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“How Does It Work?”: Using Toys to Inspire Wonder and Develop Critical Thinking Skills in Fluid Mechanics

Abstract

Many students have owned or seen wave-maker toys, in which two immiscible fluids in a closed container can be tilted to generate waves. These types of inexpensive and readily available toys can offer benefits in support of technical education in addition to their primary function as tools for fun and entertainment. They can help inspire a sense of wonder about fluid behavior (generally expressed as: “Hey, that’s pretty cool!”). However, when used as part of a class, these toys can also help students develop their observation and critical thinking skills by considering questions such as “How does it work?” and “Why does it behave the way it does?” Answering these questions requires students to examine the fluid materials in the toys very closely and to observe a familiar object in a potentially new and unfamiliar way.

In this paper, we describe several such toys that can be used to enhance student learning in Fluid Mechanics courses. Several of these toys demonstrate fundamental properties including density and viscosity. The toys can also be used to demonstrate more complex fluid behavior including drop formation and coalescence, effects of boundary shear stress, and Karman vortices. Furthermore, the toys can be used as interesting displays for outreach and informal science education.

The paper includes suggestions on how the toys can be incorporated into a class for demonstrations, group exercises, or assignments and includes discussion of some formative assessment of student learning. References to the toys and other relevant web sites are provided to assist educators who are interested in using such tools to enhance student learning.

Introduction

Classroom demonstrations add to students’ interest and their understanding of the subject matter. Many references are available that describe demonstrations, for example in physics \(^1\text{-}^4\) and engineering \(^5\text{-}^6\) courses. Demonstrations can range from simple to complex set ups, inexpensive and homemade devices to elaborate, expensive and commercially available units. Children’s toys, novelties, or science-based toys have also been employed as demonstration tools \(^7\text{-}^10\). Properly selected toys offer at least four 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;
3. they can be used to demonstrate a wide variety of scientific concepts; and
4. they require that students observe a system (the toy) in new or different ways.

With the popularity of YouTube \(^11\text{-}^12\) and other online video sources \(^13\text{-}^14\), instructors can easily learn and share ideas on effective use of toys in the classroom. Ludwig Prandtl, a leading force in Fluid Mechanics, was fascinated by toys as observed by Theodore von Karman, one of his most famous students \(^15\). The late Professor Julius Sumner Miller, who hosted many TV shows on physics demonstrations with simple devices and toys in the 1960s and 70s, found toys “enchanting.” Video clips of several of his shows are available on YouTube \(^11\).
Online databases of demonstrations, e.g., “Hands on Mechanics” allow instructors to submit a complete demonstration or module including a description of the toys, shopping lists for other materials, and information on presenting the associated theory or principle and demonstrating it using the toys. Such online sources can help promote pedagogical excellence as the modules can be accessed, tested, and implemented by others who can then provide feedback or submit their own demonstrations. In addition to their utility for classroom demonstrations, toys can be used for outreach and other educational purposes including informal science education such as provided at science museums or Engineers’ Week displays. The toys themselves can also inspire students to develop other toys and projects.

When used effectively as part of a class, demonstrations can help engage students and enhance their ability to learn the material. In particular, by including demonstrations and toys, the instructor can reach those students who tend to have strong preferences for visual, active, or hands-on learning. Use of toys and demonstrations, when well-planned, practiced, and introduced in support of class content, can liven up the classroom, engage and challenge students, and help them visualize concepts that may otherwise be outside the realm of their experience.

The literature on use of toys in education is indeed rich. Articles can be found in publications such as American Journal of Physics, The Physics Teacher, the European journal Physics Education, Prism and the Journal of Professional Issues in Engineering Education. Several suppliers including PASCO and Educational Innovations, Inc. have developed their businesses around supplying the types of toys used in support of science and engineering education. Since physics comprises the core of engineering fundamentals, the literature on toys contributed by colleagues in physics is very often relevant and applicable to engineering education. Most of the toys discussed in the literature are related to aspects of energy conservation, dynamics, or solid mechanics. These include popular and well known toys like the top, yo-yo, pendulum (balancing toy), gyroscope, slinky, buzzing magnets, rattle disk, Euler’s disk, and Newton’s cradle, among others. An online search using the keywords, “physics of toys,” will reveal many links that can help an interested reader or instructor apply existing ideas or develop new ones.

