

DEMONSTRATING COLOR TRANSITIONS OF LEUCO DYE-BASED THERMOCHROMIC INKS AS A TEACHING APPROACH IN TEXTILE AND FASHION DESIGN

MARJAN KOOROSHNIJA

THE SWEDISH SCHOOL OF TEXTILES,
UNIVERSITY OF BORÅS, BORÅS, SWEDEN

MARJAN.KOOROSHNIJA@HB.SE

ABSTRACT

Although there are a lot of interest concerning the use of leuco dye-based thermochromic inks in Textile and Fashion Design, there is still a lack of teaching approach to help students arrive at a better understanding of the color transitions of leuco dye thermochromic inks. This paper aims to share a systematic approach for teaching the behavior of leuco dye-based thermochromic inks to students in Textile and Fashion Design. Printed color-swatches and exercises were used as the central part of the approach. Through the approach it was described what printed color-swatches were and how to use them effectively to make color transitions understandable. The approach has been applied in several workshops at both Bachelor and Master level. The samples made by the students in the exercises clearly revealed that the approach created opportunities for students to craft an understanding of using leuco dye thermochromic inks through experimentation and individual exploration. Ultimately, this approach plays a

fundamental role in the design process, the creation and the development of dynamic patterns.

INTRODUCTION

Nowadays by entering leuco dye-based thermochromic inks into the textile and fashion design area, new type of challenges appear in order to use thermochromic inks effectively in design process. Albers (1975) proposes an approach to studying color and of teaching color based on learning by direct perception, and not by theories or color systems. Collis and Wilson (2012) discuss an investigation in how to deal with color accuracy in digital-printed textiles while there is dearth information about how textile digital printing is being used in textile. However, the approaches provides profound insight about how to use colors in different contexts, and how to match color and media but they are not adequate to apply to studying and of teaching Leuco dye-based thermochromic inks that are dynamic colors, and not static. Studying leuco dye-based thermochromic inks is mainly about color transition, so when I was asked to hold the thermochromic workshop I decided to plan my workshop based on notion of learning by doing (Drew, 2004), motivational framework (Wlodkowaski, 1999), and adopt it to my own way of thinking about planning (Ginsberg & Wlodkowski, 2009) to help students achieve a better understanding of the behavior of leuco dye-based thermochromic inks at various temperatures. This paper aims to share a systematic approach for teaching the behavior of leuco dye-based thermochromic inks to students in Textile and Fashion Design. It has focus on demonstrating the color changing process to facilitate the understanding and designing of dynamic surface-patterns at different temperatures. The approach introduces printed color swatches, explains what printed color-swatches are, and

discusses how they can be used in a workshop on Leuco dye-based thermochromic inks. It also describes how to use printed color-swatches to effectively demonstrate the color transition of the ink.

THERMOCHROMIC INK

Thermochromic inks constitute one of the major groups of color-changing inks. Developed in the 1970's, these inks are temperature sensitive compounds that temporarily change color with exposure to heat.

Bamfield and Hutchings (2010) describe thermochromic ink as consisting of two major types of thermochromic inks: liquid crystals and leuco dyes. Because liquid crystals are more sensitive to temperature changes than leuco dyes and require highly specialized printing techniques, they are considered difficult to work with. Leuco dyes are more easily handled and are used more frequently in screen-printing. They can be found in a variety of products, such as textile applications, color changing T-shirts (which were in high demand at the beginning of the 1990s), interactive plastic baby-safety feeding-spoons, coffee mugs, and toys. They are suitable for use in general indicators that display approximate temperatures such as cool, warm and hot.

LEUCO DYE-BASED THERMOCHROMIC INKS

Bamfield and Hutchings (2010) define leuco dye-based thermochromic inks as colored in a non-heated state (below their activation temperature) and become clear or slightly colored in a heated state (above their activation temperature). Also, they are usually blended with other pigments (non-heat sensitive pigments), allowing them to change from one color to another.

