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BYOE: Making Connections between Fluid Mechanics and Abstract Painting

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Abstract

This bring your own experiment (BYOE) paper details two iterations of a hands-on painting project that has been well-received by fluid mechanics students. In the conception of this project the authors have explored many of the relevant parameters for different painting techniques: drip painting, pendulum painting spray painting, and acrylic pours – one subset of which is spinning pours. These methods were explored both in terms of relevant fluid mechanic phenomenon as well as with hands-on experimentation, reviewing instructional videos and talking with artists. These efforts led to creation of short instructional videos that students can watch before undertaking their own attempts at creating a work of art. To date this project has been conducted as an extra credit opportunity, though discussion is presented on how the general idea could be deployed as a more traditional experimental lab or as a fun, yet relevant, end of semester lab activity. While the act of creating the fluid art inherently involves learning outcomes related to the importance of thinking creatively, exploring curiosity, prototyping and creating a product with limited project constraints, the instructor can determine the rigor of learning outcomes related to fluid mechanic principles with an accompanying written assignment. This BYOE paper is written with the goal of making the implementation of this project, or some variation of it, straightforward for instructors. Keeping material costs low was part of this consideration and set-up descriptions are provided as well as parts lists.

Introduction

Instructors of required undergraduate engineering courses do well by providing examples of where course content is applied in the real world. Such examples allow students to connect material with personal experiences, potentially spark further questions or curiosity, and implicitly demonstrate both the importance and ubiquity of a subject. Without the instructor explicitly pointing out connections, students can struggle to see the applicability of the topic. When teaching a technical engineering course it is easy for an instructor to focus on the equations, assumptions, theories, problem solving algorithms and similar material that makes up the core of a subject. Thus, for a student first learning the material, a fair and often asked question is "where is this material important?" Research has shown that understanding the relevance of learning (i.e. how it connects to reality) plays a large role in student motivation [1]. Higher levels of motivation lead to better learning outcomes and instructors are encouraged to increase the intrinsic motivation of their students by making connections between a course and students' interests [2]. Therefore, an engineering instructor who frequently points out applications of course content in the real world, and does so with a broad spectrum of applications to appeal to students' wide ranging interests, will continue to promote student motivation for learning.

In fluid mechanics it is easy to provide relevant examples of principles in multitudinous industrial applications as well as natural phenomenon such as airplanes, pipelines, birds, etc. Paint application is important from an industrial context though an additional opportunity exists to discuss the importance of fluid mechanics to painting in an artistic context. When one considers how the fluid mechanical properties of paint combine with the method of application to create different effects one finds a wealth of fluid mechanic principles of relevance including Rayleigh-Taylor, Rayleigh-Plateau, Saffman-Taylor and viscous coiling instabilities. There are many painting techniques that are compelling from a fluid mechanics standpoint that have received attention in technical literature. Jackson Pollock is well known for creating artwork by dripping threads of viscous paint as well as incorporating droplets and splashing effects. This technique is also referred to as action painting. Herczynki, Cernuschi and Mahadevan [3] present a detailed analysis by considering the paint as a gravitationally driven free viscous jet for which fluid instabilities could lead to different effects such as steady streams of varying diameter, paint drops, and coiling instabilities. The effects are dependent on the paint viscosity, density and surface tension in addition to the method of delivery to the canvas. However, a truly theoretical analysis is complicated by the fact that paint is a non-Newtonian fluid. David Alfaro Siqueros, a renowned Mexican painter, created abstract works utilizing the Rayleigh-Taylor instability that occurs when a less dense fluid is carried upwards through a fluid of higher density. Zetina, Godinez and Zenit [4] conducted experiments and an instability analysis to demonstrate this effect specifically with different paints as well as lacquer. Further analysis of fluid mechanic aspects in such abstract artistic painting techniques is found in [5].

While the intersection of fluid mechanics and artistic painting could be made through visual aids, a more impactful opportunity is to actually have students make paintings. The creation of art has been shown to have wide-ranging benefits such as improving functional connectivity between areas of the brain [6]. Artistic and creative activities are reported to improve problem-solving skills, idea creation, and creativity [7]-[9]. The impact of art creation is so strong on the brain and emotions that it is employed for its therapeutic effects with dedicated organizations and academic journals– see for example arttherapy.org, Art Therapy: Journal of the American Art Therapy Association, Arts & Health: An International Journal for Research, Policy and Practice.

In this paper we describe an activity motivated by the desire for students to see the connections between fluid mechanics and fluidic painting that also requires students to create art while promoting creativity. In the same spirit as Benedetti et al. [10] we sought to develop a "safe playground" to allow students to attempt something new. As students are most likely unfamiliar with the different painting techniques employed it would be easy for them to be intimidated or frustrated if simply asked to create something [11]-[12]. Such anxiety was partially mitigated by limiting the materials made available for the art creation (i.e., students have less choices to make). Second, the authors undertook background research and preliminary studies with different techniques so that the information could be provided to students with the goal of avoiding/reducing undesirable effects when students began working hands-on with a painting technique. The goal of the art creation was not to have the students master any technique, but rather to have a rewarding experience while seeing fluid mechanics phenomenon in action.