Some of the toys discussed in the literature are related to fundamental concepts in fluid mechanics. Possibly the oldest and most frequently documented “fluids toy” is the Cartesian diver, a floating object or eye dropper placed in a bottle of water – the object can be moved up or down by exerting or releasing a force on the bottle. The bottle itself may be deformable, or a flexible diaphragm may be placed across the top of the bottle. This toy demonstrates the concepts of hydrostatic pressure, buoyancy, and compressibility of air. While students will likely have some first-hand experience with buoyancy in a swimming pool, most have not considered the effect of an increase in hydrostatic pressure and its impact on a compressible fluid. This toy can be used as part of a class on either of these topics. Use of the Cartesian diver was documented as early as the 17th century, but has continued to the present day in several forms and modifications. 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 the effects of evaporation, vapor pressure, and center of gravity. The drinking bird is often one of the toys students may have seen previously, but when introduced as part of a class on fluid
properties, the mesmerizing bird often elicits the ‘aha!’ response as students determine how it works based on what they are learning in class.

A wonderful old toy is the putt-putt boat that demonstrates Newton’s Third Law, among other phenomena. Slime and silly putty are children’s toys that have remained popular for several decades as gooey and deformable substances. They can be passed around the class together with a bottle of water and a dish of gelatin dessert so students can observe first-hand the difference between Newtonian and non-Newtonian fluids, and examine the rheological behavior of silly putty and slime. Most K-12 students have experience with adding drops of water, one at a time, to the surface of a penny. A fun competition can encourage even University students to participate, and surfactants can be added to the different pennies, so students learn about surface tension and effects of surfactants while they conduct the hands-on activities.

**Demonstrations with Fluids Toys**

Many fluids-related toys are available that have not been documented in the literature. While these are typically marketed as novelty toys, each has great potential for enhancing student learning in fluid mechanics courses. Five inexpensive toys that display an array of fluid mechanics phenomena are shown in Fig. 1 and described below. These toys cost $7 to $11 each (when purchased in 2008), and are available through online stores specializing in science and educational kits and at science museum gift shops. Additional toys are described in two related papers.

![Figure 1 – Density differential fluids toys](image)

**Colors in Motion** - This toy, shown in Fig. 1A, is made of a clear plastic box and contains colored liquids in four equally-sized chambers. On each side, the top and bottom chambers are connected with two funnel-shaped openings, one facing downward and one upward, to allow exchange of liquids between the chambers. 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 a different color, giving the impression that four different liquids fill the chambers. There is also a small volume of air in each chamber. The liquids and the walls are non-wetting. A variety of fluid mechanics phenomena are displayed by this toy when operated, including drop formation, stream buckling, drop coalescence. These phenomena have been the subject of
contemporary scientific and engineering investigations. Using this toy is simple; invert the box and enjoy the motion created as the heavier liquids flow down while the lighter liquids flow up. Although this does seem simple and straightforward there are at least three fascinating details that students can observe. These are described next.

Fig. 2 presents snapshots at different times after the box is inverted. (The box was undisturbed for a while prior to inversion to ensure the liquids in each chamber were homogenous and without droplets or bubbles.) Upon inversion, three distinct flow conditions are observed. First, the air quickly rises from the bottom to the top chambers with a rapid succession of air bubbles, accompanied by sound, causing rapid transfer of heavier liquid droplets from the top to the bottom chambers for about 5-6 seconds (Fig. 2A). Second, after all the air has risen to the top, the liquids start replacing each other via slow and steady drop formations, with heavier drops falling and lighter drops rising (Figs. 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 1/2 minutes. Third, the downward flows of drops change into streams when, before detachment from the opening, they touch their like liquid surface below (Fig. 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 toy is ready to be inverted again and the above sequence repeated (Fig. 2E).

