The Microfluidic System for Studying the Mixing of Pigment Color by using a Smartphone

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Abstract

The concept of color mixing was taught to students from elementary to high school. However, it was observed that the students still experienced confusion in distinguishing between light color mixing and pigment color mixing. Therefore, the present research focuses on the principles of pigment color mixing and demonstrates the application of microfluidic systems and smartphone technology to achieve this objective. The design of the microfluidic system has been optimized for cost-effectiveness, accessibility, and ease to use. The fabrication of microfluidic systems was interfaced with smartphone color measurement applications to provide real-time readings of the pigment color mixing results. The Cyan, Magenta, and Yellow ink were used as the subtractive colors to perform this experiment. The concentration of each color was varied from 0.2% to 1.4% in steps 0.2 before mixing them. The study's findings revealed that the concentration of pigments influenced the mixing of color shading. The students could utilize the microfluidic system and pigment color mixing concepts from the experiment's outset to gain insights into color shading. Furthermore, the study explicated the relationship between subtraction colors and the concentration from mixing pigments.

Keywords: *pigment color mixing, microfluidic system, color application in smartphone, color theory*

1. Introduction

Studying the color of light and pigment color is essential to everyday life as it can create ambiance and evoke emotions. The science behind color mixing is fundamental but can be challenging to comprehend. Typically, physics introduces the differences between light and pigment color mixing in high school classes. However, confusion has arisen in the classroom regarding the differences between Red (R), Green (G), and Blue (B) colors in the light mixing and Cyan (C), Magenta (M), Yellow (Y) and Key or Black (K) mixing (Jan-Peter & Meyn, 2008; Claudia & Haagen-Schützenhöfer 2017; Roudlotul et al., 2020). To address this issue, researchers aimed to explain the differences and demonstrate the results of light and pigment color mixing using various techniques, including those presented in previous studies (Jerzy & Grzegorz, 2019; Burak, Melike, Turan, & Kemal, 2018).

This research focused on the subtractive mixing theory, which can explain pigment color mixing. The experimental setup design was cost-effective and straightforward to prepare. The researchers used the microfluidic technique to study the appearance of color after mixing, with Cyan (C), Magenta (M), and Yellow (Y) as primary colors. The liquid color flowed through the microfluidic pattern, and the mixing of colors was detected by a smartphone.

2. Objectives

The objectives of the research are:

1. To examine the principles of pigment color mixing and develop a technique for utilizing microfluidic systems and smartphone technology to achieve this.

2. To evaluate whether students can utilize the microfluidic system and pigment color mixing concepts to gain insights into color shading.

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3. Details

3.1 Microfluidic design

The microfluidic device was developed based on a simple concept. The design of the Y-shaped channel was utilized to create a microfluidic pattern, as shown in Figure 1. The channels within the microfluidic system were precisely 1 mm wide and measured 13-15 mm long. The square-shaped channel measuring 4x14 mm served as a mixed channel, whereas the circle with a diameter of 6 mm acted as the inlet for primary colors and the outlet. The pattern was created with a 1.25-mm-thick Y-shaped design. The primary colors, namely C or M or Y, were introduced into each inlet through double injections, and the flow of the colors was regulated using a syringe inject the primary color into the inlet. The microfluidic device is comprised of three parts. The first part is bottom, it is consisted of a clear plastic, while the second part was composed of three layers of plastic Y channels. The last part is the top layer. The clear plastic, 0.25 mm thick, was used as one bottom, three middle, and one top layer, respectively.

