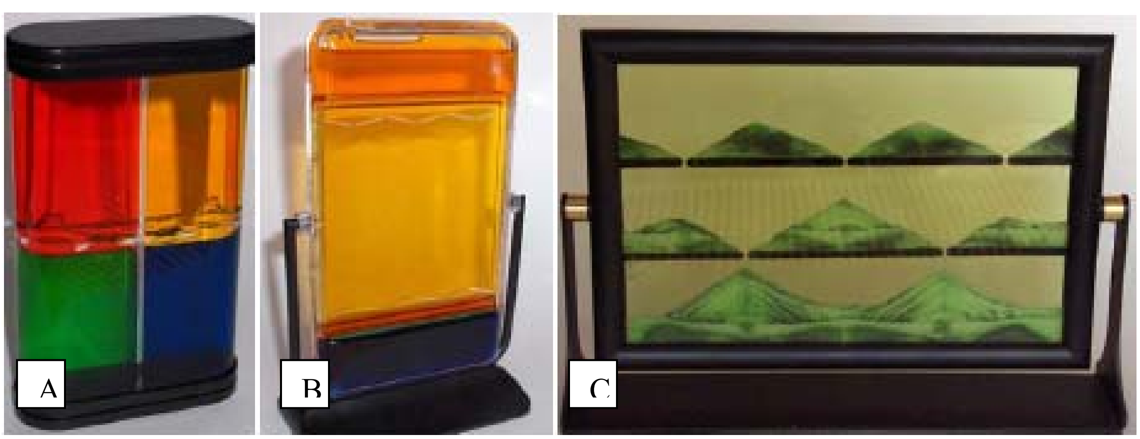

Figure 1 – Density differential fluids toys - (A) colors in motion toy # 1 (1 x 3 x 5 inches), (B) colors in motion toy # 2 (7/8 x 4 x 7 inches) , (C) sand painting (1/2 x 5 x 7 inches). These toys are trademark by Westminster, Inc. Atlanta, GA.

<u>Colors in Motion Toy # 1</u> - This simple toy as shown in Figure 1A contains colored liquids in four chambers. If observed carefully, one can see and enjoy a variety of fluid

mechanics phenomena displayed by this toy when operated. Each of the phenomena displayed namely drop formation, stream buckling, drop coalescence, etc., has been the subject of contemporary scientific and engineering investigations. The toy is made of a clear plastic box divided into four equal chambers. The left chambers are separated from the right. On each side though, the top and bottom chambers are connected to each other with two funnel-shaped openings, one downward and one upward, to allow exchange of liquids between them. Nearly equal amounts of two immiscible liquids with different densities fill the chambers on each side of the box. The liquid in each chamber is dyed with a different color, hence giving the impression that four different liquids fill the chambers. There is also a small volume of air. The liquids and the walls are non-wetting[27]. Using this toy is simple; invert the box and enjoy the motion created as heavier liquid flows down while the lighter liquid flows up. Although this does seem simple and straight forward there are at least three fascinating details that one can observe. These are described next.

Figure 2 presents snap shots at different times after the box is inverted. (The box was undisturbed for a while prior to the inversion as to ensure the liquids in each chamber were homogenous and without droplets and bubbles.) Upon inversion three distinct flow situations can be observed. First, the air quickly rises from the bottom to the top chambers with rapid succession of air bubbles, accompanied by sound, causing rapid transfer of heavier liquid in droplets from the top to the bottom chambers for about 5-6 seconds (Figure 2A). Second, after all air has risen to the top, the liquids start replacing each other via slowly and steady drop formations, heavier drops falling and lighter drops rising (Figures 2B and 2C). Each drop is encased by a film of the other liquid through which it flows. As drops settle on their like liquid surfaces, they float for a while and then coalesce. This portion of the flow takes about 4.5 minutes. Third, the downward flows of drops change into streams when, before detachment from the opening, they touch their like liquid surface below (Figure 2D). Closer observation reveals buckling of the stream as it experiences a compressive force from below. This portion of the flow lasts several seconds after which the funnel-shaped openings are covered by the other liquid. The liquid exchange continues until all liquids have completely filled their respective chambers. The entire sequence of motion takes a little over 5 minutes. Now the box is ready to be inverted again and the above sequence repeated (Figure 2E).