STRUCTURE OF LEUCO DYES

Structure of leuco dye based thermochromic ink is described by Bamfield and Hutchings (2010) as consisting of a color-former and a color-developer dissolved in a solvent, together making up the thermochromic composite. The composite is then microencapsulated in a protective coating to protect the content from undesired effects caused by the environment. In a non-heated state, the composite remains in solid form and the color-former adopts its colored form. When in a heated state, the solvent melts and the interaction between the solvent and the color-former destroys the composite, thus causing the color-former to adopt its colorless form. The activation temperature is defined by the temperature at which the solvent changes from solid to liquid state.

AVAILABLE TEMPERATURE OF LEUCO DYE

Leuco dye-based thermochromic inks are formulated to change color at temperatures ranging from -15°C to 60°C. The temperature at which the ink changes color can be chosen when it is ordered (Chromazone, accessed April, 2013).

PROPERTIES OF LEUCO DYES

Leuco dye-based thermochromic inks are produced to be reversible or irreversible. Reversible inks change from a colored state to a clear or slightly colored state as a result of increasing the temperature to above the activation temperature of the ink. The color returns upon cooling. This procedure may be repeated over a long period of time. Irreversible inks are invisible until they are exposed to high temperatures, at which time they change from a clear state to a colored state. This change in color is permanent, which means that once the change from clear to colored state has occurred, it will not revert. Kulcar states that irreversible inks normally begin color transition at 65°C and complete the transition at 90°C.

In addition, a wide range of leuco dye-based thermochromic inks are available, such as solvent-based, water-based, UV cured, epoxy, etc., and are used for printing on textiles, plastic, paper and metal (Kulcar et al 2012).

COLOR BACKGROUND

Leuco dye-based thermochromic inks must be printed over a light background. If they are printed on a background color other than white, the background color will influence the color of the ink in both the non-heated and heated state: e.g. a blue ink printed over a yellow background will change from green to yellow when heated.

COLOR OF THE INK

Leuco dye-based thermochromic inks can be produced in most colors, except for white. The most common colors are magenta, black, blue, turquoise and orange with good intensity.

STRUCTURE OF THE METHOD

Before starting work with leuco dye-based thermochromic inks, it is essential to be aware about the following factors: the ambient temperature (non-heated state of e.g. the printing lab), temperature sensitivity of the inks, and the properties of the inks. The ambient temperature at the printing lab at the Swedish School of Textiles at the University of Borås, where this study was carried out, was 20°C. The temperature sensitivity of the

chosen inks was 27°C¹ and 15°C². The inks were reversible and water-based. The most desirable printing effect would be achieved on cellulosic fabric. White plain cotton-woven fabric was used as a background. The size of the silk-screen mesh was 43 threads per centimeter. In addition, the thermochromic inks had to be mixed with binder in order to attach the ink to the fabric. In addition, binder is defined as “the chemicals, which have the ability of forming a three-dimensional film used to hold the pigment particles in place on the surface of a textile substrate” (China Tianyu Nickel Screen CO., accessed April. 2013). In this paper, binder name is acrylic-based extender.

Leuco dye-based thermochromic inks, like other pigment printing pastes, require certain equipment, such as a textile lab with high-tech temperature testing capacity. I did not have a proper chamber, so I made color-samples with the chosen leuco dye-based thermochromic inks. The samples were then measured with a spectrophotometer at three different temperatures: at the ambient temperature (20°C), after heating (up to 30°C or above), and after cooling (down to 5°C or below). These measurements were then followed by creating printed color-swatches with the produced databases, using the textile pigment printing pastes. As a result, the color-swatches I produced made it possible for me to demonstrate the color changing of leuco dye-based thermochromic inks at different temperatures (see Figure 1). In addition, scanned images of printed color-swatches were used to support the figures.



Figure 1. shows color-swatches made with textile pigment pastes to demonstrate the varying colors of leuco dye-based thermochromic inks at different temperatures.