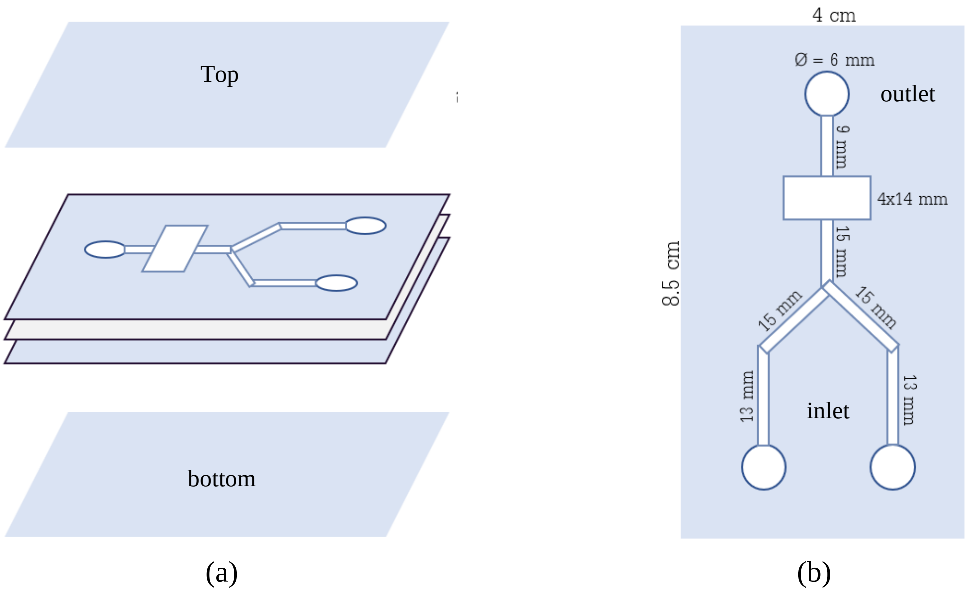


Figure 1. Microfluidic pattern of (a) side view of 5 layers and (b) top view of Y-shaped

3.2 Various concentration of primary color preparation

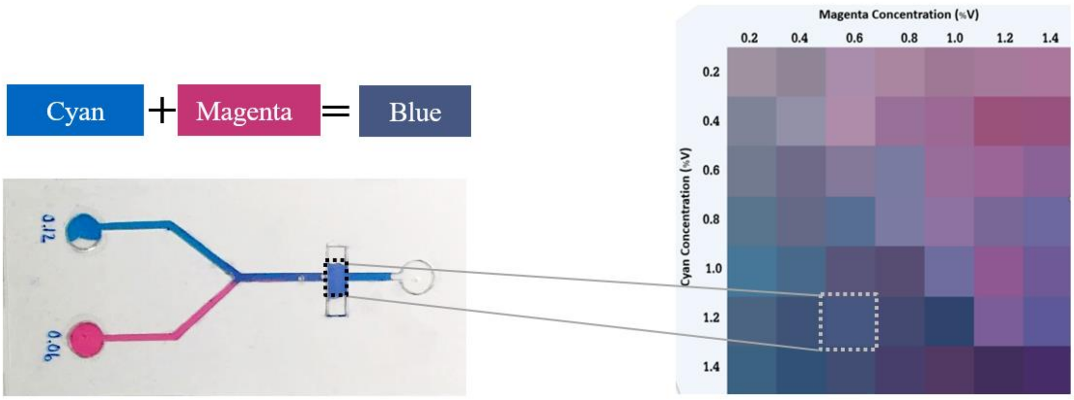
As per standard protocol, the Cyan, Magenta, and Yellow ink for inkjet printers were prepared by diluting them in water. The color concentration, as a function of volume for each color, is clearly depicted in Figure 2. In order to establish a baseline for the primary color, a smartphone application was utilized to measure the digital bit value, thus ensuring accuracy in the color representation. Their corresponding digital values were measured in both the RGB and CMYK systems. The data obtained provide a comprehensive understanding of the inkjet printer's color spectrum, facilitating accurate color representation.