![Figure 2 –Colors in Motion toy at different stages.](image)

Such a toy is an effective educational tool for students of many different ages and academic backgrounds. At its simplest level, the toy demonstrates the behavior of immiscible fluids of different densities, and the effects of differences in density between gases and liquids. This type of guided observation may be used for students at the K-12 level or for informal science education displays. However, demonstration of some of the more complex fluid phenomena can be incorporated into a fluid mechanics course at the graduate level.

Modified versions of the Colors in Motion toy are also available on the market; four examples can be seen in Figure 3.
Each of these toys contains fluids of different densities that are immiscible and non-wetting. Some versions of the toys have rails that guide falling drops (Figs. 3A and 3C). The droplets flowing on the rails, shown in Figs. 3A and 3C, can be used to demonstrate the concepts of travel time in open channel flow. As students change the angle of the toy casing, the droplets move more quickly or more slowly, demonstrating how travel time and velocity are affected by the path length and bed slope. Some incorporate wheels that turn as drops fall on them (Fig. 3B) that can be used to demonstrate how a turbine or water wheel works and to demonstrate and relate concepts of linear and angular momentum. Another recent modification is an arrangement of rows of staggered obstacles (pins) that impede droplets as they fall, seen in Fig. 3D. Watching deformation of drops as they navigate the obstacles is fascinating, and a useful demonstration of the effects of surface tension, as the drops tend to coalesce, stretch, and re-form as they fall through this maze.

Flowing Color Spectrum – This toy, shown in Fig. 1B, creates 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, made of two plates separated by a small gap (≈ 1 mm), is a well known device that has been used by researchers to investigate two dimensional flows. The toy comprises of two back to back HS cells with a common wall. The top and bottom ends – each about one inch in length – widen to hold 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 Fig. 1B. The lighter liquids are the same in both cells and are dyed with yellow color. The heavier liquids are dyed with red and green colors. A 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.

The toy is turned 180 degrees about its pivot and the ensuing flow is observed. Similar to the previously described toy, this one is also easy to operate 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 rises to the top, and air bubbles quickly move from the now lower reservoirs to the top reservoirs, see Fig. 4A. As the former takes place, mushroom-like plumes...
are created. The above flow takes only a few seconds while the heavier liquids (red and green) flow downward through the openings. As shown in Fig. 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.

Figure 4 – Snap shots of Flowing Color Spectrum toy.

The lighter liquid has to find a path through the heavier liquid to flow up to replace it. The upward flow, indicated as streaks in Figures 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 Fig. 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 change constantly especially when the pieces of froth find their way through the openings into the lower reservoirs. Progression of the froth life is shown in Fig. 5.

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

Sandscape – This novelty toy is also a modified HS cell, two glass plates with a very small gap (≤ 1 mm) containing colored fine sand (black and green) and sand dust. The sand fills approximately one third of the space in the toy; the rest is filled with air. A small amount of
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.

![Figure 6](image)

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

The toy can be rotated 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 sandscape or a painting with sand! Once the unit is turned, the sand flows down and the air flows up to replace the space vacated by the sand, see Fig. 6B. Sometimes the upward flow is clearly visible through one of the openings, where there is no downward flow, but most of the time, downward and upward flows alternate through the same opening. As sand flows down from one section to the section below elevated piles are formed underneath each opening as shown in Fig. 6C. The sand piles so formed clearly exhibit the angle of repose – the angle created as granules 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 Fig. 6D. This toy can be used to demonstrate behavior of non-cohesive sediments or granular materials, and to emphasize the relevance of soil material to bank stability in design of open channels made of natural materials.

**Colored Sand Motion** – This novelty toy, shown in Fig. 1D, contains two side-by-side flattened hourglass compartments, each containing a mixture of sand and a clear liquid. For visual effect, the sand volumes in the two compartments are dyed different colors, in this case, pink and black. On one side, the sand is more dense than the liquid, while on the other side, the sand is less dense, thus flow of sand occurs in opposite directions as the toy is rotated. The sand velocity is reduced as the slope of the toy is decreased, allowing closer observation of some fluid flow phenomena discussed in class. As the toy is slowly moved from a horizontal to almost vertical position, as shown in Fig. 7A, the onset of separation is observed just downstream of the contraction. Turbulent flow behavior is observed as sand particles collide, are deflected, then fall (or rise), collide, and continue. Observation of the sand particles allows students to visualize
the concept that while there is a mean transport velocity, which can be determined by timing the hourglass cycle several times, the velocity of each individual sand grain may deviate slightly from the mean at each instant in time.

