2025

AP® Research Academic Paper

Sample Student Responses and Scoring Commentary

Inside:

Sample A

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Academic Paper — 5 Points

Score of 1 **Report on Existing Knowledge**	Score of 2 **Report on Existing Knowledge with Simplistic Use of a Research Method**	Score of 3 **Ineffectual Argument for a New Understanding**	Score of 4 **Well-Supported, Articulate Argument Conveying a New Understanding**	Score of 5 **Rich Analysis of a New Understanding Addressing a Gap in the Research Base**
• Presents an overly broad topic of inquiry.	• Presents a topic of inquiry with narrowing scope or focus, that is NOT carried through either in the method or in the overall line of reasoning.	• Carries the focus or scope of a topic of inquiry through the method AND overall line of reasoning, even though the focus or scope might still be narrowing.	• Focuses a topic of inquiry with clear and narrow parameters, which are addressed through the method and the conclusion.	• Focuses a topic of inquiry with clear and narrow parameters, which are addressed through the method and the conclusion.
• Situates a topic of inquiry within a single perspective derived from scholarly works OR through a variety of perspectives derived from mostly non-scholarly works.	• Situates a topic of inquiry within a single perspective derived from scholarly works OR through a variety of perspectives derived from mostly non-scholarly works.	• Situates a topic of inquiry within relevant scholarly works of varying perspectives, although connections to some works may be unclear	• Explicitly connects a topic of inquiry to relevant scholarly works of varying perspectives AND logically explains how the topic of inquiry addresses a gap.	• Explicitly connects a topic of inquiry to relevant scholarly works of varying perspectives AND logically explains how the topic of inquiry addresses a gap.
• Describes a search and report process.	• Describes a nonreplicable research method OR provides an oversimplified description of a method, with questionable alignment to the purpose of the inquiry.	• Describes a reasonably replicable research method, with questionable alignment to the purpose of the inquiry.	• Logically defends the alignment of a detailed, replicable research method to the purpose of the inquiry	• Logically defends the alignment of a detailed, replicable research method to the purpose of the inquiry.
• Summarizes or reports existing knowledge in the field of understanding pertaining to the topic of inquiry.	• Summarizes or reports existing knowledge in the field of understanding pertaining to the topic of inquiry.	• Conveys a new understanding or conclusion, with an underdeveloped line of reasoning OR insufficient evidence.	• Supports a new understanding or conclusion through a logically organized line of reasoning AND sufficient evidence. The limitations and/or implications, if present, of the new understanding or conclusion are oversimplified.	• Justifies a new understanding or conclusion through a logical progression of inquiry choices, sufficient evidence, explanation of the limitations of the conclusion, and an explanation of the implications to the community of practice.
• Generally communicates the student's ideas, although errors in grammar, discipline-specific style, and organization distract or confuse the reader.	• Generally communicates the student's ideas, although errors in grammar, discipline-specific style, and organization distract or confuse the reader.	• Competently communicates the student's ideas, although there may be some errors in grammar, discipline-specific style, and organization.	• Competently communicates the student's ideas, although there may be some errors in grammar, discipline-specific style, and organization.	• Enhances the communication of the student's ideas through organization, use of design elements, conventions of grammar, style, mechanics, and word precision, with few to no errors.
• Cites AND/OR attributes sources (in bibliography/ works cited and/or intext), with multiple errors and/or an inconsistent use of a discipline specific style.	• Cites AND/OR attributes sources (in bibliography/ works cited and/or intext), with multiple errors and/or an inconsistent use of a discipline specific style.	• Cites AND attributes sources, using a discipline-specific style (in both bibliography/works cited AND intext), with few errors or inconsistencies.	• Cites AND attributes sources, with a consistent use of an appropriate discipline-specific style (in both bibliography/works cited AND intext), with few to no errors.	• Cites AND attributes sources, with a consistent use of an appropriate discipline-specific style (in both bibliography/works cited AND intext), with few to no errors.

Methylene Blue Dye Removal with Loose and Compacted Coffee Grounds

[redacted]

AP Research

April 28, 2024

Word Count: 5100

Introduction

In recent years, the concern to make clothing production ethical and sustainable has risen. People now have access to worldwide media that shows the destructive nature of the fashion industry. As a result, consumers have begun to push for more ethical practices and brand transparency. In 2013, the collapse of Rana Plaza, a major clothing manufacturer in Bangladesh, raised the question, “How are my clothes being made?” for many consumers (International Labour Organization, 2023). Clothing that reaches consumers is not a simple product; it is raw material, such as cotton, that is processed in a factory, turned into thread and yarn, made into a textile, dyed, and ultimately turned into a garment, shipped from the global south to be sold to consumers in the west. The production process in fast fashion has led to environmental ruin, most notably in waterways near dyehouses (Mustapha et al., 2023). The areas surrounding the dyehouses, the places where clothing gets dyed, are often polluted with runoff from clothing factories because paying fines is cheaper than treating the wastewater, which leads to cheaper production costs and lower prices for consumers (Niinimäki, 2021). Besides the visual effects of dye wastewater in waterways, dyes can harm people’s health. Dyes such as methylene blue can cause heart rate increase, jaundice, and quadriplegia with constant exposure (Mustapha et al. 2023). If the use of water in dyehouses can be changed to a circular model that reuses dye water, then dyed water can have minimal effects in nearby waterways, and more efforts can be spent on addressing water treatment for the current polluted bodies of water. This hypothetical model of reusing dyewater to dye clothing begins with research on dye removal. A commonly studied form of dye removal is adsorption using activated carbon, the basis of this research. Studies show that activated carbon from organic materials can be used for dye adsorption, thus suggesting that non-activated carbon can be used to remove dyes from water (Mutalib et al., 2023). An example of accessible material is coffee grounds, a waste produced by an entire industry worldwide. It is estimated that 60 million tons of used coffee grounds are produced each year globally (Nealon, 2025). This makes coffee grounds easily accessible in high quantities. Researching dye removal using waste products that are not chemically activated lowers the cost and offers the potential for a low-cost dye removal method. If the water treatment method is low-cost and efficient, companies will be more inclined to treat the water. To contribute to the objective of a low-cost dye adsorption method, this study researched the efficiency of coffee grounds as a form of dye adsorption in loose and compacted forms.

