Will It Blend?

Studying Color Mixing Perception

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Agradecimentos.

Todos aqui.

Abstract

English Abstract goes here.

Keywords: one, two, three, keywords

Resumo

Resumo Português fica aqui.

Palavras-chave: uma, duas, três, keywords

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Acronyms

CMYK Cyan, Magenta, Yellow, Key. 15, 16

CSV Comma Separate Values. 13, 14, 19

HSV Hue, Saturation, Value. 15, 16

InfoVis Information Visualization. 19

IST Instituto Superior Técnico. 12

RGB Red, Green, Blue. 15–17

RNL Rede Novas Licenciaturas. 12

RYB Red, Yellow, Blue. 41

Chapter 1

Introduction

Introduction goes here.

... USAR ESTA PARTE DA INTRODUÇÃO DO RESEARCH PROPOSAL ...

In this section, we introduce the majority of topics to be further studied, the different phases of our research, the metrics we are going to collect and how we are going to treat them. Since we aim to *study to what extent can a user distinguish different amounts of blended colors, when using color mixtures to convey information*, it is important learn from previous results, testing out not only the validity of them but also some missed opportunities.

There are several aspects to be considered when developing the broadest study possible: regarding color blending profiling tests, it exists - among others - some questions which remain unanswered; some of them were risen in the studies by Gama and Gonçalves [GG14b, GG14a]. These questions can be divided in four categories:

1.1 Dissertation Outline

Describe the organization of the dissertation document, referring to other chapters.

Chapter 2

Background

2.1 Theoretical Background

2.1.1 Color Perception

In this section, we overview the philosophy about color, relating real-world perceptions to human perception through the eye. There are two main areas of interest, called the Cones and the Rods, which will be explained with quite detail; these areas restrict how we perceive color, specially if there are visual deficiencies. Moreover, color creates mental models and codes, which are part of routines and rules followed by society, and will be exemplified in the end of this section.

Color Philosophy

Looking up for a concrete definition of color is a hard task: there are quite a few ways to perceive color. Color raises serious metaphysical questions[1], concerning the physical and psychological reality of it. Color is an important feature of subjects: it allows us to recognize objects, locate them, it fires emotions and behaviors and supports protocols over the world. Probably, the major problem of color has to do with what we seem to know about it, into what physical properties of objects and materials express about them; David Hume defended in 1739 [Hum39] that "(...) Sounds, colors, heat and cold, according to modern philosophy are not qualities in objects, but perceptions in the mind (...)", a highly subscribed dogma. This affirmation describes two important tendencies, the **elimininativism** and the **subjectivism**: the first one is the view that tells physical objects don't have an inherent color associated to themselves, the last one states that color is a subjective attribute of objects. Chirimuuta recently argued [Chi14] about the different mindsets one can have regarding color: its main argument is that color is a subjective interpretation of an objective physical stimuli and, to justify this statement, he settles a contrast between rival theories of color. Color **realists** accept that colors are indeed physical properties of objects but instantaneously, two questions arise from this: **1)** what really is color and its properties, and **2)** do objects really possess those characteristics? With respect to these questions, we can derive even more theories: **Primitivism**, **Reductive Physicalism**, **Dispositionalism**, **Projectivism**, **Subjectivism**, among others.

Chirimuuta [Chi14] also compares the **Realism** against the **Anti-Realism**, since in the last one, the metaphysical question "Can we say that objects are actually colored?" is promptly denied: colors do not physically and mentally exist and nothing is, in fact, colored; it is even said by the anti-realists that classifying color by its features is an illusion. As the author afirms, his view is close to **Relationism**, a

[1] "Stanford Encyclopedia (...)", Available at: `stanford.io/1MWp7Zh`. Last accessed on January 8th, 2016.

theory which fills the gap between the previous mindsets: to fathom color, we have to consider both the perception and the external *stimuli*, and treat color as the result of this interaction; the task of interpreting color is part of the mechanism of accessing multiple properties of objects, as shape, composition, *etc.* Colors are, therefore, relational properties, with respect to perceivers and circumstances of viewing.

Regardless of which opinion you support, color has come to be an undeniable point of major interest of studies: from philosophy, to psychology, computer science or statical analysis, color plays a major role in presenting numbers, conveying ideas and spreading information. To endorse this usefulness, different color theories were discovered all along the years and were accompanied by a profound research about the Human eye.

2.1.2 The Human Eye

The Animal visual system is a direct consequence of evolutionism: it is perfectly adjusted and adapted to the way of living of every animal. We don't hunt like wild animals, but our visual system is prepared to distinguish a wide range of green colors since we evolved as a species surrounded by green vegetation and knowing what to eat was a matter of life or death. The human visual system is adapted to do many things, specially detecting sharpness and color with great precision and sensitivity during the day light and night, although our night vision isn't quite accurate.

Light is electromagnetic radiation, but most of this radiation is invisible to the human eye: it can perceive light from under 400 nanometers until 750 nanometers, as seen on figure **??**.

When the light strikes an object, depending of the surface's material, it can either: be wholly or partly absorbed, reflected or transmitted; what we perceive as being an object is the light reflected of the surface. The human eye (Figure **??**), then, decodes light energy into neural activity: this light reaches the eye through the **cornea**, crosses the pupil and is refracted by the lens, coming to a final projection of a sharp image in the back of the eye, the **retina**. However, this image is inverted, as the light rays from the top of the object are being project on the bottom of the retina, so as the light rays coming from the right side of the object, projected in the left side of the retina. This image is going to be rearranged by the brain.

In order to be rearranged, the light is converted in the retina, which contains specialized cells - photoreceptors - that convert light energy into neural impulses, which are send to the brain. There are two main types of photoreceptors: **cones** and **rods**, retinal cells that respond to light due to the absorption of photons in their proteins. Cones are concentrated in the **fovea**, where the light rays entering the lens are focused.

The image is only sent to the brain after the signal generated by the cones and rods is processed also in the bipolar cells of the retina, where visual information begins to be analyzed. After all, the brain digests the signals sent as we discussed previously; moreover, as Attneave [Att54] states in its investigation in 1954, a major function of the human perception mechanism is to strip way some redundant information present in the *stimuli*, in order to encode or describe the incoming information in a more economical form, than the one in which it impinges on the receptors. Likewise, sensorial events from different sensory systems may create interdependencies among each other, either in space or in time, or crosscut both; over his life, any individual acquires notions about "what-goes-with what" and, as the author states [Att54], we cannot make predictions about anything, based merely on the present visual field, but also depend on previous - and, for that, familiar - visual fields.

As covered before, there are some specialized and important neurons that have the crucial task of capturing and transducing photons: they convert electromagnetic radiation into trigger-signals to be send to the organism. The photoreceptors can be classified between **Cones** and **Rods**.

Cones These cells are responsible for acquiring color vision information, at normal-to-high levels of bright light. They are condensed in the fovea, which is a rod-free zone. By the time of 1990, in a study performed by Curcio *et al.* [CSKH90] it was estimated that in the human retina, the total number of cones ranged between 4.08 to 5.29 million, Cone cells are not important to light detection, since they are not light sensitive; however, color perception is completely instrumented by them. They can be seen on Figure **??** as being the pink colored structures. These cells are named for their shapes and contain chemicals - the *photospins* - that respond to light: when the light strikes these chemicals, they break and create a signal which will be transferred to the brain. There are three kinds of light-sensitive chemicals in cones and they will be providers for the basis of color vision, creating the distinction between the number of cone types.

- S-Cones (Small Wavelength Sensitive), correspond to Blue color perception.
- M-Cones (Medium Wavelength Sensitive), correspond to Green color perception.
- L-Cones (Large Wavelength Sensitive), correspond to Green-Red color perception.

The difference between the signals derived from the three types of cones, allows the brain to perceive a continuous range of colors. The distribution of the amount of each type can differ.

Rods These photoreceptor cells function in less intense light, when compared to cone cells. They also acquire their name because of their elongated, cylindrical shape (the white colored shapes in Figure **??**); their location is on the outer edges of the retina, and the number of rods is around 78 to 107 million. These cells are much more sensitive than cones and they are responsible for night vision: in the dark, as your rods have only one type of light-sensitive chemicals (this is why your ability to see gradually increases in the dark). This limitation in the types of rods is the reason why they cannot discriminate colors, as the cones. On Figure **??**, it is possible to compare the light absorbance for different wavelenghts, distributed among Cones and Rods.

All of this color information is, then, sent to the brain where it will be processed and associated to a mental model. Psychologists tried to explain how the complete color vision works, and formulated some theories about that. **NEXT: subsection Theories of Color Vision, from main.tex**

2.1.3 Color Models and Spaces

2.2 Related Work

2.2.1 Color Blending Research and Techniques

Ver se houve desenvolvimentos na área em 2016.

2.2.2 User Color Studies Online

Ler artigos do David Flatla, investigar se existe trabalho feito na área nos últimos meses.
Procurar artigos do CHI.

2.3 Discussion

Discutir aqui possíveis questões que podem ser abordadas.

- **Questions raised Before**
  - Will perceived colors correspond to a particular fixed angular value, in the color wheel?
  - Which is the best formula to blend colors, in each color model? Is it linear interpolation or another?
  - In the case in which 3 colors are blended, do observers realize all colors at the same time or do they decompose the mixture, firstly in a mixture of two colors and then a blending of a third color?
  - What is the best way to present color, without influencing color perception?
  - Does the user *really* understands which colors are involved in a mixing?
- **Perception Questions**
  - Does the order in which colors are mixed, influence mental mixing models? Are there common patterns among mixing orders?
  - Do shapes and proximity, influence how color is perceived?
  - Until which extent does background influence the perception of a subject, in particular a blended color?
  - If color parameters like Saturation, Value or Luminance change in a blending, does it modify color blending perception?
- **Information Visualization Questions**
  - Do continuous scales yield better results than discrete color scales?
  - What is the influence of nominal color scales in perception?
  - What are the results if no color scale is presented to guide the user?
- **Cultural Questions**
  - Does the gender really influences how the color is perceived? Is it possible to observe a significant gap between male and female answers?
  - Is it possible to observe significant differences in observation, depending on user's cultural background?

Although there are these questions whose answers remains to be found, only a portion of them will meet their answers, since this is Master Thesis Research Problem. However, there is a set of these questions which was considered crucial and, consequently, had more priority above others: it was this set which was the focus of our studies. We intended to perform **three studies** and, in the following sections, it is covered the entire proposal for the first study, the conditions in which the study is ideally performed and other important details.

Chapter 3

BlendMe!

3.1 Objectives

Justificar nome
Remember the objectives.
Referir HSL com hue variante, e SL com parametros maximos.
Estabelecer questões claras e perguntas que necessitam de resposta, para nos resultados serem mapeados com respostas.
Tipo: Q1: ...

APROVEITAR...

As previously referred, only a set of questions is answered in our research. The **goals for the User Study** are as follows:

- Study one way to present color which does not influence color perception.
- Understand if there is any psychological organization of color, when detailing color mixtures' components.
- If possible, obtain results to ascertain the cultural influence in color perception.
- Study the influence of discrete and continuous color scales.

Additionally, it is relevant to understand which color model stands as the best to mix colors which are, from a perceptual point of view, more similar to the users expectation.

We have planned to develop this study in three different strands: in a **Laboratory Environment** (which will allow us to calibrate and perfectly control the entire study conditions), in an **Online Environment** (which will allow us to disseminate our study to a larger set of users, even without controlling the calibration of the testing environment) and, finally, using **Mechanical Turk Environment** (Amazon's worldwide crowdsourcing marketplace to perform Human Intelligence Tasks, which we would use in order to acquire a huge set of users, even though we can be dealing with speed-clicker users and letting go almost all environmental control).

To meet these study requirements, we drafted our study into three different phases: a **User Profiling Phase**, a **Calibration Phase**, a **Color Deficiency Test Phase** and finally, the **Core Phase**. In the following sections, we detail each of these sections.

3.2 Designing the Solution

Design the implementation, talk about the process ever since wireframing, through the mapping of concepts between what we want and how we implemented, in order to achieve what we want. Include screenshots from the implementation.

Important detail: color conversion between Excel and adapted colors with ICC profile, Spyder and all. ColorConverter.m.
Dividir secção em partes do estudo, introduzindo com Research Proposal para motivar decisões. Referir todos os detalhes de implementação. Justificar completamente todas as decisões que foram tomadas (número de placas, informações pedidas, métricas colhidas, tudo.) Falar de folha de calculo do excel com todas as cores, que depois for migrada para matlab e convertida de acordo com perfil de calibração.

3.2.1 User Profiling Phase

FALTA TEXTO AQUI...

In this phase of the study, questions about the Age, Gender, Academic Degree, Nationality, Country of Residence and the Native Language of the user should be asked: these questions will help us conceiving user profiles with key indicators about cultural background and gender relation to results of each test.

(... ACRESCENTAR AQUI MAIS INFOS RELEVANTES ...)

When this phase is concluded, the user will be guided to another stage of the study, to perform the **Calibration Phase**, where he will be asked to analyze a set of images and answer a pair of questions.

3.2.2 Testing Calibration Phase

Performing online tests - specially when trying to obtain precise values about color - carries obvious problems on how it is guaranteed the results which may appear are, in fact, compliant with certain patterns of quality, specially color and monitor calibration patterns.

To overcome this problem, the ideal solution is to develop a system capable of acquiring information about the user's monitor calibration, *e.g.* Brightness, Contrast, RGB Color Balance, Gamma or Saturation, as a pre-step of the study and apply an appropriate calibration when rendering the study's main page. Since we have not found a way to tackle this solution so far, we developed another solution: to present, as pre-step, some calibration images in which the user will have to perform a set of small tasks, indicating us a set of answers; in the end of the test, we have to analyze the answers to verify if they are compliant with a certain pattern of calibration acceptability, determining if the answers of a certain user can be considered true and not misleading.

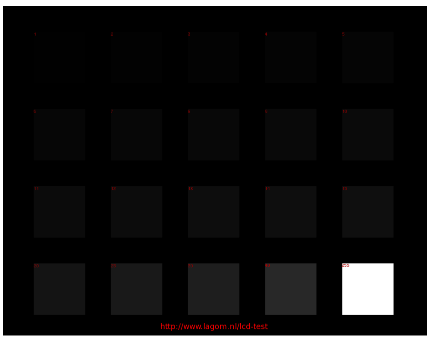

Figure 3.1: Example of Black Squares Test.[1]

We will present to the user a **pair of images**, consisting of a set of 10 squares each; in the first of them, we will test the black level of user's monitor, showing each square with a different shade of black, from brighter ones (Square 1) to darker ones (Square 10). The user is, then, asked to express which square is the last, most perceivable, darker square, and point out the word which follows it. The second image has the same job as the first one, except that this rules out the white-level of the monitor and the ten squares present different tones of white. An example of this sort of test is presented in Figure 3.1. The results of this phase are recorded for further analysis when the study finishes.

Regarding the laboratory environment, we are going to conduct the user tests in a LCD monitor, under a fixed light source; the monitor will be calibrated using a colorimeter which will consider the existing light in the environment and adjust the color of each pixel to a standard. The user will be focused on the task and no other user will be present in the room at the same time, excluding the study regulator; the user will have a fully detailed test protocol to follow. ***(... FALTA TEXTO AQUI ...)*** Referir limitação descoberta entre Chrome Safari

3.2.3 Testing Color Vision Deficiencies Phase

3.2.4 Core Test Phase

Incluir tabela com todas as cores, igual a folha de auxilio. Referir que Ciano, por erro, não esta a ser testado no formato objTwoColors.
Referir aqui que dados estão a ser guardados do utilizador, e como estão a ser guardados, (objTwoColors e twoColorsObj), etc. Referir aqui também que slider contemplava cores standard da folha de calculo para ambiente online, mas para ambiente laboratorio cores eram antes processadas no Matlab. Slider não tinha cores ordenadas para que utilizador não utilizasse algum modelo mental e aprendesse previamente a misturar. Cores foram misturadas sem qualque critério (referir ordem pela qual apareciam). Referir aqui caminho do calibrador -¿ icc -¿ matlab -¿ converter cores -¿ slider

3.3 Evaluation Criteria

Ishihara plates and more, whatever we consider relevant. Falar também de como a calibração era considerada válida ou não. Erros que poderiam ser gerados pelo field number html5, que com scrolls podia dar valores errados.

3.4 Divulgation

MTurk problems, facebook, Reddit, FacebookAds, FNAC prize money.
Como fizemos o controlo dos users (Analytics). Bridge to next chapter.

[1]"Black Level", Available at: `www.lagom.nl/lcd-test/black.php`. Last accessed on September 7th, 2016.

Chapter 4

Analyzing Color Mixing Perception

In this section, we are going to dive into the results obtained from the user study described on chapter number 3. On the first section, we will clearly explain the test protocol which was followed by the users in the laboratory environment to correctly execute the study; this section will be followed, not only by the description of how the gathered data was treated and cleaned (Section 4.2), but also the transformation of this data using *Matlab* processing tools, in order to prepare it for the statistical scrutiny (Section 4.3). Hereafter, conclusions will be drawn from the study at section 4.4, when trying to find answers to the questions/objectives raised before.

The final section of this chapter will be dedicated to summarize the results and infer important conclusions, implications and guidelines which could be relevant for the InfoVis field of research.

4.1 Protocol

The existence of a test protocol, when performing a User Study is mandatory: without it, the test may not follow a strictly previously defined standard. As written before, this user study was conducted two-pronged: in a laboratory environment and *via* online dissemination channels.

4.1.1 Laboratory Environment

The users were given always the same briefing when they arrived at the user study test site: it was explained the motivation behind the master thesis, the goals which were expected for this phase of the study and what was expected for them to execute. The most important information which was told was that ”there was no pre-defined correct and wrong answers to each question, this test was designed to test the general color mixing capabilities of the majority of the users”. Besides this information, the user study was self-contained, in the sense that every other relevant information and instruction was in the interface, adapted for each test phase, so it was not given any physical artifacts describing instructions. The instructions were available on two languages, depending on the choice of the user: Portuguese and English.

Before each session of the laboratory environment test-run, a Datacolor Spyder 5 Elite Color Calibrator was USB-connected to the computer and, using the software which is shipped along with it, the computer LCD display was fully calibrated (the software offers the option of recalibrating, the option of checking the calibration and also, the option of fully calibrating the display) by testing the pixel emission when emmiting a particular set of colors. The display was everytime fully calibrated, since the software manisfested an erratic bahaviour when using the other functions: the screen colors were presented in a very warmer/colder color profile tha it was before.

The tests were conducted at, most of the repetitions, in Rede Novas Licenciaturas (RNL) at Instituto Superior Técnico (IST), and fewers times in other locations with similar conditions: this is due to constraints in finding users, so the test site needed to have a (limited) mobility feature. However, the conditions remained the same concerning the illumination, the position of the user and the computer used: a Macbook Air 13' (Mid-2013) was prepared undeneath a fixed incadescent light-source (but slightly deviated from it, to minimize light reflections on screen), the user would sit in front of the laptop, in an almost silent environment. Ideal conditions of this test would be such that the user could be sitting alone in a completely silent room, his head would be always at the same distance from the screen, resting in a head-rest and the LCD display's inclination would be perfectly adjusted to the user's eyes.