HOW TO TEACH ACCORDING TO THE APPROACH

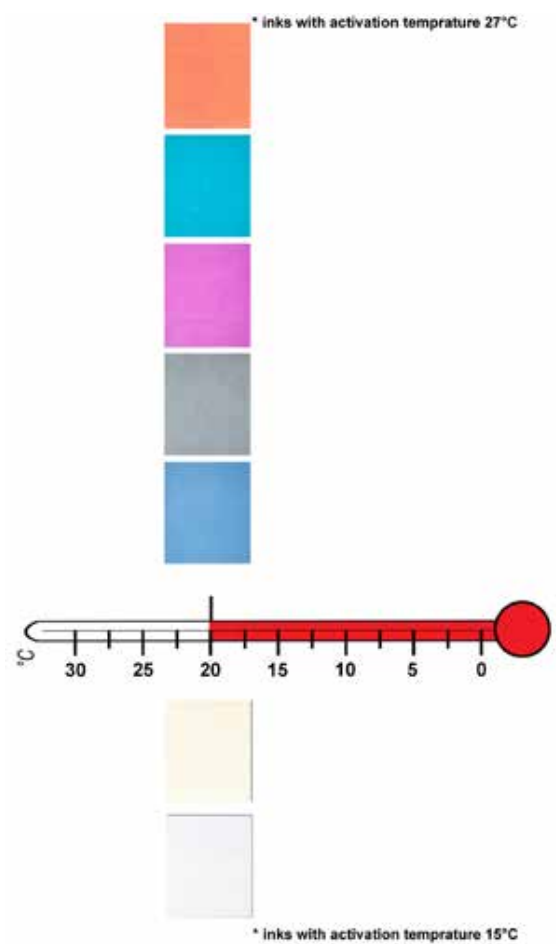
A printed thermometer was placed on the table of the printing lab in order to illustrate the ambient temperature. The ambient temperature was showing 20°C. Three grams of blue ink with activation temperature 27°C was mixed with 97 grams of acrylic-

¹ Zenit company in Sweden

² B&H Colour Changing Company in England.

based extender, hand screen-printed on the chosen fabric, and then placed on the right side of thermometer. The same recipe was used for the black, magenta, turquoise and orange inks. The prints displayed the following colors at ambient temperature (20°C): light blue (14-4214 TCX)³, light black (17-0613 TCX), magenta (17-2520 TCX), blue green (14-4811 TCX) and light orange (15-1435 TCX). Colors’ name and color-coding were used to convey information quickly for reader, as well as to facilities understanding of visual display (cf. Green, 2010).

The blue and red inks with activation temperature 15°C were screen-printed on the chosen fabric with the same recipe and method, and then placed on the left side of thermometer. The prints displayed the following colors at ambient temperature (20°C): white with a blue tint (11-4604 TCX) for the blue ink and white with a pink tint (11-1005 TCX) for the red ink (see in Figure2).



³ Although, there are more accurate color systems such as lab, L*a*b*, this paper has chosen PANTONA due to the accurate color is not important in this approach, and textile designers use more PANTONA or NSS in design process rather than color measurement. Printed colour-swatches were compared with PANTONE in order to give the reader a better picture of the colors achieved.

Figure 2. shows how the effect of printed fabrics produced by the mixture of 3gr of ink with activation temperatures 15°C and 27°C with 97gr of extender look like at ambient temperature (20°). From bottom to top: the effect of mixing 3 grams of the blue and the red inks with activation temperature 15°C and 97 grams of extender and the effect of mixing 3 grams of the blue, black, magenta, turquoise and orange inks with activation temperature 27°C and 97 grams of extender at ambient temperature (20°)

The temperature was then increased to 30°C or above. The effect of heating the fabrics printed with blue, black, magenta, turquoise and orange inks with activation temperature 27°C was, for both blue and black ink, white with a yellow tint (11-4301 TCX), white with a pink tint (11-2409 TCX) for the magenta ink, for the turquoise ink it was white with a yellow tint (12-1009 TCX), and for the orange ink it was white with a yellow tint (11-0603 TCX).