Literature Review

1. Fashion Cycles

Fast fashion is the production of clothing in response to consumer-indicated desires in an abnormally fast manner (Berhane, 2024). This increase in clothing production is not new; the University of North Carolina at Chapel Hill Ethics and Policy blog reports that consumers are buying 60% more than before because fast fashion clothing is relatively cheaper (Berhane, 2024). For a simplified comparison, individuals who used to buy five pieces of clothing on an average trip to the mall are now buying around eight pieces of clothing, most likely of a lower quality. Georgetown Journal of International Affairs reports that from 1996 to 2012, there was a 36% decrease in garment usage (Niinimäki, 2021). For the average consumer, this means that only about five of the eight garments purchased are used. This cycle will only increase over time, with the fast fashion industry projected to be worth 39.58 billion dollars this year (Hajad et al., 2024). The decrease in clothing usage, increase in fast-fashion consumption, and rapid trends will ultimately cause global textile waste to reach 132 million tons per year in 2030 (Chen et al., 2021).

2. Environmental Pollution

A major issue with the fast fashion industry is the pollution it causes. Most of the clothing made in countries such as Indonesia and Bangladesh rely heavily on clothing production to keep the workforce and economy alive, but many of the companies with textile factories in these countries will take shortcuts in manufacturing with actions such as throwing wastewater into local bodies of water (Regan, 2020). Examples of this are Gap and Brooks Brothers, both prominent figures in fashion, discharging pollutants into Indonesia's Citarum River (Elks, 2020). This ultimately plays into the garment industry being responsible for 20% of the world's water pollution (Regan, 2020). The emphasis of this study is on water pollution in the fashion industry. The water currently used in production is clean drinking water, and many articles of clothing require lots of water in the production stages (Mogavero, 2020). A single pair of jeans requires up to 7500 liters of water in manufacturing, mostly for the dying process (Regan, 2020). An increase in consumption and manufacturing indicates that an innovation in the dying process is required. In "Studies on the Removal of Acid Blue 25 from Wastewater using Activated Carbon and Turmeric", P. Santhosh reports that in 2013, there were more than 12,000 commercial dyes available to dye clothing. Now, this number could have easily doubled.

3. Textile Dyes

Textile dyes are what give clothing its color (Bawa et al., 2023). Dying clothing to appear lively and more attractive is nothing new. The distinguishing aspect of clothing now is that they are dyed with synthetic dyes (Mabuza et al., 2023). The dyes that are used to color clothing have complex aromatic structures, which means that they are stable and difficult to break apart (Ranson, 2020). As a result, the removal of dye from wastewater or bodies of water has been difficult and expensive. This recurrence of this issue has led to the research of activated carbon in treating wastewater for dye removal.

4. Dye Adsorption with Activated Carbon

Researchers have found that one of the most effective ways to remove dye from water is to use activated carbon. Activated carbon is described as a raw material, such as coconut husk, that is processed with heat and an acid or base (Bawa et al., 2024). Activated carbon can be made from any material that has a large carbon content. The study "Combined Absorbent of Corn Husks and Eggshells Activated by Sodium Hydroxide as an Adsorbent for Remazol Yellow FG dye in Textile Waste" by Bawa et al. researched how activated carbon from corn husk and eggshells with NaOH (a base) and HCl (an acid) can impact dye removal. Bawa et al. report that the optimal conditions are with a pH of 2 and a contact time of 80 minutes. These conditions, with the activated carbon, adsorbed 27.87% of the dye. Analysis showed that this process is not effective for industrial use because of the time needed to activate the carbon, and the contact time needed for results could not remove 30% of the dye from the solution. As a result, more research is needed on how a material with a high carbon percentage can be dried and used for dye adsorption. One issue addressed by Bawa was the fact that the drying oven used in the experiment took a considerable amount of time. To address this issue of drying time, Beyer conducted similar research on dye adsorption using microwaves as the drying method. Because microwave ovens operate by vibrating molecules such as water in a substance to make them produce heat, Beyer was able to reduce the drying time down to 20 minutes, making the dye adsorbent process efficient (Beyer, 2023). Further research has applied this knowledge when using coffee as the source of carbon. The study "Comprehensive functionality analysis of spent coffee grounds activated using microwave-assisted method" was successfully able to use microwaved dried spent coffee grounds to remove methylene blue from a solution (Mutalib et al., 2023). Although certain variables throughout these studies were changed, they were able to prove that activated carbon can remove dye from water, and two studies proved that it can be done with microwave assistance; most notably, activated spent coffee grounds were able to remove dye.

5. Gap

Although numerous studies have shown that activated carbon is effective at removing dye from water and can be affected by characteristics such as pH, contact time, and temperature, few studies have researched whether carbon without chemical activation can be used as a dye adsorbent. This absence led me to research the effectiveness of dried spent coffee grounds as a form of dye removal. After experimentation and additional research, the component of compaction was examined to see if it could have an impact on the effectiveness of dye removal. If spent coffee grounds could be dried and compacted, then they could remove the dye from the water without a difficult separation process after treatment. It is hypothesized that there will be a significant difference between the solution that is treated with the compacted coffee and the solution treated with loose coffee. Compaction will make the separation process more efficient because extensive filtering is not needed, which saves time, making it an efficient method of dye adsorption that uses a throwaway product. If further research is conducted on the impact of activation and compaction with spent coffee grounds as a form of dye removal, then companies can be more inclined to incorporate a water treatment method that does not revolve around waste disposal.

Methodology

This study aims to determine if methylene blue dye can be removed from a solution using dried spent coffee grounds under multiple conditions. The test procedures involved incorporating the two forms of coffee into a methylene blue solution, with six types of experiments conducted four times each. The experimentation method was a mixed qualitative and quantitative experiment. The data that was recorded was analyzed using spectrophotometry as well as visual analysis of the changes before and after treatment. The experiments manipulated the size of the coffee grounds, the mass of the coffee grounds, and the length of time the experiment ran. Each experiment was an attempt to find a correlation between treatment and dye removal through color change. Similar experimentation provided a model for dye adsorption using spent coffee grounds. Mutalib, as mentioned previously, used coffee from nearby shops and dried them at different wattages before activation. Mutalib showed that the change in color with activated coffee dried using a microwave was statistically significant (Mutalib et al., 2023). This study also showed optimal drying conditions being at 100 watts, but due to limitations of a household microwave being used, the wattage used in this study was 1000. Once the base experimentation of spent coffee grounds began, I noticed that the coffee grounds still left a substance with a yellow hue. This led to further research on the concept of compaction as it pertains to dye adsorption. The study “Effect of activated carbon compaction on water filtration efficiency” showed that activated carbon, like in Mutalib’s study, could be compacted in a puck-like filtration device to optimize the effectiveness of activated carbon when removing a pollutant (Mersal et al., 2024). With this information, the experiment set up was revised to include the “pellet” component, where the coffee was compacted into tiny disks and used as a comparison against the loose coffee grounds to determine if coffee grounds would be more effective at removing dye if the contact was indirect. This would allow the solution to be treated without the yellow tint left by the loose coffee grounds.