4.1.2 Online Environment

Performing the study online, as easily predictable, develops some characteristics which cannot be completly controlled. For the sake of calibration, it was asked the user to perform a set of six calibration easy steps before starting the test, so the online user's screen would be, somehow, in a standardized calibration fashion. The calibration steps which were asked are:

1. If possible, adjust your room lights for a comfortable usage of your device.
2. Avoid reflections on your screen, by diverting the screen from direct sources of light. This step is important, since light reflections can affect visualization of images.
3. To adjust the **Black Point** of your screen, define the Contrast and Brightness of your screen to their maximum.
4. After Step 3, gradually reduce **Brightness** value of your screen, in order to correctly distinguish the squares of each image below [calibration squares images].
5. If possible, define the **Color Temperature** of your screen to 6500 Kelvin Degrees.
6. You are now ready to answer the following questions!

The ideal conditions of this test would be such that we could control and maniupulate the color calibration of online user's LCD display, using a software piece which would acquire important informations from the screen configuration, *e.g.* resolution, white-point, black-point, brightness, among others, digest the values and present the questions from the Core Phase in a completely controled and calibrated window. Further investigation could focus in developing this system.

The users were asked to fill in a profiling questionnaire (as seeen of section 3.2.1), as well as to respond to calibration form (Section 3.2.2). A validated simplified 6-plate Ishihara color blindness test [dAK92] is, then performed (Section 3.2.3), before proceeding onto the 32 questions test-phase, in which the user is asked to slide one(two) circular object(s) placed on top of a bar, to indicate a(the) color(s) which he thought were the correct mixture answers. In the end, the user could leave feedback, by sending a message which would be stored in a Relational Database.

The instructions which were presented in each page can be consulted in Appendix A.

4.2 Data Cleaning

Throughout the user study, we collected a **total amount of four-hundred and seventy-nine (477) users** which interacted with our study and fulfilled, at least, until the Color Vision Deficiencies Test Phase. However, only **two-hundred and sixty-one (259) users went on to the core phase of the**

study, representing **54.29%** of the total amount, giving at least one answer on the set of 32 questions, loosing the other two hundred and eighteen (218) users which did not leave any answer, defining the remaining percentage **45.71%.** This large drop of users could be due to errors reported by the users, apparently the inability to submit answers when using the ”Submit” button after rating the question; there were also some complaints when users tried to perform the study in some mobile devices (namely, the *iPhone® 6*), whereon the color slider was not able to be dragged and change the color value at the user will.

Concerning the percentage of users which showed up at the **laboratory trials, there were twenty-nine (28) users who performed the entire study**. On the other hand, there were **two-hundred and thirty-two (231) users which carried out the study online**. There was also a small sample of color vision deficient users which we will analyze in a qualitative manner; this set of users contains only one (1) user from the Laboratory Environment - **3.57%** of the sample size - and two (2) online users - **less than 1%**. Lastly, we detected a small percentage of **six (6) users (2.59%) which did not presented a correct calibration of its LCD display**, evaluation based on the criteria referred before. The data presented and used in this dissertation document was gathered along roughly two months, from 15th of April until 8th of June. As said before, it was collected both with online and laboratory users, which was therefore stored in a Relational Database as previously explained in section 3.2.

In the end of the study, Comma Separate Values (CSV) files were exported from each table using a PostgreSQL for macOS called *Postico*[1], which originated five files containing raw data to be cleaned and processed. The files were as follows:

- *raw_data_user_profile.csv* - Data aggregated from ”Profiling”, ”Calibration” and ”Color Vision Deficiencies” Tables;
- *raw_data_first_profiling.csv* - Data from ”Profiling” Table;
- *raw_data_first_calibration.csv* - Data from ”Calibration” Table;
- *raw_data_first_ishihara.csv* - Data from ”Color Vision Deficiencies” Table;
- *raw_data_first_results.csv* - Data from ”Results” Table;

User ID	Type	First Color	Second Color	Third Color	Drags	Time	Rating	Resets	Question ID
5710cca334d60	objTwoColors	#0080FF	hsl(58.69565217391305,1,0.50)	hsl(98.15217391304348,1,0.50)	992	117	4	2	10
5745c1c07cc0c	objTwoColors	#8000FF	hsl(300,1,0.50)	hsl(324.13043478260875,1,0.50)	645	55	2	1	14
5745350dc1e22	objTwoColors	#0080FF	hsl(226.30434782608697,1,0.50)	NONE	115	11	5	1	10
57451c3b38192	objTwoColors	#00FF80	NONE	hsl(150,1,0.50)	462	39	5	1	15
574511e99b6d9	objTwoColors	#0080FF	hsl(15.652173913043478,1,0.50)	hsl(316.30434782608694,1,0.50)	442	40,	1	1	10
57427cf6bad0c	twoColorsObj	#00FFFF	#FFFF00	#46FF9C	6	14	3	1	32
5740bda9be3dc	objTwoColors	#FF7200	hsl(9.130434782608695,1,0.50)	hsl(50.21739130434783,1,0.50)	45	22	5	1	11
573c783748e8b	twoColorsObj	#00FFFF	#CBFF00	#00FF6B	44	25	3	1	32

Table 4.1: Excerpt of Results Table, with raw data.

The refined tables were then divided into new and more specific ones so that we could detail our results analysis according to the goals defined before; the ”Results” table was refined into Laboratory Results, Online Results and demographic results: concerning the age, we divided it on Users aged below 20 Years Results, Users aged between 20 and 29 Years Results, Users aged between 30 and 39 Years Results, Users aged between 40 and 49 Years Results, Users aged between 50 and 59 Years Results and Users aged above 60 Years Results. Respecting the division of genders, we created the categories Female Users Results, Male Users Results and Other Gender Users Results. An excerpt of raw data contained in ”Results” table can be found in table 4.1; this allows us to support the explanation of the following steps of the cleaning phase.

[1] Postico - a modern PostgreSQL client for the Mac, Available at: `eggerapps.at/postico/`. Last accessed on September 11th, 2016.

Dividing the results among smaller CSV files was the first step of the cleaning phase: the next checklist represents the detailed path which was followed to fulfill the data cleaning.

- **Remove "hsl(..., 1, 0.50)"** - It was needed to remove the extra information stored in columns *First Color, Second Color* and *Third Color*, since this is redundant because it never varies from entry to entry of the table (remember Section 3.1). These values are the *Saturation* (S) and *Value* (V), primitives of the HSV Color Model used.

- **Format Values** - This step was performed just after the previous one. The value which remains to be formatted is simply the *Hue* (H), which is equal to a very precise position on the coded color slider on the interface; the value was composed of 14 decimal numbers, giving us much more precision than what is, in fact, needed considering that the hue is measured in terms of integer numbers. The number was rounded up to its closest integer number, then. Besides that, there was still one value to be adjusted which was the missing response: *NONE* neeeded to be replaced by 0, to simplify the processing of null answers.

- **Sort Entries** - In order to favour the iteration when processing the data, each line of the "Results" Table was sorted according, firstly to the *Question ID*, and after by *User ID*.

- **Normalize Laboratory Data** - As previously said, to perform the Laboratory Study we used a Spyder Color Calibrator to manage the color representation independently of the environmental conditions of light. Since the Color Profile file generated by the calibrator was used to adapt colors to be presented to the user, those same colors had to be trackbacked to the original color, for the sake of normalization of values. This is specially useful when comparing the results from this environment to the "Online" Results, helping in data processing later.

- **Verify Duplicated Entries** - This step was performed only to ensure that the entries would not have any matching copy. As expected, there were not found any copies.

- **Normalize Profiling Info** - Regarding the "Profiling" data, there was some which was written in Portuguese and other in English, depending on the language to perform the study chosen by the user. To avoid misleading profiling categories, all of the academic degrees were normalized to its corresponding name both in English and Portuguese. Also, the raw language values contained some specification of English dialects (*e.g.* en_US, en_UK) and other languages, which was more information than we actually needed; these values were normalized to correspond only to its native and original language (like English, solely).

- **Sanitizing Users** - The tables contained many entries from users that performed the study with incorrect calibration and from users which gave unexpected values on the color deficiencies test phase; the entries which corresponded to a user that failed all 6 values on the later phase, would be deleted, leaving no trace of its participation. Concerning the bad calibration values, it "opened a window" to investigate the resilience of results when the calibration was not what it was expected - this will covered in sub-section 4.5.1. To end up the cleaning phase, it was decided to treat the color deficient users independently: we separated their values from the regular users to perform a qualitative evaluation.

An example of clean data can be found in table 4.2. The next step of data handling is processing it to prepare metrics, establish comparations to pre-calculated answers and depict results in a CIE Chromaticity Diagram. More tables can be found in Appendix C, specifically Section C.1.

User ID	Type	First Color	Second Color	Third Color	Drags	Time	Rating	Resets	Question ID
5713a02a13044	objTwoColors	#00FF00	0	137	459	56	2	0	17
573e4d0eb795b	objTwoColors	#00FF00	235	59	121	28	4	0	17
573edae85268b	objTwoColors	#00FF00	242	57	224	20	5	0	17
5740ad339507d	objTwoColors	#00FF00	228	67	205	14	3	0	17
573c70dabcfe0	objTwoColors	#00FF00	55	221	192	14	2	0	17
57582b17cd76a	twoColorsObj	#FF0000	#00FF00	#AF0049	724	65	2	0	18
573c783748e8b	twoColorsObj	#FF0000	#00FF00	#BFBE00	656	47	3	0	18
573e4022949b1	twoColorsObj	#FF0000	#00FF00	#B000FF	334	23	2	0	18
571151812791a	twoColorsObj	#FF0000	#00FF00	#C9B2A2	110	39	2	0	18

Table 4.2: Excerpt of Results Table, with clean data.

4.3 Data Processing

Processing the data was an important part of the process, since it was important to prepare the raw data collected and compute additional metrics which could be further analyzed to answer the raised questions. To perform this processing, we decided to implement a set of scripts in *Matlab* which could gauge the dataset of each question, demographic group and subset of users (non-calibrated and color vision deficients).

With this data processing, we intend to verify each answer-pair given by a certain user and compare the pairs with each other. It was important to separate the results by question ID, compare each questions' results with other questions that could conceive the same results, blend the values to check which color model answers are closer to (either Hue, Saturation, Value (HSV), Red, Green, Blue (RGB), Cyan, Magenta, Yellow, Key (CMYK), CIE-L*a*b* or CIE-L*C*h*) and also, give meaning to each value, attributing a name to each color. All these parameters and computations are describred in the next two sub-sections.

4.3.1 Data Preparation

Given the fact that questions had some differences between each other, there would have to be a cautious analysis; to achieve this, we developed a script for each question, each of file contains the particular set of characteristics ans specific comparisons and values of each question. An exemplary structure of these files can be found on pseudo-code box above. Each question file is capable of computing the following datasets:

- Laboratory Results (Regular Users);
- Laboratory Results (Daltonic Users);
- Online Results (Regular Users);
- Online Results (Daltonic Users);
- Online Results (Uncalibrated Users);
- Demographic Groups: Users Aged Below 20 Years Results;
- Demographic Groups: Users Aged Betweeen 20 and 29 Years Results;
- Demographic Groups: Users Aged Betweeen 30 and 39 Years Results;
- Demographic Groups: Users Aged Betweeen 40 and 49 Years Results;
- Demographic Groups: Users Aged Betweeen 50 and 59 Years Results;
- Demographic Groups: Users Aged Above 60 Years Results;
- Demographic Groups: Female Users Results;
- Demographic Groups: Male Users Results;
- Demographic Groups: Other Gender Users Results;
- Demographic Groups: White Answers (this computation is only available for Questions 1 to 17).

All these datasets are analyzed by a block of code similar to the one in box below __ ; all iterations over each dataset start by verifiying if any value contained in the answer pair is a white (*i.e.* zero valued) answer: if it is, it is stored in a different table, along with all white answers. This was executed **only with non-daltonic users and calibrated users and it was no applied to any type of demographic group**, since its analysis is out of the scope of this thesis. This analysis is interesting, since we can understand if the users opted to leave one value as 0 to truly indicate a white color (to blend and create a lighter color), or simply because they didn't know what to blend.

INCLUIR BLOCO DE PSEUDO CODIGO de cada ciclo Since the colors obtained in the color slider indicate values for the HSV Color Model, it was mandatory to convert the color to a common color standard: for that reason, the values were converted from HSV to CIE-XYZ Color Model. Thus, we can produce color blends in every studied color model (HSV, RGB, CMYK, CIE-L*a*b* and CIE L*C*h*) and ensure that colors obey to the same common standard; also, this is specially important to produce Chromaticity Diagrams where colors are mapped according to a set of XYZ primitives. Both of the answers were blended according to each color model referred before: for models which contained no angular values (RGB, CMYK and CIE-L*a*b*) it was only needed to interpolate the values for each primitive; but for models that have angular values (HSV and CIE-L*C*h have their Hue's value), it was needed to calculate the angular interpolation of their primitives.

$$\begin{aligned}
R_{final} &= \frac{|R_{C1} - R_{C2}|}{2} + min(R_{C1}, R_{C2});\\
G_{final} &= \frac{|G_{C1} - G_{C2}|}{2} + min(G_{C1}, G_{C2});\\
B_{final} &= \frac{|B_{C1} - B_{C2}|}{2} + min(B_{C1}, B_{C2});
\end{aligned} \tag{4.1}$$

An example of linear interpolation between primitives can be seen on Equation 4.1, in which we blend RGB primitives. The listing 4.1 shows how the angular interpolation is being calculated with our *Matlab* script.

Listing 4.1: Excerpt of *Matlab* code which interpolates the angular Hue value.

```
diff_angles = abs(Hue_C1 - Hue_C2);
if diff_angles > 180
    angle_small = (360 - diff_angles);
    sum_major = max([Hue_C1 Hue_C2]) + (angle_small / 2));
    if sum_major > 360
        hue_final = rem((max([Hue_C1 Hue_C2]) + (angle_small / 2))), 360);
    else
        hue_final = max([Hue_C1 Hue_C2]) + (angle_small / 2));
    end
else
    hue_final = min([Hue_C1 Hue_C2]) + (diff_angles / 2);
end
```

Afterwards, every resulting blending is **compared to the pre-calculated value for each color model**; the distance to the late value is stored for statistical analysis. It is also **calculated the distance to the expected HSV values**, since the colors presented to the user were too calculated in HSV Color Model. Additional comparisons are: the colors blended in HSV are **compared to the expected color pairs of other questions which generate the same (or roughly) color**, to understand if our users tended to mix other pairs than the one expected for that question. To end this comparisons, the centroids of each set of colors mixed in every color model are calculated, along with its distance to the expected pre-calculated answer.

This computation is applied to all questions from 1 to 17, when the resultant color is given and two answers expected. However, there are some differences when processing data from questions 18 to 32, which are questions where the two primitive colors are given and the resulting color is expected, which implies a much simpler analysis due to only have to process one answer: there are no white answers to process (the ones which exist are excluded) and no colors to mix with each other; it is only calculated the distance of the answered color, to the expected one.

4.3.2 Color Bins Comparation

This analysis phase had a very important step, which was to assign meaning to the answers given by the users: **to attribute names to colors indicated**, whose to be commonly used by the users. Ideally, we would conduct a separated user study to perceive which names people normaly attribute to colors; then we would gather all the data and analyze which were the most common names.

Luckily, the web page *XKCD*[2] had already conducted a widely large Color Survey[3] to study wich were the most common RGB color triples among users. They performed roughly more than 222 000 user sessions to ascertain color naming: they produced a map which shows the dominant names attributed to RGB colors over the faces of RGB cube (Figure 4.4), and they also produced a huge file comprised of 196 608 named RGB triplets, grouped by Color Bins.

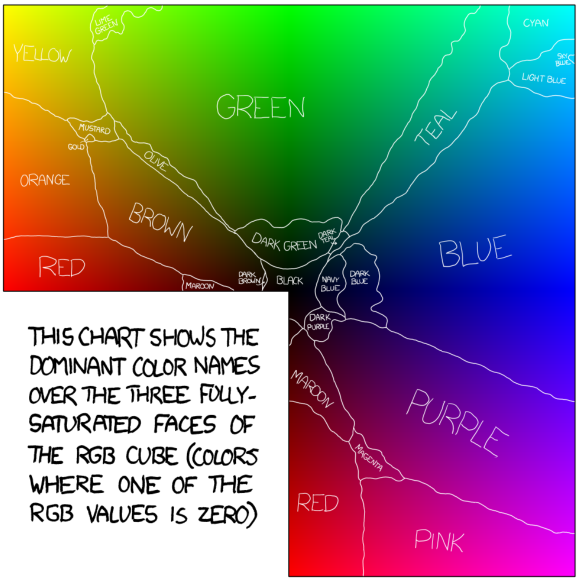

Figure 4.1: XKCD Color Survey: map of color dominant names.[4]

Despite the fact XKCD's Color Survey was not a research realized with a scientific purpose, we decided to use it since it has plenty of information available to compare our results to, and it was executed with a great amount of users which can verify it. We also found great compatibility between this survey and ours, since the values in the first were also presented in its maximum value of saturation (similar to our user study, in which we present colors in maximum hue).

As said, these represent RGB triplets but, being our user results all in accordance with the CIE XYZ Color Model, we needed some cleaning and processing to match the data our responses. We converted the RGB to CIE XYZ values and, then, divided all of the Color Bins in different tables; there are 27 names

[2] XKCD - Stick-figure strip featuring humour about technology, science, mathematics and relationships, by Randall Munroe. Available at: xkcd.com/. Last accessed on September 11th, 2016.

[3] Color Survey Results. Available at: https://blog.xkcd.com/2010/05/03/color-survey-results/. Last accessed on September 11th, 2016.

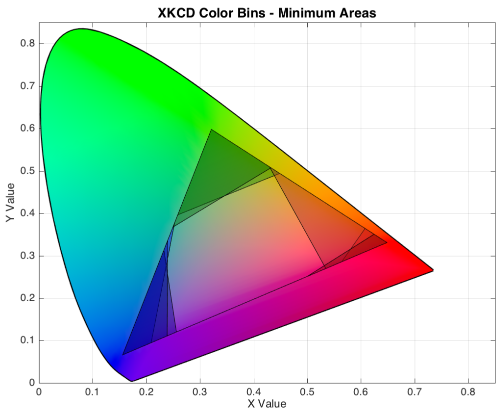

Figure 4.2: XKCD Color Survey: Color Bins Minimum Areas.

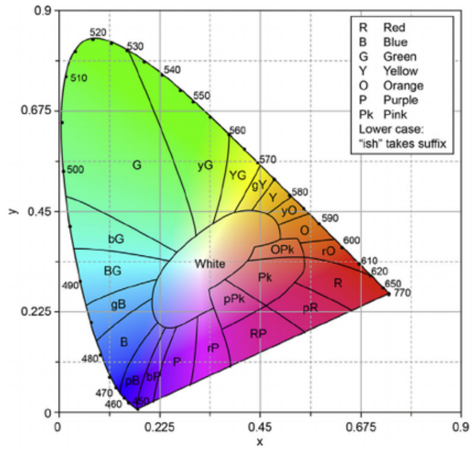

Figure 4.3: Approximate Color Regions on CIE 1931 Chromaticity Diagram. [FM97]

atributted to colors, some have more triplets (*e.g.* blue, green or purple), but some have a smaller set, which could mean greater agreement to assign names to colors. These bins of color are represent with their frequencies, in table 4.3.

