# Colorimetric analysis in Secondary Education, a simulation with portable electronic devices and food coloring substances.

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DOI: 10.62579/JAGC0008

## Abstract

Due to the widespread availability of smartphones with strong cameras and decent computing power, teachers are able to create innovative, experimental lesson plans. This study's primary goal was to use digital technologies, such cellphones, to the scientific process of colorimetry in chemistry and the Beer-Lambert law. Students made solutions using candy colors in varying quantities for this lab practice. They recorded the Hue (H) value on a white background using a cell phone that has software installed to measure color using the HSV model. They plotted the H color parameter against the quantity of droplets per 100 milliliters using these values. The outcome was a straight line, which effectively validated the method's underlying premise that is, the Beer-Lambert law. The solution used for the most recent measurement had an unknown concentration. The groups were able to accurately calculate the concentration of the unknown solution by using the reference curve they had generated. Students produced solutions, measured particulars, used software and smartphones as scientific instruments, made graphs, evaluated data, and came to scientific findings during this lab exercise.

**Keywords**: Smartphones, Colorimetry, School chemistry.

## INTRODUCTION

People now use cellphones for a variety of purposes in their daily lives, making them omnipresent in society in recent years. Smartphones, however, have a great deal of potential as scientific instruments in addition to being communication and entertainment devices, especially in educational settings like schools. With its many capabilities, including internet access, high-resolution cameras, and a plethora of applications, smartphones may be extremely helpful tools for educators and students alike. They can help with data collection, analysis, and research for science. They can also improve critical thinking and increase scientific knowledge. One way to characterize smartphones is as versatile gadgets with the potential to completely transform scientific research and teaching. They can even be used for strictly scientific objectives, such taking pictures of bacterial colonies in a Petri dish or tracking changes in the temperature, using specific apps for virtual reality or educational activities in schools [1,2]. Research indicates that cellphones can function as dependable measuring devices, creating new avenues for data collecting and scientific investigation [3].There are opportunities for the quick and low-cost development of qualitative and quantitative methods due to the popularity and mobility of smartphones, the use of digital pictures, and the development of smartphone applications. Furthermore, a growing number of businesses, individuals, and governments are using digital picture colorimetry for various analytical processes, measurements, processing, and online result sharing [4].

## 1 METHODOLOGY

The goal of the experimental process outlined in this paper is to help students understand how a colored solution's color and concentration relate to one another and how this relationship can be used to determine the concentration of a solution containing the same substance but with an unknown concentration. In addition, it provides an introduction to the scientific method used in many analytical chemistry techniques and enables students to identify a legitimate scientific application for their mobile devices through the use of basic materials to measure things that appear to match actual chemical issues encountered in chemical analysis. The three elements that affect how an object appears to be colored are the type of lighting, the object's visual characteristics, and the eye's reaction. Either straight from the light source or after being reflected or absorbed by an object, light can enter the eye. The observer's eye is exposed to this altered light, which evokes the sense of the material's hue. As a result, perception of color is subjective, and the observer must be considered [5].

Three variables can be used to fully characterize a color: i) hue, which is the color as it is perceived (e.g., red); ii) lightness, which is the color's brightness or darkness (e.g., bright or dark red); and iii) saturation, which is the color's intensity in relation to its associated spectral color (e.g., vivid or intense red) [6]. Color models like RGB, XYZ, L*A*B*, and L*C*H are frequently employed in order to precisely identify colors and quantify these parameters [5].

In colorimetric assays, a colorimeter (spectrophotometer) is used to measure a chemical compound's spectral absorbance at a certain wavelength in order to calculate the compound's concentration in a solution. A color is produced when the target substance and detecting chemical interact. Using a spectrophotometer to measure the color intensity, one can estimate the amount of the desired component. Colorimeters are low-cost, basic instruments that function by utilizing a range of filters. They work well in scenarios when a rapid estimate is wanted but high precision is not necessary. Colorimetric tests are quick, simple, and affordable, but they are not highly sensitive, and the pH and temperature of a solution can easily affect them [7].

The basis of quantitative spectroscopy is the Beer-Lambert equation, which states that the amount of radiation absorbed by a sample constituent, A (absorbance) ,is precisely proportional to the product of its molar absorptivity (e),route length (b), and concentration (c) for a homogeneous, non-scattering liquid sample. A = e*b*c is the formula for the Beer-Lambert law, where b for solution thickness [6].

