Paper
Phys. Educ. **55** (2020) 025008 (9pp)
iopscience.org/ped

Innovative hands-on activities for teaching the colors of pigment

Kemal Yurumezoglu

Department of Gifted Education, Dokuz Eylul University, Buca, Izmir 35150, Turkey

E-mail: kemal.yurumezoglu@deu.edu.tr

CrossMark

Abstract
In this article, a consecutive series of four hands-on experiments are recommended to teach the colors of paint/pigment and their mixtures. These activities, which are effective in learning about how to make a simple observation and help to build argument-based knowledge about colors, offer an integrated and innovative way of teaching colors of pigment through the colors of light (RGB).

S Supplementary material for this article is available online

Introduction

With the technological developments taking place today, the colors of light and paint continue to color our lives with their timeless appeal. Technological innovations are constantly bringing us new opportunities concerning what we can do with the colors of light and pigment. To understand these innovations and use them more effectively in everyday life, we need to increase our experiences related to color. It is for this reason that it is important that schools provide a basis of introducing the concept of color to children when they are young. In this article, an innovative series of hands-on activities are recommended that everyone can find easy to do. The activities have been designed to be executed with materials that people of every age can easily access and their processes are very simple. The fundamental aim is to facilitate learning through a series of consecutive and innovative experiments related to the colors of pigment/paints, based on the colors of light. Recently, many innovative methods have emerged to teach the colors of pigment/paint. The experiment conducted on teaching absorption of pigment colors using artificial rainbow colors (Yurumezoglu *et al* 2015), a comprehensive hands-on application for light and pigment colors (Ruiz and Ruiz 2015), a detailed study of how light and pigment colors are perceived with a digital camera (Rosi *et al* 2016) and lastly, studies on the combining properties of shade with respect to light and pigment colors (Yurumezoglu *et al* 2017) were reconstructed and implemented to support the present study.

It is taught in science/physics classes that the primary colors of light are red–green–blue (RGB), and that the secondary colors are cyan–magenta–yellow (CMY). To make the transition from the colors of light to the colors of pigment, there needs to be some kind of consistent point of connection. All consistencies related to colors have been formulated in the context of the color theory of complementarity (Babič and Čepič 2009). The basic connection is that the colors cyan, magenta and yellow (CMY), created when the primary colors of light are added one on top of another, are defined as primary pigment colors. The primary colors of light—red, green and blue (RGB)—are added one on top of another to produce *white* (white light) (figure 1) and the primary colors of pigment—CMY create black (absence of light) (Karabey *et al* 2018).

In the figure above (see figure 1), we will begin with the basic knowledge about the colors of light and try to find answers to questions about which color(s) of light are absorbed in the primary colors and mixtures of pigment and which color(s) of light are reflected or transmitted, making use of hands-on activities that we designed with CMY filters and CMY paints. The aim of each activity in this process is to observe the interaction of light and pigments, to draw inferences from our observations, to use the evidence obtained in the process of observation for an argumentative discussion and lastly, to reinforce concept-based and integrated knowledge about colors.

In the experiments to be carried out in this study, our **materials** will be: three transparent water-filled glass containers, CMY printer ink, CMY fine and transparent filters (figure 2(a)) and magenta-colored Bourgainvillea (Bougainvillea spectablis) flowers (figure 2(b)). The activity was devised as a series of experiments carried out in four consecutive stages.

Stage 1. Why are the primary colors of ink CMY?

The first stage of the activity consists of three experiments. We begin by putting in 4–5 drops of the CMY ink into the water-filled small containers to attain cyan-, magenta- and yellow-colored water (figure 3(a)). Then we place first the cyan, secondly the magenta, and thirdly, the yellow filters in the CMY-colored water-filled containers and in each instance, note whether or not there is a change of color in each container (figures 3(a), (b), 4(a), (b) and 5(a), (b), and also Video 1 (stacks.iop.org/PhysEd/55/025008/mmedia)).

