experimental design

This document will summarize the experimental process followed for our “show-and-tell” component.

materials:

textiles	dyes	additives
Cotton (cellulose)	Pink, Purple, and Blue (mixed) Neon ClubHouse Food Colouring (acid)	Salt (neutral)
Jute (cellulose)	Purple Tulip One-Step Tie Dye (reactive)	Detergent (alkaline)
Paper Towel (pulp)	Royal Purple Rit DyeMore for Synthetics (disperse)	Vinegar (acidic)
Bamboo (regenerated synthetic)	Majestic Purple Diamine Fountain Pen Ink (ink)	
Polyurethane (synthetic)		
Nylon (synthetic)		
Acrylic (synthetic)		
Polyester (synthetic)		
Polyethylene (synthetic)		
Wool (protein)		
Silk (protein)		

- Due to resource constraints, not all the colours are ideal. Some of the textiles are unbleached, which is chemically ideal, but difficult to interpret visually. On the other hand, there are some with dyed neutral colours.
- There will be 32 dye baths. Only one dye bath must be prepared for each variation. All the fabric samples will be added to the *same dye bath*.
- Based on this, we will need about 16 mL of each dye. Note that these values may vary, since the dyes were each originally intended for different applications.

major experiment:

NOTE: Given the nature of different fabrics and dyes, it is unlikely that this experiment will give a perfect representation of the effectiveness of whole dye categories. Always maintain a holistic perspective when performing at-home experiments.

For safety, it is recommended that you do not use the same pots for dyeing that you use for cooking food. You may also wish to wear a mask when working with powdered dyes, as well as gloves should it be necessary to touch the dye solution.

1. Cut swatches of fibrous materials, approximately 1" by 6" each. (For yarn samples, cut pieces 24" long and fold them into quarters.) Aim for a total of 9 g.
2. Presoak in room temperature water. Do not add anything to this solution. Leave to soak for 10 minutes. Gently squeeze to get rid of excess water before adding to the dye bath.
3. Add 225 mL water to a clean jar. Note that this jar should be transparent to facilitate notetaking and must be heat-resistant to ensure safety.
4. IF RELEVANT: bring 2 L of water to a boil. Place a cooling rack over the pot, then place the jar on top of the rack. (Another double boiling set up may be used if more accessible. Alternatively, the jar can be skipped entirely, and the dye bath can go directly into the pot. Do whatever is most accessible and safe in your environment.)
5. IF RELEVANT: add 2.5 mL additives to the dyebath.
6. Add 2 mL of dye to the jar. Stir well. (This concentration may vary when working with different pigmentations. See the math for the procedure in this regard.)
7. Add textile subjects to the dyebath, submerging fully.
8. Let sit for 30 minutes, maintaining a constant temperature. Do not stir. You may wish to use a chopstick or other small utensil to keep textiles submerged.
9. Remove fabrics from the dyebath. Lay flat to dry.
10. IF RELEVANT: Rinse half of each strip in cool water until water runs clear.
11. OPTIONAL: Add scrap fabric to the dye bath to exhaust any remaining colour. You may wish to change additives or temperature in order to best use up resources.

This experiment should shed light on the wicking properties of fibre, the colour fastness of the dye, and the speed of bonding. Take notes and record the process throughout to ensure that nothing is missed.

minor experiments:

In order to prove smaller points that relate to the topic at hand, minor experiments were also performed. These applied to a smaller range of test subjects.

The purpose of this experiment is to demonstrate the composition and chemical properties of various fibres.

1. Cut a small piece of fabric.
2. Pick up the piece of fabric using tweezers.

3. Using a lighter, apply flame to the fabric.
4. Remove from flame.
5. If the flame continues to burn, extinguish it.
6. Once the fabric has cooled, gently crush the burned area between fingers.
7. Document observations.

The purpose of this experiment is to demonstrate the pH levels of various fibres and dyes. This explains why certain dyes can adhere to certain fibres.

1. Boil water. Test acidity with a pH strip. The result should show that the water is neutral. In any case, this value should be *treated* as neutral, since we are making a comparative examination.
2. Add undyed fabric. Test acidity again, and note any changes.
3. In a separate container, add dye, and test the acidity.

appendix: math

Calculations were done before to draw conclusions regarding how much material should be used.

I. water level

To allow for free movement of the fabric, average liquor ratios (grams material : milliliters liquid) tend to be between 1:15 and 1:40, per a [ResearchGate forum](). Since this is a range, we will use it to make sure that our results are reasonable.

In order to effectively examine dye uptake, it is necessary that the water level of the dye bath significantly exceeds the thickness of the textiles. Liquid absorption should also be taken into account, as should potential evaporation.