In the context of optical sensors, the hue, or H component of the hue, saturation, and value (HSV) color space, has been investigated as a quantitative analytical parameter. Numerous variables, such as the sample concentration, the detector's spectral sensitivity, and the lighting, affect the accuracy of the H value. Studies that compare this metric to RGB absorption intensity and red, green, and blue (RGB) intensity have demonstrated its superiority. It can be used in commercial products like digital cameras and scanners because of its reliability and simplicity of computation. Moreover, it has enormous potential for a variety of uses, such as quality control, automated analysis, pharmaceutical analysis, imaging, and Lab-on-a-chip devices [8].

For paper-based applications, colorimetry, which makes use of picture resolution and RGB or HSV data is frequently employed in optical detectors and other complex devices [9]. The effects of chemical concentrations, such as ochratoxin A in beverage samples, have been studied using the color model HSV [10]. The absorbance of varying concentrations of the same solution is measured at the same wavelength in colorimetry in order to determine the concentration of a solution. The absorption of each solution at each known concentration is then graphically represented by a reference curve that is created using this data. By comparing the absorption of an unknown sample to the reference curve, this method can be used to determine the sample's concentration [11]. The process of creating a reference curve will also take place in the school laboratory's experimental area, but absorption will be measured in place of another variable. The significance of improving pupils' problem-solving skills has increased in the modern era. Because they essentially practice with a simple methodology in the scientific method, students' problem-solving abilities in scientific fields depend not only on their ability to recall and apply the pertinent details of their subject and domain-specific knowledge, but also on their analytical thinking abilities [12]. This paper aims to address these issues.

In the school laboratory, the pupils are first split up into groups of four to five individuals. Phase I involves projector-slide presentations on how color is viewed by humans and how transparent solutions, like $KMnO_4$ or $CuSO_4$, seem colored in a lab setting. Phase II describes the hue, saturation, and value (HSV) color model parameters because the subsequent experiment will use a smartphone to measure parameter H. A webpage called CSS HSL Colors (https://www.w3schools.com/css/css_colors_hsl.asp) is also provided, where students can manipulate values in the H variable to observe changes in color and intensity [13].

Phase III involves the graphic presentation of a colorimeter in conjunction with an online movie (https://youtu.be/yTabfxvMdCM?si=EiSv4yxkKOnUV7LY) that provides a basic explanation of the analytical method's principle. Every group in the fully experimental Phase IV receives a distinct color of food coloring. The hues that are readily available are blue, red, and yellow, all of which are accessible from any grocery. Using a volumetric cylinder, they transfer 100 milliliters of water into three transparent plastic cups. Next, they add one, two, and four drops of the specified dye, respectively. When building the calibration curve, these solutions will be used as the reference solutions to be measured.

A whiteboard is supported on a bench that has been installed at a certain location in the lab. The solution to be measured is put in front of and slightly away from the white background. In addition, the program is used to measure the desired variable by placing the mobile phone in front of the sample [14] (Fig.1).

*Figure 1. Measuring the parameter H with Color Grab app for android.*

An alternative would be to use a stationary arm to hold the mobile device vertically while the sample to be examined was positioned directly below the camera at a location determined by the application's focus point (Fig 2).