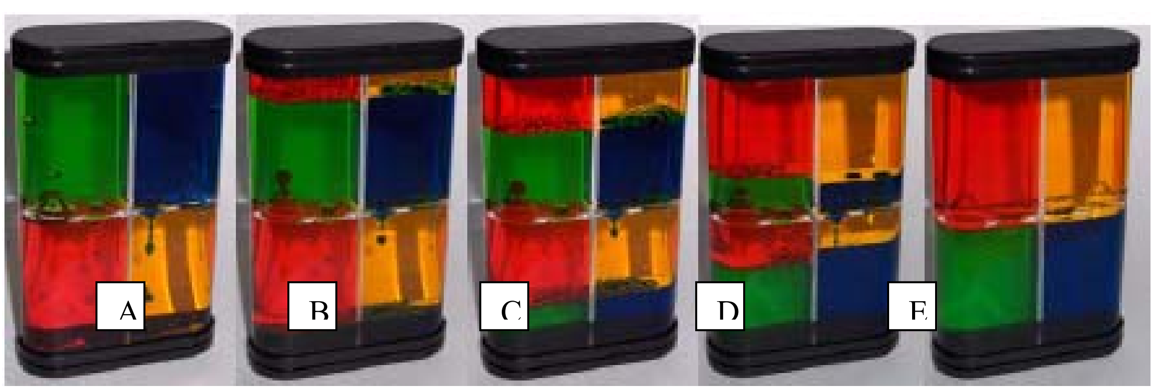

Figure 2 – Snap shots of colors in motion toy # 1.

While the above description dealt with the normal operation of the toy, other interesting situations can be created and observed. These could be assigned as challenges to students who have seen the normal demonstration of the toy. Two examples are presented later in the paper but there are more possibilities.

Several modified versions of this toy have also appeared in the market; four samples can be seen in Figure 3. Some incorporate wheels that turn as drops fall on them and some have rails that guide falling drops. Another recent modification is an arrangement of rows of staggered obstacles through which drops have to pass. Watching deformation of drops as they navigate the obstacles is fascinating. In all these toys the primary concept is to have fluids of different densities that are immiscible and non-wetting.

Figure 3 – Samples of density driven fluids toys.

<u>Colors in Motion Toy # 2</u> – This is a simple toy that creates beautiful overlapping patterns of colored liquids as they flow down through two narrow gaps between vertical plates. The toy can be considered a modified Hele-Shaw (HS) cell. The HS cell, basically made of two plates separated by a small gap (≤ 1 millimeter) is a well known device that has been used by researchers to investigate two dimensional flows[28]. The toy comprises of two HS cells side by side with a common wall. The top and bottom ends (about 1 inch in length) are widened to allow for holding adequate amounts of liquids. In each cell, there are two immiscible liquids with different densities. When the toy is oriented vertically, the heavier liquid just fills the lower reservoir and the rest of the cell is filled with the lighter liquid as shown in Figure 1B. The lighter fluids are the same in both cells and are dyed with yellow color. The heavier fluids are dyed with red and green colors. Small volume of air is present in each cell (in its top reservoir). At both ends of the narrow section in each cell, a series of thin plastic strips are positioned in a zigzag pattern with small gaps (~ 1 mm) through which liquids flow as they exchange their spaces. The toy comes with a swivel-frame and a base.

To use the toy, it is simply turned 180 degrees about its pivot and the ensuing flow is observed. Similar to the previously described toy, this one also has simple operation but displays a variety of intriguing fluid mechanics situations. First, upon turning the toy, a small amount of froth that had been collected on the heavier liquid surfaces rise to the top, and air bubbles quickly move from the now lower reservoirs to the top reservoirs, see Figure 4A. As the former takes place, mushroom-like plumes are created. The above takes only a few seconds while the heavier liquids (red and green) flow downward through the openings. As shown in Figure 4B, the drops in the narrow gaps are squeezed into flat blobs of liquid. Notice the overlap of the red and green blobs, which resembles a third color, violet in the photos. Some blobs tend to break into two or more pieces and are deformed into new shapes as they flow down. The lighter fluid has to find a path through the heavier liquid to flow up to replace it. The up flow, indicated as streaks in Figure 4B and C, takes place mostly through the openings situated at the peaks of the zigzag strips. The patterns created by the blobs are never the same during the one minute operation. Near the end, packets of froth start to flow down, but at a much slower pace compared to the liquid blobs and with their own physical characteristics, see Figure 4D. Elongated pieces of froth sometimes divide into two parts and the elastic rebound is quite noticeable. Those froth pieces that have a larger liquid fraction flow down faster, sometimes bumping into and merging with the ones down below. The froth dynamics is ever changing especially when the pieces of froth find their way through the openings into the lower reservoirs. Figure 5 captures several interesting instants of the froth life!