Color Bin	Frequency	Color Bin	Frequency
Black	1782	Lime-Green	878
Blue	37725	Magenta	990
Brown	10499	Maroon	3283
Cyan	2625	Mustard	711
Dark-Blue	2233	Navy-Blue	922
Dark-Brown	30	Olive	1336
Dark-Green	2927	Orange	9152
Dark-Purple	669	Pink	12627
Dark-Red	2	Purple	25747
Dark-Teal	163	Red	15474
Gold	49	Sky-Blue	32
Green	47858	Teal	9007
Light-Blue	2078	Yellow	7808
Light-Green	1		

Table 4.3: XKCD Color Survey: color bins.

The idea was to compare our answers with each color bin, to create a mapping between our users' values and commonly-used names; in order to simplify and speed up the computation of the comparations, each color bin was drawn and the lowest polygon formed by the set of triplets of each bin was used to compare the values (instead of comparing each answer with every triplet). Moreover, when processing these sets of RGB triplets, we left 3 color bins out of the game: *Black* since it has no expressivity in the Chromaticity Diagram, *Dark-Red* and *Light-Green* because they have very few triplets to be drawn.

However, we expected that when these color bins were drawn on a chromaticity diagram, they would create independent and more comprehensive shapes: we found that there are overlapping values for some color bins (Figure 4.2), which ultimately complicates the analysis because there is more than one possible name for the same color. For example, *Blue* and *Dark-Blue* share 5 triplets: (0,0,76), (0,0,77), (0,0,78), (0,0,79) and (0,0,80); *Green* and *Dark-Green* share only 1 triplet, (0,57,0). No value was excluded from any color bin, instead we solve the problem by allowing the program to find only one of the names and look no more after finding it. Moreover, the shapes created by each color bin can be

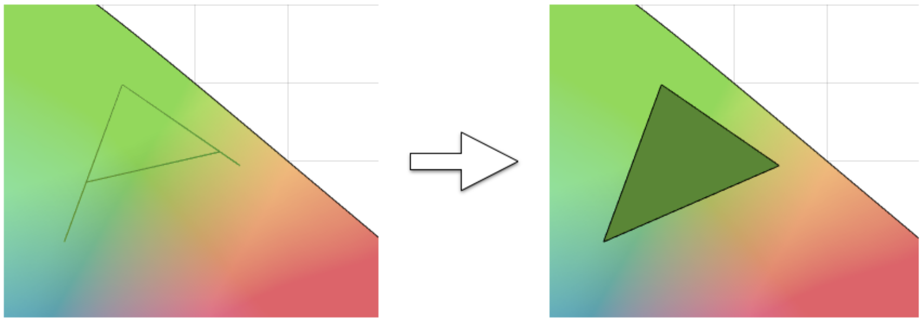

Figure 4.4: XKCD Color Survey: Color Bins Transformation from line of points, to minimum polygon.

depicted as **lines** if they present contiguous values in the same edge of the triangle, or as **triangles** if the values are near the corner of the triangle and are distributed along two edges. The late situation is represented in Figure **??**

Alternatively, we could have opted for another kind of color name detection, but its implementation would be out of the scope of this Master thesis and would take a much longer analysis than the one performed. For instance, one could have gone for identifying the colors by analyzing their values and processing the wavelength originated, comparing the resulting value with calculated areas, roughly defined by Brand Fortner [FM97] and represented on Figure 4.3. This idea had one problem, which was the longevity of its solution (dated from 1997), and the inexistence of a ready-to-go implementation, completed with an svg with all areas defined, had added weight on the decision.

Another possible method to decode color into name would be to interpret color values and associate a color temperature, being the late one compared against a well defined table of values; the problem here was the non-existence of table of well defined values of color temperature. Further investigation is needed to ascertain the possibility of creating such table.

4.3.3 Outputs Generated

Each script ends its execution when saving all the outputs contained in table 4.4: it generates a set of CSV tables ready for being analyzed by SPSS Program, besides creating a great amount of CIE chromaticity diagrams to support the analysis. As referred before, questions 18 to 32 do not generate any output about white answers.

4.4 Results

In the following section, we perform a statistical analysis of the processed data obtained from the user study. The main data to be analyzed is the one obtained in the laboratory environment, being the online data only the corroboration of the main data. We start by drawing a profile of users who responded the survey, characterizing them as the age, country of residence, academic degree, along with other characteristics; after, we begin mapping answers to the questions raised in the beginning of study, also referred in section 3.1, which comprises topics about *Color Mixtures*, *Color Models*, *Color Naming* and consider differences between *demographic groups*.

By the end of this chapter, we are going to discuss the results of the analysis and consider eventual implications for Information Visualization (InfoVis) field of research. The following table **??** summarizes how the study is characterized: how many responses were given *per* question, from which environment

Tables	Diagrams
age_20_results	For each Demographic Group:
age_20_29_results	- RGB, HSV and CMYK Responses
age_30_39_results	- CIE-L*C*h* and L*a*b* Responses
age_40_49_results	For Laboratory Results:
age_50_59_results	- Regular and Daltonic Responses
age_60_results	- RGB, HSV and CMYK Responses
gender_female_results	- CIE-L*C*h* and L*a*b* Responses
gender_male_results	For Online Results:
gender_other_results	- Regular and Daltonic Responses
lab_regular_results	- Uncalibrated Responses
lab_daltonic_results	- RGB, HSV and CMYK Responses
online_regular_results	- CIE-L*C*h* and L*a*b* Responses
online_daltonic_results	For White Answers:
online_uncalibrated_results	- White Responses
white_answers	

Table 4.4: Generated Outputs of Data Processing Phase.

they came and the user sample from each demographic group.

INCLUIR TABELA COM CONTAGEM.

4.4.1 User Profile

As previosuly said on section 4.2, we gathered a total amount of 259 users with, at least, one valid answer: from the laboratory environment we collected 28 users, and 231 from the online strand. All of these users gave valid answers along the Profiling, Calibration and Color Deficiencies Tests Phases: the information collected in the Profiling page is the most important to compose a user profile.

Recalling section 3.2.1, we stablished that the most important informations to collect were the *age*, the *gender*, *academic degree*, *nationality* and *country of residence*, as well as the *native language* of each user. The table 4.5 represents the frequencies of genders, ages and academic degrees.

Environment	Users	Ages						Gender			Academic Degree					
		[0; 20[	[20; 29]	[30;39]	[40;49]	[50;59]	[60;90]	Female	Male	Other	College	High-School	Bachelor	Master	Doctor	NoDegree
Laboratory	28	0	17	5	3	1	2	10	18	0	0	5	13	10	0	0
Online	231	38	145	15	16	11	6	95	134	2	38	42	79	64	5	3
Total	259	38	162	20	19	12	8	105	152	2	38	47	92	74	5	3

Table 4.5: Results: Profiling Information (Gender and Academic)

As seen above, our user sample is composed by 259 (100%) users, being **105 (40.5%) Females**, **152 (58.7%) Males** and a minority of **2 (0.8%) Other gendered users**: this sample age can be characterized as being generally young ($\mu =$ 29.77, $\overline{X_{Age}} =$ 23, $\sigma =$ 40.30), surprinsigly having **8 users (3.09%) aged above 60 years old** which could enhance some interesting differences between age groups. Generally, our users have hight academic qualifications, representing **66.02% of all users (Bachelor, Master and Doctoral Degrees)**, being **38 (14.67%) users qualified with College degree**, **47 (18.15%) have a High-School degree** and only **3 (1.16%) subjects do not presented any academic degree**. Between the laboratory and online environment, the distribution of users remains with the same proportions: more male users than females, mostly aged between 20 and 29 years old (60.71%) and the majority having a superior academic degree (46.43% BSc and 35.71% MSc).

The table 4.6 depicts nationalities, current countries of residence and native languages spoken by our users. From the 259 (100%) participant users, **215 (83.01%) of them have Portuguese nationality**, **217 (83.78%) live in Portugal** currently and **216 (83.40%) speak Portuguese**; the second most

Environment	Users	Nacionality						Country of Residence						Languages		
		CA	ES	PT	UK	US	Others	CA	DE	GB	PT	US	Others	PT	EN	Others
Laboratory	28	0	0	27	1	0	0	0	0	0	28	0	0	28	0	0
Online	231	5	3	188	6	11	18	5	3	9	189	11	14	188	29	14
Total	259	5	3	215	7	11	18	5	3	9	217	11	14	216	29	14

Table 4.6: Results: Profiling Information (Nationalities, Countries of Residence and Languages)

influent group of users are from english-speaking countries (United Kingdom, United States of America, and others). Other minor users which contributed to our survey came from Turkey, France, New Zealand, Sweden or even Antarctica (among others) - **these countries represent only 5.41%**. An ideal distribution of users would be such that it included enough users from all continents, which would give us room to investigate better the cultural implications on the results; another interesting aspect would be to have the users of non-industrialized countries included in the sample, which was not accomplished in this study since an isolated vietnamese user (0.39% of the user sample) contributed to the study.

4.4.2 Color Models

In this section, we will start by analyzing the results from each question, comparing the statistics collected from each color model. Then, we are going to decompose the results by color models and evaluate which questions had the best and worst results. Along with the statistics we are going to present, in the end we are going to map them against the questions exposed before, clearly identifying them whenever they are answered. We would like to emphasize that the important results are the ones collected in the laboratory environment: the online results will bridge and support the conclusions extracted from the laboratory conditions. The values presented as "distances" are measured inside the finite interval between zero and one ($([0; 1])$), since the Chromaticity Diagram has its values comprised between this interval.

In order to improve this analysis, we present Table 4.7 which contains the mean value for the distances to ideal color mixtures according to each color model: in green, it is marked the best answer for each question, in each study environment (laboratory and online).

Question ID	Presented Color	Expected Colors		Laboratory Environment					Online Environment				
		C1	C2	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*
1	#FFFF00	Red	Green	0.13	0.2	**0.09**	0.12	0.12	0.07	0.21	**0.06**	0.07	0.07
2	#FF00FF	Red	Blue	0.22	0.16	**0.11**	0.17	0.16	0.15	0.16	**0.08**	0.1	0.12
3	#80FF00	Red	Cyan	**0.045**	0.215	0.05	0.095	0.11	**0.04**	0.21	0.06	0.11	0.11
4	#7F00FF	Red	Cyan	0.12					0.11				
5	#FF0080	Red	Magenta	0.17	0.15	**0.13**	0.14	0.14	0.16	0.15	**0.13**	0.14	0.11
6	#FF8000	Red	Yellow	0.07	0.13	0.06	0.08	**0.05**	0.03	0.14	0.03	0.04	**0.02**
7	#0000FF	Cyan	Magenta	0.16	0.23	**0.10**	0.15	0.17	0.13	0.18	**0.11**	0.17	0.22
8	#FF0000	Magenta	Yellow	**0.10**	0.17	**0.10**	0.13	0.13	0.10	**0.09**	0.12	0.14	0.16
9	#00FF80	Green	Cyan	0.13	0.16	**0.09**	0.10	0.11	0.11	0.13	**0.10**	**0.10**	0.11
10	#0080FF	Green	Magenta	0.30	0.26	**0.13**	0.21	0.20	0.17	0.27	**0.13**	0.20	0.22
11	#FF8000	Green	Magenta	**0.06**					**0.04**				
12	#80FF00	Green	Yellow	**0.11**	0.23	0.13	0.15	0.17	**0.08**	0.24	0.12	0.13	0.15
13	#0080FF	Blue	Cyan	0.27	**0.17**	0.19	0.25	0.23	0.14	0.20	0.14	**0.13**	0.14
14	#8000FF	Blue	Magenta	0.12	0.30	**0.10**	0.13	0.13	0.10	0.29	**0.09**	0.11	0.12
15	#00FF80	Blue	Yellow	0.09	0.30	**0.06**	0.11	0.13	0.11	0.30	**0.06**	0.11	0.13
16	#FF007F	Blue	Yellow	0.21					0.19				
17	#00FF00	Cyan	Yellow	0.07	0.16	**0.05**	0.10	0.11	0.08	0.17	**0.05**	0.10	0.11

Table 4.7: Results: Distances of Results Mixed in each Color Model, for each question, with the distance from itself to the ideal pre-calculated answer. Colored in green are, the color model which has the best result, *per* question, in each environment.

As referred before, each answer pair given from our users on questions 1 to 17 (one color given, two colors asked) was blendend in 5 color models: HSV, CIE-L*C*h*, CMYK, RGB and CIE-L*a*b*. Then, the XY coordinates of each resulting mixture were mapped on a CIE Chromaticity Diagram, the centroids of each group of mixtures was calculated, and the distance from each centroid to the (ideal) pre-calculated answer was measured. The table 4.7 represents the distance measured associated to each color model, for every laboratory result.

Analyzing Questions

The importance of breaking down the evaluation into questions is such that, it is relevant to understand, at least, which color models have the best results for each mixture. The results from this section will be critical to determine later which color models are more compatible with each mixture, which model yields better results and others who do not. A crucial reminder is that each question set for this user study is blended in HSV Color Model: the primitives anticipated for the blends are, then, colors required to produce the result according to the HSV Color Model. The triples presented in each shaded cell of tables below, are XYZ coordinates for the CIE XYZ Color Model.

Question One This is the only question in the entire study which has yellow as the resulting color of the blending. The expected colors are Red and Green, two primitives from RGB Color Model. Table 4.8 shows the expected colors when mixing in each color model: HSV, CIE-L*C*h*, CMYK, RGB and CIE-L*a*b*.

As said before, each answer-pair was blended according to those 5 models; after processing data from each question, we performed the mean calculation over the entire set of distances, between each resulting blend and the ideal blend (according to every color model). This produced the results reported on Table 4.8.

One can observe that the model which presents the lowest mean value is the CMYK ($\tilde{x} = 0.09$), possibily indicating that this model yields the best results for this question, while HSV, RGB and CIE-L*a*b* have closer values. A Friedman Test showed that there are, indeed, significant differences ($\chi^2 = 48.568$, $p < 0.05$) between each color model.

Further analyis with the Wilcoxon Test reveals that CMYK ($p < 0.05$) has, in fact, very different responses from the other color models, which leads us to conclude that **the CMYK Color Model is the best model to represent yellow blends**. Since HSV, RGB and CIE-L*a*b* have similar mean values, we tried to compare them between each other: **there is no statiscally significant differences among HSV, RGB and CIE-L*a*b*, whereby there is insufficient information to evaluate this color models regarding this color mixture**. According to table, it is also possible to say that **CMYK Color Model presents a low deviation**, not only in laboratory results ($\sigma_{lab} = 0.06$), but such value is corroborated by the online users ($\sigma_{online} = 0.06$).

It is safe to say that **CIE-L*C*h* has the worst performance against the other color models**, since its mean is the highest of all ($\tilde{x} = 0.20$), and the values from Wilcoxon Test ($p < 0.005$) indicates that this color model has statistically signifcant differences every other model. **This results are corroborated by the online users**.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
1	(77, 93, 14)	Red	Green	(77, 93, 14)		(42, 42, 6)		(17, 20, 3)		(17, 20, 3)		(39, 42, 6)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.13	0.08	0.2	0.06	**0.09**	0.06	0.12	0.08	0.12	0.08
Distance to Objective - Online				0.07	0.09	0.21	0.07	**0.06**	0.06	0.07	0.09	0.07	0.08

Table 4.8: Question 1, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Two This question presents a Magenta color and expects to receive, from the user, the Red and Blue colors according to the HSV Color Model.

The colors were blended, and again the mean values over distances were calculated, as Table 4.9 shows. It is observable that CMYK Color Model presents, yet again, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.11$), whilst its standard deviation is also the lowest between both study environments.

However, it is not safe to say that which color model had the worst results: judging by laboratory values, the HSV Color Model would not only the have highest mean distance, but also the largest deviation of answers; yet, evaluating the online results, it would CIE-L*C*h* to occupy such position. Performing a Friedman Test, we can conclude that there are, in fact, significant differences ($\chi^2 = 22.041$, $p < 0.05$) between the color models; post hoc Wilcoxon Analysis ($p < 0.05$) reveals CMYK has statistically different results from every other color model, therefore concluding that **CMYK has the best solution for this blending**, according to users' responses.

The tendency of results to blend Magenta in CMYK Color Model, could be explained by the fact that magenta is a primitive color of such model, therefore leading the user to blend it accordingly.

In this question, **CIE-L*C*h* has only significant differences with HSV ($p < 0.05$)**, which is far opposite from question 1. The online results for this question validate the laboratory experience.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
2	(59, 28, 97)	Red	Blue	(59, 28, 97)		(44, 22, 22)		(13, 6, 21)		(13, 6, 21)		(29, 14, 25)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.22	0.13	0.16	0.09	**0.11**	0.06	0.17	0.11	0.16	0.08
Distance to Objective - Online				0.15	0.13	0.16	0.08	**0.08**	0.04	0.1	0.08	0.12	0.05

Table 4.9: Question 2, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Three This question presents a Green color and expects to receive, from the user, the Red and Cyan colors. According to the HSV Color Model, Red and Cyan are positioned in opposite angles in the Hue Circle of Colors: therefore, blending these opposite colors that output two different colors. It is important to study to which color the users tend to blend; this question should be evaluate along with Question Four, which has the contrary output.

The colors were blended, and again the mean values over distances were calculated, as Table 4.10 shows. It is observable that CMYK Color Model presents the lowest mean value for distance to ideal answer ($\tilde{x} = 0.05$); however, the standard deviation for the HSV Color Model is the highest between both study environments ($\sigma = 0.12$).

Running the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 84.448$, $p < 0.05$) between the color models; Wilcoxon Analysis ($p < 0.05$) reveals CMYK has statistically different results from other color models (except RGB), therefore concluding that **CMYK has the best solution for this blending**, according to users' responses. CIE-L*C*h* is again the lower color model being significantly different from every other color model. The second best color model is **CMYK**, with statistically different results with every color model, except for **HSV**.

Once again, these results are validated by the online users' dataset. The results from this question will be useful later, when analyzing question twelve.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
3	(45, 76, 12)	Red	Cyan	(45, 76, 12)		(31, 44, 8)		(21, 22, 24)		(21, 22, 24)		(47, 44, 27)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.094	0.12	0.23	0.06	**0.061**	0.03	0.11	0.06	0.12	0.04
Distance to Objective - Online				**0.07**	0.09	0.23	0.06	**0.07**	0.03	0.12	0.06	0.13	0.04

Table 4.10: Question 3, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Four As explained in previous question, this one is the second possible output from the blend of Red and Cyan colors. This color has no matching color pairs in the other models, since this color is only obtained in the HSV Color Model. Comparing the results for the HSV Color Model of both questions, mean distances are quite lower for question thirteen ($\tilde{x} = 0.045$), whilst the deviation of answers is higher in both questions.