The effect of heating the fabrics printed with blue and red inks with activation temperature 15°C were white with a yellow tint (11-4604 TCX) for the blue ink and for the red ink it was white with a pink tint (11-2309 TCX) (see Figure 3).

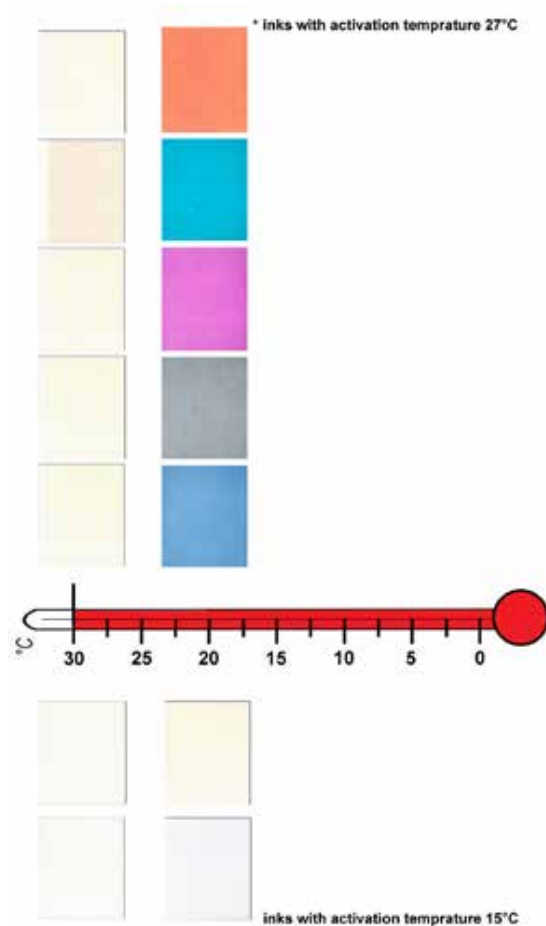


Figure 3. shows (from bottom to top) how the effect of heating the printed fabric produced by the blue and red inks with activation temperature 15°C and the blue, black, magenta, turquoise and orange inks with activation temperature 27°C look like at 30°C compered with the one at 20°C.

The first result is that by increasing the temperature to a level equal to or above the activation temperature of the ink, the reversible leuco dye-based thermochromic ink always changes from a colored state to a clear or slightly colored state.

Four grams of yellow textile pigment printing paste (14-0756 TCX) was mixed with each of the leuco dye-based inks (blue, black, magenta, turquoise and orange) with activation temperature 27°C, screen-printed on the chosen fabric, and then placed on the right side of thermometer. At the ambient temperature (20°C), the prints made with the mixture of inks and yellow pigment paste displayed the following colors: green-ochre (16-0540 TCX), gray-ochre (16-0540 TCX), reddish-brown (16-1350 TCX), greenish-yellow (15-0343 TCX) and orange (15-1157 TCX).

The same recipe and method was used to mix the blue and red inks with activation temperature of 15°C with the yellow textile pigment paste, and then placed on the left side of thermometer. The colors displayed by the prints at the ambient temperature (20°C) were a light greenish-yellow (11-0620 TCX) for the blue ink and for the red ink it was a light pinkish-yellow (12-0721 TCX) (see Figure 4).