Color		0.2%	0.4%	0.6%	0.8%	1.0%	1.2%	1.4%
C	RGB	64,184,218	6,146,197	0,126,198	0,110,199	0,104,190	0,103,195	0,93,195
	CMYK	70,15,0,14	90,25,0,22	100,30,0,22	100,41,0,21	100,45,0,25	100,47,0,23	100,52,0,23
M	RGB	203,117,166	231,80,161	196,53,117	189,42,97	178,34,70	168,27,70	158,23,56
	CMYK	0,42,18,20	0,65,30,9	0,72,40,23	0,77,48,25	0,80,60,30	0,83,58,34	0,85,64,38
Y	RGB	236,240,156	223,225,98	221,220,78	199,200,62	201,196,40	195,184,30	209,169,12
	CMYK	1,0,34,5	0,0,56,11	0,0,64,13	0,0,69,21	0,2,80,21	0,5,84,23	0,19,94,18

Figure 2 The Cyan, Magenta and Yellow of inkjet printer with various concentrations by volume and digital value of each color in RGB and CMYK system.

4. Results and Discussion

Double injection of Cyan and Magenta pigment colours were carried out in the microfluidic channels, and the resulting findings are presented in Figure 3. The homogeneity of mixing colours in the square shape was evaluated through photography using a smartphone, thus ensuring accurate measurements and analysis of the data obtained.



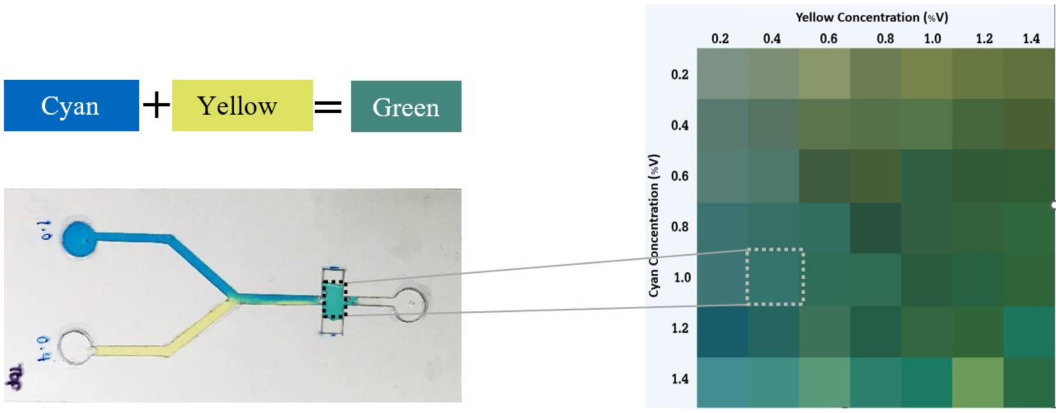
(a) (b)

Figure 3. (a) The Cyan and Magenta inkjet printers were mixed at concentrations of 1.2% and 0.6% by volume, respectively. (b) The shading of pigment color mixing of Cyan and Magenta was evaluated at various concentrations.

C%V \ M%V		0.2%	0.4%	0.6%	0.8%	1.0%	1.2%	1.4%
0.2 %	RGB	159,145,160	144,133,150	170,140,172	170,134,160	159,120,149	166,122,155	171,119,157
	CMYK	0,9,0,37	4,11,0,41	1,15,0,32	0,21,5,33	0,24,6,37	0,26,6,34	0,30,8,32
0.4 %	RGB	126,131,152	147,145,168	175,140,170	153,112,152	156,105,148	154,82,122	151,82,128
	CMYK	17,13,0,40	12,13,0,34	0,19,2,31	0,26,0,40	0,32,5,38	0,40,20,39	0,45,15,40
0.6 %	RGB	114,122,143	111,106,136	132,121,153	121,123,161	152,109,154	155,101,151	138,98,151
	CMYK	20,14,0,43	18,22,0,46	13,20,0,40	24,23,0,36	1,29,0,39	0,34,2,39	8,35,0,40
0.8 %	RGB	89,117,141	100,105,134	86,110,146	123,122,162	142,114,162	120,104,151	109,104,160
	CMYK	36,17,0,44	19,21,0,47	41,24,0,42	24,24,0,36	12,29,0,36	20,31,0,40	37,35,0,37
1.0 %	RGB	70,119,152	72,105,138	89,85,122	87,77,114	111,109,159	143,88,146	111,89,151
	CMYK	53,21,0,40	47,23,0,45	27,30,0,52	23,32,0,55	30,31,0,37	2,39,0,42	26,41,0,40
1.2 %	RGB	75,100,130	63,83,120	70,87,130	68,73,113	46,68,109	123,93,153	93,88,152
	CMYK	42,23,0,49	47,30,0,52	46,33,0,49	39,35,0,55	57,37,0,57	19,39,0,40	38,42,0,40
1.4 %	RGB	59,98,129	49,81,119	65,77,115	71,62,107	82,57,99	65,46,92	70,44,105
	CMYK	54,24,0,49	58,31,0,53	43,33,0,54	33,42,0,58	17,42,0,61	29,50,0,63	33,58,0,58