This project supports core concepts in fluid mechanics, particularly regarding the properties of density, viscosity and vapor pressure. In a typical lecture course these properties would be numbers taken from tables to be used in problems while their practical importance may remain nebulous. With the painting techniques presented here, the relevance of these fluid properties, their magnitudes and their modification to achieve desired effects gives students a clearer understanding for their importance. For example, by explaining that the unique smell of spray paints relates to the inclusion of hydrofluorocarbons with high vapor pressures whose phase change propels the paint from the can a student can see potential design goals related to vapor pressure. Additionally, the painting techniques allow students a glimpse into graduate-level fluid mechanics phenomenon such as the aforementioned instabilities.

While the activity described departs from a more typical engineering lab experience of taking measurements, analyzing data, answering technical questions, etc. we feel that as a hands-on learning experience within an engineering program it merits consideration. This paper describes the first iteration of the project and key insights followed by what has been learned to-date in the second iteration including desciptions of the fluid painting technique, relevant fluid mechanics principles, materials used, lessons learned, and examples of final products.

First Iteration

The first attempt at having students make their own fluid art was conducted in spring 2021. Students taking fluid mechanics were offered up to 0.5% extra credit towards their final grade if they made a painting and completed a short assignment. This iteration focused solely on drip/splatter painting and spray painting and students could use one or both techniques when painting. Materials were provided for the students. The engineering faculty were asked to donate extra house and spray paints from home and this supply was supplemented by paints stored by the department (including some paint balls) and a small number of store-bought paints in order to increase the color options. Instead of canvas, students applied the paint to scrap plywood and siding, most of which was primed by student mentors for the course. On the last day of lecture, students were shown short YouTube videos of the two fluid art techniques. Then, in the afternoon of that day, the instructor brought all of the painting materials to the lawn outside the engineering building and students could play with the supplies as they saw fit. Figure 1 shows examples of art made in the first iteration.

Figure 1. Drip painting and spray paint art made during first iteration of fluid art project

Upon making the art, student were then asked to write a short report to address the following:

- Explain how fluid mechanics was involved and any fluid mechanics principles at play
- Explain how you created the work (materials used, steps, etc.)
- Explain what you find interesting about the piece of art or - how does it make you feel?

These questions led to many interesting conversations where the instructor could point out fluid mechanic phenomenon that the students would look-up in order to complete the assignment. Key insights from the first iteration include:

- Project was more popular than anticipated – 63% of the class participated
- Some students made multiple pieces of art so that they could keep one for themselves
- Incredible atmosphere during the afternoon of art creation – depsite being a stressful time of the semester students were smiling, encouraging each other
- Paintball paint is not great to use – ours was very oily and refused to dry
- Assignment questions seemed to evoke more creative responses and less depth on fluid mechanic principles (which was OK with instructor)
- Much of the art work created now decorates the walls of the fluid mechanics lab – receives interest from new students in course and during student tours

Second Iteration

Due to the success from the first implementation, both in terms of participation rate and enthusiasm, a more intentional and systematic approach was applied in order to grow the number of painting techniques made available to students to include spray painting, drip/splatter painting, pendulum painting, acrylic pour painting and spin painting. For each of these techniques there are many variables that lead to different effects which can be desireable or undesireable depending on what aesthetic the user is intending. In order to better understand these variables and explain how they can impact the fluid art that is generated, background research was conducted for the techniques. The goal of these efforts was not an attempt to make a science of the artistic process, but rather to understand cause and effect relationships whose understanding could serve as a starting point for somebody new to a painting technique. This research was then used to create short videos for students interested in pursuing a given technique. Even with the research conducted it is clear that one benefits greatly from hands-on experience. However, the preliminary work creates a knowledge base that can be shared with students considering a given technique (ex. "this painting was made using this paint mixed at this ratio and applied using…"). Thus, a student can look at completed works, learn how they were made and use that as a starting point for their creations. As the number of projects increases in the future, with proper documentation, the database of knowledge will continue to grow.

A common thread to these fluid painting techniques is the importance of paint consistency. Artists commonly modify the paint as it comes from the manufacturer as a means of getting desired properties. These modifying agents are called pouring medium, or paint conditioners, and can involve multiple products being combined in various ratios. Floetrol is a lower cost, readily available option for conditioning paint and our hands-on research used this as the sole conditioner in order to reduce the number of variables. The mixing of a paint with Floetrol can modify the viscosity (most importantly) as well as the density. This typically results in a less viscous paint that is self leveling and has an increased dry time. Floetrol generally increases the volume of paint mixture that one applies with limited modication of paint color. The consistency of the latex and acrylic paints varied from paint to paint. Thus, there is not a single mixing ratio that can be applied for all paints to achieve a desired effect. A gallon of Floetrol costs ~$15 which is a smaller dollar per volume price than most paints. This helps with cost savings as the volume of more expensive paints are expanded by the addition of Floetrol as viscosity alterations demand.

For the second iteration it was decided to use hardboard panels as the substrate upon which paint would be applied. This was considered a reasonable compromise between buying more expensive stretched canvases and using free/scrap materials. If one cuts up a large panel of hardboard and primes it (two coats recommended but not necessary) it costs roughly five times less than buying stretched canvases of similar size. It is easy to reuse these boards by applying more coats of primer. In reality one could use paper or cardboard for some of the painting methods, however the substrate can warp due to moisture absorption from the paint. What follows is a brief description of things learned from the background research on different painting techniques.