Based on these results, corroborated by the online users, we can conclude **users tend to blend in CMYK Color Model to obtain a green color**, **mixing red and cyan does not generate a purple shade, according to users' expectations**. The results from this question can be found in table 4.11.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
4	(27, 12, 95)	Red	Cyan	(59, 28, 97)		-		-		-		-	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.12	0.13	-	-	-	-	-	-	-	-
Distance to Objective - Online				0.11	0.15	-	-	-	-	-	-	-	-

Table 4.11: Question 4, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Five This question expected Red and Magenta colors as response to a shade of red presented. As observed in Table 4.12, when this mixture is blended according to each color model, it generates fairly the same color.

The colors were blended, and again the mean values over distances were calculated, as Table 4.12 shows. It is observable that CMYK Color Model presents, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.13$), whilst its standard deviation is also the lowest between both study environments.

However, it is not safe to say that which color model had the worst results: judging by laboratory and online values, every color model have closer values from each other, being the standard deviation the differentiator between them. The HSV Color Model has, again, not only the have highest mean distance, but also the largest deviation of answers; yet, evaluating the result from Friedman Test, we can conclude that there are, in fact, significant differences ($\chi^2 = 32.720$, $p < 0.05$) between the color models; post hoc Wilcoxon Analysis ($p < 0.05$) reveals CMYK only has statistically different results from HSV color model, and RGB and CIE-L*a*b* have both statistically significant differences with HSV.

Evaluating this question by the values only, it would be possible to affirm that CMYK has the best results; despite, **there is no substantial differences to declare that**, which leads us to allege that **every color model studied yield acceptable results when blending red and magenta**.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
5	(45, 23, 22)	Red	Magenta	(45, 23, 22)		(45, 23, 22)		(45, 23, 22)		(45, 23, 22)		(45, 23, 25)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.17	0.10	0.15	0.08	**0.13**	0.07	0.14	0.09	0.14	0.08
Distance to Objective - Online				0.16	0.13	0.15	0.07	**0.13**	0.06	0.14	0.10	0.11	0.07

Table 4.12: Question 5, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Six This question expected Red and Yellow colors as response to a shade of Orange presented. As observed in Table 4.13, when this mixture is blended according to each color model, it generates fairly the same color (HSV, RGB and CMYK all generate the same shade).

The colors were blended, and again the mean values over distances were calculated, as Table 4.13 shows. It is observable that CIE-L*a*b* Color Model presents, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.05$).

However, it is not safe to say that which color model had the worst results: judging by laboratory and online values, every color model have closer values from each other, being the standard deviation the differentiator between them. In fact, **HSV, CMYK and RGB have similar values due to the similarity between their outputs**: their mean values, though not the lower ones, are still very good and closer to the objective colors ($\tilde{x}_{CMYK} = 0.06$, $\tilde{x}_{HSV} = 0.07$ and $\tilde{x}_{RGB} = 0.08$).

The CMYK Color Model has, again, the lowest deviaton of results. Performing a Friedman Test, we can conclude that there are, in fact, significant differences ($\chi^2 = 45.396$, $p < 0.05$) between the color models; post hoc Wilcoxon Analysis ($p < 0.05$) reveals CIE-L*a*b* only has no statistically different results from CMYK color model, and CIE-L*C*h* has statistically significant differences with every color model.

Evaluating this question by the values only, it would be possible to affirm that CIE-L*a*b* has the best results; despite, **there is no substantial differences to declare that**, since every color model besides CIE-L*C*h offers great results, which leads us to allege that **HSV, RGB, CMYK and CIE-L*a*b* color models provide quite good results when blending red and yellow**.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
6	(49, 37, 5)	Red	Yellow	(49, 37, 5)		(54, 46, 6)		(49, 37, 5)		(49, 37, 5)		(54, 47, 6)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.07	0.10	0.13	0.09	0.06	0.06	0.08	0.09	**0.05**	0.07
Distance to Objective - Online				0.03	0.05	0.14	0.07	0.03	0.03	0.04	0.05	**0.02**	0.03

Table 4.13: Question 6, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Seven This question expected Cyan and Magenta colors as response to Blue, presented. The range of colors generated as possible outputs from color models, varying between blue, cyan, purple and pink.

The colors were blended, and mean values over distances were calculated, as Table 4.14 shows. It is observable that CMYK Color Model proves to be again the lowest mean value for distance to ideal answer ($\tilde{x} = 0.10$), whilst offering the lowest value for deviation along with CIE-L*a*b* ($\sigma = 0.08$). CIE-L*C*h* has the highest mean result of distances, but the one which has the highest deviation is the HSV Color Model. In fact, **HSV, RGB and CIE-L*a*b* have similar**.

Performing a Friedman Test, we can conclude that there are, in fact, significant differences ($\chi^2 = 60.886$, $p < 0.05$) between the color models; Wilcoxon Analysis ($p < 0.05$) shows HSV has no statistically different results from any color model and CIE-L*C*h* has statistically significant differences only with CMYK color model. In general, this question gathers a low quantity of statistically significant differences: between CIE-L*C*h* and CMYK, CMYK and RGB, and CMYK and CIE-L*a*b*

Based on these results, corroborated by the online users, we can conclude **users tend to blend in HSV to obtain a blue color**. However, it should be considered that **HSV, RGB and CIE-L*a*b* also yielded good results, particularly the last one which had the lowest deviation of answers**. The results from this question can be found in table 4.14.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
7	(18, 7, 95)	Cyan	Magenta	(18, 7, 95)		(39, 49, 102)		(35, 27, 98)		(35, 27, 98)		(56, 50, 101)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.16	0.21	0.23	0.10	**0.10**	0.08	0.15	0.13	0.17	0.08
Distance to Objective - Online				0.13	0.21	0.18	0.08	**0.11**	0.06	0.17	0.11	0.22	0.07

Table 4.14: Question 7, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Eight This blending question expected Magenta and Yellow colors as response to **Red** presented. As observed in Table 4.15, when this mixture is blended according to each color model, it generates fairly the same color, similarly to question five.

The colors were blended, and again the mean values over distances were calculated, as Table 4.15 shows. It is observable that CMYK and HSV Color Model presents, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.10$), whilst standard deviation for the CMYK Color Model is also the lowest between both study environments.

Surprisingly, CIE-L*C*h has the lowest result for the mean distance of online results ($\tilde{x} = 0.09$), which is quite lower than the maximum value of this parameter in the online environment ($\tilde{x}_{lab} = 0.16$). This result is different from the laboratory data, in which this same color model has the highest mean value for distance to ideal answer. With this said, **it is not safe to say that which color model had the worst results**.

Also, there should be some sort of affinity between RGB and CIE-L*a*b* models, regarding the laboratory results: they both have the same mean distance and deviation values. Evaluating the data with the Friedman Test, we can conclude that there are, in fact, significant differences ($\chi^2 = 27.377$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) does not reveal a significant difference between color models.

Evaluating this question by the values only, it would be possible to affirm that CMYK has the best results, due to the commitment between the mean value and standard deviation; despite, **there is no substantial differences to declare that**, which leads us to allege that **every color model studied yield acceptable results when blending magenta and yellow**, but further depth studying should be applied.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
8	(41, 21, 2)	Magenta	Yellow	(41, 21, 2)		(48, 32, 12)		(53, 38, 25)		(53, 38, 25)		(62, 51, 43)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				**0.10**	0.16	0.17	0.13	**0.10**	0.05	0.13	0.09	0.13	0.09
Distance to Objective - Online				0.10	0.17	**0.09**	0.12	0.12	0.05	0.14	0.07	0.16	0.07

Table 4.15: Question 8, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Nine This blending question expected Magenta and Yellow colors as response to **Red** presented. As observed in Table 4.16, when this mixture is blended according to each color model, it generates fairly the same color, similarly to question five.

The colors were blended, and again the mean values over distances were calculated, as Table 4.16 shows. It is observable that CMYK and HSV Color Model presents, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.10$), whilst standard deviation for the CMYK Color Model is also the lowest between both study environments.

The results show that CIE-L*C*h* is the worst-generating values Color Model, having the higher mean value of all models across study environments. There is also the same tendency of RGB, CIE-L*a*b* and HSV present closer values between each other. Evaluating the data with the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 48.252$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) does reveal there are almost no significant difference between color models: mostly, the significant differences reside in CIE-L*C*h*, when compared again with CMYK, RGB and CIE-L*a*b*.

Evaluating this question by the values only, it would be possible to affirm that CMYK has the best results, due to the commitment between the mean value and standard deviation; despite, **there is no substantial differences to declare that**, which leads us to allege that **every color model (except CIE-L*C*h*) studied yield acceptable results when blending green and cyan**. The results from this question will be useful when analyzing question fifteen.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
9	(40, 73, 32)	Green	Cyan	(40, 73, 32)		(44, 75, 57)		(40, 73, 32)		(40, 73, 32)		(44, 75, 44)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.13	0.10	0.16	0.07	**0.09**	0.05	0.10	0.08	0.11	0.07
Distance to Objective - Online				0.11	0.08	0.13	0.06	**0.10**	0.04	**0.10**	0.08	0.11	0.06

Table 4.16: Question 9, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Ten This question presents a shade of Blue color and expects to receive, the pair Green and Magenta. As in question 3, according to the HSV Color Model, Green and Magenta are positioned in opposite angles in the Hue Circle of Colors: therefore, blending these opposite colors that output two different colors. This question should be evaluate along with Question Eleven, which has the opposite output.

These two colors, when blended, produce substantitally different colors according to each model interpolation: this question could produce significaaly different results from model to model, since the users would be clearly indicating which color they would tend to.

The colors were blended and the mean values over distances were calculated, as Table 4.17 shows.

It is observable that CMYK Color Model presents the lowest mean value for distance to ideal answer ($\tilde{x} = 0.013$); its standard deviation is also the lowest between both study environments ($\sigma = 0.05$), which could indicate a preference for this color model. Notwithstanding, all the mean values are substatially high when compared with previous questions, which could indicate that **none of these models produce the color blending according to the users' expectations, nor blending green and magenta to produce a blue shade**.

Running the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 37.700$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) reveals CMYK has statistically different results from other color model, therefore concluding that **CMYK has the best solution for this blending**, according to users' responses. HSV is the lower color model, being significantly different from every other color model excluding CMYK. CIE-L*C*h*, RGB and CIE-L*a*b* all afford similar mean values.

Once again, these results are validated by the online users' dataset. The results from this question will be useful later, when analyzing question thirteen. Figures 4.5 and 4.11 demonstrates the placement of answer-pairs, and the pairs blended in HSV Color Model.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
10	(26, 23, 98)	Green	Magenta	(26, 23, 98)		(47, 33, 4)		(21, 22, 24)		(21, 22, 24)		(47, 48, 41)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.30	0.16	0.26	0.12	**0.13**	0.05	0.21	0.06	0.20	0.10
Distance to Objective - Online				0.17	0.17	0.27	0.09	**0.13**	0.04	0.20	0.04	0.22	0.07

Table 4.17: Question 10, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

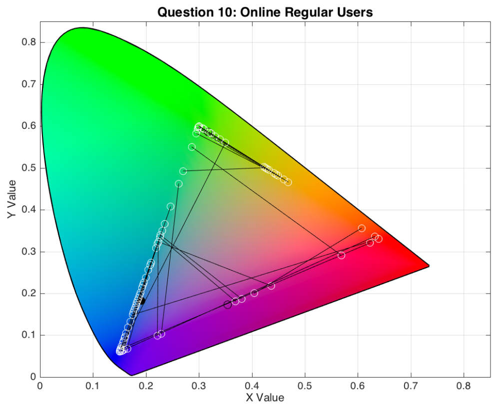

Figure 4.5: Online Results: Answers for Question 10, from regular users.

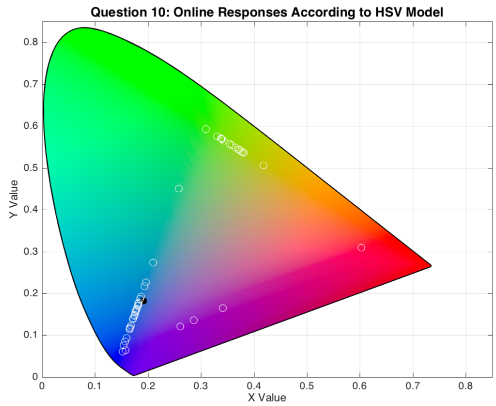

Figure 4.6: Online Results: Answers for Question 10, from regular users, mixed in HSV Color Model.

Question Eleven As explained in previous question, this one is the second possible output from the blend of Green and Magenta colors. This color has no matching color pairs in the other models, since this color is only obtained in the HSV Color Model. Comparing the results for the HSV Color Model of both questions, mean distances are dramatically lower for question fourteen ($\tilde{x} = 0.06$), whilst the deviation of answers is also lower in question fourteen.

However, there is an interesting feature: instead of believing in a Green-Magenta blending to produce Orange, **the users tend to use again Red and Yellow** as on question six, which explains the low HSV mean value for question eleven. Based on these results, corroborated by the online users, we can conclude **the orange color is a strongly implemented color in mental models of our users**. The results from this question can be found in table 4.18. These differences can be seen on Figures 4.7 and 4.8, which largely demonstrates the placement of answer-pairs, and the pairs blended in HSV Color Model.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
11	(49, 37, 5)	Green	Magenta	(49, 37, 5)		-		-		-		-	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.06	0.09	-	-	-	-	-	-	-	-
Distance to Objective - Online				0.04	0.06	-	-	-	-	-	-	-	-

Table 4.18: Question 11, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

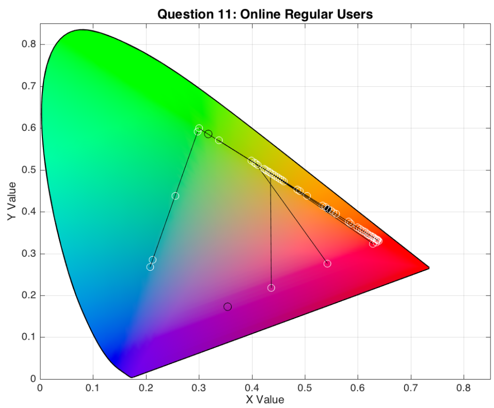

Figure 4.7: Online Results: Answers for Question 11, from regular users.

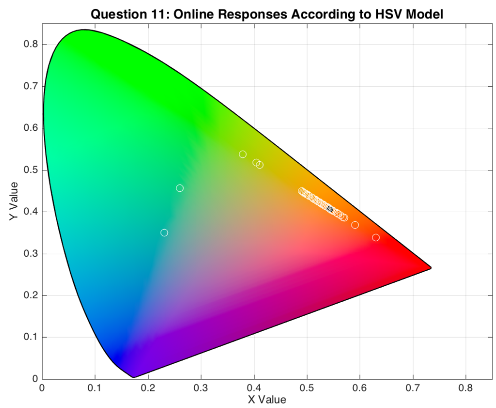

Figure 4.8: Online Results: Answers for Question 11, from regular users, mixed in HSV Color Model.

Question Twelve This blending question expected Green and Yellow colors as response to a tone of **Green** presented. This green tone is equal to the one presented in question three, therefore its results are interesting to compare with this question. As observed in Table 4.19, when this mixture is blended according to each color model, it generates almost the same green color, so distances and their statistics are expected to be closer to each other.

The colors were blended, and again the mean values over distances were calculated, as Table 4.19 shows. It is observable that HSV Color Model presents, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.11$), whilst standard deviation for the CMYK Color Model provides the lowest value between both study environments ($\sigma_{lab} = 0.04$, $\sigma_{online} = 0.05$).

The results show that CIE-L*C*h* the worst-generating values Color Model, having the higher mean value of all models across study environments. There is also the same tendency of RGB, CIE-L*a*b* and CMYK present closer values between each other. Evaluating the data with the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 71.788$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) does reveal **there are significant difference between color models**: when analyzing the results for the tests between HSV and other color models, it presents significant differences between all models except CMYK; the model which consistently presents the larger distances is CIE-L*C*h* against every color model, leading to statistically significant differences with every other model.

Comparing the results of this question with number three, we can observe that the later has shorter values: HSV Color Model still presents the best mean values between questions. The fact that question three has lower values, leads us to conclude that **mixing Red and Cyan to achieve this green tone is more similar with the users' expectations, than blending a Green and Yellow color**. Figures 4.9 and 4.10 compare the results from both question three and twelve, blended in HSV (the model which yields the best results).

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
12	(45, 76, 12)	Green	Yellow	(45, 76, 12)		(54, 81, 13)		(45, 76, 12)		(45, 76, 12)		(53, 81, 13)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				**0.11**	0.13	0.23	0.07	0.13	0.04	0.15	0.08	0.17	0.07
Distance to Objective - Online				**0.08**	0.11	0.24	0.06	0.12	0.05	0.13	0.09	0.15	0.09

Table 4.19: Question 12, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

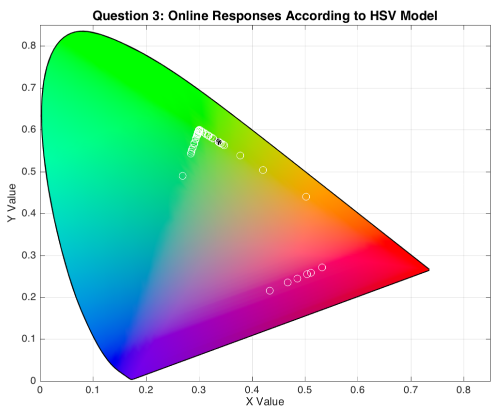

Figure 4.9: Online Results: Answers for Question 3, from regular users, mixed in HSV Color Model.

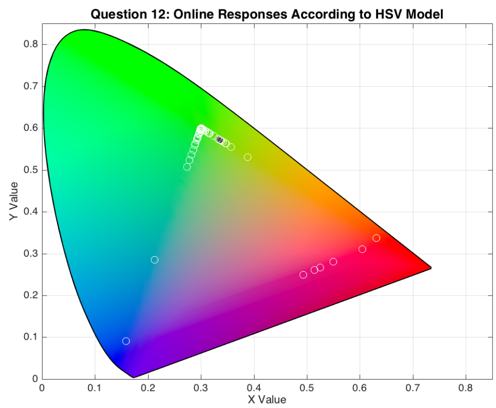

Figure 4.10: Online Results: Answers for Question 12, from regular users, mixed in HSV Color Model.

Question Thirteen This mixture expected in this question contains Blue and Cyan colors as response to a lighter tone of **Blue**, which was presented. Similar to previous question, this one had presented a repeated color: this blue shade is equal to the one presented in question ten, therefore its results are interesting to compare with this question. As observed in Table 4.20, when this mixture is blended according to each color model it generates similars colors, except for CIE-L*C*h* that has a ligher blending than others.

The colors were blended, mean values over distances calculated, as Table 4.20 shows. It is interesting to see CIE-L*C*h* overcoming the lowest result in the laboratory environment, against other color models which regularly had best results in previous questions; however, this results are not consistent with the online users, which indicated responses closer to the RGB Color Model ($\sigma_{online} = 0.13$).