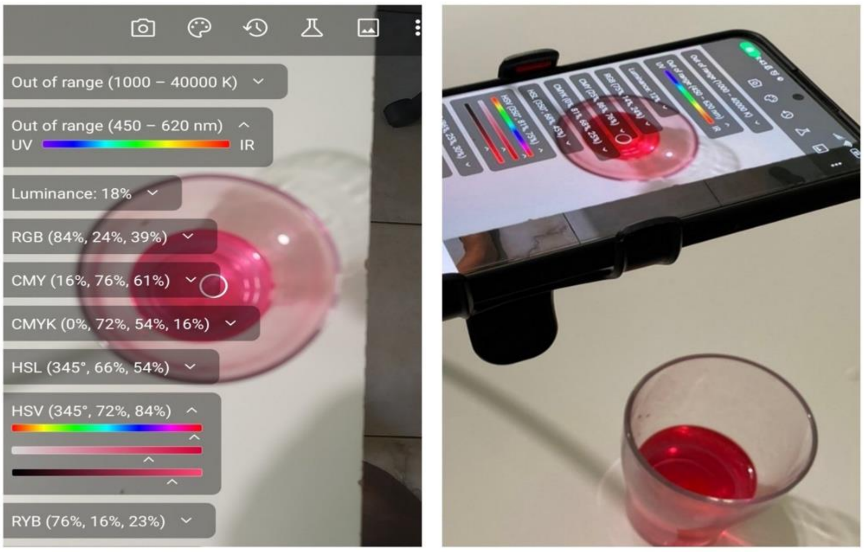


*Figure 2 . Vertical measurement with Color Picker app for android.*

A color detection program that measures colors using the HSV model is loaded on each group member's smartphone. Smartphones running iOS and Android have a wide variety of applications available. An online converter (such as https://colordesigner.io/convert/hextohsv) can be used to convert HEX color values used by the mobile application to HSV values. Of course, an iPad or tablet can also be used to take the measurements.

## 2 RESULTS

Each solution is positioned in relation to the smartphone camera at a fixed, modest distance, and the phone marks the same spot for each measurement. The mobile phone might be secured by the steady arm, guaranteeing the reference point's stability. Following sample placement, the attention is moved to a specific location inside the solution, and the parameter H value is measured using the mobile application. The results are then recorded in a computer program called Numbers (macOS) or a comparable spreadsheet program (like Excel) in order to generate a graphical depiction of the data and build the reference curves (Fig. 3, 4, 5). The values are functions of the droplet per 100ml of solution.

## 2 .1 The measurements of Hue (H)

### *2.1.1 The measurements of the blue dye*

Measurements of the value H for three solutions with varying concentrations in drops of blue dye are displayed in the table (Table 1) below. A reference curve (Fig.3) is created using these data.

*Table 1. Measurements - Blue coloring drops / 100 ml - Hue(H)*

| ***drops/ 100mL*** | ***Hue(H)*** |
|---|---|
| One | 196 |
| Two | 199 |
| Four | 208 |

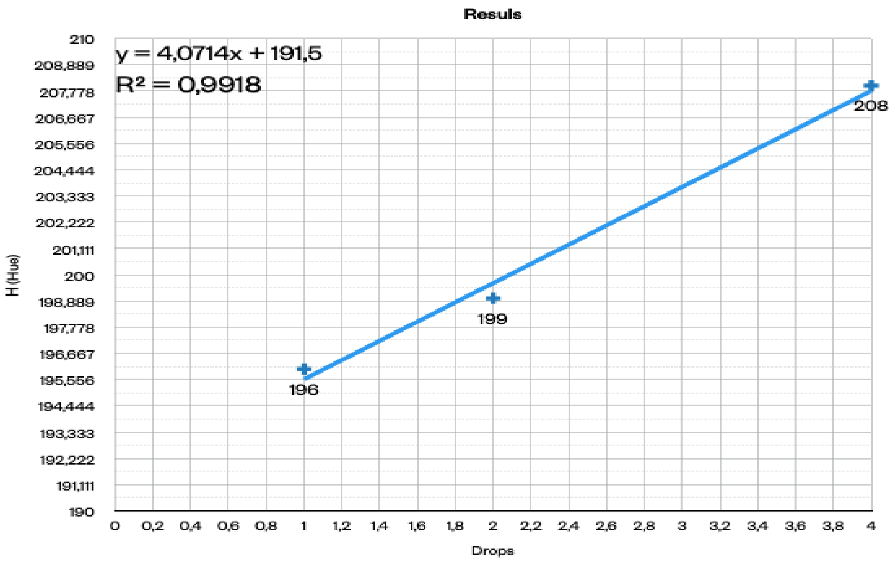


*Figure 3. Reference Curve of Blue coloring*

### *2.1.1 The measurements of the Red Dye*

Below in the table (Table 2) , measurements of the value H are shown for three solutions of different concentrations in drops of blue dye. Using these values, a reference curve (Fig.4) is constructed.