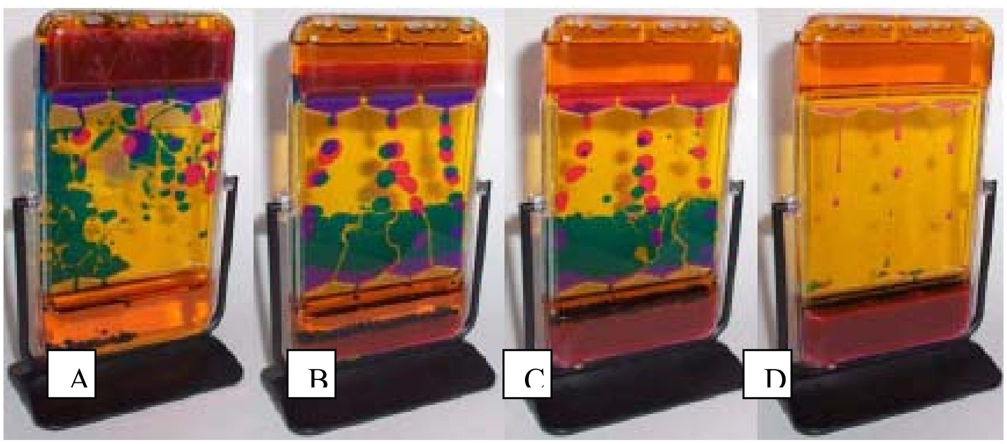

Figure 4 – Snap shots of colors in motion toy # 2.

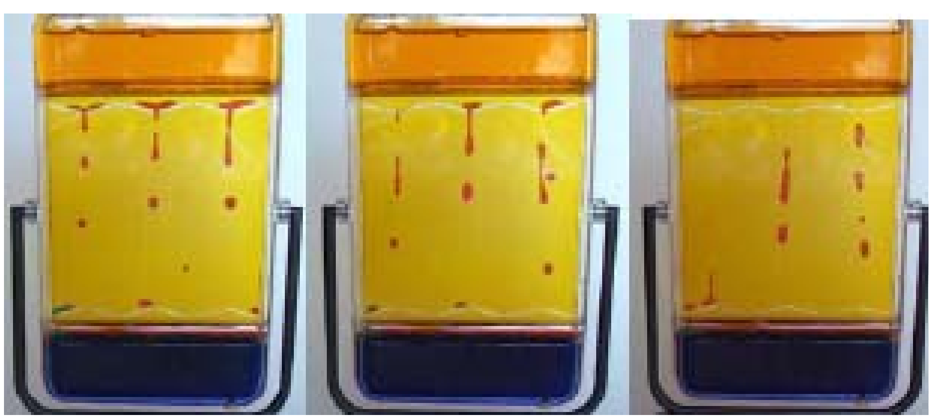

Figure 5 – Dynamics of froth life displaying stretching, break off, and bumping.

Sand Painting Toy – This novelty toy is also a modified HS cell, two glass plates with a very small gap (less than a millimeter) containing colored fine sand (black and green) and sand dust. The sand roughly fills one third of the space in the toy with the rest filled by air. Small amount of tiny reflective confetti added to the sand enhances the visual appearance of the toy. The cell is divided into three equal horizontal sections with narrow strips of dividers, with two or three small openings between each pair of adjacent sections as shown in Figure 6A. The toy can rotate along its horizontal axis in a frame with a base. Again, the instruction is simple: rotate the toy by one half a turn and observe the sand flow, and even air flow, which at the end create a beautiful sandscape or a painting with sand! Once the unit is turned, the sand flows down and the air has to flow up to replace the space vacated by the sand, see Figure 6B. Sometimes the up flow is clearly visible through one of the openings, where there is no down flow. But most of the times down flow and up flow take place alternatively through the same opening, and this requires careful observation. As sand flows down from one section to the one below it, mountains are formed underneath each opening as shown in Figure 6C. The mountains so formed clearly exhibit angle of repose – the angle created as granulates fall freely, a common situation observed in transport of granular materials. It takes about 6 minutes for the motion of sand particles to come to rest, and then the toy is ready for another half a turn to start a new sand painting, see Figure 6D.