Analyzing the laboratory results, it shows HSV is the worst-generating values Color Model, having the higher mean value ($\tilde{x}_{HSV} = 0.27$) of all models. When comparing it to the online dataset, HSV, CMYK and CIE-L*a*b* have all the same mean values. Evaluating the data with the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 38.993$, $p < 0.05$) between the color models on the laboratory results; a Wilcoxon Analysis ($p < 0.05$) does reveal **there are significant difference**

between color models: when analyzing the results for the tests between HSV and other color models, it presents significant differences between all models except CIE-L*C*h*.

The fact that online users' data indicate a slight tendency to the RGB Color Model, could be justified as **the blue color is a primitive of such color model, making it easier to map against a mental model of color**.

Comparing the results of this question with number ten, we can observe that this question has shorter HSV value; however we know that HSV was not the lowest mean value on question thirteen These results leads us to conclude that **there is insufficient values to ascertain the best color model to achieve this blue tone**. Further studies are required to unveil the appropriate color model and clarify this matter. Figures 4.11 and **??** compare the results from both question three and twelve, blended in HSV and RGB respectively, (the model which yielded the best results in each question).

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
13	(26, 23, 98)	Blue	Cyan	(26, 23, 98)		(33, 37, 100)		(26, 23, 98)		(26, 23, 98)		(32, 30, 99)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.27	0.16	**0.17**	0.10	0.19	0.13	0.25	0.16	0.23	0.12
Distance to Objective - Online				0.14	0.16	0.20	0.09	0.14	0.11	**0.13**	0.15	0.14	0.11

Table 4.20: Question 13, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

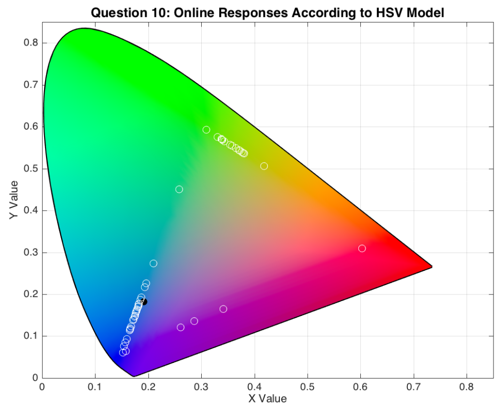

Figure 4.11: Online Results: Answers for Question 10, from regular users, mixed in HSV Color Model.

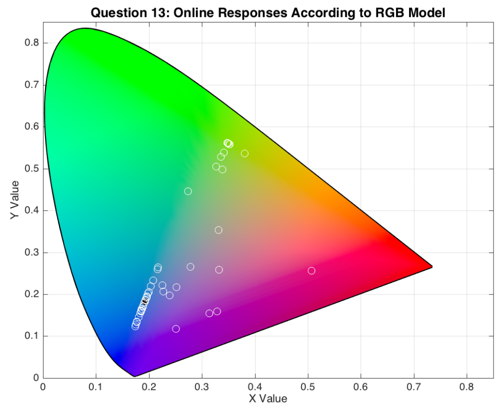

Figure 4.12: Online Results: Answers for Question 13, from regular users, mixed in RGB Color Model.

Question Fourteen This blending question expected Blue and Magenta colors as response to a resulting color of **Purple** (presented to the user). As in Table 4.21, when this mixture is blended according to each color model, it generates fairly the same color (precisely the same between HSV, RGB and CMYK).

The colors were blended, and again the mean values over distances were calculated, as Table 4.21 shows. It is observable that CMYK Color Model presents, the lowest mean value for distance to ideal answer ($\tilde{x} = 0.10$ laboratory, and $\tilde{x} = 0.09$ online), whilst standard deviation for the CMYK Color Model is also the lowest between both study environments presenting exactly the same value.

The results show that CIE-L*C*h* the worst-generating values Color Model having, by far, the higher mean value of all models across study environments ($\tilde{x} = 0.30$). There is also the same tendency of

RGB, CIE-L*a*b* and HSV present closer values between each other. Evaluating the data with the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 51.726$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) does reveal there are no significant difference between color models: mostly, the significant differences reside in CIE-L*C*h*, when compared with HSV, CMYK and CIE-L*a*b*.

Evaluating this question, it is possible to affirm that **CMYK has the best results when mixing purple, a color derived from magenta**, due to the commitment between the mean value and standard deviation, which could be justified by the fact that **magenta is a primitive from such model, combined with the indication shown throughout the study to demonstrate a subtractive mental model of color**.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
14	(27, 12, 95)	Blue	Magenta	(27, 12, 95)		(36, 16, 96)		(27, 12, 95)		(27, 12, 95)		(35, 16, 96)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.12	0.14	0.30	0.09	**0.10**	0.05	0.13	0.13	0.13	0.09
Distance to Objective - Online				0.10	0.12	0.29	0.13	**0.09**	0.05	0.11	0.12	0.12	0.09

Table 4.21: Question 14, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Question Fifteen This question presents a shade of Green color and expects to receive, the pair Blue and Yellow. According to the HSV Color Model, Blue and Yellow are positioned in opposite angles in the Hue Circle of Colors: therefore, blending these opposite colors that output two different colors. This question should be evaluate along with Question Sixteen, which has the opposite output. This question also presented a repeated color: this green shade is equal to the one presented in question nine, therefore its results are interesting to compare with this question.

These two colors, when blended, produce substantitally different colors according to each model interpolation: this question could produce significaaly different results from model to model, since the users would be clearly indicating which color they would tend to.

The colors were blended and the mean values over distances were calculated, as Table 4.22 shows. It is observable that CMYK Color Model presents the lowest mean value for distance to ideal answer ($\tilde{x} = 0.06$); its standard deviation is also the lowest between both study environments ($\sigma = 0.03$). Though, it is important to analyze this result: since we are mixing opposite colors, both CMYK and RGB generate a neutral color, which means that the closer the users' answers are from the ideal answers (Blue and Yellow), the shorter the distance on these color models, and greyer the shade. **This value, in fact, sustents the result of HSV Color** ($\tilde{x}_{HSV} = 0.09$), which is very acceptable since the answer pairs are very close to the expected one.

Running the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 63.068$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) reveals that there are statistically different results among all color models, except for HSV and RGB and HSV and CIE-L*a*b*, which do not have statistically signifcant differences.

Comparing the results of this question with number nine, we can observe that this question has shorter values: HSV Color Model still presents the best mean values between questions, and deviations of question 15 answers are lower for all models against question 9. This fact leads us to conclude that **mixing Blue and Cyan to achieve this green shade is more similar with the users' expectations, than blending a Green and Cyan color**. Figures 4.13 and 4.14 compare the results from both question nine and fifteen, blended in HSV (the model which yields the best results).

HSV has statistically different results from other color models, therefore concluding that **HSV has the best solution for this blending**, according to users' responses. It is necessary to analyze pairwise the next question to evaluate the efectiveness of this output, for Blue and Yellow colors blending.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
15	(40, 73, 32)	Blue	Yellow	(40, 73, 32)		(43, 22, 10)		(21, 22, 24)		(21, 22, 24)		(41, 34, 42)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.09	0.04	0.30	0.08	**0.06**	0.03	0.11	0.05	0.13	0.06
Distance to Objective - Online				0.11	0.08	0.30	0.07	**0.06**	0.03	0.11	0.04	0.13	0.06

Table 4.22: Question 15, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

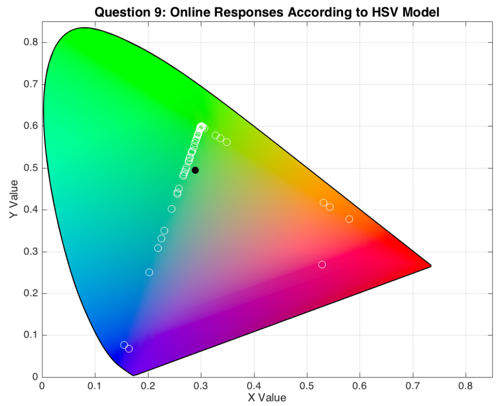

Figure 4.13: Online Results: Answers for Question 9, from regular users, mixed in HSV Color Model.

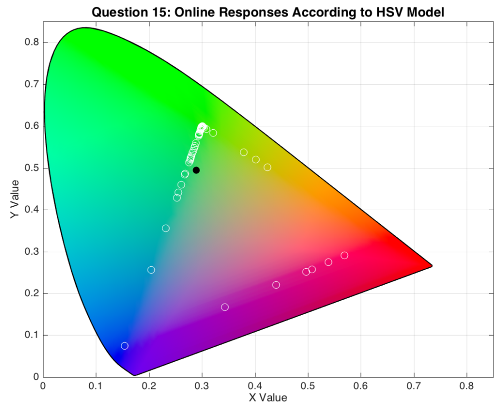

Figure 4.14: Online Results: Answers for Question 15, from regular users, mixed in HSV Color Model.

Question Sixteen As explained in previous question, this one is the second possible output from the blend of Blue and Yellow colors. This color has no matching color pairs in the other models, since this color is only obtained in the HSV Color Model. Comparing the results for the HSV Color Model of both questions, mean distances are largely high for question sixteen ($\tilde{x}_{lab} = 0.21$, $\tilde{x}_{online} = 0.19$), whilst the deviation of answers is also lower in question fifteen.

Whilst the color presented was fairly similar with Magenta, the users tended to answer with Red-Blue pair of colors (which, as seen on question two, produces magenta according to the HSV Color Model).

Based on these results, corroborated by the online users, we can conclude that **blending Blue and Yellow, according to users' mental model of color, produces Green instead of Magenta**. It is also possible to conclude that **to produce Magenta, according to user's mental model of color, it is needed to blend Red and Blue**. The results from this question can be found in table 4.23. These differences can be seen on Figures 4.15 and 4.16, which largely demonstrates the placement of answer-pairs, and the pairs blended in HSV Color Model.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
16	(45, 23, 22)	Blue	Yellow	(45, 23, 22)		-		-					
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.21	0.10	-	-	-	-	-	-	-	-
Distance to Objective - Online				0.19	0.12	-	-	-	-	-	-	-	-

Table 4.23: Question 16, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

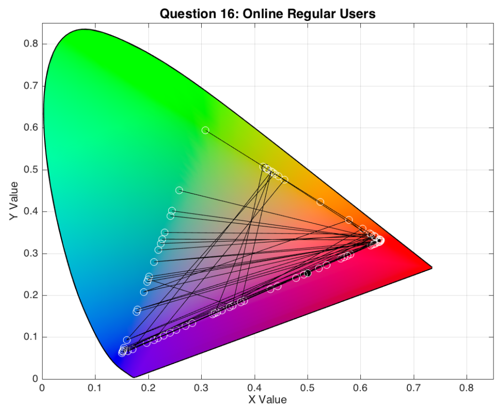

Figure 4.15: Online Results: Answers for Question 16, from regular users.

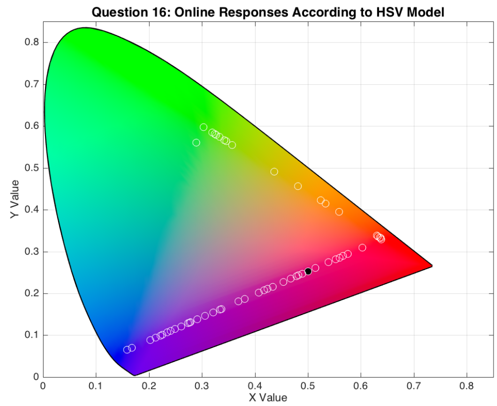

Figure 4.16: Online Results: Answers for Question 16, from regular users, mixed in HSV Color Model.

Question Seventeen The last question in which we ask the user to indicate two colors is this: we expected to receive Cyan and Yellow colors as response, to a resulting color of **Green** (presented to the user). As in Table 4.24, when this mixture is blended according to each color model, it generates fairly the same color (precisely the same between RGB and CMYK).

The colors were blended, and mean values over distances were calculated. It is observable that CMYK Color Model presents the lowest mean value for distance to ideal answer ($\tilde{x} = 0.05$ laboratory, and $\tilde{x} = 0.05$ online), whilst standard deviation for the CMYK Color Model is also the lowest between both study environments presenting exactly the same value.

The results show that CIE-L*C*h* the worst-generating values Color Model having the higher mean value of all models across study environments ($\tilde{x} = 0.16$), which is consistent with the entire user study. There is also the tendency of RGB and CIE-L*a*b* to present closer values between each other. Evaluating the data with the Friedman Test, we can conclude that there are significant differences ($\chi^2 = 86.654$, $p < 0.05$) between the color models; a Wilcoxon Analysis ($p < 0.05$) does reveal there are clearly significant difference between color models: mostly, every color model has significant differences between each other, except for HSV-CMYK, and RGB-CIE-L*a*b* which in fact present no statistically significant differences.

Evaluating this question, it is possible to affirm that **CMYK has the best results when cyan and yellow**, due to the commitment between the mean value and standard deviation, which could be justified by the fact that **cyan and yellow are primitives from such model, combined with the indication shown throughout the study to demonstrate a subtractive mental model of color**.

Question ID	Given Color	Expected Colors		Possible Results									
		C1	C2	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
17	(36, 72, 13)	Cyan	Yellow	(36, 72, 13)		(49, 77, 47)		(49, 78, 33)		(49, 78, 33)		(66, 87, 46)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.07	0.10	0.16	0.06	**0.05**	0.02	0.10	0.06	0.11	0.05
Distance to Objective - Online				0.08	0.13	0.17	0.06	**0.05**	0.03	0.10	0.06	0.11	0.05

Table 4.24: Question 17, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

Analyzing Color Models

Now that we have broke down the results for each question, it is important to evaluate the values according to each color model. Based on table 4.7, which presents the mean values for each color model decomposed by question, we can run descriptive statistics over its column and produce table 4.26 that is going to be helpul when inspecting the results *per* color model. We have also gathered the results from the previous section, displaying the three best and worst results of each color model, identified as green and red, respectively: this information is condensed in table 4.25.

Question ID	HSV		CIE-L*C*h*		CMYK		RGB		CIE-L*a*b*	
	Mean ($\tilde{x}$)	Std-Dev (σ)	Mean ($\tilde{x}$)	Std-Dev (σ)	Mean ($\tilde{x}$)	Std-Dev (σ)	Mean ($\tilde{x}$)	Std-Dev (σ)	Mean ($\tilde{x}$)	Std-Dev (σ)
1	0.1258	**0.08275**	0.2042	**0.0644**	0.0926	0.06118	0.1237	0.07925	0.1232	0.0807
2	**0.2173**	0.13014	**0.1573**	0.09445	0.106	0.05642	**0.166**	0.10521	0.156	0.08399
3	0.0941	0.12308	0.23	**0.05855**	0.0609	**0.03379**	0.1114	**0.06034**	0.1227	**0.03918**
4	0.1162	0.12975								
5	0.1683	0.10113	**0.15**	0.08	**0.1322**	0.06787	0.1389	0.09106	0.135	0.07579
6	**0.0741**	0.10418	**0.1332**	0.08671	**0.0577**	0.06164	**0.0777**	0.0973	**0.0509**	0.07374
7	0.1577	**0.20679**	0.2323	**0.10038**	0.0986	0.07523	0.1455	**0.12835**	0.1705	0.07925
8	0.0954	**0.16302**	0.17	**0.12845**	0.1008	**0.4974**	0.1292	0.08967	0.1292	0.08986
9	0.1258	0.0989	0.1642	0.07463	0.0911	0.04642	**0.1005**	0.07524	**0.1142**	0.06694
10	**0.3**	**0.15792**	**0.2557**	**0.1164**	**0.1314**	0.04769	**0.2107**	0.06403	**0.2043**	**0.09581**
11	**0.0587**	0.08828								
12	0.1067	0.12639	0.2343	0.06638	**0.1314**	0.03966	0.151	0.07758	**0.1743**	0.07284
13	**0.2713**	0.15607	0.1663	0.09701	**0.1875**	**0.13097**	**0.245**	**0.15795**	**0.2269**	**0.12224**
14	0.1186	**0.014423**	**0.2995**	0.08936	0.0973	**0.4901**	0.1327	**0.13406**	0.1336	**0.09444**
15	0.09	**0.03559**	**0.3031**	0.07872	**0.0625**	**0.02696**	0.11	**0.04705**	0.1256	**0.06229**
16	0.2087	0.10378								
17	**0.0683**	0.10228	0.1626	**0.05902**	**0.0452**	**0.0162**	**0.103**	**0.0574**	**0.113**	**0.05112**

Table 4.25: Laboratory Results: Statistics for distances *per* question, of Results Mixed in each Color Model, for each question. In Green/Red shade, the three best/worst results for each descriptive statistic.

Descriptive Statistics	Laboratory Environment					Online Environment				
	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*
Mean ($\tilde{x}$)	0.14	**0.20**	**0.10**	0.14	0.14	0.11	**0.20**	**0.09**	0.12	0.13
Std-Dev (σ)	**0.08**	0.06	**0.04**	0.05	**0.04**	**0.04**	**0.06**	**0.04**	**0.04**	0.05
Maximum Value	0.30	0.30	0.19	0.25	0.23	0.17	0.30	0.14	0.20	0.22
Minimum Value	0.05	0.13	0.05	0.08	0.05	0.03	0.09	0.30	0.04	0.02
Range	**0.26**	0.17	**0.14**	0.17	0.18	0.14	**0.21**	**0.11**	0.16	0.20
Variance (σ^2)	**0.006**	0.003	**0.001**	0.002	0.002	0.002	**0.004**	**0.001**	0.002	0.003

Table 4.26: Condensed Statistics for Distances to Ideal Results, mixed in each Color Model. In Green/Red shade, the best/worst result for each descriptive statistic.

The Color Model which presented the lowest mean value for distances was the CMYK Color Model ($\tilde{x} = 0.10$), followed by HSV, RGB and CIE-L*a*b* (all with $\tilde{x} = 0.14$), being CIE-L*C*h the model which has the highest calculated distances ($\tilde{x} = 0.20$). Consistently, the color model which has the lowest variance and range of answers is the CMYK ($\sigma^2 = 0.001$, $range = 0.14$), opposed to the HSV ($\sigma^2 = 0.006, range = 0.26$).

By analyzing the results from the online users, we can verify that they corroborate the smallest data set (from laboratory users). In pursuance of fully understanding which color model provides the best results, we are going to break down the results according to Color Models *per* question, describing it in the following sub-subsections.

HSV Color Model Blendings The HSV Color Model, along with CMYK and RGB, is the one which presents the lowest standard deviation of distances between the results from the online environment; it is also one of the color models which has the lowest ranges of values on the same environment, which could indicate greater agreement between distances to the ideal HSV Color Model answer.

The questions which have shorter distances are number eleven (given orange and expected green and magenta), number seventeen (given green, expected blue and yellow) and number six (given orange, expected red and yellow). The mean values distances for this questions were $\tilde{x}_{11} = 0.0587$, $\tilde{x}_{17} = 0.0683$ and $\tilde{x}_6 = 0.0741$. On the other hand, we consider that the questions which generate the worst results are number two (given magenta, expected red and blue), number thirteen (given a shade of blue, expected blue and cyan) and number ten (given a shade of blue, expected green and magenta), with correspondent mean values $\tilde{x}_2 = 0.2173$, $\tilde{x}_{13} = 0.2713$ and $\tilde{x}_{10} = 0.3$.