Drip/Splatter Painting

Many of the relevant fluid mechanic principles for drip painting are described in [3]–[5]. Jackson Pollock used many tools when painting: new paint brushes, old dried out paint brushes, wooden sticks (stir sticks), turkey basters, direct pours from paint cans. Other tools can be used to create similar effects including rubber spatulas and letting paint drip/stream from handles of paint brushes. Generally, using higher viscosity paint is better for creating lines of paint and lower viscosity paint is better for a splatter effect. Paint viscosity can be reduced with water, in addition to Floetrol, however if the paint viscosity is too low the splatter effect can be less distinct. The following videos offer a good breakdown of various methods for creating a Pollock-like painting [13]-[14].

Experiments were conducted in which the paint viscosity, tool and application techniques were varied. The experiments were done with multiple latex paints to confirm the repeatability of the trends. The two application techniques involved an arm/wrist flick motion to throw paint towards the canvas and a drip technique where gravity caused paint to stream from the tool. Figures 2-3 show many of the results. When using a flicking motion, a 2” rubber spatula throws more paint resulting in bigger/more splats plus some smaller droplets in comparison to a 2” nylon bristle brush. This results was consistent for both high and low viscosity paints. The high viscosity paint shown in Fig. 2 had a viscosity too large to be measured with a #3 Zahn cup. Its consistency was between gravy and pudding. The low viscosity paint mixture shown in Fig. 2 is the high viscosity paint mixed with Floetrol at a 1:7 (paint:Floetrol) volume ratio. Measuring the viscosity of this mixture with a #3 Zahn cup revealed a viscosity of 55 Zahn-seconds, or 556 centiStokes, which is slightly more viscous that SAE 30 oil at room temperature.

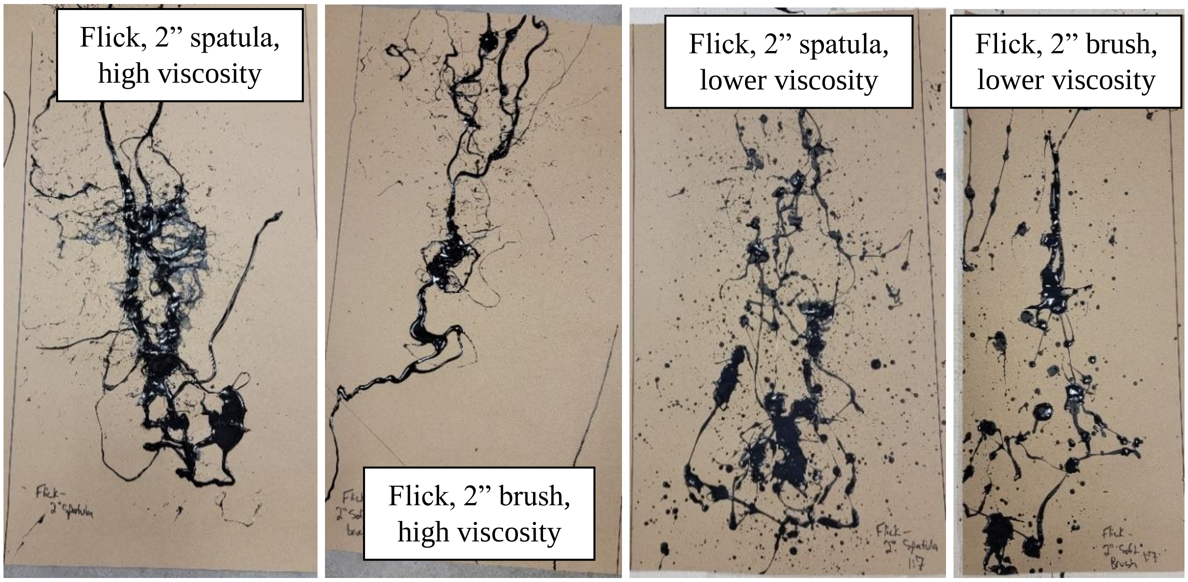

Figure 2. Comparison of flicking paint from a rubber spatula vs. 2" nylon brush at different viscosities

Similar experiments were conducted where the application technique was letting gravity pull the paint off the tool (drip technique). Tool choice had a small impact on the resulting paint pattern. When a clean 2" nylon brush was used to drip viscous paint, the lines that formed were slightly thicker than when using the handle of a spatula (Fig. 3). Results also showed that a higher viscosity paint is more likely to give solid lines without breaks while a lower viscosity paint is more likely to give drips of paint, or lines that are interspersed with drips. Figure 3 also shows evidence of viscous coiling when the high viscosity paint was applied.