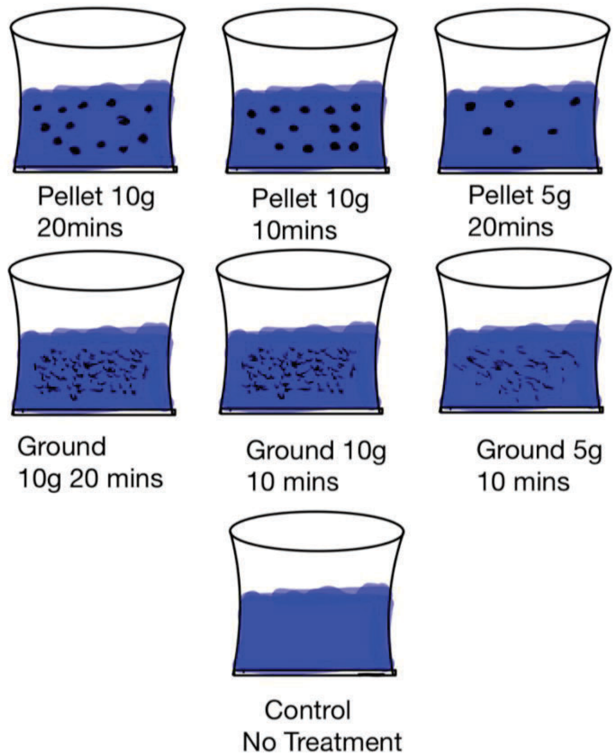


Figure 1. Different Treatments Used to Remove Methylene Blue Dye From a Solution

1. Preparing the Methylene Blue Solution

The first step in the experiment was preparing the methylene blue solution. The methylene blue solution consists of methylene blue powder and distilled water. The distilled water ensures minimal impurities, reducing the possibility of the experiment being impacted by the water used. The methylene blue powder was weighed on a digital scale for an amount of .32 grams to prepare the methylene blue solution. This amount was added to 100 ml of water for a molarity of .001. Then, in a one-liter volumetric flask, three milliliters of the .001 M methylene blue solution were added with distilled water until the one-liter mark was met. The concentration of the methylene blue had to be diluted for changes to be easily observed. A piece of parafilm

Figure 2 Methylene Blue Solution

was then placed on top of the container's opening to distribute the powder evenly by turning the container upside down. This solution was then stored under a fume hood away from light.

2. Preparing the coffee grounds

The preparation for both forms of coffee starts the same. Coffee grounds were used due to their accessibility, and when researching carbon/activated carbon, few studies showed coffee grounds as its carbon source (Mutalib et al., 2025). To obtain used coffee grounds for the experiment, spent coffee must be made. Spent coffee is coffee that has been used to make brewed coffee. To have consistency in the experiments, the same coffee beans were used and freshly ground before the brewed coffee was made. The coffee beans used in the experiments were of Guatemalan origin and roasted between December 2024 and January 2025. The brewed coffee was prepared using the French press method. Each batch of brewed coffee used 80 grams of coffee beans that were ground in an electric coffee bean grinder for 30 seconds. Then, they were added to a French press, and hot water was poured onto the grounds until water fully covered them; they were left to sit for 15 seconds. After 15 seconds, a liter of hot water was added to the French press and covered with the French press top. The coffee was left to sit for 5 minutes. After 5 minutes, the plunger was slowly pushed down to separate the brewed coffee from the grounds. The brewed coffee was then poured out until there was no liquid left in the French Press. Then, the French press plunger was removed from the container. To the French press container, three folded Bounty paper towels were added on top of the coffee grounds and then pressed down with the plunger to absorb any excess moisture left in the grounds. This was left to sit for 5 minutes. After 5 minutes, the coffee grounds were removed and evenly distributed on a ceramic plate. The next step in the coffee preparation process is the drying process. Most research conducted on drying organic materials for activated carbon used drying ovens, but this study used a microwave for the method of drying (Mutalib et al., 2025). This experiment used a standard home microwave oven with a power output of 1000 watts. The plate was placed in the microwave for a total of 15 minutes, stopping every 3 minutes to move around the coffee grounds. Once the coffee grounds were in the microwave for 15 minutes, they were removed from the plate and placed in an airtight container. This was the last coffee preparation step for the experiments that used loose ground coffee. For future experimentation, consistency measures with the temperature of coffee should be recorded after microwaving to ensure that the microwave is producing similar heat.

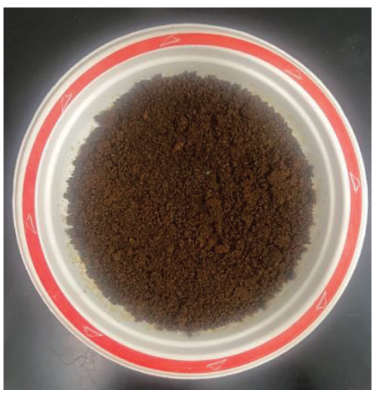


Figure 3 Dried Coffee Grounds

3. Preparation of the Coffee Pellets

Half of the experiments conducted used a “pellet” form of dried coffee. Unlike the regularly microwaved coffee grounds, the coffee pellets are combined with ground flax seeds. Ground flax seeds with water form a gel-like consistency, which aids the pellets in staying intact. Flax seeds also have a composition of 60% carbon. The pellets are with a ratio of approximately 1:2:2, one part flax seed, two parts microwaved coffee grounds, and two parts distilled water. Each batch of pellets made for the experiments was made with 24 grams of ground flax seeds, 45 grams of microwaved coffee grounds, and 50 milliliters (ml) of distilled water. In a mixing bowl, the ground flax seeds and microwaved coffee grounds (MCG) were combined. Once everything was fully combined, the distilled water was added until a soil-like consistency was reached. When pinched, the mixture was able to hold its shape. To form the pellets, a silicone mold with mini cavities of the dimensions 0.5-inch diameter and 0.31-inch height was used. The mixture was added to the mold, with each cavity being pressed down. The molds then go through the same microwaving process described in section two. After microwaving, the pellets were stored in an airtight container.

4. Experiments with Loose Ground Coffee (LGC)

In total, 12 trials utilized the LGC method. Each experiment had 4 trials, with the following three being the experiments: 10 grams of LGC in 100 ml of methylene blue solution for 20 minutes, 5 grams of LGC in 100 ml of methylene blue solution for 20 minutes, and 10 grams of LGC in 100 ml of methylene blue solution for 10 minutes. The basis of each experiment was composed of coffee being added to methylene blue solution, mixed for a consecutive amount of time with a magnetic stirrer. To a 250 ml beaker, 100 ml of methylene blue solution was added along with a stir bar. A stir bar is a tiny magnet that attracts to the magnetic plate to stir a solution evenly. Once the beaker is set up, it is placed on top of the magnetic stirrer. The magnetic stirrer was turned on to a setting where the solution had a whirlpool that was strong enough to stay consistent but not so strong that the center of the whirlpool touched the bottom of the flask. Once the whirlpool was made, the designated amount of LGC was added and left to stir for 10 or 20 minutes, depending on which experiment was being conducted. After the time for

Figure 4 Coffee Pellets

Figure 5 Loose Coffee Grounds in Methylene Blue Solution

each experiment passed, the magnetic stirrer was turned off, and the solution was ready for filtration.