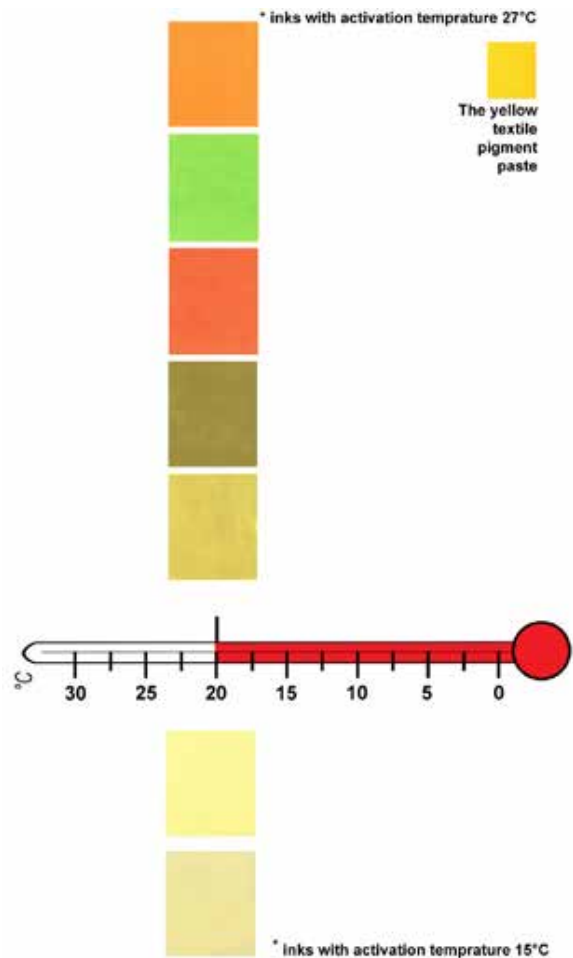


Figure 4. shows how the effect of printed fabrics produced by the mixture of ink with activation temperatures 15°C and 27°C with yellow textile pigment paste look like at ambient temperature (20°). From bottom to top: the result of mixing the blue and red inks with activation temperature 15°C and blue, black, magenta, turquoise and orange inks with activation temperature 27°C and the yellow textile pigment paste at ambient temperature (20°).

The temperature was then increased to 30°C or above. The result of heating the fabric printed with the inks with activation temperatures 27°C and 15°C were colors identical to the mixed yellow pigment paste, only slightly lighter (12-0752 TCX) (see Figure 5).

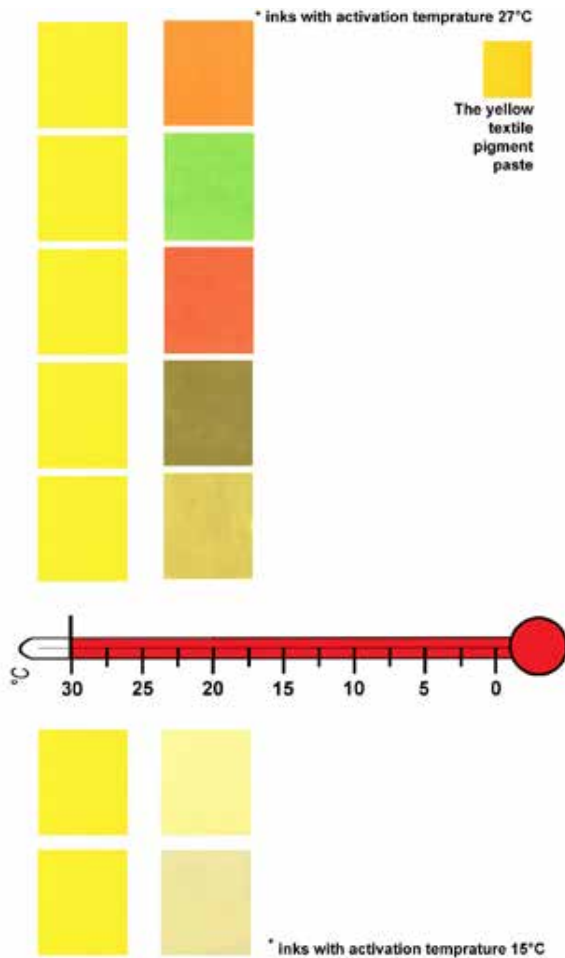


Figure 5. shows how the effect of heating the printed fabric produced by the inks with activation temperatures 15°C and 27°C look like compared with the one at 20°C. The effect of heating (at 30°C) the fabrics printed with the mixture of the inks with activation temperatures 27°C and 15°C with yellow textile pigment paste was identical to the mixed yellow pigment paste, just slightly lighter.