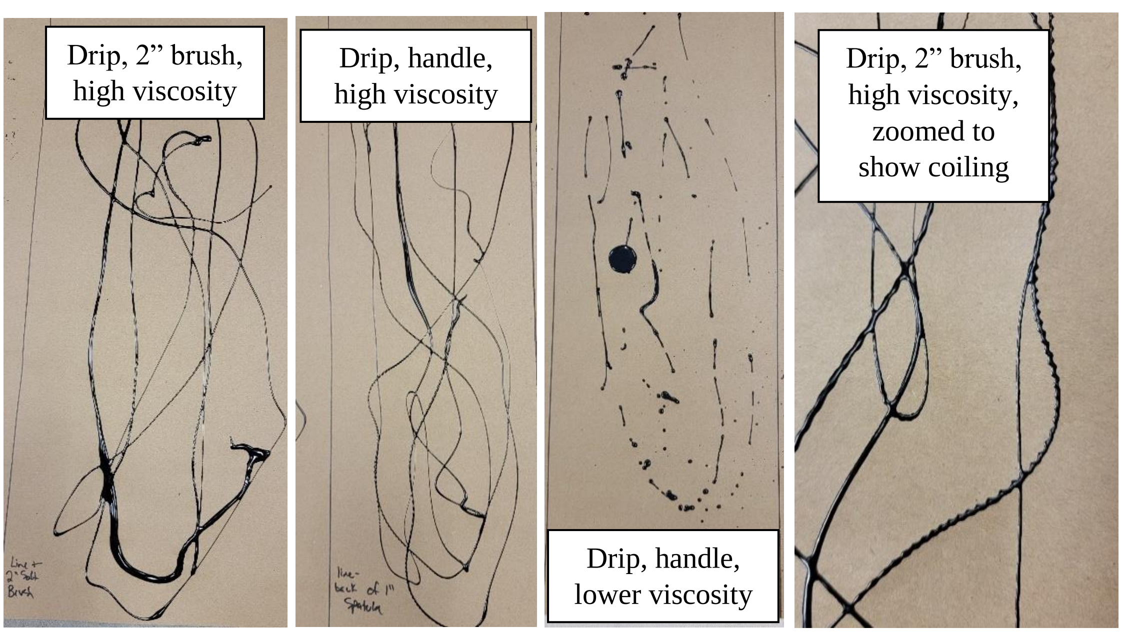

Figure 3. Comparison of paint lines formed using drip technique with different tools and viscosities

Figure 4 shows a painting made by a student after practicing with the different tools, paints and paint viscosities. The drip painting technique is one that is relatively fast to learn. In practice a student could learn what they need to know by testing tools, arm techniques and paints on a drop cloth prior to making their final piece of art.

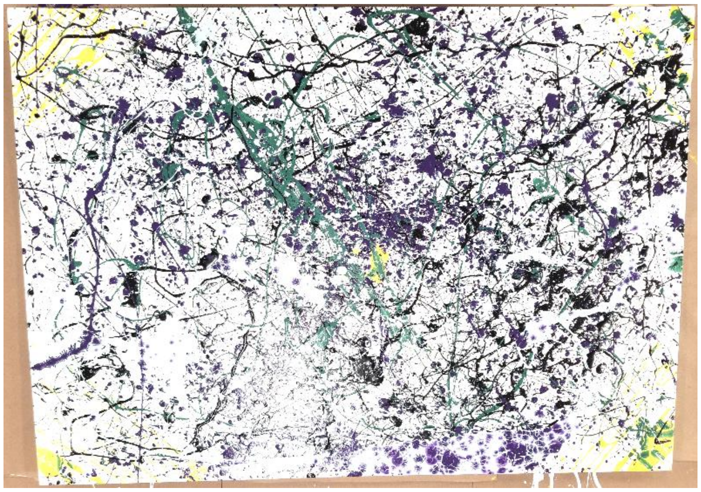

Figure 4. Example of drip painting technique completed after short training

Materials used: leftover latex paints, Floetrol, 1” and 2” rubber spatulas, 1” and 2” nylon bristle paint brushes, craft sticks (for dripping off of), mixing cups, white primer, hardboard panel

Pendulum Painting

Pendulum painting involves paint streaming from a hole in the bottom of a paint-filled cup as it swings like a pendulum over a canvas. The visual features of the painting depend on the fluid properties of the paint as well as the cup motion. This painting method represents a gravitationally driven flow through an orifice resulting in a viscous free jet that may be affected by Plateau-Rayleigh instabilities. The pendulum motion also presents a periodic variation in the forces driving the paint through the orifice. When the cup is at the top of its swing it has a smaller acceleration compared to when it is at the bottom of its swing. The pendulum motion also makes it possible to form both oval shaped patterns as well as Lissajous patterns with a simple modification to the set-up [15].

A series of experiments using latex paints was performed to understand the importance of variables that can effect this painting technique including: length of pendulum, distance of cup above the canvas/board, paint viscosity, volume of paint in the cup, orifice diameter and amount of added weight taped to the outside of the cup. Many of these variables affected the look of the painting with the main obersvations relating to the thickness of the paint line that formed and the propensity for paint to hit as drips vs. a stream. Figure 5 shows the difference between paint that dripped compared to paint that nicely streamed out of the cup and Table 1 summarizes many of the observations. It is noted that these results held true for different latex paints, however the ratio of Floetrol needed to maintain a steady stream of paint could change depending on the consistency of the paint.