By analyzing table 4.26, we can conclude that the HSV color model is the one which has a wider range of distances (laboratory environment) compared to other models: this could be due to the fact that **the color sliders which were in the user study, presented a color scale with the spectrum of hues from the HSV Color Model**.

When comparing the results from the HSV color model with other color models' results, we detect some statiscally significant differences with other models: performing a Wilcoxon Test ($p < 0.05$), we can infer that HSV does have statistically significant differences with CIE-L*C*h*, CMYK, RGB and CIE-L*a*b* in the majority of questions. The model which HSV has least statistically significant differences with is RGB, with seven questions.

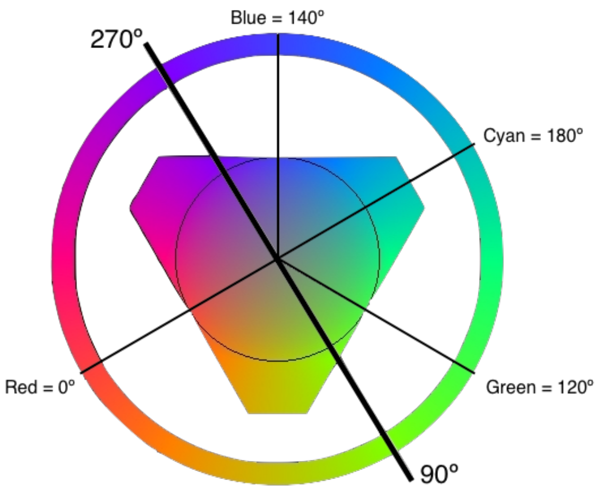

Figure 4.17: Example of HSV Hue Circle, with opposed hue values. Depicted: Questions 3 and 4, with resulting hues 270^{o} and 90^{o}.

As referred before, there are some color blends that, due to the fact that primitives of the mixture are precisely opposed (180^{o}) in the HSV hue circle, the blending in HSV Model could produce two different outputs. This occurs if one mixes the colors obeying to a positive or negative rotation on the circle (as seen on figure 4.17). There are in this study three pairs of colors which blend onto two possible colors: pair Red-Cyan (with possible outputs question three and four), pair Green-Magenta (questions ten and eleven) and pair Blue-Yellow (questions fifteen and sixteen). By placing these questions, we intended to understand which side the user would tend to follow (or even if he follows one) when asked to indicate the blending-basis. The results for each question were already analyzed in the previous subsection, therefore we present the essence of them in the following topics:

1. Red & Cyan Blend - Analyzing answers for questions three and four, they produce fairly similar results: they are both a bit far from the expected colors ($\tilde{x}_{distance-3} = 0.0941$ and $\tilde{x}_{HSV-4} = 0.1162$), although the mean distance to the HSV precalculated blending for question three has a slightly lower value than question four. This could be also compared to question 12, which also produces **Lime-Green** like question three, but even when compared, question three still has the best results when generating this tone of green. This leads us to specifiy that, although the mean distances to the ideal HSV Color blend for this mixture, are not the lowest among all questions, **the users show a tendency to associate the blending of red and cyan to a result of lime-green, instead of shade of purple**. When comparing these results with online, we found that the later ones corroborate and prove this conclusion.

2. Green & Magenta Blend - Unlike the previous blend, the results bewteen these questions were quite different between each other concerning the distance to the expected colors: $\tilde{x}_{HSV-10} = 0.3$ and $\tilde{x}_{HSV-11} = 0.0587$. However, the lower results associated with question eleven are due to the simple fact that **users indicated answers pairs which contained Red and Yellow**, which is the pair analyzed previously that also blended into orange; if the distance to the ideal answer pair for this question was measured, its mean value would be $\tilde{x}_{distanceC1-C2} = 0.645$, which is largely different from the expected colors. Therefore we can conclude that **it is hard for the users to blend green and magenta, to obtain either a blue or an orange shade**; we can also conclude that **the blending of red and yellow onto an orange color, is a strongly implemented color mixture, in mental models of our users**.

3. Blue & Yellow Blend - Evaluating the results obtained on question fifteen and sixteen, we obtain different results for both. Analyzing results of question fifteen, we know that the distance to the expected pair of colors it presents one of the lowest values among all results for HSV Color Model ($\tilde{x}_{HSV-15} = 0.09$, $\sigma_{HSV-15} = 0.03559$); however, when comparing the result-pairs given on this question, with the ones given on question nine (which presented the exact same shade of green, when asked for pair Green-Cyan), question fifteen still presents the results to generate this color. As it can be seen on Figure 4.18, the resulting blend in HSV Color Model tend to be close to the ideal HSV answer: despite being nearer to the top corner of the HSV Model Triangle, **we can still consider the answers to be a tone of green color**. Regarding the results from question 16, they present themselves to be one of the worst for this color model: the distance to the expected colors is $\tilde{x}_{HSV-16} = 0.2087$ and the standard deviation for the distances of answers blended in HSV is $\sigma_{HSV-16} = 0.10378$. Since the presented color had a strong value of red component, users tended their answers to the red shade, while blending it with a purple or pink one, to indicate a mixture close to magenta. This indicates that **blending Blue and Yellow, in HSV Color Model, does not correspond to a red shade, but to a green one, according to the users' expectations**.

Another interesting example is Question ten and thirteen: they both present a shade of blue, which

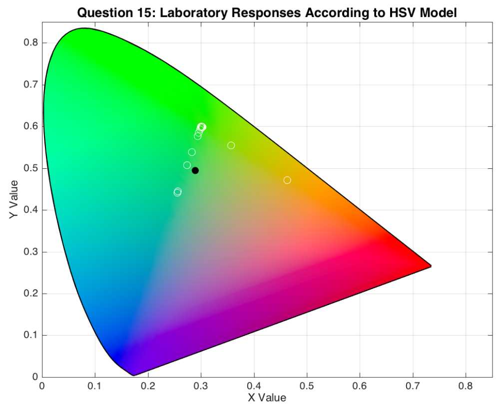

Figure 4.18: Laboratory Results: Answers for Question 15, from regular users, mixed in HSV Color Model.

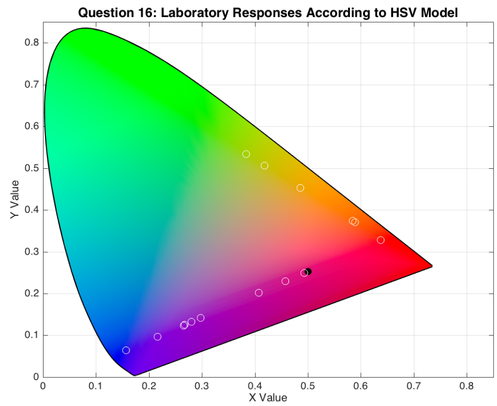

Figure 4.19: Laboratory Results: Answers for Question 16, from regular users, mixed in HSV Color Model.

could be obtained by two strands, either Green and Magenta (Question ten) or Blue and Cyan (Question thirteen). Particularly, the late question had a fairly simple expected pair (two shades of blue), but the users demonstrated some dispersion when aswering the question: moreover, the statistics prove it, by having a rather high standard deviation ($\tilde{x}_{HSV-10} = 0.3$, $\sigma_{HSV-10} = 0.15792$) when compared to the standard deviation of the whole model ($\sigma_{HSV} = 0.08$). These results are, thus, consistent with the know fact [**COLOCAR REF**] that **human color perception is poorer in the blue region of the color spectrum, than in others**, *e.g* the green zone, which produced the best results for this color model; these results are extensible to the purple region of the spectrum, which is contiguous to the blue one.

The diagram of Figure 4.20 contains the three top and bottom-valued questions, disposed on top of an interval $[0; 0.5]$ of differences. Each question is mapped according to its mean value for distance to the ideal HSV Color Model response, while is accompanied by the range of values which compose its answers.

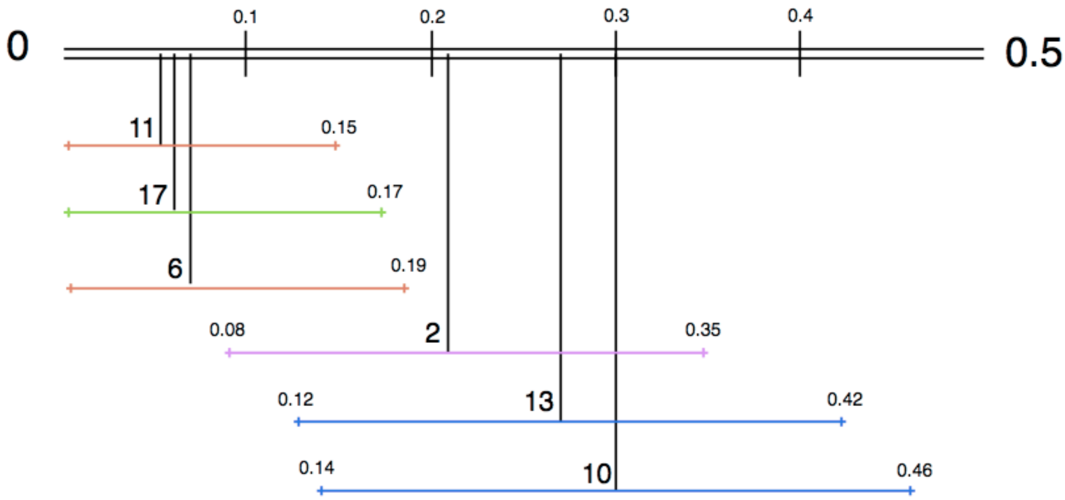

Figure 4.20: Best and Worst Questions, according to HSV Color Model.

CIE-L*C*h* Color Model Blendings In turn, the CIE-L*C*h* Color Model is the one which presents the worst results for most of the descriptive statistics present on Table 4.26: it has the highest mean value on laboratory and online environment, and the highest standard deviation, range and variance exclusively on the online environment. These results are consistent with the individual questions' values, seen before this section.

The three questions which have shorter distances are number six (given orange, expected red and yellow), number five (given a shade of red, expected red and magenta) and number two (given magenta, expected red and blue). The mean values distances for this questions were $\tilde{x}_6 = 0.1332$, $\tilde{x}_5 = 0.15$ and $\tilde{x}_2 = 0.1573$ which, contrary to the previous color model, are all values above 0.1 (a quite high value in the scale which results are presented), that could represent a significant change in the resultant color.

On the other hand, we consider that the questions which generate the worst results are number ten (given a shade of blue, expected green and magenta), number fourteen (given a shade of purple, expected blue and magenta) and number fifteen (given a shade of green, expected blue and yellow), with correspondent mean values $\tilde{x}_{10} = 0.2557$, $\tilde{x}_{14} = 0.2995$ and $\tilde{x}_{15} = 0.3031$. Curiously, the standard deviations of distances (for the laboratory environment) in this color model are fairly low when compared to the previous color model.

When comparing the results from the CIE-L*C*h* color model with other color models' results, we detect some statiscally significant differences with other models: performing a Wilcoxon Test ($p < 0.05$), we can infer that CIE-L*C*h* does present statistically significant differences with HSV, CMYK, RGB and CIE-L*a*b* in the majority of questions (between 8 to 10 questions). The model which CIE-L*C*h* has most statistically significant differences with is CMYK, with eleven questions.

Question six presented again a constant top value for the mean value, on this model, which reinforces the theory that the **orange color is commonly used and mixed by the users**. On the other hand, question number ten kept having one of the worst mean ($\tilde{x}_{10} = 0.2557$) and deviation ($\sigma_{10} = 0.1164$) values, strengthening the theory that **blue shades and tones will probably wild worst results, due to the fact that it is the color which human have less descriptive power**.

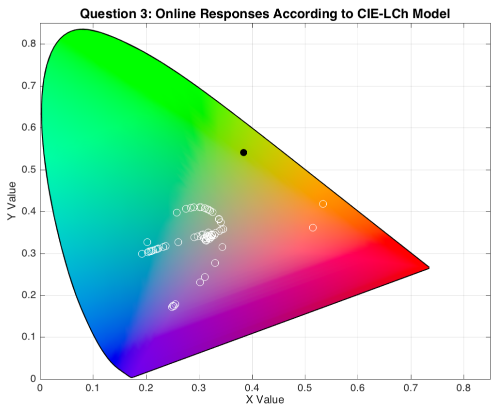

Figure 4.21: Online Results: Answers for Question 3, from regular users, mixed in CIE-L*C*h* Color Model.

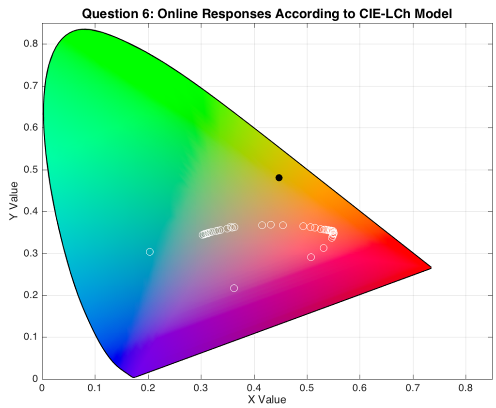

Figure 4.22: Online Results: Answers for Question 6, from regular users, mixed in CIE-L*C*h* Color Model.

The question which revealed one of the lowest standard deviation value (meaning less osccilation of results), relating the online environment, was question three ($\sigma_3 = 0.05855$): this question help us illustrate the difference between each of the descriptive statistics, since it has one of the highest mean value of distances ($\tilde{x}_{17} = 0.23$) and, at the same time, lowest standard deviation. This could portray a scenario in which the users agreed on a quite distant answer. This question is illustrated in Figure 4.21.

The question which has the lowest mean value of distances was question six ($\sigma_{LCh-6} = 0.1332$), and it is represented on Figure 4.22. Nonethless, we can observe that **these questions have all answers pairs which, when blended according to CIE-L*C*h*, generate results that are farther apart from**

the ideal answer of each question, therefore concluding that **CIE-L*C*h* is not the color model which hatches the best results when blending colors, according to users' expectations**.

The diagram of Figure 4.23 contains the three top and bottom-valued questions, disposed on top of an interval $[0; 0.5]$ of differences. Each question is mapped according to its mean value for distance to the ideal CIE-L*C*h* Color Model response, while is accompanied by the range of values which compose its answers.

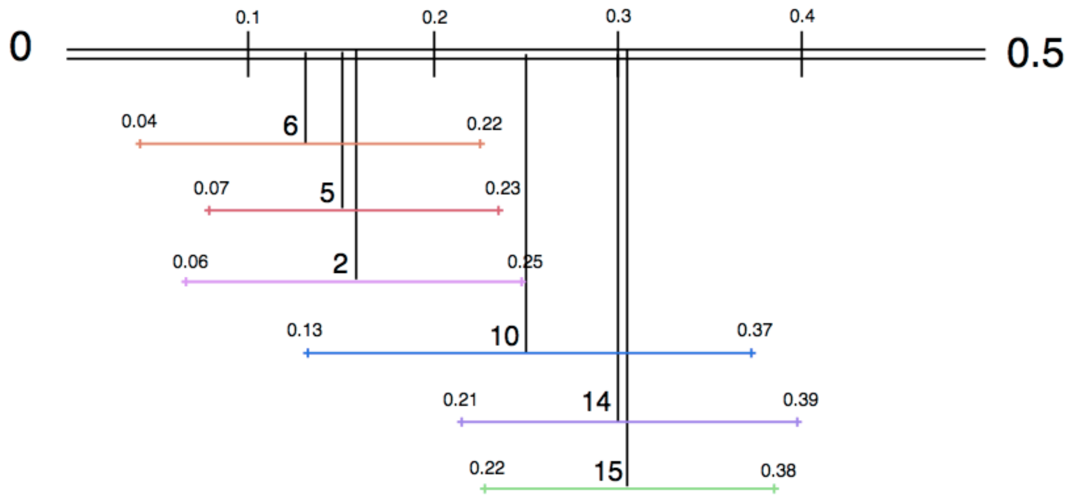

Figure 4.23: Best and Worst Questions, according to CIE-L*C*h* Color Model.

<u>**CMYK Color Model Blendings**</u> The CMYK Color Model is, by far, the one which presents the best results for most of the descriptive statistics present on Table 4.26, being authenticated by the results from the online environment: it has the lowest mean value of distances ($\tilde{x}_{lab} = 0.10$, $\tilde{x}_{online} = 0.09$), lowest standard deviation ($\sigma_{lab} = 0.04$, $\sigma_{online} = 0.04$), the lowest range of values ($range_{lab} = 0.14$, $range_{online} = 0.11$) and, finally, the lowest variance value ($\sigma^2_{lab} = 0.001$, $\sigma^2_{online} = 0.001$).

The three questions which have shorter distances are number seventeen (given a green, expected cyan and blue), number six (given orange, expected red and yellow) and number fifteen (given a shade of green, expected blue and yellow). The mean values distances for this questions were $\tilde{x}_{17} = 0.0452$, $\tilde{x}_6 = 0.0577$ and $\tilde{x}_{15} = 0.0625$ which, contrary to the previous color model, are all values <u>below 0.1</u>, that does not represent a significant change in the resultant color.

On the other hand, we consider that the questions which generate the worst results are number ten (given a shade of blue, expected green and magenta) and twelve (given a tone of green, expected green and yellow), number five (given a shade of red, expected red and magenta) and number thirteen (given a shade of blue, expected blue and cyan), with correspondent mean values $\tilde{x}_{10-12} = 0.1314$, $\tilde{x}_5 = 0.1322$ and $\tilde{x}_{13} = 0.1875$. Comparing them with the CIE-L*C*h* Color Model, we can easily observe that these values are very low when compared with the later's worst results.

Question six keeps presenting a constant top value for the mean value, on this model, while question number ten and thirteen (both presented blue shades) kept having the worst mean and deviation values ($\tilde{x}_{13} = 0.1875$, $\sigma_{13} = 0.13097$), strengthening the theories aforementioned.

When comparing the results from the CMYK color model with other color models' results, we detect some statiscally significant differences with other models: performing a Wilcoxon Test ($p < 0.05$), we can infer that CMYK does present statistically significant differences with HSV, CIE-L*C*h*, RGB and CIE-L*a*b* in the majority of questions. The model which CMYK has most statistically significant differences with is RGB, with thirteen questions.

Question seventeen presented consistently another low value: along with question three and fifteen, these presented different shades of green and all had yielded favorable results. Having this in mind, this may lead us to form another conclusion: **questions which presented shades of green color may produce better results, according to users' expectactions**. This is coherent with the fact that **humans have more descriptive power in the green zone of the spectrum, due to the amount of cones which exist in the human eye**.

As it was explained before in the theoretical background, this color model is mainly a subtractive one, meaning it will naturally darken the colors when they are blended; the questions which yielded **better results are majorly related to primitives of the CMYK color model**. This success could be related to the fact that **people tend to formulate mental models of color based on ink mixing in childhood** [GC04], mostly associating it to Red, Yellow, Blue (RYB) and CMYK Color Models without even knowing it.