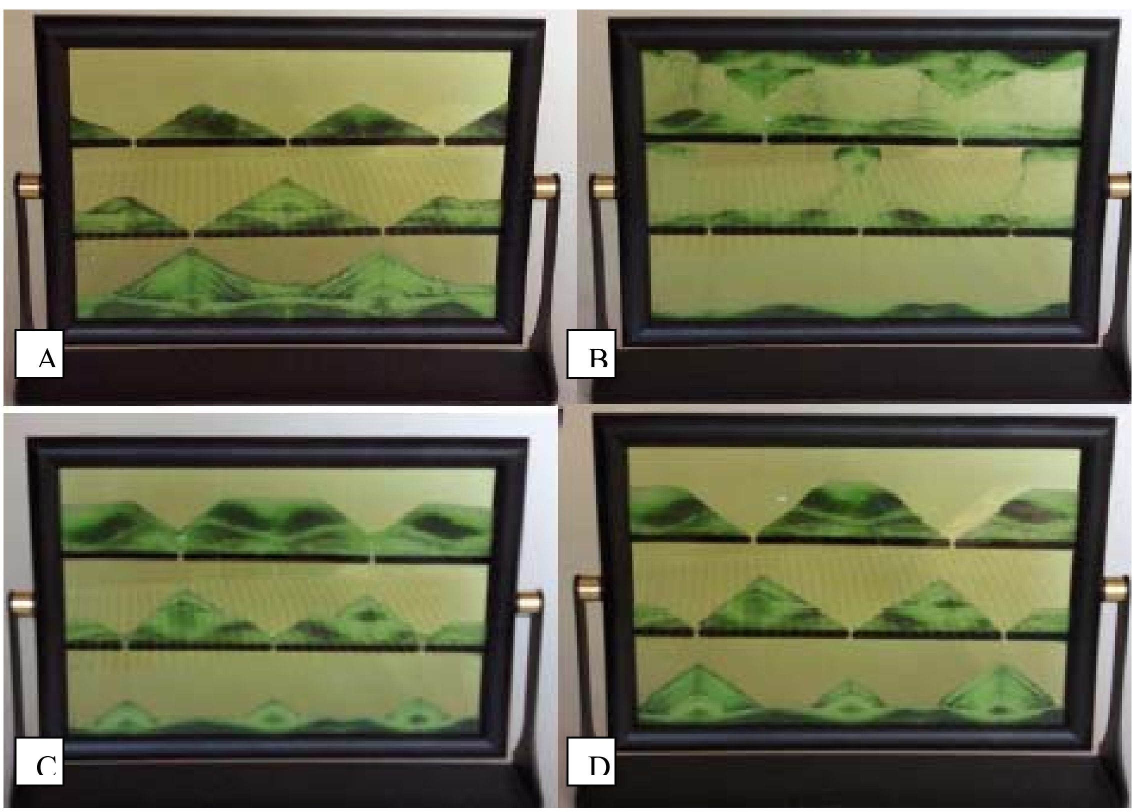

Figure 6 – (A) The instant before toy was inverted; (B and C) snap shots as sand falls down and air flows up; (D) the sand painting at the end.

Activities with Toys

The toys described above can be used to enhance lectures, and to motivate students to make observations of simple things around them, which quite often can be educational. To encourage students to practice and boost their observational skill, four assignments are provided here as student challenges. Interested readers can find out answers to these challenges by contacting the author.

Challenge # 1. Create the flow situation shown in Figure 7A, where a volcanic like eruption is taking place. This is in contrast with the steady and slow upward moving drops observed during the normal operation.

Challenge # 2. Create the situation shown in Figure 7B, where the liquid levels are different on the two sides, as opposed to the same level during the normal operation.

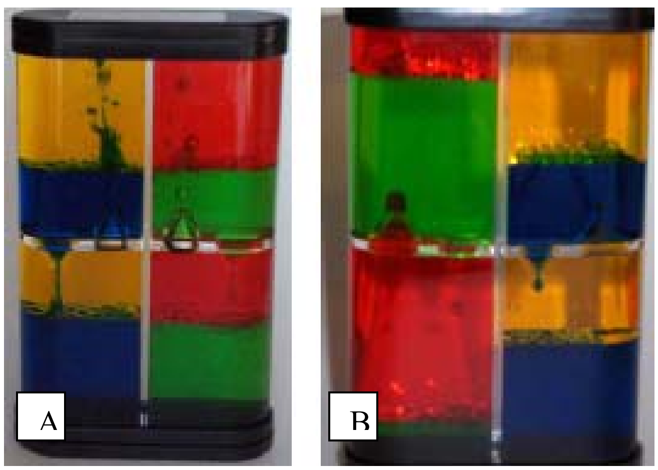

Figure 7 – (A) Volcano like eruption takes place in the upper chambers. (B) Light-heavy liquids' interfaces are different on the two sides.