The greatest thickness is about ⅛″ for some of the yarn subjects (8 wpi). Consequently, the dye should rise to at least 1″ above the fabric to ensure full coverage.

The bottle's diameter is 2.75″.

$$
\begin{aligned}
A_{base} &= \pi r^2 \\
&= \pi \frac{2.75^2}{2} \\
&= \pi 1.89 \\
&= 5.94
\end{aligned}
$$

In order to obtain at least 1″ water level, we would therefore require about 6 cubic inches of water. This converts to 98.32 mL, which I will round to 100 mL.

The volume of the fabric itself is not easily calculated, so we will go with an extremely approximate estimate instead. I somehow decided that the density of fabric is probably about the same as rolled oats, and used [this]() chart from AllRecipes to calculate what this meant numerically. Since we need about 10 grams of fabric, this is about ⅛ cup, or 31.25 mL. About 4 times this amount is needed to ensure the fabric can breathe, so the total here is 125 mL. Summing this with 100 mL yields 225 mL. Consequently, the minimum amount of water needed based on the size of the jar is 225 mL.

Using 225 mL for 10 g is a liquor ratio of 22.5:1. This is reasonable, per our range from 15:1 to 40:1. Therefore, we will use 225 mL water in our experiment.

II. liquid dye concentration

This recipe calls for a ratio of 20 drops of food coloring to ½ cup of water. It also includes vinegar, which is used later as an additive but is not part of our base recipe. If we convert these values to milliliters using conversion factors, we get the following:

$$20\ drops \times \frac{0.05\ mL}{1\ drop} = 1\ mL$$
$$0.5\ c. \times \frac{250\ mL}{1\ c.} = 125\ mL$$

We have a mL ratio of 1:125. In our experiment, we use 250 mL of water.

$$\frac{1\ mL}{125\ mL} = \frac{x}{225\ mL}$$
$$\frac{225\ mL}{125} = x$$
$$1.8\ mL = x$$

Therefore, 1.8 mL of food colouring should be used in our experiment.

Rit's instructions for dyeing can be found here. For DyeMore, Rit recommends that 1 bottle -- which contains 206 mL of dye -- be used to dye 2 lbs of fabric. (They recommend doubling the quantity of dye for either a darker shade or if dyeing polyester. We disregard this instruction, since observing the behaviour of different fibres is part of our experiment.) This means that ½ a bottle should be used per pound of fabric. Furthermore, they recommend using 3 gallons of water per pound of fabric.

$$3\ gal \times \frac{3785.41\ mL}{1\ gal} = 11356.2\ mL$$
$$0.5\ bottle \times \frac{206\ mL}{1\ bottle} = 103\ mL$$

$$\frac{103\ mL}{11356.2\ mL} = \frac{x}{225\ mL}$$
$$\frac{23175\ mL}{11356.2} = x$$
$$2.04\ mL = x$$

We can now take an average of these values. This yields 1.92 mL. The closest measurement we can realistically achieve is 2 mL. Therefore, we will use 2 mL liquid dye in each of our dye baths.

III. powder dye concentration

We can use these numbers to derive values for the Tulip dyes. It is worth noting that Tulip is not particularly precise about how much their products can dye. Since they are intended for children's tie-dye, use can vary wildly. Furthermore, they come in powdered form, and simply tell you to fill the bottle with water and then shake -- not exactly the most precise measurement. Their pack of 18 dyes up to 36 "projects", while their pack of 8 dyes up to 12 "projects". 10 dyes are somehow enough for 30 "projects". These ratios are quite clearly different, despite the fact that the bottles of dye for each kit are sized exactly the same (2.75 fl oz, or about 80 mL). There is also no real specification for what a "project" comprises -- it could be one sock, or it could be a puffer jacket. No one knows.

Consequently, this math is mostly used to check that the numbers for this product are not wildly different from the liquid dyes. It will not be used for precision. I'm going to look at all three kits mentioned above, so that we can get a holistic view of what the manufacturers might have *meant*. We will calculate projects/bottle, and then mL/project. Recall that there are 80 mL in each bottle.

18 pack:

$$\frac{36\,projects}{18\,bottles} = 2\,projects/bottle$$
$$\frac{80\,mL}{2\,projects} = 40\,mL/project$$

10 pack:

$$\frac{30\,projects}{10\,bottles} = 3\,projects/bottle$$
$$\frac{80\,mL}{3\,projects} = 26.67\,mL/project$$

8 pack:

$$\frac{12\,projects}{8\,bottles} = 1.5\,projects/bottle$$
$$\frac{80\,mL}{1.5\,projects} = 53.33\,mL/project$$

This averages to 40 mL/project.