In the first experiment of the first stage, the cyan-colored filter was placed inside the CMY colored water-filled containers one by one and the following results were obtained, as seen in the table (see table 1). In the observation results displayed in table 1, there was no color change upon the interaction between cyan-colored filter and cyan-colored water, however it was observed that cyan-colored filter transmitted blue light in the magenta-colored water, green and yellow-colored water. The result of the experiment is the observation that the cyan-colored filter transmitted blue and green light but absorbed the red light. The basic principle in this conclusion is that, based on color theory, the daylight in the environment is composed of the sum of the RGB spectrum. This basic principle will be our starting point in the conclusions we draw from the other experiments.

Figure 1. The primary colors of light (RGB) and their mixtures in a dark setting.

In the second experiment of the first stage, the magenta-colored filter was placed inside the CMY-colored water-filled containers one by one and the following results were obtained, as seen in the table (see table 2). In the observation results displayed in table 2, there was no color change upon interaction between magenta-colored filter and magenta-colored water, however it was observed that magenta-colored filter transmitted blue light in the cyan-colored water, red and yellow-colored water. The result of the experiment is the observation that the magenta-colored filter transmitted blue and red light but absorbed the green light.

In the third experiment of the first stage, the yellow-colored filter was placed inside the CMY-colored water-filled containers one by one and the following results were obtained, as seen in the table (see table 3). In the observation results displayed in the table 3, there was no color change upon the interaction between yellow colored filter and yellow colored water, however it was observed that yellow-colored filter transmitted green light in the cyan-colored water, red and magenta-colored water. The result of the experiment is the observation that the yellow-colored filter transmitted green and red light but absorbed the blue light.

The common conclusion drawn from the three experiments was that each of the primary (*a*) (*b*)

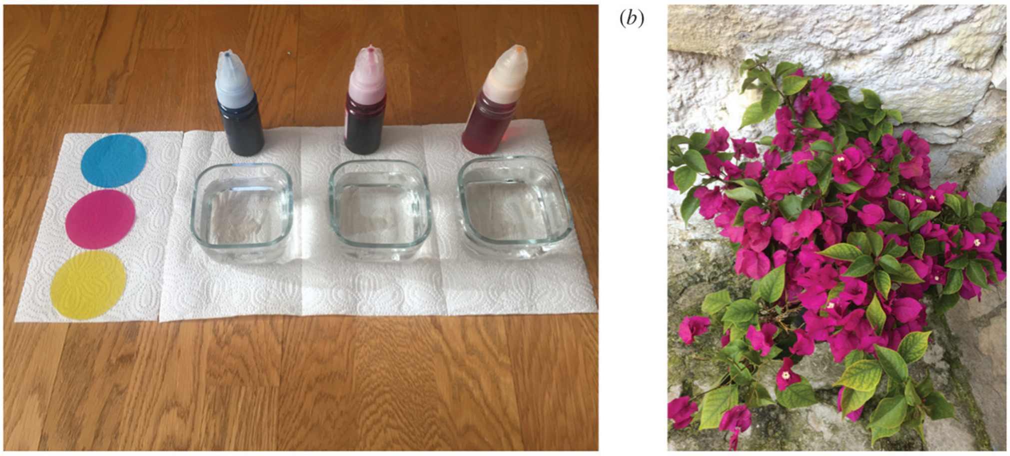


Figure 2. (a) CMY ink, CMY filters and water-filled containers. (b) magenta-colored Bourgainvillea.

(*a*) (*b*)

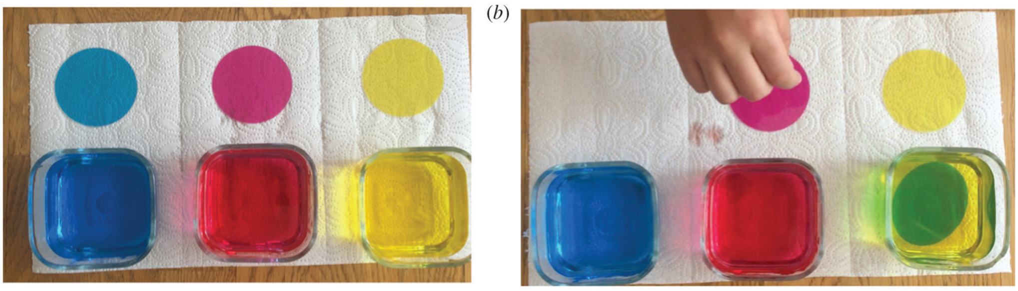


Figure 3. (a) Before experiment 1. (b) After experiment 1 (in this example, cyan-colored filter transmits green light in the yellow-colored water).