Figure 4. The digital value of RGB and CMYK of pigment color mixing of Cyan and Magenta at various concentration

The results indicate that the pigment of the subtractive color of Cyan and Magenta at equal concentrations, specifically 1.4% by volume, indicates that the sum of Cyan and Magenta (C + M) results in the color blue, thus corroborating established color theory. Additionally, the color that appears after color mixing is dependent on the concentration ratio of the mixing color. The color that we perceive is determined by the wavelengths of light that are reflected back to our eyes. When Cyan and Magenta are mixed together, the resulting color is typically a shade of blue. However, the specific shade of blue can vary depending on the concentrations of the two colors used in the mixture. In these cases, if we see at the Cyan 1.4% mix with Magenta 1.4%, the resulting color may appear more violet than blue. This is because violet is a color that is located between blue and magenta in the visible spectrum. Additionally, the way colors are represented in digital images such as smartphone photos can also affect our perception of the color. The color reproduction on different devices, such as screens, may not be consistent or accurate, leading to further variation in color perception. Moreover, the color application in smartphone extracts the digital value as seen in Figure 4. In Figure 4, a comparison of digital values in both the RGB and CMYK systems demonstrates that the shading of light when reflected from the surface to the human eye varies at different concentrations. This comprehensive understanding of the color spectrum facilitates accurate color representation, thus ensuring optimal outcomes in various applications.



(a) (b)

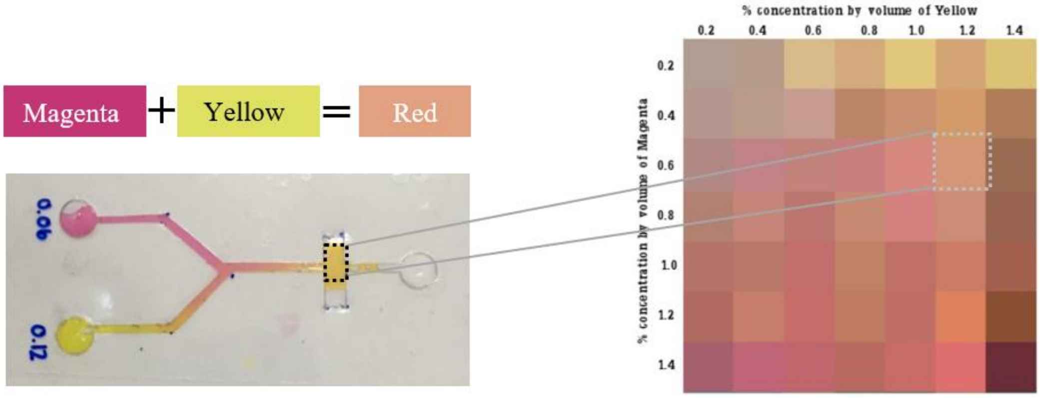
Figure 5 (a) The Cyan and Yellow inkjet printers were mixed at concentrations of 1.0% and 0.4% by volume, respectively. (b) The shading of pigment color mixing of Cyan and Yellow was evaluated at various concentrations.

The Cyan and Yellow inkjet printers were mixed according to established protocols, and the results are presented in Figure 5. The results of the experiment show that when Cyan and Yellow inkjet printers are mixed together in equal concentrations (specifically 1.4% by volume), the resulting subtractive color pigment is green, in accordance with established color theory. This finding is corroborated by the empirical results obtained, which provide compelling evidence for the validity of the additive and subtractive color mixing models. The Figure 6, a comparison of digital values in both the RGB and CMYK systems demonstrates of Cyan and Yellow mixture were shown.