![Figure 7 – Colored Sand Motion toy (A) almost vertical, (B) almost horizontal.](image)

Velocity gradients and the concept of the no-slip boundary condition, not readily evident in liquid flow in pipes, can be demonstrated using the hourglass toy. When held in an almost horizontal position, as shown in Fig. 7B, sand grains at the wall move more slowly than the grains that are one, two, or more sand grain diameters away from the wall. The hourglass is not symmetric at the contracted section, as seen in Fig. 7B; the sides between the compartments have a more pronounced contraction than at the outer edges, where the contraction-expansion transition is more gradual. By comparing the behavior of sand through each contracted section, students can observe the phenomena that lead to local friction losses at a bend or contraction. The sand grains flow smoothly around the gradual contraction, while they appear to fall out in clumps and form eddies as they pass around the pronounced contraction. The behavior can be discussed in class as the students watch the sand behavior, and the instructor can guide students in formulating an explanation as to why local losses occur and why they are reduced when a transition is streamlined.

**Ooze Tube** – The Ooze Tube, shown in Fig. 8, contains a highly viscous liquid, in this case dyed blue for visual effect, which flows through an orifice plate partitioning a cylindrical vessel. The rest of cylinder is filled with air. A wide variety of dynamic flow phenomena can be observed with this novelty toy, including the Rayleigh-Taylor instability, Euler instability and liquid coiling (Figs. 8B and C). Bubble dynamics that can be observed in slow motion include bubble formation, bubble pinch-off, and bubble burst, seen in Figs. 8B–D, as several bubbles form sequentially through the process. The Ooze tube can also be used in an exercise to estimate Reynolds Numbers for laminar and turbulent flows. The viscosity of a similar high viscosity fluid such as glycerin may be used together with measurements of the orifice diameter, the fall distance and the fall time for the liquid stream. For comparison purposes, the Reynolds Number can be calculated for flow of water, oil, and other liquids under similar conditions, and the flow patterns can be observed for each of the other liquids as they are poured from their containers.
Figure 8. The Ooze Tube. Various stages of bubble dynamics and liquid coiling demonstrated in a highly viscous liquid.

Birefringent Liquid Display - As this paper was being developed, a new novelty liquid toy was brought to our attention, which deserves to be briefly presented here. The novelty item (protected by US patent nos. 7,210,809 and 7,334,910), consists of a 3.5 in diameter cylindrical case that holds a disk filled with a birefringent liquid, two polarizing filters, an LED-array light source for back lighting, and a battery pack. A small magnet is placed in the disk that holds the liquid and is free to be moved around, which can be accomplished via an external magnet. The liquid is highly sensitive to shear force exerted on the liquid. A slight motion imposed on the liquid, by either moving the case or the magnet, causes swirling color bands that correspond to shear layers to appear in the liquid. Two examples of color bands are shown in Fig. 9; these were produced by rotating the case (Fig. 9A) and moving the magnet in a straight line (Fig. 9B). A short video clip of another version of this novelty item can be viewed in the image/video gallery section of efluids.com (submission # 625).

Figure 9 – Birefringent Liquid Display - (A) Color bands created by rotating the case, (B) Vortices formed by moving the magnet across the case.

Students learn that for a fluid, application of a shear stress will result in fluid motion, that the fluid will deform continuously as long as the shear stress is applied, and that there is relative motion between adjacent fluid layers. These fundamental concepts can be demonstrated very clearly using the birefringent liquid toy.
Effect of Toys on Student Learning

The title of this paper is “How Does It Work? Using Toys to Inspire Wonder and Develop Critical Thinking Skills in Fluids Mechanics”. The degree to which wonder is inspired is difficult to measure, to say the least, but may be assessed in-situ and qualitatively in one of two ways. First, by observation of students’ level of participation, as determined by their willingness to ask and answer relevant questions, and second, by their ‘aha’ looks or general comments regarding the toys. Longer term effects are much more difficult to assess – a student’s interest may be piqued by their experiences with the demonstrations, but their performance in the class may be a stronger factor in determining their desire to pursue this field of study.