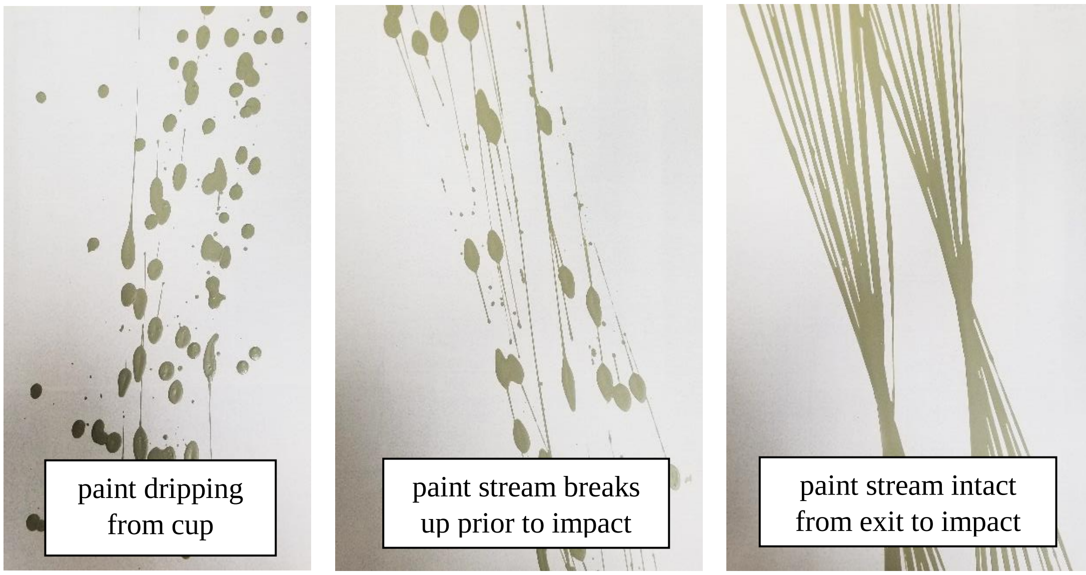

Figure 5. Patterns made via pendulum paint

Table 1. Conclusions made from pendulum paint experiments

Cause	Effect
paint viscosity too low	paint flows too fast, stream could break-up
paint viscosity too high	paint comes out of hole as drops, not stream
cup displacement from center too high	more wasted paint that misses canvas
cup displacement from center too low	paint lines fall more closely together, also depends on angular rate
paint volume in cup too low	lower driving pressure = paint more likely to drip than stream
added weight too low	cup more likely to wobble = paint stream can break up into drips and lines
added weight too high (max tested = 20 oz.)	no problem seen on painting; slighly cumbersome to tape a lot of weights on
shorter line length	thinner paint lines
paint cup too high above canvas	paint stream breaks into droplets
exit orifice diameter too low	paint more likely to drip

While one may like the look of drips, should they prefer to have solid lines of paint on their canvas/board we note the following from our experiments:

- keep cup exit orifice close to the canvas/board, ~1-2”
- 5/64” diameter exit hole worked well, smaller diameters resulted in dripping (possible this could be overcome with greater viscosity reduction than we did)
- paint volumes below 80 mL (~3 liquid ounces) resulted in drips

- be ready to block paint from cup from hitting canvas/board and catch cup if you notice drips start

A few additional notes may prove helpful to others starting out with the pendulum paint method. The period (T) of the pendulum depends on the line length (L) and gravity: $T = 2\pi\sqrt{\frac{L}{g}}$. Thus, the cup speed is determined by the displacement from its resting position in combination with the length of the pendulum. Higher cup speeds, as wells as smaller exit orifice diameter and lower viscosity paint made thinner paint lines possible. To get a sense for what kind of lines or drips one will get for a given set of conditions, one can test their paint flow by swinging the cup without a canvas/board in place. Though it may waste a small amount of paint, it can save a lot of time should the flow effect be undesired. If the paint stream looks good simply catch the cup, cover the hole with tape, and position your canvas/board appropriately then start the pendulum with paint flowing. This approach does not guarantee that drips will not start to form as the amount of paint in the cup decreases, but is good practice nonetheless.

Finally, in order to have a portable pendulum apparatus that could be stored easily we clamped a unistrut channel between two step ladders as shown in Fig. 6. Lumber could be used in place of the unistrut as well. Another good example of an inexpensive set-up is found in [16].

Figure 6. Simple paint pendulum set-up

As with drip painting, one can make progress quickly with pendulum painting resulting in a relatively low threshold to overcome in order to achieve desired aesthetic results. The orderly and mathematical patterns generated are likely to appeal to engineering students. While not yet explored directly, this technique allows for creative exploration of layering paints of different colors within the pendulum cup, developing a tray that would allow multiple cups to distribute many colors simultaneously or modifiying the set-up to create Lissajous patterns. We saw that the majority of instructional Youtube videos on pendulum painting utilize acrylic paints; our experiments show reasonable results with latex paints as well. The simple set-up required, low cost of materials in order to practice and clear ties to fluid mechanic phenomena make it an attractive option for meeting the outcomes of the fluid art exercise.

Materials used: leftover latex paints, Floetrol, mixing cups, white primer, hardboard panel, eye bolt, unistrut between two ladders, braided fishing line, fish hooks, fishing leader wire, 2.5 oz. bank sinkers (or similar added weight)

Spray Painting

Spray paints present numerous fluid mechanic phenomenon including atomization, the expansion of hydrofluorocarbons as a means of propelling paint, mechanical mixing of fluids that have fallen out of suspension (i.e., why you shake the can and hear a rattle), and the use of solvents to reduce viscosity to permit fine atomization. Industrial paint sprayers can use compressed air to achieve the desired atomization qualities thus preventing the need for liquefied gasses found in commercial spray paint cans. The hydrofluorocarbons used as propellants in commercial cans have high vapor pressures to ensure they expand and maintain a large driving pressure within the can. For example, Butane 40 has a vapor pressure of 40 psi [17]. Since much of the propellant stays in liquid form it can be mixed in with the paint as it travels out of the can and its expansion during this process also drives atomization.