Table 1. 1st experiment and inferences.

1st experiment	1st pigment (on filter)	2nd pigment (in water)	Observed color	Color change	Transmitted light color	Absorbed light color
Container 1				No	GB	R
Container 2				Yes	B	RG
Container 3				Yes	G	RB

pigment colors (CMY) transmitted two colors of light but absorbed one. Each primary pigment color transmitting two colors of light is equivalent to one secondary color of light. Because of this, accepting the primary colors of pigment as the secondary colors of light verifies the consistency of the theory we are working with regarding the primary colors of pigment and their mixtures. In this context, we can infer from the conclusions drawn from our experimenting with the colors of light and pigment/paints that we can find an answer to the question as to why the primary colors of pigment are CMY.

Another conclusion reached from our observations in the first stage is that although the CMY-colored filters and CMY-colored water-filled containers do not display a change of color in the interaction of the same colors, the colors appearing in the area of interaction between the filters and the ink are more **vivid and intense**

Table 2. 2nd experiment and inferences.

2nd experiment	1st pigment (on filter)	2nd pigment (in water)	Observed color	Color change	Transmitted light color	Absorbed light color
Container 1				Yes	B	RG
Container 2				No	RB	G
Container 3				Yes	R	GB

Table 3. 3rd experiment and inferences.

3rd experiment	1st pigment (on filter)	2nd pigment (in water)	Observed color	Color change	Transmitted light color	Absorbed light color
Container 1				Yes	G	RB
Container 2				Yes	R	GB
Container 3				No	RG	B

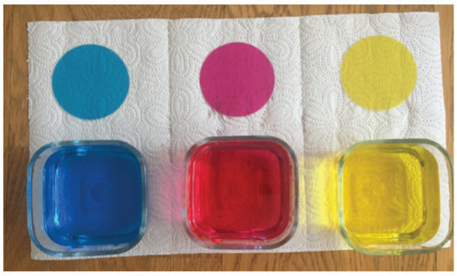
(*a*)  (*b*) 

Figure 4. (a) Before experiment 2. (b) After experiment 2 (in this example, magenta-colored filter transmits blue light in the cyan-colored water).

than they appeared before the interaction. The reason for this is that the density of the pigment has increased and pigments produce a stronger transmission in the daylight (figure 6(a) and (b)).

Stage 2. How are secondary colors of pigment (RGB) obtained from the primary colors of pigment (CMY)?

In this stage, as in Stage 1, 4–5 drops of CMY ink are introduced into small water-filled containers in equal proportions and mixed to obtained cyan-, magenta- and yellow-colored water (figure 4(a)), or the same colored water-filled containers used in the previous experiment can be used here as well. Then, the CMY filters are placed inside the containers with CMY-colored water, the magenta being put into the yellow first, then the yellow into the cyan and lastly the cyan into the magenta. At the end of this experiments (figure 7(b) and also Video 2), an observation is made of the color of the water in the containers and of the change of color in the filters.

The results attained from Experiment 4 are summarized in the table below (see table 4). The results of the experiment summarized in table 4 indicate that the water colored with the colors CMY and the CMY revealed a change of color in their one-to-one interaction and the previous color changed in the area of interaction of both materials. At the end of this experiment, it was observed that the cyan-, magenta- and yellow-colored water and the area of interaction with the CMY filters changed into the colors RGB (this

Table 4. 4th experiment and inferences.