5. Experiments with Pellet Coffee

For the twelve experiments using pellet coffee, the only change was the structure of the coffee. Instead of adsorbing the textile dye using LGC, these experiments used a structured coffee pellet form. Each experiment had 4 trials with the following three being the experiment: 10 grams of coffee pellets in 100 ml of methylene blue solution for 20 minutes, 5 grams of coffee pellets in 100 ml of methylene blue solution for 20 minutes, and 10 grams of coffee pellets in 100 ml of methylene blue solution for 10 minutes. The same setup is used as described in section 4, except for the LGC being exchanged for pellet coffee.

6. Filtration Process

For all the trials conducted, the same filtration process was used. After each trial, a coffee filter filtered the solution into an empty beaker. The coffee filters used in the experiments were the *Melitta Super Premium Coffee Filters*. To set up the filtration containers, the coffee filters were placed on top of the beaker opening in a funnel shape for the liquid to pass through. Once the filter was added to a beaker,

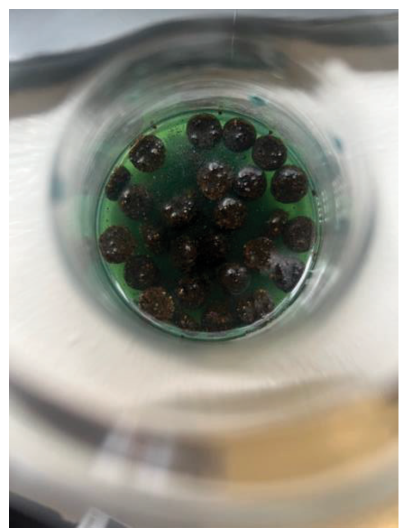


Figure 6 Coffee Pellets in Methylene Blue Solution

the solution in each experiment was poured through to separate the coffee from the solution. After this, the solution was prepared for analysis.

Figure 7 Solution Being Filtered

7. Concentration Curve

Apart from the experiments that took place, a separate concentration curve was made. The concentration curve was several dilutions that were made to compare the concentration of the methylene blue solutions post-filtration. The concentration curve was made of the following concentrations: 100%, 80%, 60%, 40%, 20%, and 0% (distilled water). Each dilution was created in a test tube with a volume of 10 ml. 100% was pure methylene blue solution. 80% was 8 ml of methylene blue solution and 2 ml of distilled water. 60% was 6 ml of methylene blue solution and 4 ml of distilled water. 40% was 4 ml of methylene blue solution and 6 ml of distilled water. 20% was 2 ml of methylene blue solution and 8 ml of distilled water. Each of the six dilutions was then put into cuvettes using a pipette to be analyzed in the spectrophotometer for red, green, and blue color intensities. The concentration curve allowed for comparison between the original solution and the treated solutions with the use of a spectrophotometer.

Figure 8 Concentration Curve

8. Analysis with a Spectrophotometer

A spectrophotometer was used to analyze each trial and the six concentration curve dilutions. In this study it determined the red, green, and blue values for each of the 30 liquids but in an industrial lab, more wavelength values would be recorded, leading to more data that this study if replicated, could analyze. To have a reference in the spectrophotometer, a cuvette was filled with distilled water and placed into the spectrophotometer to measure as a reference. The concentration curve dilutions were the only liquids measured at the same time. After creating a reference in the spectrophotometer, each dilution was placed in a cuvette using a pipette and transported into the spectrophotometer to measure its red, green, and blue values. This same process occurred for each of the 24 trial solutions after filtration. The spectrophotometer works by putting light waves through the solution at different frequencies, so that the values that are being absorbed by a given solution can be recorded (LabXChange). For example, the original solution that was analyzed is blue to the human eye, and blue light wavelengths can pass through a blue solution, making it look blue to humans. On the contrary, red-light wavelengths cannot pass, so it is absorbed by the solution. A blue substance will record a high red value and a low blue value in the spectrophotometer. This study had the goal of removing blue dye from a solution; therefore, the final expected values in the spectrophotometer were low red values and high blue values.

Discussion

For each of my trials, I used a spectrophotometer to analyze the differences in the solution after they were treated with a form of coffee. Spectrophotometry allowed me to quantify the changes in the solutions color. While the data I collected included three colors, I focused on interpreting the changes in the R values before and after treatment, as shown in Table 2. The highest recorded value in the original Methylene Blue solution is the red value because a blue solution will reflect blue light but will absorb red light. Therefore, the higher the red value recorded, the bluer the solution appears. Each of the six experiments recorded a red value under half of the original recorded value. The data in Table 3 shows the averages of all experiments. In each category, there was no major difference between pellet and ground coffee as a form of dye removal, but 5 grams of ground coffee stirred in the methylene blue solution for 20 minutes did have the lowest recorded red value. In all, the coffee grounds were able to remove 73% to 89% of the methylene blue dye from water. To determine if the experiments were statistically significant, two ANOVA tests were performed. An ANOVA test allows for a comparison of the 7 categories in the study to determine if there was statistical significance between the means of each experiment or if the differences were from random chance. The first test compared the six experiments to the control, which was the untreated methylene blue solution. In comparison, the change in the red values recorded after treatment shows that the treatments were statistically significant with a p value < 0.001, as shown in Appendix H. The second test was to determine if there was any significant difference in outcomes with the different experiment setups. In this case, the differences among the six experiments were not statistically significant. This result was unexpected because it was hypothesized that the pellets would be more effective at removing dye from water. It was hypothesized that the pellet coffee would result in lower red values, but there is no statistical difference; therefore, the hypothesis is rejected. Although the changes were not drastic, they can still be observed in Figures 7 and 9. The tint in Figure 7 from treatment with loose coffee grounds seems opaque in comparison to the solution treated with coffee pellets. In addition to comparing the red values, observations were made with the filtration process. It was noticed that the LGC was significantly more difficult to remove from the solution than the pellet coffee was. Removing the coffee pellets from the solution was easier than removing the loose coffee grounds, and it took less time. In some trials with the loose coffee grounds, the solution needed to be filtered twice because some particles could still fall through the filter, but this did not occur with the pellets. Therefore, even though there is no statistical difference between the coffee pellets and the loose coffee grounds, the coffee pellets are more practical for dye removal because they are easier to filter. The conditions of this study also could not distinguish other conditions that could have made the adsorption process “ideal,” but if optimal conditions could be studied and identified, then the use of coffee pellets could be an efficient method to treat wastewater on a large scale. The pellets can remove dye from water at a fast rate and do not require extensive filtration processes.