Artists who use spray paint have an incredible variety of spray paints that can be acquired from specialty stores. For example spray paints can come with different pressures that determines the rate of paint output. These specialty paints are often higher-priced and were not considered within the scope of our project. An interested reader is directed to [18] for more information. The cap from which the paint exits is a key variable in creating different visual effects. The cap that comes with the paint is called a stock cap, though this can be swapped out with a fat cap or a skinny cap which can be purchased separately (sprayplanet.com). Typically an adapter is needed so that the fat or skinny cap can fit the female connection of a commercial spray paint can. These caps effectively control the pattern of paint spray. Fat caps are commonly used to generate large spray patterns that can fill in large areas in a short time, though with a reduction in control. Skinny caps are useful for detailed work such as outlining.

The other main factor that determines the appearance of the applied spray paint is “can control.” Can control is a combination of multiple factors that pertain to the can orientation and trajectory relative to the canvas/board/wall as well as how the cap is being pressed. Variables that fall within the umbrella of can control include: distance of can from canvas, speed of can motion, angle between spray cap and canvas and pressure applied to cap. For a given paint can pressure and cap choice, many different painting effects can be created through can control techniques as shown in Fig. 7. Two useful references for better understanding cap choice and can control are [19]-[20]. Our hands-on research with spray painting techniques was limited due to our good fortune to have an in-house spray painting artist as a lab manager.

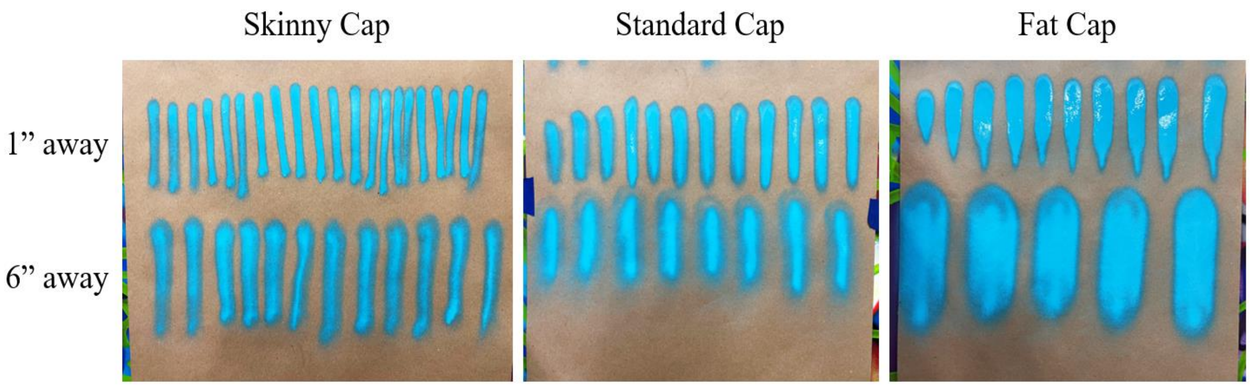

Figure 7. Lines made using different caps with can 1” away (top row) and 6” away (bottom row) from paper

It is noted that the use of spray paints was particularly popular among students. Many students enjoyed applying the drip painting technique on top of a spray painted backgroud. We have a smaller supply of left over spray paints than latex paints and plan to supplement with more purchased paints in the future. This technique is quite forgiving in that the paint dries quickly so a student can paint over anything they find displeasing. One common problem involved caps becoming clogged. To address this in the future we will have extra caps on hand as well as a small pin/needle and brake cleaner to try to clear clogs.

Materials used: leftover spray paints, male-female cap adapter, fat caps, skinny caps, extra standard caps, hardboard panels, brake cleaner, small pin/needle

Acrylic Pour Painting & Spin Art

Acyrlic pour painting involves pouring acrylic paints of different colors onto a canvas/board. There are many methods for spreading the paint on the canvas and good resources that detail this variety are [21]-[23]. In this study we focused on two techniques for spreading the paint: 1. tilting the canvas/board to allow the paint to flow, 2. mechanically spinning the canvas/board thus using angular acceleration to cause the paint to flow. The viscosity of the paint is particularly important for controlling not just the rate of flow during tilting or rotation, but also the amount of mixing between colors.

As paints of varying density can be layered in this technique is is possible to develop Rayleigh-Taylor cells within the art. Density measurements of the acrylic paints used in our trials are shown in Table 2. It is noted that these densities are for the paints prior to being mixed with Floetrol which had a density of 1 g/mL. Zetina, Godinez and Zenit [4] demonstrate the formation of Rayleigh-Taylor cells in paint by pouring a denser paint on top of a less dense paint. With a paint density difference of 10% (Atwood number = 0.05) their cells formed after ~225 seconds demonstrating the relevance of density ratio and time for cell formation. Additionally we found that paint viscosity also affects the formation of cells. Figure 8 shows that larger cells were created with less viscous paint than more viscous paint despite a smaller density ratio.