4th experiment	1st pigment (on filter)	2nd pigment (in water)	Observed color	Color change	Transmitted light color	Absorbed light color
Container 1				Yes	R	G and B
Container 2				Yes	G	R and B
Container 3				Yes	B	R and G

(*a*) (*b*)

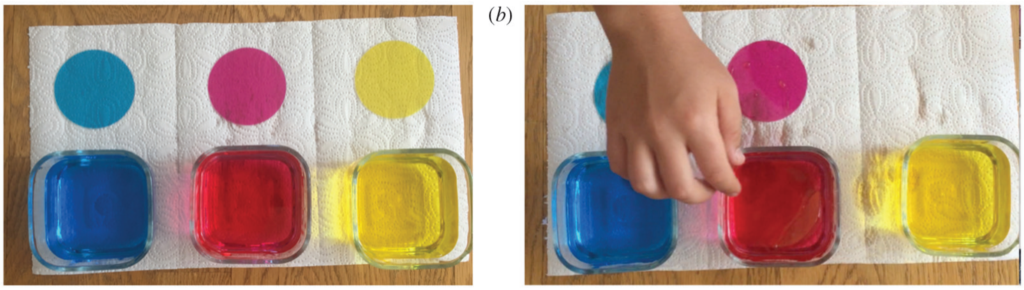


Figure 5. (a) Before experiment 3. (b) After experiment 3 (in this example, yellow-colored filter transmits red light in the magenta-colored water).

Table 5. 5th Experiment and inferences.

5th experiment	1st pigment (on filter)	2nd pigment (in water)	Observed color	Color change	Transmitted light color	Absorbed light color
Container 1				Yes	No	R and G and B
Container 2				Yes	No	R and G and B
Container 3				Yes	No	R and G and B

experiment may be designed to produce similar results using different possibilities). The observed evidence for this change can be explained as follows: When the results of the experiment shown in table 4 are reviewed, we see that only the colors RGB reached our eyes in the area of interaction. From this we can infer that in the area of interaction, the CMY-colored water and the CMY-colored filters transmits only one color of light and absorb two. Our common inference from this experiment is that the secondary pigment colors only transmits one color of light. This means that these colors are less bright than the primary pigment colors that transmits two colors of light.

Stage 3. How do primary colors of pigmentturn into black (absence of color)?

Based on the results of Experiment 4, this time we put 4–5 drops of CMY ink two by two into the water-filled small containers and mixed these to get Red, Blue and Green colored water (figure 8(a)). Then we placed the CMY filters into the RGB-colored containers, putting the magenta into the green, the yellow into the blue and lastly, the cyan into the red. The basis for this is using complementary colors in the context of color theory (Babič and Čepič 2009, Karabey *et al* 2018). At the end of this experiment (figure 8(b) and also Video 3), it is observed that the color has

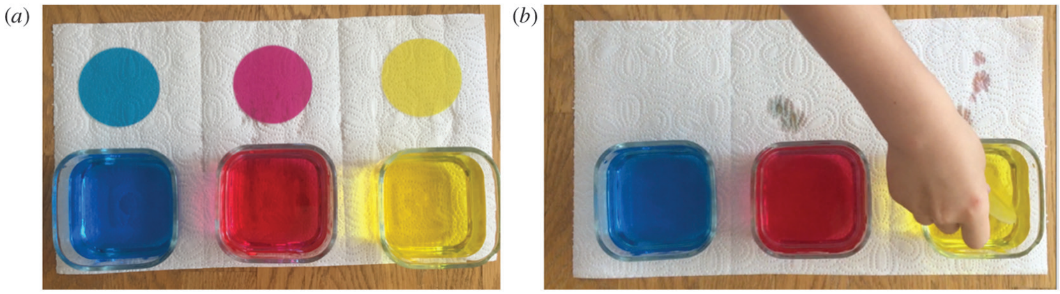


Figure 6. (a) CMY filters and CMY pigment interaction before the experiment. (b) CMY filters and CMY pigment interaction after the experiment.

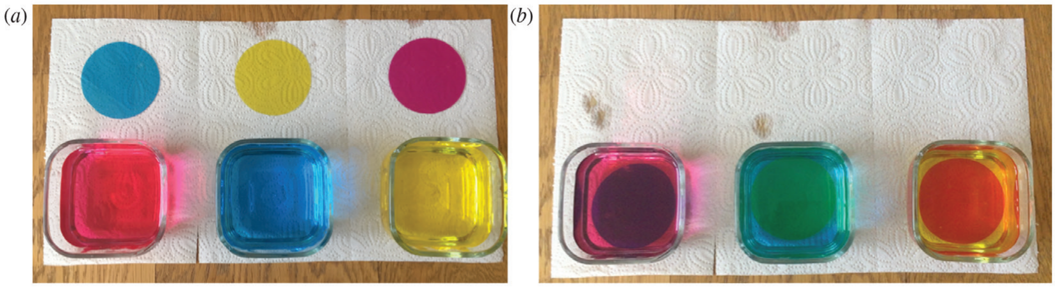


Figure 7. (a) Before experiment 4. (b) After experiment 4.