Figure 9 Solution After Treatment with Five Grams of Coffee Pellets for 20 Minutes

1. Limitations

The study faced limitations in its setup due to materials, factors that were not recorded, and, most notably, the fact that it is a theoretical approach to adsorbing dye from polluted bodies of water. Only three colors absorbed by the solutions were able to be recorded with the school-provided spectrophotometer, but in a well-funded lab, a spectrophotometer can be able to record light absorbances at different wavelengths, not just three colors. The lab was also conducted without considering factors that could also impact results, such as the temperature of the coffee grounds when they were microwaved, the temperature of each solution, the pH of each solution, and the use of flasks that were not sterilized. These factors could have impacted the results of each trial in some way, as studies such as Bawa’s have been able to find conditions that make activated carbon dye adsorption optimal, such as having a pH of 2 (Bawa et al., 2023). Finally, the dye solution used was not wastewater. Polluted waters, such as the Dravyavati River in India, are impacted by multiple toxins, not just dyes like methylene blue. The solution used in this study was highly controlled compared to river water that is polluted with wastewater. The wastewater is composed of several dyes, acids, salts, and metals, something that cannot be easily created artificially. The water in the rivers is also impacted by climate and local flora.

2. Implications

The research currently available on dye adsorption using carbon focuses mainly on how carbon can adsorb dye once it is activated, but the research presented in this paper uses the example of how a carbon source that is not activated can still remove dye from water. The source of carbon used was also intentional. Coffee grounds are the waste of an entire industry. In every corner of the world, there are coffee shops that dispose of coffee grounds daily because they do not have a use for them. Coffee is also an accessible form of carbon because it can be accessed within residential and commercial areas. Therefore, when applied to a large cycle of repurposing spent coffee grounds to use them in dye removal, the grounds can keep up with the quantity needed to remove dye from polluted bodies of water. One of the experiments in this study used a ratio of 1:20, which implies that lower quantities can be studied in the future to determine if they can still be effective at removing dye with less mass. The implication of this research shows that sources of carbon, like coffee, do not need to be activated to remove dye. Knowing that non-activated carbon can be effective at removing dye, future research can be directed toward optimizing conditions for efficiency. By using coffee grounds as the source of carbon and not activating it, most of the costs of activated carbon are removed. The coffee grounds can be obtained from the mass waste of coffee grounds produced in coffee shops worldwide, making it accessible. Because dye pollution is the result of costs that dyehouses do not want to have in processing water, the low-cost alternative of using coffee grounds to remove dye from water can be used for future development in recycling the water used to dye clothing, so it does not get disposed of in bodies of water. Once future studies can determine which conditions can make a nonactivated source of carbon the most efficient at dye removal, then engineering can be used to design a circular use of dye water.

Although lab results show that this method, as it is now, is effective at removing dye, the transition to using it as an industrial treatment must also be tested and observed. The coffee used in this study is single origin, but on a large-scale treatment system will most likely rely on grounds from different areas with different processing methods.

100%	1.254	0.132	0.142
80%	0.876	0.098	0.102
60%	0.636	0.074	0.094
40%	0.456	0.068	0.076
20%	0.226	0.03	0.064
0%	0	0	0

Table 1 Red, Green, and Blue Values for Each Concentration

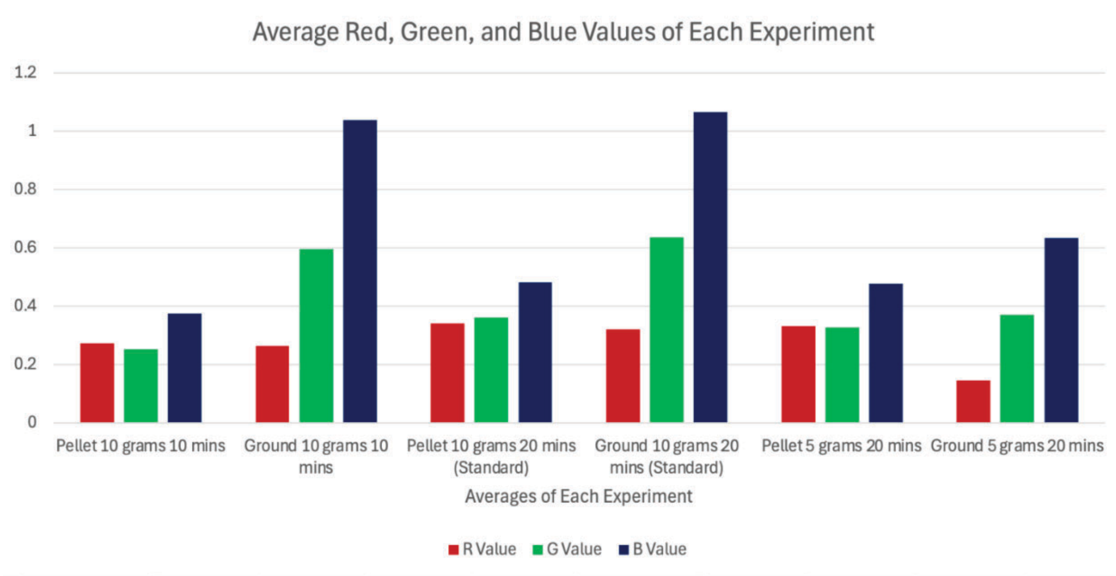


Table 3: Average Value of Each Experiment Compared to the Concentration Curve Values