The last of mixture is Magenta and Yellow. When Magenta and Yellow inkjet printers are mixed together, the resulting subtractive color pigment is typically a shade of red, with the specific shade depending on the concentrations of Magenta and Yellow used in the mixture as seen the Figure 7. This is because Magenta is a primary subtractive color that appears as a shade of red-purple, and when mixed with Yellow, which is a secondary subtractive color that appears as a shade of green, the resulting color is red due to the cancellation of green.

Y%V \ C%V		0.2%	0.4%	0.6%	0.8%	1.0%	1.2%	1.4%
0.2 %	RGB	124,146,133	124,142,116	138,151,105	108,125,83	118,131,75	102,119,65	95,113,61
	CMYK	15,0,8,42	12,0,18,44	8,0,30,40	13,0,33,50	9,0,42,48	14,0,45,53	15,0,46,55
0.4 %	RGB	89,122,111	86,115,97	92,117,78	89,114,74	85,118,75	69,101,60	74,95,52
	CMYK	27,0,9,52	25,0,15,54	21,0,33,54	21,0,35,55	27,0,36,53	31,0,40,60	22,0,42,62
0.6 %	RGB	86,126,117	77,121,106	61,92,61	68,95,54	49,95,67	49,89,53	47,92,51
	CMYK	31,0,7,50	36,0,12,52	33,0,33,63	28,0,43,62	48,0,29,62	44,0,40,65	48,0,44,63
0.8 %	RGB	60,115,112	54,111,102	49,110,95	40,82,62	49,94,65	51,97,59	46,103,60
	CMYK	47,0,2,54	51,0,8,56	55,0,13,56	51,0,24,67	47,0,30,63	47,0,39,61	55,0,41,59
1.0 %	RGB	63,117,117	52,116,109	47,109,86	46,108,83	42,91,62	41,98,65	47,100,56
	CMYK	46,0,0,54	52,0,6,54	47,0,21,57	57,0,23,57	53,0,31,64	58,0,33,61	52,0,43,60
1.2 %	RGB	24,92,105	36,101,95	61,114,88	36,94,70	52,102,65	48,101,55	29,117,93
	CMYK	77,12,0,58	64,0,5,60	46,0,22,55	61,0,25,63	49,0,36,60	52,0,45,60	75,0,20,54
1.4 %	RGB	66,141,146	65,142,132	89,155,120	43,128,109	26,123,98	107,156,91	41,107,69
	CMYK	54,3,0,42	54,0,7,44	42,0,22,39	66,0,14,49	78,0,20,51	31,0,41,38	61,0,35,58

Figure 6 The digital value of RGB and CMYK of pigment color mixing of Cyan and Yellow at various concentration



(a) (b)

Figure 7 (a) The Magenta and Yellow inkjet printers were mixed at concentrations of 0.6% and 1.2% by volume, respectively. (b) The shading of pigment color mixing of Magenta and Yellow was evaluated at various concentrations.