Table 2. Densities of different color acrylic paints

Acrylic Paint	density (g/mL)
Mural Paint Calypso Turquoise	1.11
Mural Paint Scorched Yellow	1.17
Mural Paint Pucker Magenta	1.17
Mural Paint Slime Green	1.06
Mural Paint Purple Haze	1.06
Mural Paint Blacktop	1.22
Mural Paint Polar White	1.39

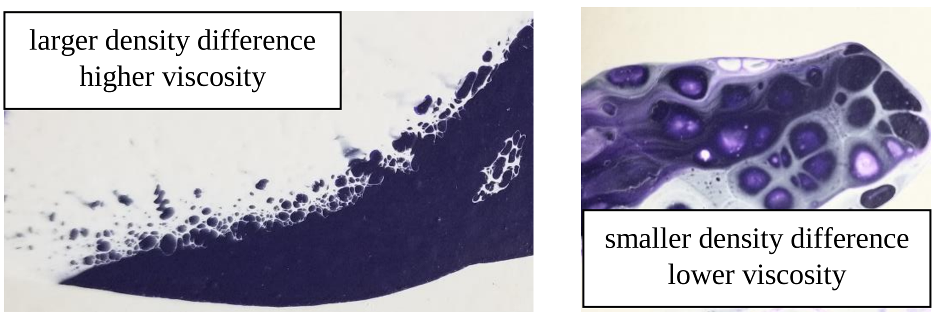

Figure 8. Example of Rayleigh-Taylor cells formed in trials

In creating an acrylic pour painting one can pour individual colors onto a canvas, or add colors as layers into a single cup before pouring (Fig. 9). This latter method is called a dirty pour. By putting denser paints into the cup and layering less dense paints on top of them, one creates conditions that can lead to cell formation once the paint is poured. Another method artists use to ensure cell creation in their painting is the addition of low density additives, such as silicone oil, to the paints. The silicone can travel up through the paints while dragging different colors to create unique patterns.

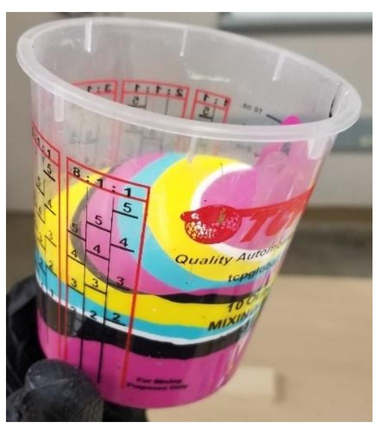

Figure 9. Example of a dirty pour cup to be used for acrylic pour painting

The number of variables that impacts the final look of an acrylic pour painting was deemed too large to approach systematically when considering the dirty pour method. These variables include the consistency of each paint used, how they are added to the dirty pour cup, whether additives are used to promote cell creation, how the paint was poured from the cup onto the canvas/board and how the board was tilted to spread the paint around. Also, if the spin apparatus is used then one has decisions on whether the board is spinning during the pour or spun afterwards and what RPM to use. Our background research started with lessons from those with experience followed by hands-on practice targeting key variables. Those with experience shared the following information:

- to estimate how many ounces of paint to use, divide the area of your canvas/board in inches^2 by 25 [21]
- paint consistency of warm honey or heavy cream is desirable [22]
- more viscous paint = less likely to blend with other paints, but harder to move by tilting
- less viscous paint = colors more likely to blend and turn muddy [22]
- to have colors blend less, pour paints down the side of the dirty pour cup when layering them [22]
- when doing spin art, put down a layer of white paint before pouring - this helps paint travel once it is spun [22]
- let dry for 2-3 days [23]

Our hands-on trials confirmed the above and allowed for additional conclusions that may be of use for an instructor looking to get started with pour painting. Perhaps the most important lesson was that attractive paintings can be made without requiring a significant commitment, though the trend of practice leading to better results holds true. For example, Fig. 10 shows the third acrylic pour painting made during our practice (left) and the second painting made with the spin apparatus (right) both of which we find visually appealing. We recommend erring on the side of more viscous paints and less colors (3-5) when starting in order to mitigate problems with too much color blending and the compostion looking busy.

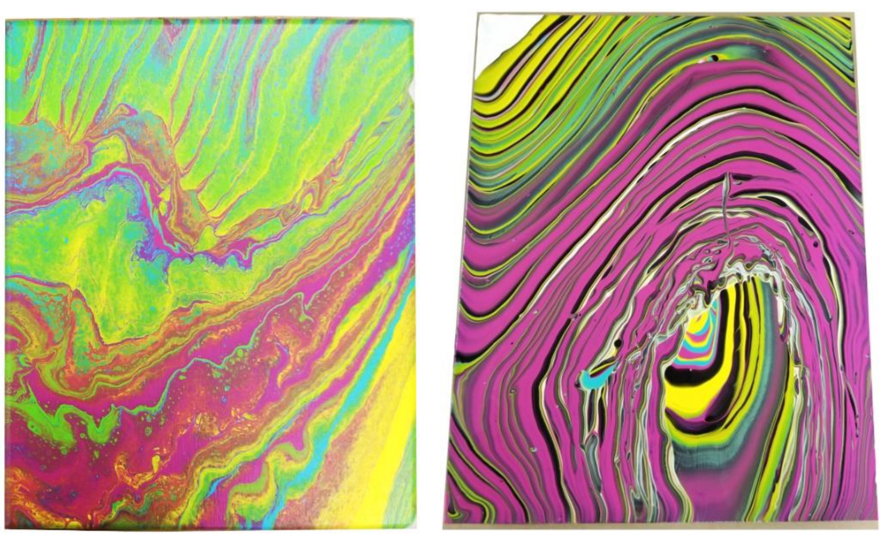

Figure 10. Acrylic pour paintings made in research phase using the tilt (left) and spin (right) techniques