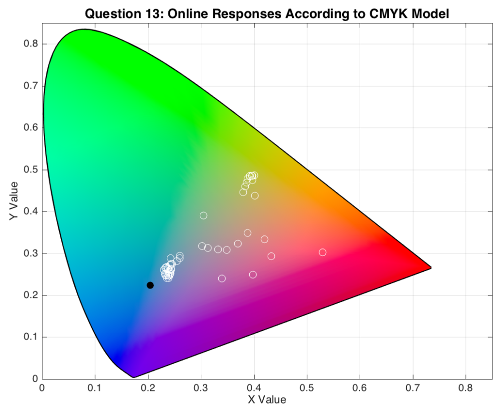

Figure 4.24: Online Results: Answers for Question 13, from regular users, mixed in CMYK Color Model.

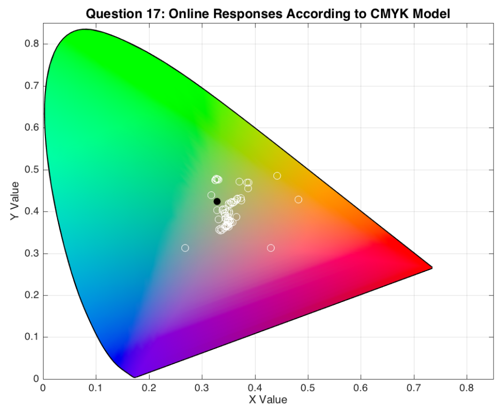

Figure 4.25: Online Results: Answers for Question 17, from regular users, mixed in CMYK Color Model.

These results indicate that **CMYK is a highly compatible color model with the users expectations**, as this model presents statistics which prove that CMYK had smaller distances to ideal answers and lower deviation of answers. Figure 4.24 represents the results of Question 13, which had wider distances to the pre-calculated CMYK blend, and Figure 4.25 show the results for Question 17, the question with closer distances. The diagram of Figure 4.26 contains the three top and bottom-valued questions, disposed on top of an interval $[0; 0.5]$ of differences. Each question is mapped according to its mean value for distance to the ideal CMYK Color Model response, while is accompanied by the range of values which compose its answers.

RGB Color Model Blendings This color model, as covered before, is complementary to the CMYK color model. Feedback collected from the users was such that, sometimes, the users which knew how to blend in subtractive color models, tended to be confused and tried to mix additive color models, also. Based on the results collectd from the laboratory users, we can tell that the results from this color model are quite similar to CMYK results: the descriptive statistics present on Table 4.26, authenticated by the results from the online environment, prove RGB has one of the lowest mean value of distances ($\tilde{x}_{lab} = 0.14$, $\tilde{x}_{online} = 0.12$) and one of the lowest standard deviations ($\sigma_{lab} = 0.05$, $\sigma_{online} = 0.04$ equal to $\sigma_{CMYK-online}$).

The three questions which have shorter distances are number number six (given orange, expected red and yellow), number nine (given a shade of green, expected green and cyan) and seventeen (given

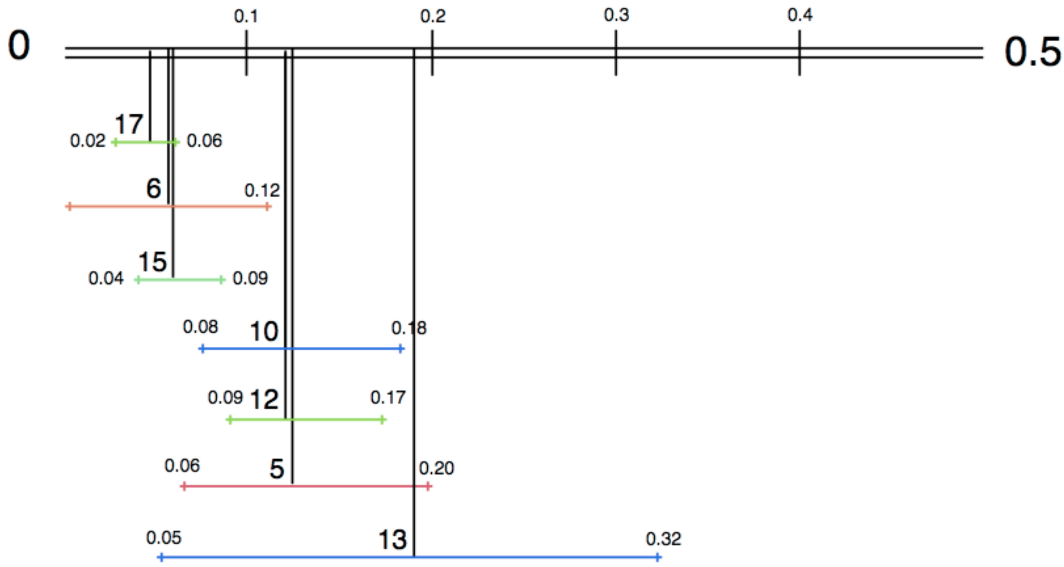

Figure 4.26: Best and Worst Questions, according to CMYK Color Model.

a green, expected cyan and blue). The mean values distances for this questions were $\tilde{x}_6 = 0.0777$, $\tilde{x}_9 = 0.1005$ and $\tilde{x}_{17} = 0.1030$.

On its turn, we consider that the questions which generate the worst results are number two (given magenta, expected red and blue), number ten (given a shade of blue, expected green and magenta) and, again, number thirteen (given a shade of blue, expected blue and cyan), with correspondent mean values $\tilde{x}_2 = 0.1660$, $\tilde{x}_{10} = 0.2107$ and $\tilde{x}_{13} = 0.2450$. Comparing them with the CIE-L*C*h* Color Model, we can observe these values are likely to be similar when compared with the later's worst results, but a little high when compared with CMYK results. **The colors orange and green continue to present the best values, while the blue shades are the lowest**.

When comparing the results from the RGB color model, the majority of users did reveal lack of knowledge in mixing the colors according to an additive color model, as they tended to mix colors according to the CMYK color model. However, this color model has a high degree of compatibility with every other model, excepting CMYK: performing a Wilcoxon Test ($p < 0.05$), we can infer that RGB does not present statistically significant differences with HSV, CIE-L*a*b* and with CIE-L*C*h* in the majority of questions (ten questions), while presenting statistically significant differences with CMYK in thirteen questions.

Relating to the fact that people either tend to blend colors in an additive or subtractive way, we can compare the results from this color model with CMYK model and state that **users tend to formulate subtractive mental models of color blending**. However, **there is room for further investigation, to fully understand if users are influenced by additive color models (*e.g.* RGB) or subtractive ones (*e.g.* CMYK)**.

Figure 4.27 represents the results of Question 6, which had the shortest distances to the pre-calculated RGB blend, and Figure 4.28 show the results for Question 13, the question with wider distances. The diagram of Figure 4.29 contains the three top and bottom-valued questions, disposed on top of an interval $[0; 0.5]$ of differences.

CIE-L*a*b* Color Model Blendings This color model has results very similar to CMYK and RGB, since its descriptive statistics have comparable values to this model.

The three questions which have shorter distances are number number six (given orange, expected

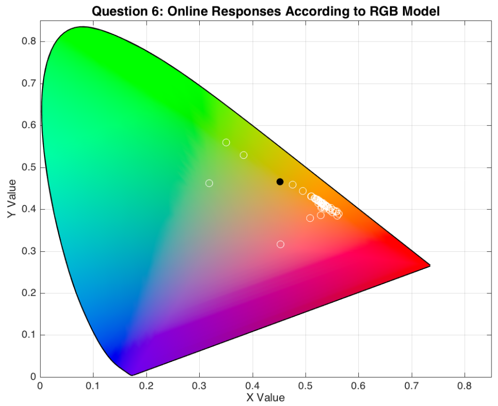

Figure 4.27: Online Results: Answers for Question 6, from regular users, mixed in RGB Color Model.

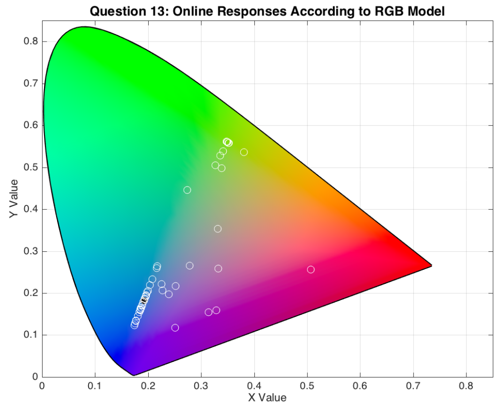

Figure 4.28: Online Results: Answers for Question 13, from regular users, mixed in RGB Color Model.

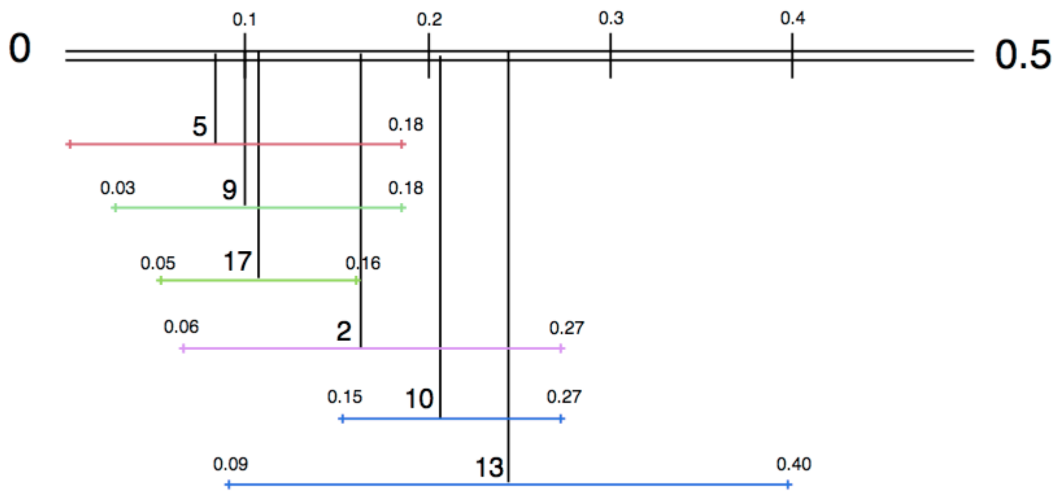

Figure 4.29: Best and Worst Questions, according to RGB Color Model.

red and yellow), seventeen (given a green, expected cyan and blue) and number nine (given a shade of green, expected green and cyan), which are exactly the same as before. The mean values distances for this questions were $\tilde{x}_6 = 0.0509$, $\tilde{x}_{17} = 0.1130$ and $\tilde{x}_9 = 0.1142$.

Considerint the questions which generate the worst results are number twelve (given a tone of green, expected green and yellow), number ten (given a shade of blue, expected green and magenta) and number thirteen (given a shade of blue, expected blue and cyan), with correspondent mean values $\tilde{x}_{12} = 0.1743$, $\tilde{x}_{10} = 0.2107$ and $\tilde{x}_{13} = 0.2450$. Comparing them with the CIE-L*C*h* Color Model (which is currently the worst-valued color model), we can check that these values are (similar to RGB and HSV) nearer to the later's worst results, but still high when compared with CMYK results (so far, the best-valued color model). **The colors orange and green proved, once again, that they are capable of producing the best values, while the blue shades provided the lowest again**.

When comparing the results from the CIE-L*a*b* color model, we detected that this model has significant differences with all other color models: performing a Wilcoxon Test ($p < 0.05$), we can infer that CIE-L*a*b* does present statistically significant differences with HSV, CMYK and with CIE-L*C*h* in only nine questions, while presenting no statistically significant differences with RGB in ten questions.

Since the CIE-L*a*b* conveys the entire set of perceived by the human eye, it **explains why the results associated with this color model are so close to others which yield the best results**. Figure

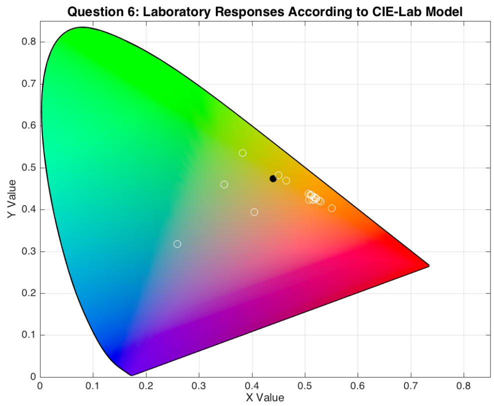

Figure 4.30: Laboratory Results: Answers for Question 6, from regular users, mixed in CIE-L*a*b* Color Model.

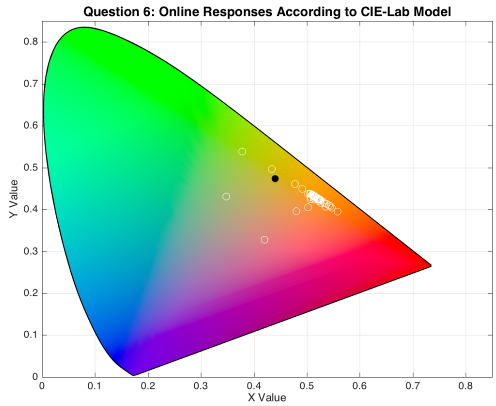

Figure 4.31: Laboratory Results: Answers for Question 6, from regular users, mixed in CIE-L*a*b* Color Model.

4.30 represents the laboratory results of Question 6, which not only had the best mean value to the pre-calculated RGB blend, but also its best mean value across all color models, and Figure 4.31 shows the results for the same question, but the online results which confirm the laboratory ones. The diagram of Figure 4.32 contains the three top and bottom-valued questions, disposed on top of an interval $[0; 0.5]$ of differences.

Color Blending Expectation

Besides asking our users to indicate us the two primitives which composed a color blending of two colors, we intended to go further: **comprehend if more than detecting two colors of a mixture, a user is capable of mentally blend two given colors and indicate us its results**.

Therefore, we reverted the previously analyzed seventeen questions, giving the two primitives of the blending to the user, offering at the same time a color slider which contained discretized pre-calculated values (which were nothing more than all the results of all questions, blended accordingly to all color models). Contrary to what was done previously, **we did not blend the answer given by the user,**

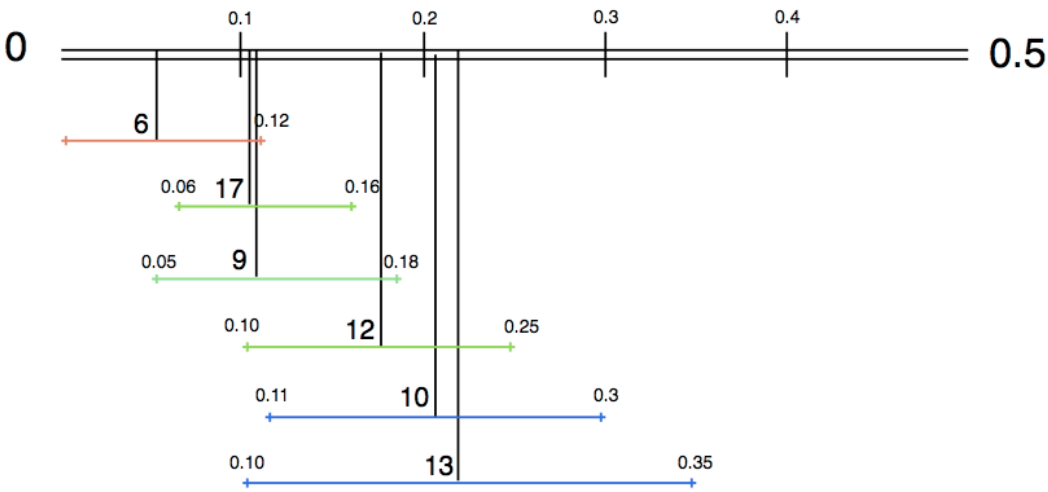

Figure 4.32: Best and Worst Questions, according to CIE-L*a*b* Color Model.

since the colors presented were already blended, missing only to calculate the distance of answers to the ideal ones: the results for these questions are expressed on Table 4.27, with cells shaded in green which represent the best value for each one of questions.

Question ID	Presented Colors		Expected Color	Laboratory Environment					Online Environment				
	C1	C2		HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*
Question 18	Red	Green	(77, 93, 14)	0.14	0.14	**0.11**	0.15	0.14	0.12	0.12	**0.08**	0.12	0.11
Question 19	Red	Blue	(59, 28, 97)	**0.16**	0.23	0.17	**0.16**	0.19	**0.13**	0.24	0.19	0.14	0.19
Question 20	Green	Blue	(54, 79, 107)	0.13	0.17	0.14	0.13	**0.11**	0.12	0.17	0.13	0.12	**0.10**
Question 21	Red	Cyan	(45, 76, 12) (27, 12, 95)	0.28 0.23	0.26	0.13	**0.12**	0.17	0.29 0.23	0.26	0.13	**0.12**	0.16
Question 22	Red	Magenta	(45, 23, 22)	**0.18**	0.20	0.25	0.21	0.20	**0.14**	0.16	0.20	0.17	0.16
Question 23	Red	Yellow	(49, 37, 5)	**0.16**	**0.16**	**0.16**	0.18	**0.16**	0.09	**0.08**	**0.08**	0.10	**0.08**
Question 24	Cyan	Magenta	(18, 7, 95)	0.27	0.12	**0.08**	0.12	**0.08**	0.28	0.11	**0.09**	0.13	**0.09**
Question 25	Magenta	Yellow	(41, 21, 2)	0.27	0.18	0.12	0.13	**0.10**	0.21	0.12	0.07	0.07	**0.06**
Question 26	Green	Cyan	(40, 73, 32)	0.12	**0.10**	**0.10**	0.14	0.11	0.12	**0.11**	0.12	0.14	0.12
Question 27	Green	Magenta	(26, 23, 98) (49, 37, 5)	0.20 0.24	0.27	**0.12**	**0.12**	0.13	0.27 0.18	0.21	0.10	0.10	**0.09**
Question 28	Green	Yellow	(45, 76, 12)	0.19	0.17	**0.15**	0.18	0.17	0.17	0.15	**0.12**	0.16	0.15
Question 29	Blue	Cyan	(26, 23, 98)	0.13	**0.07**	0.09	0.13	0.09	0.13	**0.07**	0.09	0.13	0.09
Question 30	Blue	Magenta	(27, 12, 95)	0.16	**0.12**	0.13	0.15	**0.12**	0.18	**0.13**	**0.13**	0.17	0.13
Question 31	Blue	Yellow	(40, 73, 32) (45, 23, 22)	0.11 0.24	0.29	**0.10**	**0.10**	0.14	**0.10** 0.26	0.29	0.12	0.13	0.17
Question 32	Cyan	Yellow	(36, 72, 13)	0.16	0.09	0.09	0.09	**0.07**	0.15	0.08	0.07	0.08	**0.05**

Table 4.27: Results: Distances of Results according to each Color Model, for questions 18 to 32, with the distance from itself to the ideal pre-calculated answer. Colored in green are, the color model which has the best result, *per* question, in each environment.