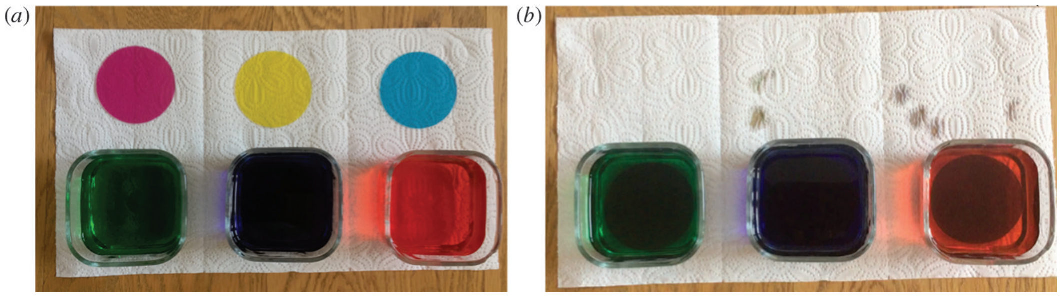


Figure 8. (a) Before the experiment 5. (b) After the experiment 5.

disappeared in the area of the filter-ink interaction, in the water in the containers and also in the filters.

The results attained from Experiment 5 are summarized in the table below (see table 5). The results of the experiment summarized in table 5 point to the observation that in the interaction of the RGB-colored water and the CMY filters, the colors that appeared before the experiment disappeared in the area of interaction of the two materials. When we review the results of experiment, as shown in table 5, we observe that there is no color reaching our eye from the area of interaction. Thus, it is seen that the RGB-colored water and the CMY-colored filters in the area of interaction have absorbed all of the colors of light. The overall inference we draw from this experiment is that, on the basis of the results of the previous experiments (see 1st, 2nd and 3rd experiments), we can say that each of the primary colors of pigment have absorbed a color of light. In this experiment, in each area of interaction of each color mixture, three pigment/paints have interacted, with all colors of light being absorbed and no light reaching us from the object. The non-reflection/non-transmission of light from the

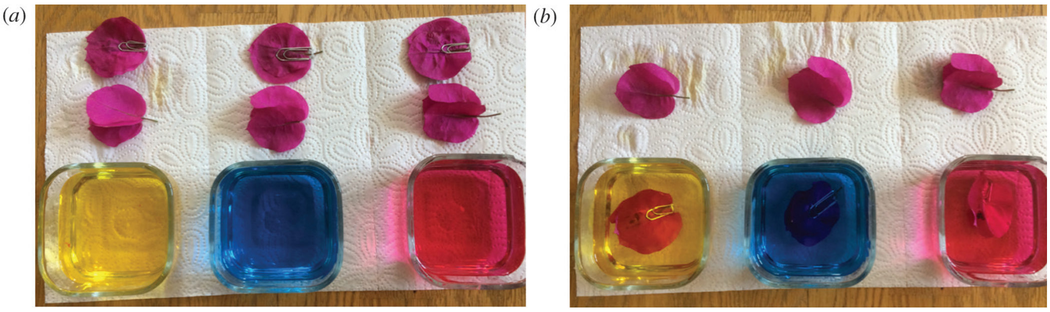


Figure 9. (a) Before experiment 6. (b) After experiment 6.

Table 6. 6th experiment and inferences.