These numbers can be compared to the Rit dye. A t-shirt weighs 4.5-5.3 oz, so we can approximate that 1 lbs comprises about 3.5 t-shirts.

$$\frac{103\ mL}{3.5\ projects} = 29.43\frac{mL}{project}$$

This is fairly different from the average value obtained for the Tulip dyes. However, the Tulip dyes were literally all over the place. Ultimately, it is determined that given the unpredictability of the Tulip dyes, it is most convenient to simply use the same volume of dissolved Tulip dye as bottled Rit dye.

IV. ink concentration

Fountain pen inks are not meant for dyeing. As a result, there are no specifications anywhere for what a reasonable concentration might be. We must resort to educated guesses. On that note, a warning for this section: since ink isn't professionally used for dyeing, there is not really any reliable information to cite. Instead, internet chatter will be linked in order to give at least some support to our admittedly flimsy hypotheses.

Here, a user on Fountain Pen Network posted their experiments with using Procion as fountain pen ink. Their experiment used 5 drops of photo flow, 5 drops of glycerine, 18 mL of deionized water, and 0.5 tsp of Procion Fire Engine Red dye powder. This recipe is obviously engineered for use in a fountain pen rather than for dyeing, but it will give us important information on the conversion of dye to fountain pen ink (and vice versa) nonetheless.

A drop is generally considered to be about 0.05 mL. A teaspoon measures 5 mL. Using this information, we can calculate the total volume of liquid used to dissolve the dye powder:

$$\left(5\ drops \times \frac{0.05\ mL}{1\ drop}\right) + \left(5\ drops \times \frac{0.05\ mL}{1\ drop}\right) + 18\ mL = V$$
$$18.5\ mL = V$$

Jacquard, who produces the Procion MX dyes, has their own recipe for standard preparation of dye stock. It is linked on this webpage. Of note, they suggest adding soda ash and salt to the mixture as well -- very much a valid point, but one that we will be ignoring here, since it regards helping the dye to bind rather than the dye concentration itself.

For immersion dyeing, they recommend 3 gallons of water to one pound of fabric, which is the same as Rit. They have different recommendations for dye amounts depending on the desired shade. We will use the "medium" recipe, which is 1 tablespoon dye to 3 gallons of water. Converting this to mL, we get 15 mL dye to 11356.24 mL water.

At this point, we can begin to compare the recipe for ink and the one for dye.

$$\frac{18.5\ mL}{2.5\ mL} = 7.4$$
$$\frac{11356.24\ mL}{15\ mL} = 757.08$$

These numbers are *wildly* different. There is about 100 times the ratio of water to powder when preparing dye stock. The logical assumption, then, must be that the concentration of ink is 100 times that of dye. This number is too large to accept based on such a small amount of evidence.

On the other hand, this Redditor's experiments seem to suggest that food colouring can be used as fountain pen ink (although it is perhaps a little too unconcentrated). This would suggest that food colouring and ink have approximately the same concentration. This is contradictory to the math above. *However*, as the food colouring used in that experiment was not from an English company, I'm not familiar with the brand, and I've been unable to find it online. Consequently, I do not have any clue how saturated *that* food colouring is compared to the food colouring that *I* am working with. We must therefore find more information before drawing any conclusions.

Another Fountain Pen Network user posted their experiments with Queen Food Colouring. Much like the previous Redditor, they used food colouring straight out of the bottle. I *was* able to find this company online, and it seems that it's a gel food colouring. This means that it's more saturated than the liquid food colouring used in our experiments, although all the internet wants to tell me is that "gel is more concentrated than liquid", which is not a scientific ratio. More math is required.

I looked up some recipes from both ClubHouse (the brand of food colouring we are using) and Queen (the brand of food colouring the Fountain Pen Network user used). After a bit of looking, I located some samples of coloured frosting. I ended up narrowing the colour selection down to two dark blues that look relatively close in shade (left: ClubHouse, right: Queen):

(CW: blurry images)

Both recipes use homemade frosting, so it's difficult to nail down what the volume is. However, we know that the ClubHouse recipe ices 18 cupcakes, and that it says to divide the frosting into 2 bowls. Ergo, each recipe ices 9 cupcakes. AllRecipes says that you need 4-6 tablespoons of frosting to pipe one cupcake. Since the cupcakes feature frosting swirls, we lean on the side of more frosting -- 6 tablespoons.

$$6\,T \times 9 = 54\,T$$
$$54\,T \times \frac{15\,mL}{1\,T} = 810\,mL$$

$$100\,drops \times \frac{0.05\,mL}{1\,drop} = 5\,mL$$
$$\frac{810\,mL}{5\,mL} = 162\,mL$$

Therefore, this recipe calls for 162 mL frosting per 1 mL food colouring.