Students’ abilities to observe and think critically about the toys were evaluated quantitatively as part of their first exam in Fluid Mechanics in Fall 2009. Different toys were used for in-class demonstrations and during labs prior to the exam. For the exam, students were required to examine two toys they had not seen previously in the course and to answer questions based on their observations. This portion of the exam was worth 5 out of 100 points and the grading was relatively generous; if the student’s answer alluded to the correct fluid behavior or property, the student was given the point for the question. The exam questions, topics addressed, level of difficulty, and the number of correct responses are summarized in Table 1.

Analysis of the students’ scores shows that >75% could identify and explain fundamental properties and characteristics such as density differences, immiscibility, and surface tension causing the observed behaviors for each toy. Students were also able to answer the question about the velocities of droplets - i.e., that equal-sized droplets moved at the same rate down the incline - likely based on personal experience or intuition because the topic had not yet been addressed in class. These responses indicate that the students were able to apply their knowledge gained from the course and to develop an answer based on their past experience. Only 25 – 33% of the students were able to answer the challenging questions. The topics had not been covered in class, but some students were able to think critically about the topic, and give reasons for the observed behaviors. The most surprising result was that only 7 out of 24 students were able to answer a question of middle-level difficulty. This discrepancy may be more likely due to the students’ observation skills than to their ability to think critically or apply their knowledge because the topic was very similar to the topic addressed in the second question. Additionally, since the questions were only worth 1 point each in a timed exam, students may have decided that their time was better spent on the rest of the exam, where problems were worth more points.

The approach presented here was a preliminary one. First, the exam questions about the toys ideally would be administered to two separate cohorts: one group that had seen and worked with the toys and one that had not, to compare effects on student learning. However, since our university is small, all students are enrolled in the same section of Fluid Mechanics, typically taught only once per year. Second, the sample size was small; only 24 students were enrolled in the course. Results of similar exercises, improved and used over several years would provide a better indication of the effects on student learning. Finally, the quality of the questions can be improved: multi-part questions should be separated and simplified to focus on a single topic each.
Table 1. Evaluating comprehension and critical thinking skills using toys.

<table>
<thead>
<tr>
<th>Question</th>
<th>Topic addressed</th>
<th>Difficulty level</th>
<th>Number of correct responses (#/24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explain why the fluid flows more quickly when you first flip the unit (for about 10 seconds) than later on (after 10 seconds).</td>
<td>Density of liquids vs. gases</td>
<td>Middle</td>
<td>7</td>
</tr>
<tr>
<td>Explain why the red and green fluids travel to separate compartments, and why each compartment fills with one single color of liquid.</td>
<td>Density, immiscibility</td>
<td>Fundamental</td>
<td>23</td>
</tr>
<tr>
<td>Explain why the falling droplets are the same size and are flowing at an evenly spaced distance from one another.</td>
<td>Drop formation</td>
<td>Middle</td>
<td>6</td>
</tr>
<tr>
<td>Explain why the pink/blue liquids stay as droplets, instead of forming a steady stream to flow through the clear liquid?</td>
<td>Surface tension, gravity driven flows, fluid velocity</td>
<td>Fundamental</td>
<td>18</td>
</tr>
<tr>
<td>When drops fall on (or flow up into) to their-like liquid, or the pink/blue droplets catch up with the ones ahead of them, they do not mix immediately to form one bigger drop, or join the existing pool. Explain why this occurs, and what causes the drops to break up.</td>
<td>Liquid films, drop coalescence</td>
<td>Advanced</td>
<td>8</td>
</tr>
</tbody>
</table>

One approach to improving students’ observation and critical thinking skills is to develop exercises that require them to look for and explain unexpected behaviors. This paper describes how the toys were used in class to demonstrate topics that were being taught – the students knew what to look for. Several ideas for assignments and projects are presented in the Appendix – these can be used as a starting point for helping students develop their skills in observation, analysis, and critical thinking. The assignments may serve as more useful measures of student learning because students can take as much time as they need to examine the toy and formulate their answers.