M%V \ Y%V		0.2%	0.4%	0.6%	0.8%	1.0%	1.2%	1.4%
0.2 %	RGB	177,157,146	182,155,138	217,186,139	212,169,124	226,200,126	213,165,117	220,194,117
	CMYK	0,11,17,30	0,14,24,28	0,14,35,14	0,20,41,16	0,11,44,11	0,22,45,16	0,11,46,13
0.4 %	RGB	181,151,143	186,155,137	199,157,145	187,134,103	201,144,114	211,155,106	177,124,90
	CMYK	0,16,20,29	0,16,26,27	0,21,27,21	0,28,44,26	0,28,43,21	0,26,49,17	0,29,49,30
0.6 %	RGB	177,136,132	193,131,136	194,131,124	201,127,126	215,137,127	212,150,119	154,107,83
	CMYK	0,23,25,30	0,22,29,24	0,32,36,23	0,29,37,21	0,36,40,15	0,29,44,17	0,30,45,39
0.8 %	RGB	179,129,114	199,133,121	189,117,111	199,139,115	212,129,127	204,141,118	153,99,81
	CMYK	0,28,36,30	0,33,39,22	0,38,41,26	0,30,42,22	0,39,40,17	0,31,42,20	0,35,47,40
1.0 %	RGB	181,116,105	184,121,105	194,110,109	191,130,103	191,113,101	204,124,102	163,96,78
	CMYK	0,36,42,29	0,34,43,28	0,43,44,24	0,32,46,25	0,41,47,25	0,39,50,22	0,41,52,36
1.2 %	RGB	176,106,97	199,125,107	199,109,105	191,124,98	191,111,101	222,129,93	138,80,52
	CMYK	0,40,45,31	0,37,46,22	0,45,47,22	0,35,49,25	0,42,52,27	0,42,58,13	0,42,62,46
1.4 %	RGB	166,96,109	191,101,119	191,103,109	184,106,97	201,107,103	222,111,111	107,45,55
	CMYK	0,42,34,35	0,47,38,25	0,46,43,25	0,42,47,28	0,47,49,21	0,50,50,13	0,58,49,58

Figure 8. The digital value of RGB and CMYK of pigment color mixing of Magenta and Yellow at various concentration

5. Conclusions

The use of microfluidic technology in studying pigment color mixing and obtaining digital values in RGB and CMYK using a smartphone application is demonstrated in this research. The results obtained are in agreement with the established color theory as depicted in Figure 9, where the overlapping of C, M, and Y inks generates the subtractive secondary colors (R, G, and B), forming the basis for color printing. Furthermore, this technique can be utilized to consider the absorption of pigment colors perceived by the human eye. The research findings indicate that Cyan + Magenta mixture produces a blue shade, and RGB - R - G = B. Similarly, Cyan + Yellow mixture produces a green shade, and RGB - R - B = G. This simple and cost-effective experimental setup can be employed as an educational tool for studying pigment color mixing. Additionally, this technique can inspire further study of color theory, as it is both accessible and easy to fabricate. The findings of this study thus suggest a promising new direction for research into the practical applications of microfluidics and color measurement in science education.

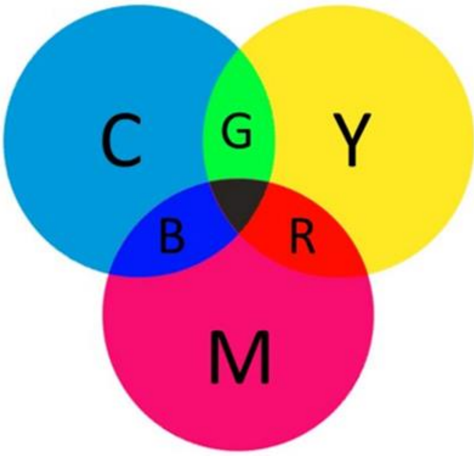


Figure 9 Displays a CMYK subtractive mixing diagram.

6. Acknowledgements

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7. References

Jan-Peter, M. (2008). Colour mixing based on daylight. *European Journal of Physics*, *29*, 1017-1031.

Claudia, H. S. (2017). Students' conceptions on white light and implications for teaching and learning about colour. *Physics Educations*, *52*, 044003.

Roudlotul, I., Farida, A.S. and Winda, S.U. (2020). Computer-based "Color-Mixing Maze Game" to stimulate symbolic thought for the development of learning science in early childhood, *Journal of Physics: Conference Series*,*1511*, 012112.

Jerzy, B. and Grzegorz, S. (2019). Arduino-based light source used to demonstrate mixing of colors and as a simple system for luminescence observations, *Physics Educations*, *54*, 023005.

Burak, K., Melike, Y.K., Turan, E. and Kemal, Y. (2018). Discovering complementary colors from the perspective of steam education, *Physics Educations*, *53*, 035001.