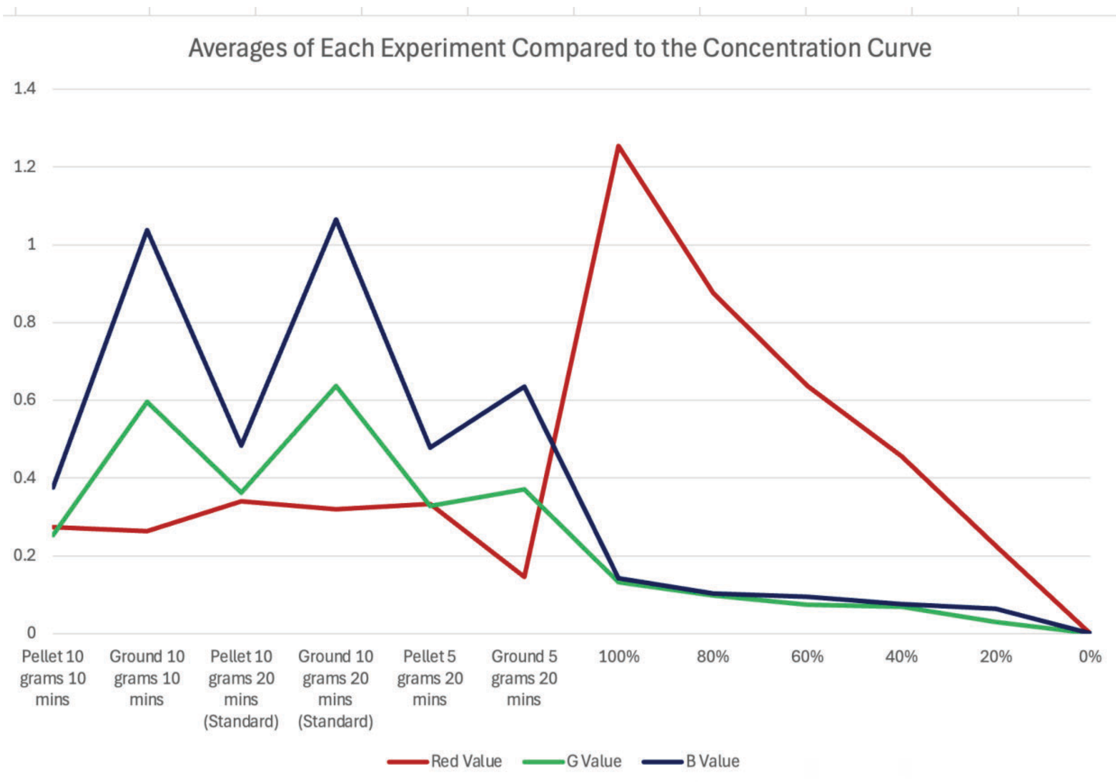


Table 2: Average Values of Each Experiment

Conclusion

Spent coffee grounds can be a low-cost alternative to treating dye-polluted water. Not having to activate the coffee grounds removes most of the costs because the coffee grounds do not need to be processed with an acid or base, and the coffee itself is a byproduct of a beverage that over half of Americans consume daily. Considering the implications of non-activated coffee grounds as a low-cost method of dye removal, further studies can be done on the properties of treated water and the conditions of the treatment. The results identified in this paper only show the visual and numerical changes of one dye solution that has been treated with coffee grounds. This study only looked at absorbency and color changes, but when applied to dye wastewater, other factors must be considered, such as different pollutants in the water. Factors not observed in this study could also be researched to determine how efficiency can be obtained with a material that is not chemically processed. Results with stronger accuracy can be obtained by doing experimentation with bodies of water from areas where clothing is made, as well as identifying the type of coffee grounds used to treat the water and the dyes present in water polluted with runoff from dyehouses. The mentioned accuracy of coffee grounds as dye removal can also be researched with quantifiable factors such as pH and temperature.

References

Abdul Mutalib, A. A., Jaafar, N. F., Miskam, M., & Shafie, S. (2023). Comprehensive functionality analysis of spent coffee grounds activated using a microwave-assisted method. *Journal of Dispersion Science and Technology*, *46*(1), 72–87. https://doi.org/10.1080/01932691.2023.2278495

Bawa, I. G. A. G. et al. (2023). Combined absorbent of corn husks and eggshells activated by sodium hydroxide as an adsorbent for Remazol Yellow FG dye in textile waste. Journal of Applied and Natural Science, 15(4), 1582 - 1586. https://doi.org/10.31018/jans.v15i4.5124

Berhane, H. (2024, April 26). *Rethinking clothing consumption: understanding the human cost of fast fashion*. Retrieved April 27, 2025, from UNC Policy: https://universitypolicy.unc.edu/news/2024/04/26/rethinking-clothing-consumption-understanding-the-human-cost-of-fast-fashion/

Beyer, K. (2024). "The adsorption of methylene blue by activated carbon from spent coffee grounds by microwave-induced phosphoric acid activation." *Winona State University.* Retrieved April 27, 2025, from https://openriver.winona.edu/rca/2024/schedule/31/

By analyzing the absorption spectrum of the bright blue dye, researchers gain valuable insights. (n.d.) LabXchange. Retrieved April 27, 2025, from https://www.labxchange.org/library/items/lb:LabXchange:df4ebab4:html:1#:~:text=By%20analyzing%20the%20absorption%20sp

Chen, X., Memon, H. A., Wang, Y., Marriam, I., & Tebyetekerwa, M. (2021). Circular Economy and Sustainability of the Clothing and Textile Industry. *Materials Circular Economy*, *3*(1), 12. https://doi.org/10.1007/s42824-021-00026-2

Elks, J. (2013). *Polluting paradise: Gap, Ince among companies exposed in Indonesian toxic water scandal*. Retrieved April 27, 2025, from Sustainable Brands: https://sustainablebrands.com/read/polluting-paradise-gap-inc-among-companies-exposed-in-indonesian-toxic-water-scandal

Hsu, C. (2018, August 27). This bright blue dye is found in fabric. Could it also power batteries? Research shows that the chemical, a component of wastewater in textile-making, is good at tasks associated with energy storage. *University at Buffalo News*. Retrieved April 27, 2025, from https://www.buffalo.edu/news/releases/2018/08/026.html

Letsiwe Mabuza, N. S.-P. (2023, April 4). *Natural versus synthetic dyes: Consumers' understanding of apparel coloration and their willingness to adopt sustainable alternatives.* Retrieved April 27, 2025, from ScienceDirect.

Mersal, M. E., Kuok, K. K., Rahman, M. R., Chan, C. P., Bin Bakri, M. K., Chowdhury, M. D. A., and Patwary, M. A. M. (2024). Effect of activated carbon compaction on water filtration efficiency. *BioResources* 19(3), 5300-5315.

Mogavero, T. (2020, April 16). *Clothed in Conservation: Fashion & Water*. Retrieved April 27, 2025 from FSU: https://sustainablecampus.fsu.edu/blog/clothed-conservation-fashion-water

Mustapha, O. R., Osobamiro, T. M., Sanyaolu, N. O., & Alabi, O. M. (2023). Adsorption study of Methylene blue dye: an effluents from local textile industry using *Pennisteum pupureum* (elephant grass). *International Journal of Phytoremediation*, *25*(10), 1348–1358. https://doi.org/10.1080/15226514.2022.2158781

Nealon, S. (2025, March 21). *Researchers advance efforts to turn spent coffee grounds into food packaging*. Retrieved April 27, 2025, from Oregon State University News Room: https://news.oregonstate.edu/news/researchers-advance-effort-turn-spent-coffee-grounds-foodpackaging#:~:text=An%20estimated%2060%20million%20tons,methane%2C%20a%20potent%20greenhouse%20gas.