*Table 2. Measurements - Red coloring drops / 100 ml - H*

| ***drops/ 100mL*** | ***Hue(H)*** |
|---|---|
| One | 355 |
| Two | 356 |
| Four | 358 |

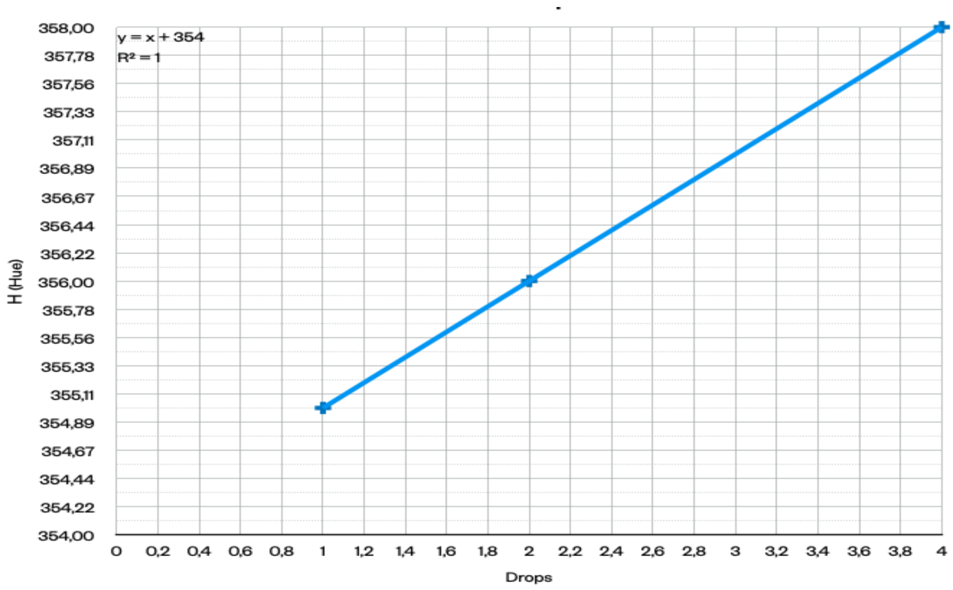


*Figure 4.Reference Curve of Red coloring.*

### *2.1.3 The measurements of the Yellow Dye*

Below in the table (Table 3) , measurements of the value H are shown for three solutions of different concentrations in drops of blue dye. Using these values, a reference curve (Fig.5) is constructed.

*Table 3. Measurements - yellow food dye drops / 100 ml - H*

| ***drops/ 100mL*** | ***Hue(H)*** |
|---|---|
| One | 56 |
| Two | 55 |
| Four | 53 |

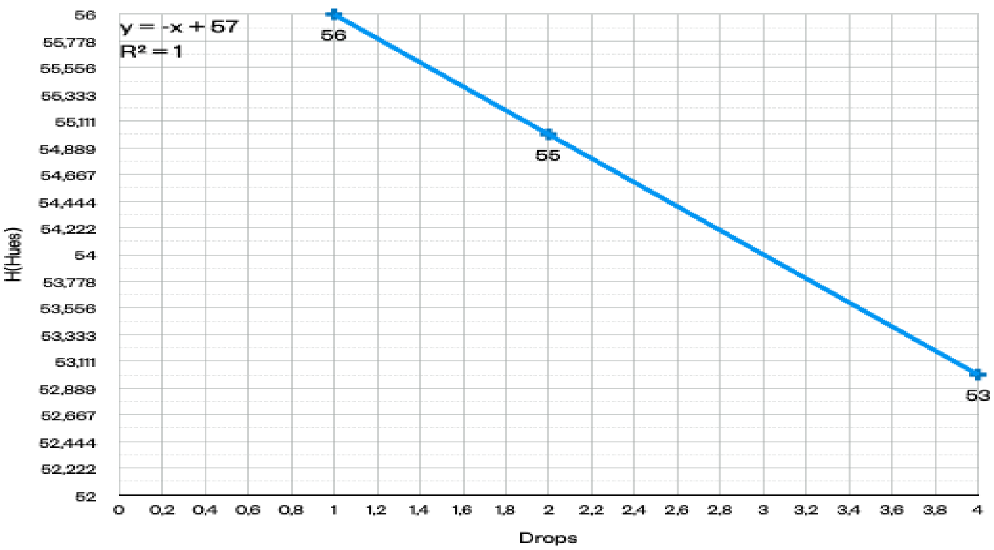


*Figure5. Reference Curve of Yellow coloring.*

## 2.2 PRESENTATION OF THE RESULTS

The graphical representations that each group produces are showcased during the class assembly. The way the results are presented makes it very plain that the dye concentration in drops with different color shades is linear. These findings are consistent with the link between concentration and colored solution absorption provided by the Beer-Lambert equation. For the yellow dye, there is a discernible variation in the gradient, though (Fig. 5). The analysis of the color model will reveal the solution. Students consult the website [7], where they can alter the values for the yellow dye and see that our eyes' ability to perceive color declines as the dye's H value rises.