We can now examine the Queen recipe. The colour I picked is Royal Blue, which uses 10 blue drops and 1 black drop per batch of frosting. Queen's recipe for frosting can be found here. It also does not give us a yield size. Fortunately, this cupcake recipe uses pretty much the same buttercream recipe -- 250 g unsalted butter, 3 cups of icing sugar, and then flavouring and colouring. It yields 12 cupcakes, so we will assume that the frosting recipe can ice 12 cupcakes.

$$6\,T \times 12\,cupcakes = 72\,T$$
$$72\,T \times \frac{15\,mL}{1\,T} = 1080\,mL$$

$$10\,drops + 1\,drop = 11\,drops$$
$$11\,drops \times \frac{0.05\,mL}{1\,drop} = 0.55\,mL$$

$$\frac{1080\,mL}{0.55\,mL} = 1963.64$$

This time, there is only a difference of about 12 times, rather than 100 times.

Of note, the food colouring appears to be *slightly less saturated* than the Diamine ink in the poster's photos. There is only a comparison for the red, but I will take what I can get. Based on this, it is likely that the food colouring is not concentrated enough to fully behave as a fountain pen ink.

It is most reasonable to use somewhere between 20 and 100 times the concentration. It is not necessary to determine exact numbers within this range. We do not have the tools required to measure out such precise amounts of ink, so there is no point in trying to suss it out further. We thus concluded that we should aim for approximately 2 mL of fountain pen ink in total for all the dye baths; this is the smallest measurement we can realistically achieve. This treats the ink as 32 times more concentrated than the dyes. For accuracy within the experiment, we prepared this large dye bath all at once, then divided it into smaller portions for each of the experiments. This ensured that we could draw consistent results between trials.

math pt. v: additive concentration

The additives used in this experiment are all applied at the same concentration, since there is no real way to directly compare their strengths (unlike with dyes vs. inks). Perhaps an analysis might be done based on pH value, but frankly, each additive does far more than just alter pH. Consequently, it does not make sense to do calculations on that sole basis.

In this recipe for their All Purpose dye (a blend of acid, disperse, and direct), Rit recommends using 1 cup of additive. Naturally, they do not really say how much dye this is for -- but given that they earlier spoke about using 1 bottle for 2 pounds of fabric, I am going to assume that this is the case. They are also using 3 gallons of water for each pound of fabric, which is 6 gallons of water for 2 pounds. This gives us a ratio of 1 cup additive : 236 mL dye : 6 gallons water. Converting all of these values to mL, we get 250 : 236 : 22712 mL.

$$\frac{x}{225\ mL} = \frac{250\ mL}{22712\ mL}$$
$$x = \frac{56250\ mL}{22712}$$
$$x = 2.48\ mL$$

This is rounded to 2.5 mL (½ teaspoon) for practicality reasons.

math pt. vi: fabric weight

Now, we calculate the ideal total fabric weight. Since we are using swatches of various weights, this is not going to be applied (or calculated) with the utmost precision.

Lightweight fabrics can be 40 gsm, while heavier ones can be upwards of 300 gsm. A healthy balance can be found at about 200-250 gsm. We are working with a wide range of materials, some of which are multitudes denser than others. I will err on the lower side (200 gsm) since many of the textiles used in this experiment (e.g. chiffon, organza, etc.) are of lighter weight.

1 pound is equal to 453.59 grams. We can thus calculate the requisite weight of our fabric swatches based on the ratios established under section ii.

$$\frac{453.59\ g}{11356.2\ mL} = \frac{x}{225\ mL}$$
$$\frac{102058.2\ gmL}{11356.2\ mL} = x$$
$$8.99\ g = s$$

We are going to want about 9 grams of fabric. Based on this value, we can calculate the approximate area of fabric necessary. (Reminder: we are using a value of 200 gsm.)

$$\frac{9\ g}{x} = \frac{200\ g}{1\ m^2}$$
$$\frac{9\ g}{200\ g} = \frac{x}{1\ m^2}$$
$$0.045\ m^2 = x$$

$$0.045\ m^2 \times \frac{1550\ sqin}{1\ m^2} = 69.75\ sqin$$
$$69.75\ sqin \div 11 = 6.34\ sqin$$

This means that each strip should be close to 6.34 square inches. We used 1-by-6 inch strips, which is fairly close (and justifiable since some of the textiles may be heavier).

It is perfectly reasonable to point out that this means that there will likely be a significant amount of excess dye. For this reason, salvageable dye was recovered and used to dye other scraps (where possible).