6th experiment	1st pigment (on filter)	2nd pigment (in water)	Observed color	Color change	Transmitted light color	Absorbed light color
Container 1				Yes	B	R and G
Container 2				No	R and B	G
Container 3				Yes	R	G and B

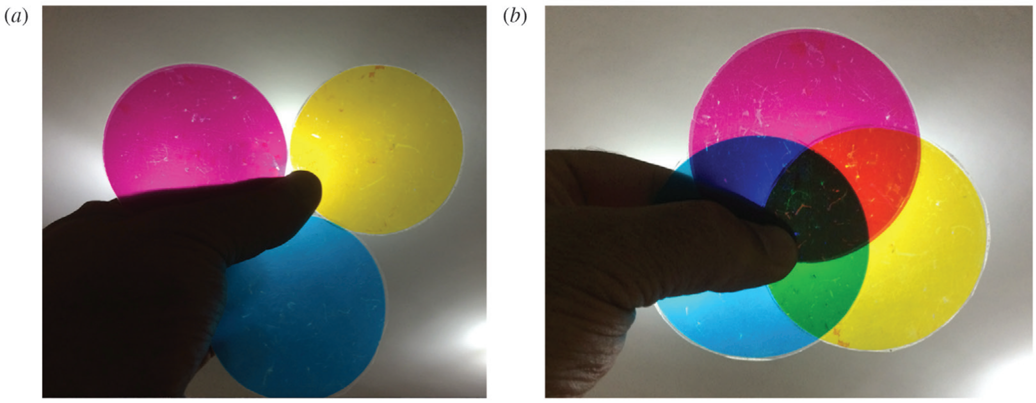


Figure 10. (a) Primary color filters made with CMY printing ink. (b) Secondary colors and the darkest color emerging when primary color filters overlap.

object/material in the area of interaction is the reason we see the object/material appear to be dark in the color we describe as black.

Stage 4. An example of pigments in nature and their change of color

In this stage, we again begin by similarly putting in 4–5 drops of the CMY ink into the water-filled small containers to attain cyan-, magenta- and yellow-colored water (figure 9(a)). Then, we place a magenta-colored Bourgainvillea flower into each CMY-colored water-filled container. At the end of the experiment (figure 9(b) and also Video 4), in the first part, there is no change of color in the magenta-colored flower or in the magenta-colored water, but there is a change of color observed in the other two containers.

The results attained from Experiment 6 are summarized in the table below. The results of the experiment summarized in table 6 show that in the interaction between the CMY-colored water and the magenta-colored flower, there was no change of color in the interaction with

(a)  (b) 

Figure 11. (a) During the experiments in the classroom. (b) Pigment colors demonstration in Kucuk Kulup Kindergarden.

the Magenta pigment but the cyan-colored water turned blue, the yellow-colored water turned Red. The conclusion drawn from this experiment is the source of color in plants is pigment and this pigment interacts with light in line with the theory of color. Similar to this experiment, discoveries may be made with different colored flowers or plants to find new colors from different types of interactions. This activity, very closely related to real life, can instill associations that will lead to sustainable motivation to learn about fundamental concepts of color, making us as individuals more astute observers of the environment.

Conclusions and implications

If we were to put the CMY filters used in the experiments described above one on top of another to make an integrated observation of the interaction between pigment/paint colors, we would obtain the following visual (figures 10(a) and (b)). In this experiment, it can be seen that at the parts of the filters that are not overlapping, the CMY filters directly transmits the light whereas in the overlapping areas, two or three pigments/paints interact to work against the light. In the non-overlapping areas of the CMY-colored filters, **two** colors of light are transmitted, while **one** color of light is transmitted in the overlapping of two filters and **no** transmission of color of light is seen in areas where there are three filters overlapping.

When CMY filters overlap, or as in the experiments above, when CMY pigment/paints overlap with colored paints, we observed that each color reciprocally changes in the area of interaction. These hands-on experiments explain the nature of interactions and show what lies in the background. In this context, our common inferences from the above experiments are as follows:

Firstly, when primary pigment colors interact with the white light in the environment, they display a natural behavior towards the light. Each primary pigment/paint color interacts with the white light that falls on it, absorbing one color of light and transmitting two colors, appearing as secondary colors (CMY).

Secondly, when CMY-colored water and CMY-colored filters interact one on one in the presence of white light in the environment, they maintain their previous colors but because the density of the pigment increases in the area of interaction, the colors become more **intense** and **vivid** compared to before the interaction. We call this vividness produced by the density of the pigment in the colors, **saturation**. This provides us with a wonderful opportunity to teach the topic of color saturation.