## 2.3 THE "UNKNOWN" CONCENTRATION

Each group receives a solution with an undetermined dye concentration in terms of the quantity of drops during the final stage. This solution had three drops per 100 milliliter for every dye. Students' goal is to determine how many drops are in the unknown sample by utilizing the reference curve they have developed. For instance, a group studying the blue dye discovered that the unknown sample had a value of 212. By using the straight line equation, it can be ascertained that the sample had 3.2 drops in it. Considering that the dyes are added with a dropper that isn't very precise, the accuracy of the determination is fairly high, but it mostly aligns with the experiment's objectives, which were to demonstrate the connection between the solution's color and concentration and the practical application of analytical methods to real-world chemical problems like determining a solution's concentration.

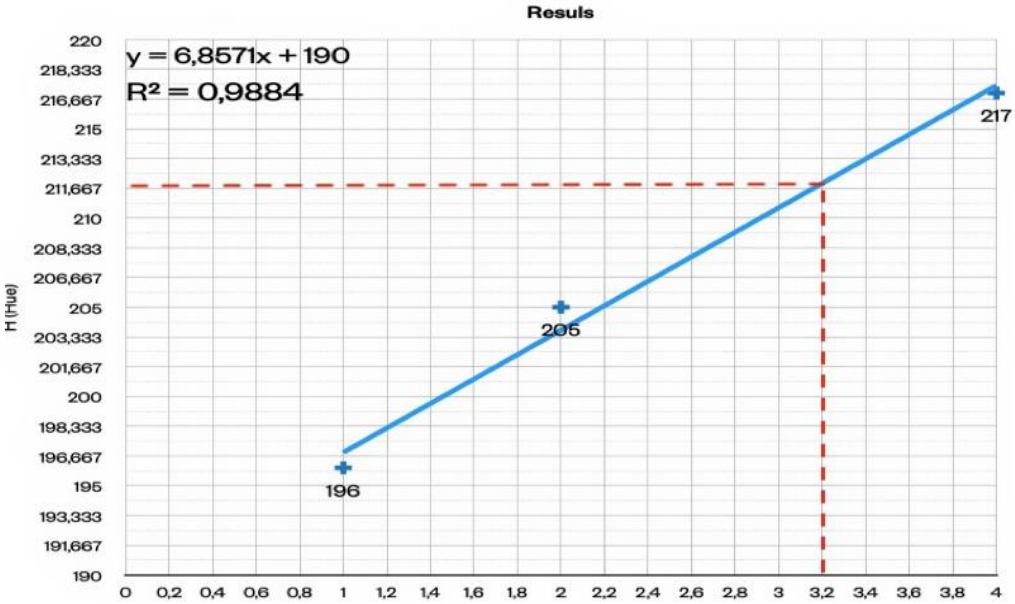


*Figure 6. The value H (212) for the unknown sample is determined from the reference curve and corresponds to 3.2 drops /100mL .*

## 3 DISCUSSION

Wanting to compare the linearity provided by measurements using the paremeter Hue of the HSV model, measurements were made in the final stage of the study using the RGB model, measuring a different parameter each time (Red - Green - Blue). The measurements were made with the same software, in solutions with different amounts of Red dye (Figure 7) and Bue dye (Figure 8), and the graphical representations were made on the same diagram. From the calculation of $R^2$, it is evident that parameter H provides better results .