As seen on the table, the results are roughly similar to the ones found on Table 4.25, which depited the mean values for the results of questions which presented the result of a given mixture. However, there are some differences which we would like to comment.

- Cyan - As referred before, mistakenly the cyan color was not presented to the user in order to indicate a blending-basis which could create such color. However, we can analyze the results of this question present on table 4.28; as seen, the color model which has the closest ideal result is the CIE-L*a*b* ($\tilde{x}_{lab} = 0.11$, $\tilde{x}_{online} = 0.10$), opposite to CIE-L*C*h* which has the farthest response, according to users' responses in both laboratory and online environment. Curiously, HSV, RGB and CMYK all have very close results from each other. Further studies may focus in unraveling which is, in fact, the best color model, since **there is insufficient information to affirm which color model originates the closest distances, according to users' expectactions**. Figure 4.33 depicts the answers given by the online users: although this user sample has the lowest distance to ideal answer, it is possible to observe that data is a bit scattered across the chromaticity diagram.

Question ID	Presented Colors		Expected Color	Possible Results									
	C1	C2		HSV		CIE-L*C*h		CMYK		RGB		CIE-L*a*b*	
20	Green	Blue	(54, 79, 107)	(54, 79, 107)		(32, 34, 100)		(12, 17, 23)		(12, 17, 23)		(26, 28, 40)	
				$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ	$\tilde{x}$	σ
Distance to Objective - Laboratory				0.13	0.06	0.17	0.09	0.14	0.08	0.13	0.06	**0.11**	0.05
Distance to Objective - Online				0.12	0.06	0.17	0.08	0.13	0.07	0.12	0.06	**0.10**	0.06

Table 4.28: Question 20, with expected colors, possible results, mean and standard deviation of distances to Objective colors.

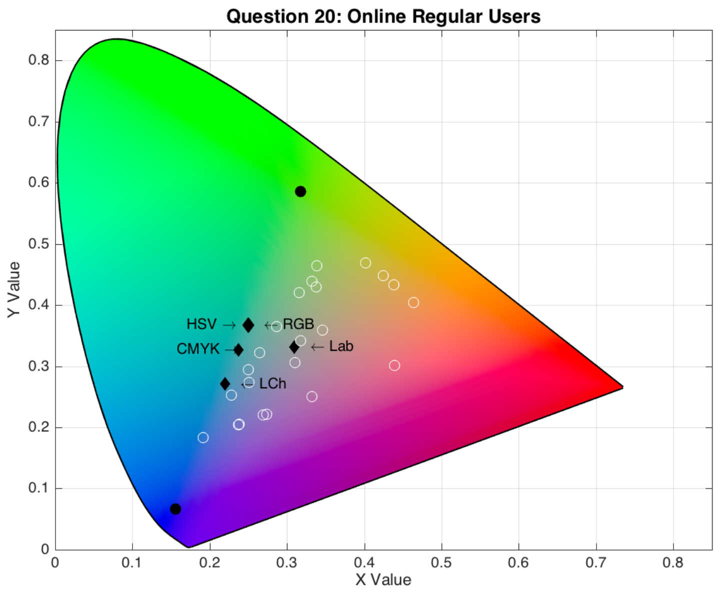

Figure 4.33: Online Results: Answers for Question 20, from regular users.

- Distances - Comparing the mean distances obtained previously on Table 4.26 which were obtained by questions one to seventeen, the distances generated by the answers from questions eighteen to thirty-two are a bit higher on the HSV Color Model. However, this could be due to the fact **we have only presented discretized colors as options, and did not leave any wiggle-room for the user to indicate other colors which he thought it could be more appropriate**; moreover, this could be related to **users tended to explore and choose answers from other color models, instead of HSV possible answers**. Even so, the values are similar to the previous studied, being only the HSV and CMYK mean values higher than previously ($\tilde{x}_{HSV} = 0.18$, $\tilde{x}_{CMYK} = 0.13$).
  Blending Cyan and Yellow to produce green is an example of a question which had one a higher value ($\tilde{x}_{Green=Cyan+Yellow} = 0.11$) when asked the user to indicate the blending-basis with subsequential blending in CIE-L*a*b* (question seventeen), and when it was asked the result of the same blending (question nineteen), it provided one of the lowest mean distance values when compared to the ideal CIE-L*a*b* response ($\tilde{x}_{Cyan+Yellow=Green} = 0.05$); this example if pictured in Figures 4.34 and 4.35.
- Orange Blending - Comparing the results from all questions, we end up concluding that the question which constantly had best results among all color models was the blending of red and yellow to create orange. However, as it is observable, these results represent much higher distances to the ideal answer in any color model, than when given the user the resulting color of the blending. This fact could indiciate that **it is harder for the users to detect the result of a color blend, when**

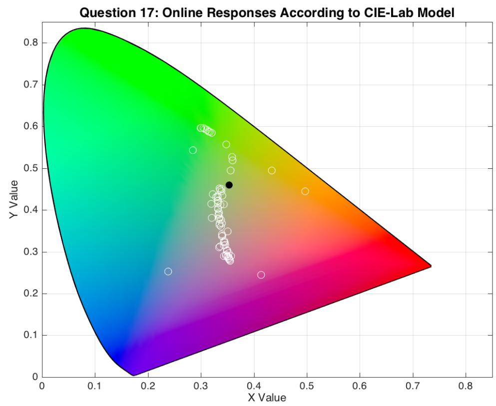

Figure 4.34: Online Results: Answers for Question 17, from regular users, mixed in CIE-L*a*b* Color Model.

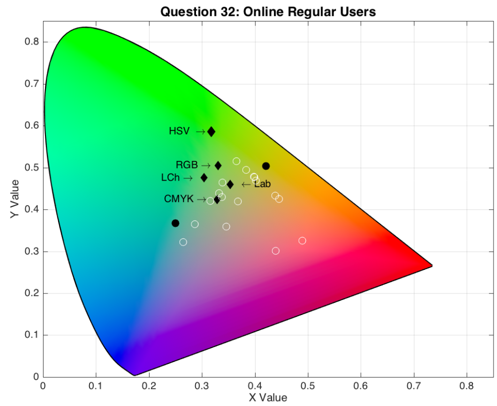

Figure 4.35: Online Results: Answers for Question 32, from regular users.

two blending basis are given, than when the resulting color is given, even for the orange color blending which produced great results in the previous analysis. This could be related to the lack of descriptive power which the color slider supplied the user, which was referred before. This conclusion is corroborated by the online users which, although generating lower mean values than the laboratory ones, are coeherent with being higher than the ones previously studied.

- Blue Blending - Recalling the previous analysis, the results for mixtures which resulted in a blue shade all had the worst results among all questions, across all color models. *Per contra*, the results for questions which present a blending basis for creating a blue color had presented much closer distances than before. For example, question twenty-four presented Cyan and Magenta seeking a Blue answer: when the users were asked to indicate the basis (question seven), it generated higher standard deviations which are illustrated in Table 4.25. However, as seen on Table 4.29, the results substantially improve when the users were asked to formulate the result of such blending. This could potentially suggest that **according to the users' expectation, it is easier for them to indicate the result of a blue mixture when the blending-basis is given, than when the user is asked to create the blending-basis according to their mental color model**.

Blending Basis		Resulting Color	Results									
			HSV		CIE-L*C*h		CMYK		RGB		CIE-L*a*b*	
Cyan	Magenta	(18, 7, 95)	Laboratory ($\tilde{x}$)	Online ($\tilde{x}$)	Laboratory ($\tilde{x}$)	Online ($\tilde{x}$)	Laboratory ($\tilde{x}$)	Online ($\tilde{x}$)	Laboratory ($\tilde{x}$)	Online ($\tilde{x}$)	Laboratory ($\tilde{x}$)	Online ($\tilde{x}$)
Given Result, Expected Basis			**0.16**	**0.13**	0.23	0.18	0.10	0.11	0.15	0.17	0.17	0.22
Given Basis, Expected Result			0.27	0.28	**0.12**	**0.11**	**0.08**	**0.09**	**0.12**	**0.13**	**0.08**	**0.09**

Table 4.29: Results of Blending Cyan and Magenta, obtaining Blue.

- Color Models Analysis - There were some changes concerning the descriptive statistics associated with distances values from each color model, specially when discovering which models yielded the best and worst results. To help us establish the comparisons between color models, we created an auxiliary Table (4.30) which contains the values. Contrary to questions in which the user was asked to indicate the blending basis, **the color model which has the worst results is the HSV Color Model** ($\tilde{x}_{HSV} = 0.18$) while the one which has **the shortest mean distance value continues to be CMYK, along with CIE-L*a*b*** ($\tilde{x} = 0.13$). Though, when processing the values for the whole statistics, RGB Color Model turns out to be the one which contains the best results: this not only is confirmed by the online users' data, but also is contrary to the results from the first analysis which dictated that the best color model was CMYK. This is particularly interesting, since it reveals that **when the users are asked to combine colors after a resulting one is given, they tend to blend according to a subtractive color model (*e.g.* CMYK); but, when the blending-basis is given, the users are likely to mix the colors according to an addictive color model (*e.g.* *RGB*).**

On its turn, CIE-L*C*h* continues to reveal itself as the worst-valued Color Model, having the highest standard deviation ($\sigma = 0.07$), the highest range of distances ($range = 0.22$) and the highest variance of values ($\sigma^2 = 0.005$), across both study environments.

Descriptive Statistics	Laboratory Environment					Online Environment				
	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*	HSV	CIE-L*C*h*	CMYK	RGB	CIE-L*a*b*
Mean ($\tilde{x}$)	**0.18**	0.17	**0.13**	0.14	**0.13**	**0.17**	0.15	**0.11**	0.13	0.12
Std-Dev (σ)	0.06	**0.07**	0.04	**0.03**	0.04	**0.07**	**0.07**	0.04	**0.03**	0.04
Maximum Value	0.28	0.29	0.25	0.21	0.20	0.29	0.29	0.20	0.17	0.19
Minimum Value	0.11	0.07	0.08	0.09	0.07	0.09	0.07	0.07	0.07	0.05
Range	0.17	**0.22**	0.17	**0.12**	0.13	0.20	**0.22**	0.13	**0.10**	0.14
Variance (σ^2)	0.003	**0.005**	0.002	**0.001**	0.002	0.004	**0.005**	0.002	**0.001**	0.002

Table 4.30: Condensed Statistics for Distances to Ideal Results, according to each Color Model, for questions 18 to 32. In Green/Red shade, the best/worst result for each descriptive statistic.

Therefore, we can summarize the results in one table, which ranks the color models *per* color blending, dividing it between two strands: based on the values that represent questions in which the user was asked to indicate the blending-basis, and based on the values that represent questions in which the user was asked to point out the correct blending result when given two colors. These results are presented in table 4.31. The color models were ranked according to the descriptive statistics' values generated by each question, weighted with the results from the laboratory environment and the validation from the online users; marked in **bold** are the color models which we have concluded to yield the best results, according to each type of question asked.

Blending Basis		Blending Result	Given the Result, Asked for Basis					Given the Basis, Asked for Result				
C1	C2	C3	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
Red	Green	(77, 93, 14)	**CMYK**	CIE-L*a*b*	RGB	HSV	CIE-L*C*h*	**CMYK**	**CIE-L*a*b***	HSV	RGB	CIE-L*C*h*
Red	Blue	(59, 28, 97)	**CMYK**	CIE-L*a*b*	CIE-L*C*h*	RGB	HSV	HSV	RGB	**CMYK**	**CIE-L*a*b***	CIE-L*C*h*
Green	Blue		-					**CIE-L*a*b***	HSV, RGB		CMYK	CIE-L*C*h*
Red	Cyan	(45, 76, 12) (27, 12, 95)	**CMYK**	HSV	RGB	CIE-L*a*b*	CIE-L*C*h*	RGB	**CMYK**	**CIE-L*a*b***	HSV	CIE-L*C*h*
Red	Magenta	(45, 23, 22)	**CMYK**	CIE-L*a*b*	RGB	CIE-L*C*h*	HSV	HSV	**CIE-L*C*h*, CIE-L*a*b***		RGB	**CMYK**
Red	Yellow	(49, 37, 5)	CIE-L*a*b*	**CMYK**	HSV	RGB	CIE-L*C*h*	**CMYK, CIE-L*C*h*, CIE-L*a*b***			HSV	RGB
Cyan	Magenta	(18, 7, 95)	?	?	inconclusivo	?	?	**CMYK, CIE-L*a*b***		CIE-L*C*h*	RGB	HSV
Magenta	Yellow	(41, 21, 2)	**CMYK**	CIE-L*C*h*	HSV	RGB	CIE-L*a*b*	**CIE-L*a*b***	**CMYK**	RGB	CIE-L*C*h*	HSV
Green	Cyan	(40, 73, 32)	**CMYK**	RGB	CIE-L*a*b*	HSV	CIE-L*C*h*	CIE-L*C*h*	**CMYK**	**CIE-L*a*b***	HSV	RGB
Green	Magenta	(26, 23, 98) (49, 37, 5)	**CMYK**	RGB	CIE-L*a*b*	HSV	CIE-L*C*h*	RGB	**CMYK**	**CIE-L*a*b***	HSV	RGB
Green	Yellow	(45, 76, 12)	HSV	**CMYK**	RGB	CIE-L*a*b*	CIE-L*C*h*	**CMYK**	**CIE-L*C*h*, CIE-L*a*b***		RGB	HSV
Blue	Cyan	(26, 23, 98)	?	?	inconclusivo	?	?	CIE-L*C*h*	**CIE-L*a*b***	**CMYK**	HSV, RGB	
Blue	Magenta	(27, 12, 95)	**CMYK**	HSV	RGB	CIE-L*a*b*	CIE-L*C*h*	**CIE-L*C*h*, CIE-L*a*b***		**CMYK**	RGB	HSV
Blue	Yellow	(40, 73, 32) (45, 23, 22)	**CMYK**	RGB	HSV	CIE-L*a*b*	CIE-L*C*h*	**CMYK**	RGB	HSV	**CIE-L*a*b***	CIE-L*C*h*
Cyan	Yellow	(36, 72, 13)	**CMYK**	HSV	RGB	CIE-L*a*b*	CIE-L*C*h*	**CIE-L*a*b***	**CMYK**	CIE-L*C*h*	RGB	HSV

Table 4.31: Colors Models, ranked from best to worst, associated to every color blending studied.

4.4.3 Color Mixtures

Regarding the color mixtures' related questions, we would like to make the following analysis. We asked at Section 3.1 ...

Ver também se existe cor preferida para começar mistura.

Ver misturas que tiveram maior distancia às cores esperadas. Analisar e perceber se respostas dadas também produzem a mesma cor pedida. Ver misturas que tiveram menor distancia às cores esperadas.

Primary Colors

fazer analise concreta das questões 1, 2, 7, 8 e 17, que são as primitivas. perceber se resultados são positivos para a geração de primitivas com base noutras.

Comparar misturas que originam a mesma cor, com base em primárias diferentes e perceber se utilizadores conseguem detectar várias misturas para uma mesma cor.

Difficulty While Blending Colors

Fazer também mistura mais fácil, comparando os ratings das questões e ver qual a mistura que apresenta melhores resultados.
Falar de respostas em branco, analisar somente valores e perceber se é desconhecimento.

4.4.4 Color Naming

Cores mais comuns em algumas perguntas; existe alguma ordem caracteristica quando utilizador especifica uma mistura?
Comparar se, mais do que pelos valores anteriormente calculados, se users identificam ”uma mistura de vermelho com azul” como dando um resultado magenta, ou mais afinado para uma dada cor.

4.4.5 Demographic Results

Fazer apenas comparação de faixas etárias entre si, e géneros entre si.
Uma ánalise interesse seria comparar faxias etárias por género, mas seria necessária uma amostra bastante mais significativa para cada grupo.

Age Groups

Gender Groups

Color Deficient Users Group

4.5 Discussion

Fazer apanhado dos resultados todos.
abordar questão de que modelos originaram melhores respostas, se são aditivos ou subtrativos.
Referir que é preciso estudos para perceber de facto qual é o melhor entre o HSV, Lab e RGB.
CMYK claramente melhor
LCh claramente pior.

4.5.1 Calibration Resiliency

Como verificamos ainda alguns users com calibração imprópria para teste, considerámos que poderia ser uma fonte de resultados interessantes. Como tal, criámos um dataset para os mesmos e comparámos com os resultados dos utilizadores calibrados. Os resultados são os que se seguem...

4.5.2 Creation of Color Scales

Aproveitar resultado de respostas em branco

4.5.3 Color Organization

4.5.4 Implications for InfoVis

Resumo dos resultados todos e regras que se podem levar deste trabalho para a área de InfoVis em geral.

Chapter 5

Conclusion

5.1 Limitiations

Most of the data cleaning would be avoided if the collected were saved in a different fashion (NONES, HSL)...

5.2 Future Work

Software de calibração remota.

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Appendix A

User Study Protocol

A.1 Motivation

By conducting this first study, we intend to:

- Conclude if there is any chance that cultural behaviours influence the user's color perception.
- Realize which color mixtures are more easily perceived by humans.
- Understand if, by using color, it is possible to clearly and easily convey information. This can be particularly interesting and useful when visualizing graphs or maps.
- Conclude if a person is capable of, not only building a mental color mixture model, but also deconstructing mixtures into their basic components.

A.2 User Profiling Phase

This study is anonymous and should take you up to 15 minutes. Please, answer the following answers accordingly.

A.3 Testing Calibration Phase

In this step, it's going to be presented to you a set of images. You should tune you screen definitions, in order to answer the questions, keeping them until the end of this study.

Please, follow the steps below indicated and answer the questions.

1. If possible, adjust your room lights for a comfortable usage of your device.
2. Avoid reflections on your screen, by diverting the screen from direct sources of light. This step is important, since light reflections can affect visualization of images.
3. To adjust the **Black Point** of your screen, define the Contrast and Brightness of your screen to their maximum.
4. After Step 3, gradually reduce **Brightness** value of your screen, in order to correctly distinguish the squares of each image below [calibration squares images].
5. If possible, define the **Color Temperature** of your screen to 6500 Kelvin Degrees.

6. You are now ready to answer the following questions!

NOTE: These 6 steps are only available to the Online Users, since the Laboratory Users do not need to perform these steps as the LCD display is already calibrated.

A.4 Testing Color Vision Deficiences Phase

This is the Color Vision Deficiencies Test.
In this step, it is going to be presented six plates with a colored pattern. Your job is to identify the number present in each plate, typing it down in the text box below. According to your answer, this test will inform us if you have any type of color vision deficiency which may undermine the job of color detection.

A.5 Core Test Phase

Choose the Resulting color which you believe it is the result of mixing the First and Second color, by adjusting the slider below the Resulting color.
Choose two colors with which you can achieve the Resulting color, by adjusting the sliders below each color.

NOTE: These instructions appear alternately, depending on the type of question which is shown.

Appendix B

Chromaticity Diagrams

Include Diagrams generated of CIE Horseshoe.

Appendix C

Tables

C.1 Results Tables

Users

Um exemplo de uma tabela de resultados raw

Um exemplo de uma tabela de resultados clean

Um exemplo de uma tabela de calibração