The acylic pour techniques do present some challenges. The use of additives adds another layer of complexity and reduces the repeatability of the process. It seems that having better control over cells takes more practice than what would be expected of students in this project. As it will take the instructor more practice to gain competency with intentional cell formation we advise students against using additives or at least give a disclaimer to keep reasonable expectations. The acrylic pour method is harder to practice at a small scale than the drip art, pendulum painting or spray painting. Thus, students may need to make a larger painting during practice, possibly even full size in order to know what effects will be revealed. Due to this, and the fact that acrylic paints likely need to be purchased as opposed to donated, this method is the most cost and material intensive. To examine cost savings potential we did some limited trials with latex pours. These did not produce great results– colors seem more likely to blend, potentially due to viscosity of paint mixtures being too low. Despite these challenges, the act of acyrlic pour painting can be very enjoyable and create attractive paintings.

The paint spinning apparatus (Fig. 11) developed for this project costs ~$150 and consists of a 12V 250W electric DC motor, a pulse-width modulation (PWM) speed controller, and a 12V battery. The motor is rated for 3000 RPM, but has a built in gear reducer of about 10:1, making the maximum operable speed about 300 RPM. The motor is mounted on wooden frame made from 2x4's. A small adapter plate made by welding the motor output shaft gear to a 2.5" stainless steel disc (Fig. 9) that connects the motor shaft with a spinning wood arm. A canvas/board can be easily attached to the spinning arm using hook and loop tape or screws.

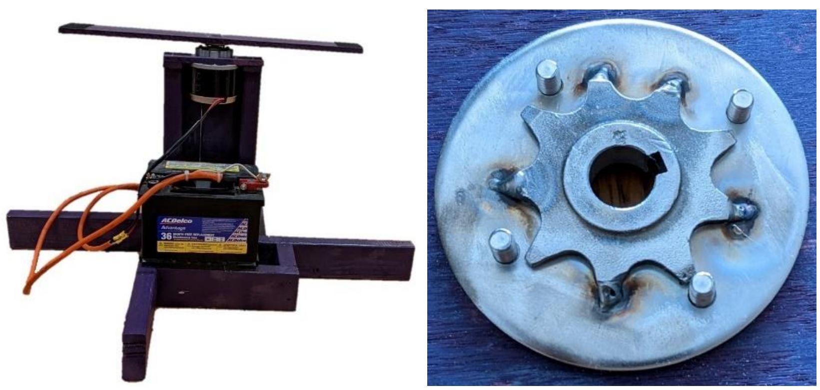

Figure 11. Spin art appartaus and adapter plate

Materials used: variety of acrylic paints (Mural Paint), Floetrol, mixing cups, white primer, hardboard, nitrile gloves (it gets messy) – spin apparatus specific parts include 12V 250W gear reduction electric DC motor, 7-70V PWM DC motor speed controller, 12 V battery, 16' of 2x4 lumber, 2' of ½ thick oak dimensional board (spinning arm), 1/8" thick 2.5" stainless steel disc (adapter)

Specific parts links: 250W electric DC motor and 7-70V (PWM) speed controller

- https://www.amazon.com/dp/B071NQ5G71?psc=1&ref=ppx_yo2_dt_b_product_details
- https://www.amazon.com/dp/B08BYQBVWY?psc=1&ref=ppx_yo2_dt_b_product_details

Potential Related Lab Activities

The fluid painting exercise can be incorporated into a course in many ways. As described, we have used it as an optional extra credit opportunity but there is potential for using it as inspiration for more traditional lab activities related to fluid mechanics. Below are some ideas for labs that could cover course content, provide insights relevant to the creation of fluid art and produce mixed paint in the process that could then be used to make art once measurements are complete.

1. Fluid property measurement and manipulation via paint conditioner – measure density, viscosity, and surface tension (needle drip technique [24]) of paint and examine how those values change when mixed with a paint conditioner. If a rotational viscometer is available this exercise could also examine non-Newtonian properties to identify if paint behaves as a Newtonian fluid at low shear rates as suggested by [4].

2. Rayleigh-Taylor cell formation and its dependence on density, viscosity, film thickness and time – similar to experiments done in [4] (acrylic pour painting relevance)

3. Dimensional analysis of jet break-up length [25]-[26]

4. Gravity driven flow through orifice as quasi-steady minor loss experiment

While one can make the project more rigorous as described, one could also consider reducing the rigor and using a painting project simply as a fun activity for students to try. The act of creating art and letting students explore their creativity will still involve learning, though perhaps in a more subtle way. Additionally, demonstrating an interest in the students having fun as part of one's class is a wonderful way to cultivate an atmosphere that promotes curiosity, student-instructor connection and questions.

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