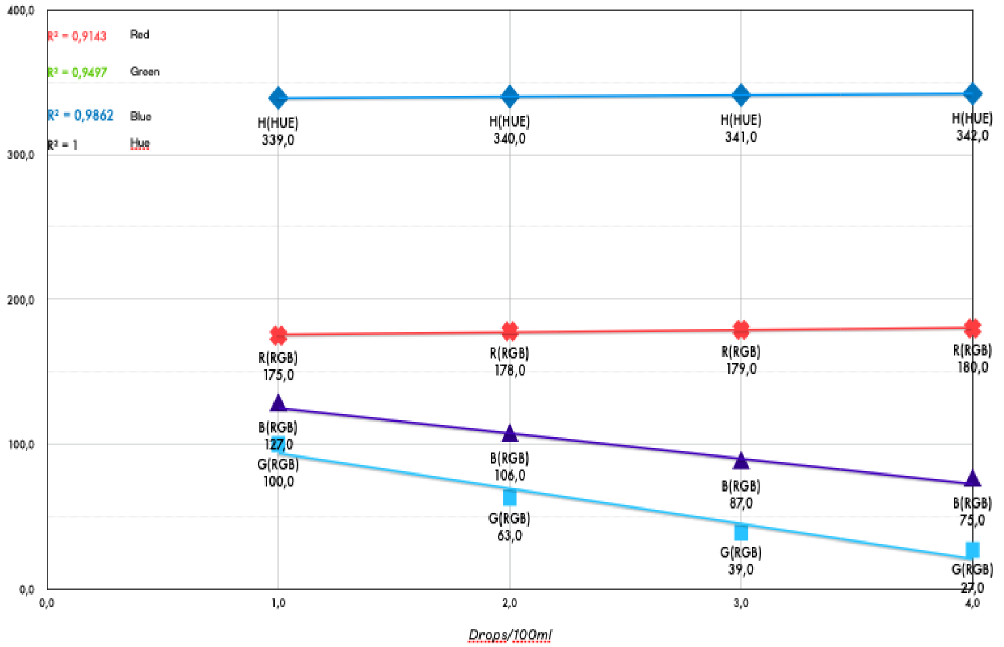


*Figure 7: Measurements of different parameters with the number of Red dye drops per 100ml.*

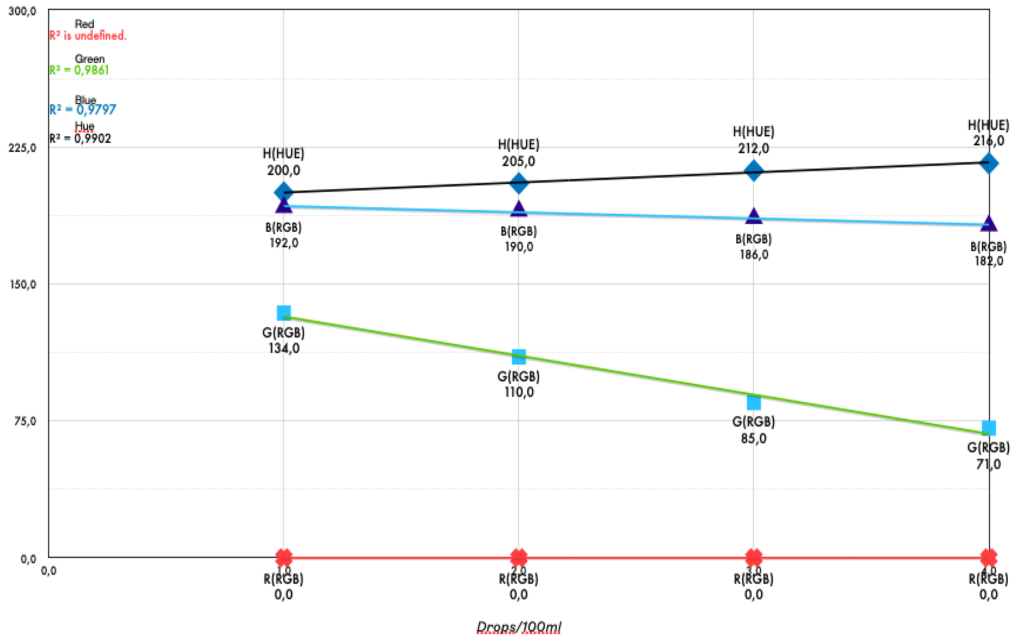


Figure 8: Measurements of different parameters with the number of *Blue dye drops per 100ml.*

## 4 CONCLUSIONS

Students learn about the scientific methods of inorganic chemical analysis, including colorimetry, through the aforementioned process. The relationship between color intensity and solution concentration is ultimately ascertained by applying the scientific approach of chemical analysis with reference curves. This method's simplicity is important since it employs readily prepared solutions, making it possible to take a lot of measurements from various colored solutions. Naturally, the mobility that cellphones offer allows for flexibility in terms of where tests may be conducted. Lastly, students prepare solutions, take measurements and make graphical representations, draw conclusions, and solve chemical issues using smartphones as scientific tools. It is an experimental method that defies the clichés of classroom laboratory activities and sparks students' curiosity about chemistry as a subject that offers solutions to practical issues.

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