Challenge # 3. This relates to color in motion toy # 2. Create the situation shown in Figure 8, where the heavier liquids are divided between the reservoirs at the two ends of the cells but almost absent in the narrow gap region between the reservoirs.

Figure 8 – Challenge # 3. Heavier liquids at the two ends with little in the middle.

Challenge # 4. Create a situation similar to the one shown in Figure 9, where a sand painting is skewed to the right. This is markedly different than that obtained during the normal operation (shown in Figure 6).

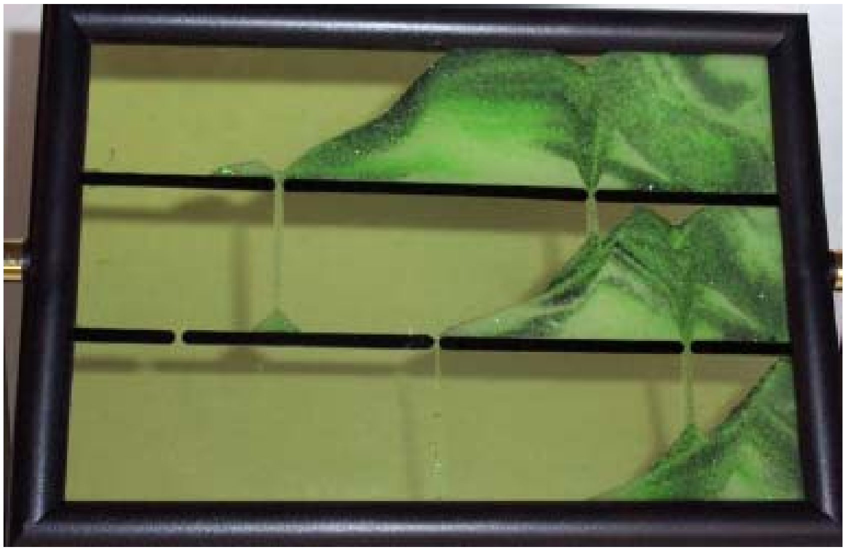

Figure 9 – Challenge # 4. Skewed sand painting.

The following ideas can be assigned as projects to students in design and other classes.

Project # 1. Based on the second toy, design an apparatus to investigate scientific questions such as: what will happen if two immiscible liquids with different densities (e.g., oil and vinegar) are in a HS cell separated by a partition with only one opening? How does the opening size affect the flow?

Project # 2. Design and construct larger scale of the second or third toy or modifications of them as engineering art objects for displays in the hallways of engineering buildings. Adding iron shavings to the sand and incorporating electromagnets controlled by the user in the sand painting device can add element of interactivity to the final product!

Project # 3. Design educational toys as part of various course projects to demonstrate a scientific principle. For example, use magnets to show forces; vacuum cleaner as a source of air flow to show drag and lift on objects; and impacting balls of different materials to show coefficient of restitution. A good starting point for toy design and construction can be found at *sciencetoymaker.org*. An example of a toy, "variable pitch drum," designed as part of assignments in an engineering course can be seen in reference[29].

Furthermore, the toys can be used in educating public about aspects of science that could be well considered artistic at events such as Engineering Week, university open houses, etc. They can also be shown to younger students in K-12 grades to excite and motivate them for considering carrier paths in science and engineering.

The ultimate goal of using educational toys is to promote student learning as well as to increase public awareness of and appreciation for science and engineering.

Conclusion

Properly selected toys continue to be used in teaching to illustrate physical concepts in order to enhance students learning. Three simple and inexpensive toys that exhibit an amazing array of fluid mechanics phenomenon were introduced and described in the paper. These educational toys could be used to spice up student learning and to excite general public about beauty of science. Several assignments for students were presented that encourage development/enhancement of keen observational skill. As quoted by Ascher Shapiro in the preface to the book on fluids films[30], "fluid mechanics is a photogenic subject," and as such these fluid mechanics toys would most probably be of interest to general public as well as students of science and engineering.

Acknowledgement

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Biographical Sketch

Said Shakerin is a professor of mechanical engineering at the University of the Pacific in Stockton, California, where he has been since 1986. He is a registered professional engineer in California, and he was educated at Arya-Mehr (now Sharif) University of Technology in Iran, Portland State, Oregon State, and Colorado State Universities in the USA. He served as department chairman in 1995-1998 but stepped down due to medical condition. His interests include development of teaching tools to enhance students learning and design of water fountains with special effects.