Niinimaki, K. (2021, August 30). *From fast to slow: how to construct a better balance in the fashion system*. Retrieved April 27, 2025, from Georgetown Journal of International Affairs: https://gjia.georgetown.edu/2021/08/30/from-fast-to-slow-how-to-construct-a-better-balance-in-the-fashion-system/

P. Santhosh, A. S. (2013). *Studies on the removal of acid blue 25 from wastewater using activated carbon and turmeric (curcuma longa L.) as adsorbent* . Retrieved April 27, 2025, from Nature Environment and Pollution Technology : https://neptjournal.com/upload-images/NL-42-24-24.pdf

Pujol, D., Liu, C., Gominho, J., Olivella, M. À., Fiol, N., Villaescusa, I., & Pereira, H. (2013). The chemical composition of exhausted coffee waste. *Science of the Total Environment, 463-464*, 858–866.https://doi.org/10.1016/j.scitotenv.2013.06.029

Ranson, B. (2020). *The true cost of colour: The impact of textile dyes on water systems*. Retrieved April 27, 2025, from Fashion Revolution: https://www.fashionrevolution.org/the-true-cost-of-colour-the-impact-of-textile-dyes-on-water-systems/

Regan, H. (2020, September 28). *Asian rivers are turning black. And our colorful closets are to blame*. Retrieved April 27, 2025, from CNN: https://www.cnn.com/style/article/dyeing-pollution-fashion-intl-hnk-dst-sept/index.html

Stacey, N. (2024). Buy Now! The Shopping Conspiracy. Netflix. Retrieved April 27, 2025, from https://www.netflix.com/lu-en/title/81554996

Statistics Kingdom. (n.d.). *ANOVA calculator - One way ANOVA and Tukey HSD test*. Retrieved April 27, 2025, from https://www.statskingdom.com/180Anova1way.html

The Rana Plaza disaster ten years on: what has changed? (2023, April). Retrieved April 27, 2025, from International Labour Organization: https://webapps.ilo.org/infostories/en-GB/Stories/Country-Focus/rana-plaza#intro

Vellayati Hajad, H. I. (2024). Unveiling the political impact of fast fashion consumption: the role of lower middle class in environmental crisis in Indonesia? *Jurnal Wacana Politik*, DOI: 10.24198/jwp.v9i2.49065.

Appendix

Appendix A

I. Chart of All Trials and the Corresponding Data

Trial 1	Water	Pellet 10 grams 20 mins (Standard)	Pellet 5 grams 20 mins	Pellet 10 grams 10 mins	Ground 10 grams 20 mins (Standard)	Ground 5 grams 20 mins	Ground 10 grams 10 mins
R Values	0	0.25	0.34	0.2	0.36	0.13	0.18
G Values	0	0.25	0.33	0.24	0.68	0.34	0.6
B Values	0	0.35	0.46	0.4	1.06	0.63	1.02
Trial 2							
R Values	0	0.37	0.34	0.19	0.19	0.16	0.27
G Values	0	0.38	0.33	0.24	0.62	0.4	0.57
B Values	0	0.49	0.51	0.34	1.01	0.64	1
Trial 3							
R Values	0	0.27	0.34	0.2	0.38	0.37	0.31
G Values	0	0.26	0.37	0.27	0.72	0.65	0.64
B Values	0	0.33	0.54	0.43	1.14	0.94	1.1
Trial 4							
R Values	0	0.47	0.31	0.5	0.35	0.29	0.29
G Values	0	0.56	0.28	0.26	0.53	0.56	0.57
B Values	0	0.76	0.4	0.34	1.05	0.83	1.03

Appendix B

I. Data from Standard Ground Trials

Ground 20g

Experiment 1	R	G	B	Column1	Experiment 2	R2	G3	B4	Column5	Experiment 3	R6	G7	B8	Column9	Experiment 4	R10	G11	B12
Ground	0.36	0.68	1.06		Ground	0.19	0.62	1.01		Ground	0.384	0.722	1.14		Ground	0.35	0.53	1.053
100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142
80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102
60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094
40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076
20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064
0%	0	0	0		0%	0	0	0		0%	0	0	0		0%	0	0	0

Average Standard Ground		
R values	G values	B Values
0.36	0.68	1.06
0.19	0.62	1.01
0.38	0.72	1.14
0.35	0.53	1.01
0.32	0.6375	1.055

Appendix C

I. Data from 5 Grams 20 Minutes Ground Trials

Ground 5g											High							
Experiment 1	R	G	B	Column1	Experiment 2	R2	G3	B4	Column5	Experiment 3	R6	G	B7	Column8	Experiment 4	R9	G10	B11
Ground 5g	0.13	0.34	0.63		Ground 5g	0.16	0.4	0.64		Ground 5g	0.37	0.65	0.94		Ground 5G	0.29	0.56	0.83
100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142
80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102
60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094
40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076
20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064
0%	0	0	0		0%	0	0	0		0%	0	0	0		0%	0	0	0

Average Values Ground 5g 20mins		
R Values	G Values	B Values
0.13	0.34	0.63
0.16	0.4	0.64
0.37	0.65	0.94
0.29	0.56	0.83
0.2375	0.4875	0.76

Appendix D

I. Data from 10 Grams 10 Minutes Ground Trials

Ground 10g 10 mins																		
Experiment 1	R	G	B	Column1	Experiment 2	R2	G3	B4	Column5	Experiment 3	R6	G7	B8	Column9	Experiment 4	R10	G11	B12
Ground 10g 10 mi	0.18	0.6	1.02		Ground	0.27	0.57	1		Ground	0.31	0.64	1.1		Ground	0.29	0.57	1.03
100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142
80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102
60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094
40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076
20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064
0%	0	0	0		0%	0	0	0		0%	0	0	0		0%	0	0	0

Average Values of Ground 10g 10mins		
R Values	G Values	B Values
0.18	0.6	1.02
0.27	0.57	1
0.31	0.64	1.1
0.29	0.57	1.03
0.2625	0.595	1.0375

Appendix E

I. Data from Standard Pellet Trials

Experiment 1	R	G	B	Column1	Experiment 2	R2	G3	B4	Column2	Experiment 3	R6	G7	B8	Column3	Experiment 4	R10	G11	B12
Pellet 10 g	0.25	0.25	0.35		Pellet 10g	0.37	0.38	0.49		Pellet 10g	0.27	0.26	0.33		Pellet 10g	0.47	0.56	0.76
100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142
80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102
60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094
40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076
20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064
0%	0	0	0		0%	0	0	0		0%	0	0	0		0%	0	0	0

Average Values for Standard Pellet		
R Average	G Average	B Average
0.25	0.25	0.35
0.37	0.38	0.49
0.27	0.26	0.33
0.47	0.56	0.76
0.34	0.3623	0.483