Thirdly, when CMY-colored water and CMY-colored filters interact in different combinations in the presence of white light in the environment, each pigment absorbs one color of light but only one color of light is transmitted in the area of interaction. When these primary colors (CMY) of the pigment interact two by two, they turn into secondary pigment (RGB) colors. These secondary pigment colors (RGB) appear to be less bright than the primary pigment colors (CMY). Expressed in another way, the luminosity of the pigment/paint secondary colors (RGB) is lesser than the luminosity of the primary pigment/paint colors (CMY). This experimental result may provide a good opportunity to teach the concept of **luminosity,** one of the main components of teaching concepts of color.

Fourthly, in the areas of overlapping of the CMY-colored water and the CMY-colored filters where three colors overlap in the presence of white light, this time three colors are in reciprocal interaction. This three-way interaction takes place in areas where each color of pigment/paint absorbs one color of light. The white light reaching the area of interaction is not let out of this three-way intersection and therefore the environment becomes lightless or dark. In this case, the luminosity is reduced even more than in the previous example, reaching a minimum value. Just as luminosity will diminish as the interactions between the pigment/pain colors increase, it will also diminish when the intensity of the source of light drops. In the most extreme case, in the non-presence of light, the environment will be dark and the color of the object will disappear.

The result of the experiment carried out with the magenta-colored Bourgainvillea flower, chosen from the close environment, showed the children the existence of the magenta pigment, by which they were greatly excited. Such associations help us to better understand the colorful world around us, giving us at the same time, an opportune moment to engage in effective teaching concerning the topic of color.

The fact that the hands-on experiments carried out in this study can be executed by anybody both in and out of the classroom using materials that are easily accessible as well as the simplicity of the processes followed facilitates the evidence-based teaching of pigment/paint colors through the interaction of light-pigment/paint colors. The activities were tried out with many student groups of different ages (such as figures 11(a) and (b)), both those exhibiting normal development and highly gifted children, and it was found that interest was abundant and quite good results were obtained in the context of inquiry and conceptual understanding.

Acknowledgment

I thank Dr Ekin BOZTAŞ for her help in the careful preparation of the filters and Dr Turan Enginoğlu for his support in the general implementation of the experiment. My deepest thanks to my son Ferda (age 9) and my daughter Feryal (age 6) for their insatiable curiosity during the development of the experiment and throughout the video shooting sessions and for being my guides in finding the best way to reach my goal.

ORCID iDs

Kemal Yurumezoglu https://orcid.org/0000-0002-3288-9890

Received 10 November 2019, in final form 3 December 2019
Accepted for publication 11 December 2019
https://doi.org/10.1088/1361-6552/ab60dc

References

Babič V and Čepič M 2009 Complementary colors for a physicist *Eur. J. Phys.* **30** 793

Karabey B, Koyunkaya M Y, Enginoglu T and Yurumezoglu K 2018 Discovering complementary colors from the perspective of steam education *Phys. Educ.* **53** 035001

Rosi T, Malgieri M, Onorato P and Oss S 2016 What are we looking at when we say magenta? Quantitative measurements of RGB and CMYK colors with a homemade spectrophotometer *Eur. J. Phys.* **37** 065301

Ruiz F and Ruiz M J 2015 Color addition and subtraction apps *Phys. Teach.* **53** 423–7

Yurumezoglu K, Isik H, Arikan G and Kabay G 2015 Teaching the absorption of light colors using an artificial rainbow *Phys. Educ.* **50** 402

Yurumezoglu K, Karabey B and Koyunkaya M Y 2017 Shadows constructing a relationship between light and color pigments by physical and mathematical perspectives *Phys. Educ.* **52** 025008

Kemal Yurumezoglu is a professor in the Department of Gifted Education at Dokuz Eylul University in Turkey. He received his master's degree in physics education in 2000 from the University of Paris Diderot (Paris 7), France, and his PhD in science education in 2005 from the University of Strasbourg, France. His research interests are in conceptual physics and inquiry-based physics activities. He was involved in the Pri-Sci-Net Project funded through the European Union Seventh Framework Programme. He is the coordinator of Science Curriculum of Gifted Students in Turkish Ministry of National Education.