Conclusion

Several inexpensive toys were introduced in this paper. Despite their simplicity, each can be used to demonstrate an array of fluid characteristics and flow phenomena and to enhance the quality and relevance of classroom instruction. Effective use of toys can help engage students and enhance learning. When used in conjunction with examples, problems, and applications, these hands-on toys can help address learning styles of those students who may not respond as positively to the verbal and inductive teaching styles traditionally used in engineering classrooms.
Preliminary analysis of student learning showed that most students were able to explain fundamental characteristics and behaviors based on material learned in the course and on their past experiences. However, few students were able to formulate reasons for some of the more advanced or unusual fluid behaviors observed. These topics may be more appropriate for an advanced or graduate level course, but specific exercises focused on developing students’ observation skills can help develop their ability and confidence to formulate theories for observed phenomena.

Beyond the classroom, these toys can help younger (K-12) students and the general public find the ‘wow’ factor in science and its applications in engineering. As noted in the preface to the book on fluid films 40, “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.

Acknowledgements

Funding from the Committee on Academic Planning and Development at the University of the Pacific is greatly appreciated which allowed purchase of the toys described here and several others. Dr. Ed Pejack provided helpful comments on the manuscript including some of the ideas presented in projects # 2 and 3 listed in the appendix. Two earlier and shorter versions 35, 36 of this paper were presented at the 2009 ASEE-PSW Section Conference, San Diego, CA, March 19-20, and the 2009 ASME-FED Summer Meeting, Vail, CO, August 2-5.

References


Appendix A - Challenge Assignments and Projects

Additional assignments can be provided to challenge students and to encourage them to practice and boost their observational skills. Interested readers can obtain answers to these challenges by contacting the authors.

Challenge # 1. Create the flow situation shown in Fig. 10A, 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. Explain why this occurs.

Challenge # 2. Create the situation shown in Fig. 10B, where the liquid levels are different on the two sides, as opposed to the same levels found during normal operation.

Figure 10 – (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 Flowing Color Spectrum toy. Create the situation shown in Fig. 11, where the heavier liquids are divided between the reservoirs at the two ends of the cells but are almost absent from the narrow gap region between the reservoirs. Explain how this condition can be achieved in practice, and identify some applications.

Figure 11 – Challenge # 3. Heavier liquids at the two ends, with little in the middle.
Challenge # 4. Create a situation similar to the one shown in Fig. 12, where a sand painting is skewed to the right. This is markedly different than that obtained during the normal operation of Sandscape toy (shown in Fig. 6).

Figure 12 – Challenge # 4. Skewed sand painting.

Student design projects can include modifications or extensions of the toys presented in this paper or in the literature. The projects can require students to develop a toy or demonstration, relate it to the course material, and demonstrate the toy to K-12 students, at outreach events, or to their classmates. Example projects include:

Project # 1. Modify any of the toys described in this paper to investigate how a small change in one component affects fluid behavior. For example, using Flowing Color Spectrum toy, how does flow behavior change if the HS cell is separated by a partition with only one opening? How does the opening size affect the flow rate and flow patterns?

Project # 2. Based on any of the designs shown in this paper or in the literature, develop a larger scale hands-on display that can be used as a museum display, for informal science education, in classroom visits to K-12 classes, or at outreach events. Identify scaling issues – does the fluid in a large model behave the same way as in a hand-held toy? How do different materials affect the behavior, e.g. if iron filings are added to the sand and magnets are applied to the outside of the display, how are the flow of sand and the deposit height affected?

Project # 3. Design an educational toy to demonstrate a principle in fluid mechanics. Example topics include air flow to show drag and lift on objects and toys that demonstrate continuity principles. A good starting point for toy design and construction can be found at the following web sites: sciencetoymaker.org, arvindguptatoys.com, and http://www/ucke.de/christian/physik/, and the book titled Science Projects About the Physics of Toys and Games. Also, a series of books by Peter Holland give lucid instructions to make toys and models made of ordinary materials. An example of a class project assigned in a fluid mechanics class, a “variable pitch drum,” can be seen on YouTube.