Appendix F

I. Data from 5 Grams 20 Minutes Pellet Trials

Experiment 1	R	G	B	Column1	Experiment 2	R2	G3	B4	Column5	Experiment 3	R6	G7	B8	Column9	Experiment 4	R10	G11	B12
Pellet 5g	0.34	0.33	0.46		Pellet 5g	0.34	0.33	0.51		Pellet 5g	0.34	0.37	0.54		Pellet 5g	0.31	0.28	0.4
100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142
80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102
60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094
40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076
20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064
0%	0	0	0		0%	0	0	0		0%	0	0	0		0%	0	0	0

Average Values Pellet 5g 20 mins		
R Average	G Average	B Average
0.34	0.33	0.46
0.34	0.33	0.51
0.34	0.37	0.54
0.31	0.28	0.4
0.333	0.328	0.478

Appendix G

I. Data from 10 Grams 10 Minutes Pellet Trials

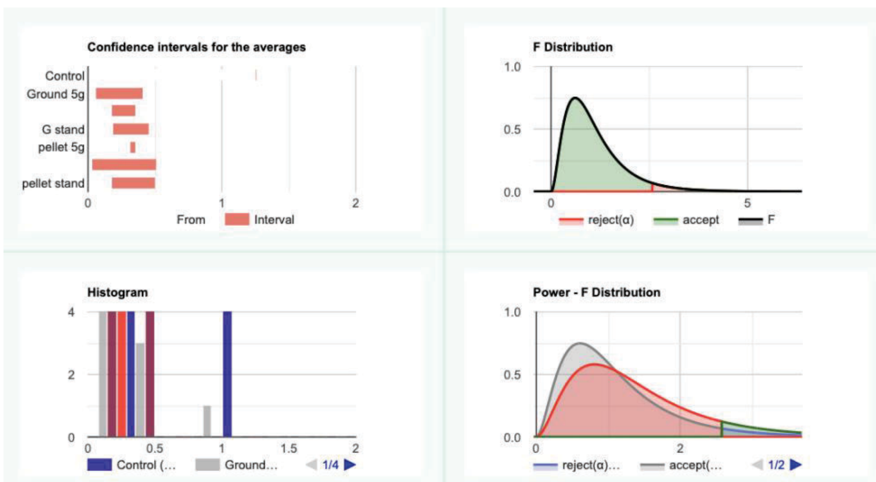
Experiment 1	R	G	B	Column1	Experiment 2	R2	G3	B4	Column5	Experiment 3	R6	G7	B8	Column9	Experiment 4	R10	G11	B12
Pellet 10 g	0.2	0.24	0.4		Pellet 10g	0.19	0.24	0.34		Pellet 10g	0.2	0.27	0.43		Pellet 10g	0.5	0.26	0.34
100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142		100%	1.254	0.132	0.142
80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102		80%	0.876	0.098	0.102
60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094		60%	0.636	0.074	0.094
40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076		40%	0.456	0.068	0.076
20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064		20%	0.226	0.03	0.064
0%	0	0	0		0%	0	0	0		0%	0	0	0		0%	0	0	0

Average of 10g 10mins Pellet		
R	G	B
0.2	0.24	0.4
0.19	0.24	0.34
0.2	0.27	0.43
0.5	0.26	0.34
0.2725	0.2525	0.3775

Appendix H

I. ANOVA Test Data and Chart

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	6	3.195	0.5325	65.3467	1.699e-12
Error (within groups)	21	0.1711	0.008149		
Total	27	3.3662	0.1247		



Academic Paper

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

NEW for 2025: The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

Sample: A
Score: 5

This paper earns a score of 5. The introduction discusses the real-world significance of the study, grounded in background research, culminating in the paper's narrow research focus on p. 3: "To contribute to the objective of a low-cost dye adsorption method, this study researched the efficiency of coffee grounds as a form of dye adsorption in loose and compacted forms." The literature review beginning on p. 3 places scholarly sources in conversation with each other to provide a logical line of reasoning defending the research gap detailed on p. 6: "few studies…have researched whether carbon without chemical activation can be used as a dye adsorbent." This discussion culminated in the hypothesis "that there will be a significant difference between the solution that is treated with the compacted coffee and the solution treated with loose coffee. Compaction will make the separation process more efficient because extensive filtering is not needed, which saves time, making it an efficient method of dye adsorption that uses a throwaway product" (p. 6). The study's implications are a natural extension of this discussion, "If further research is conducted on the impact of activation and compaction with spent coffee grounds as a form of dye removal, then companies can be more inclined to incorporate a water treatment method that does not revolve around waste disposal" (p. 6).

The paper's method on pp. 6-14 is comprehensive, clearly explained, and provides sufficient detail to replicate the experiment. Research design choices, including the use of coffee grounds as a non-activated carbon source, drying and compaction, and dye absorption, are well defended using relevant background research (e.g., see pp. 7-10 Mutalib et al., 2023 and Mersal et al., 2024 references). As such, the rich description and design choice defense clarifies the alignment between the research focus and the method.

The results are presented and discussed on pp. 14-16 and provide a logical progression to the research conclusions and implications. See p. 15: "In all, the coffee grounds were able to remove 73% to 89% of the methylene blue dye from water," p. 16: "Therefore, even though there is no statistical difference between the coffee pellets and the loose coffee grounds, the coffee pellets are more practical for dye removal because they are easier to filter," and p. 20: "Spent coffee grounds can be a low-cost alternative to treating dye-polluted water. Not having to activate the coffee grounds removes most of the costs because the coffee grounds do not need to be processed with an acid or base, and the coffee itself is a byproduct of a beverage that over half of Americans consume daily. Considering the implications of non-activated coffee grounds as a low-cost method of dye removal…" The implications are fully explained within the context of prior research and potential real-life applications.

Academic Paper (continued)

The paper does not overstate its conclusions in that the conclusion limitations are acknowledged and discussed on p. 16. See the hypercritical discussion of how the controlled experiment varied from real life (e.g., use of clean vs. actual samples of polluted river water) and prior research design conditions (e.g., pH conditions). For example, on p. 16: "These factors could have impacted the results of each trial in some way, as studies such as Bawa's have been able to find conditions that make activated carbon dye adsorption optimal, such as having a pH of 2 (Bawa et al., 2023)."

This paper does not earn the score of a 4 because the conclusions are aligned to a narrow, focused research goal and justified via a progression of logical inquiry choices. The limitations and implications are detailed and fully explained within the context of prior research. The paper makes many choices that enhance the communication, for example by explaining technical procedures (e.g., "The concentration curve allowed for comparison between the original solution and the treated solutions.. p. 13; discussion of spectrophotometer wavelength analysis on p. 14) and including pictures of process to guide the discussion through the method.