The second result is that by increasing the temperature to a level equal to or above the activation temperature of the ink, the color of the mixture of reversible leuco dye-based thermochromic ink and textile pigment paste always changes to the color of the mixed pigment paste, only slightly lighter.

When the activation temperature of the ink is lower than the ambient temperature, we may produce an additional

color transition by cooling the printed fabric. Both groups of printed fabrics (produced by the inks alone and also by the mixture of inks and yellow textile pigment paste) were shown at 5°C. The result of cooling the fabrics printed with the inks with activation temperature 27°C was colors identical to those displayed at ambient temperature (20°C). However, cooling the fabrics printed with the blue and red inks with activation temperature 15°C produced the colors dark blue (18-4045 TCX) and dark red (15-1920 TCX) (see Figure 6).

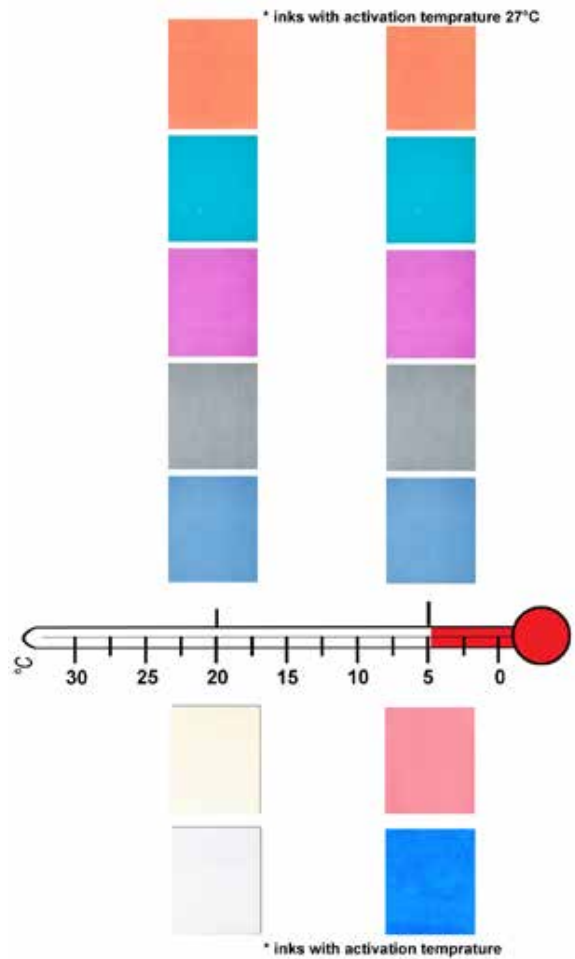


Figure 6. shows how the effect of cooling the printed fabrics produced by the inks with activation temperatures 15°C and 27°C look like compared with the one at 20°C. The effect of cooling the fabrics printed with the inks with activation temperature 27°C was identical to those displayed at ambient temperature (20°C). However, cooling the fabrics printed with the blue and red inks with activation temperature 15°C produced the dark blue and dark red.

The third result is that by decreasing the temperature to a level equal to or lower than the activation temperature of the ink, the ink will display its actual color.

Following, the colors displayed when cooling the fabrics printed with the mixture of inks with activation

temperature 27°C and the yellow textile pigment paste were identical to those displayed at the ambient temperature (20°C). However, the fabrics printed with the blue and red inks with activation temperature 15°C became dark bluish-green (17-5111 TCX) and light reddish-yellow (16-1632 TCX) (see Figure 7).

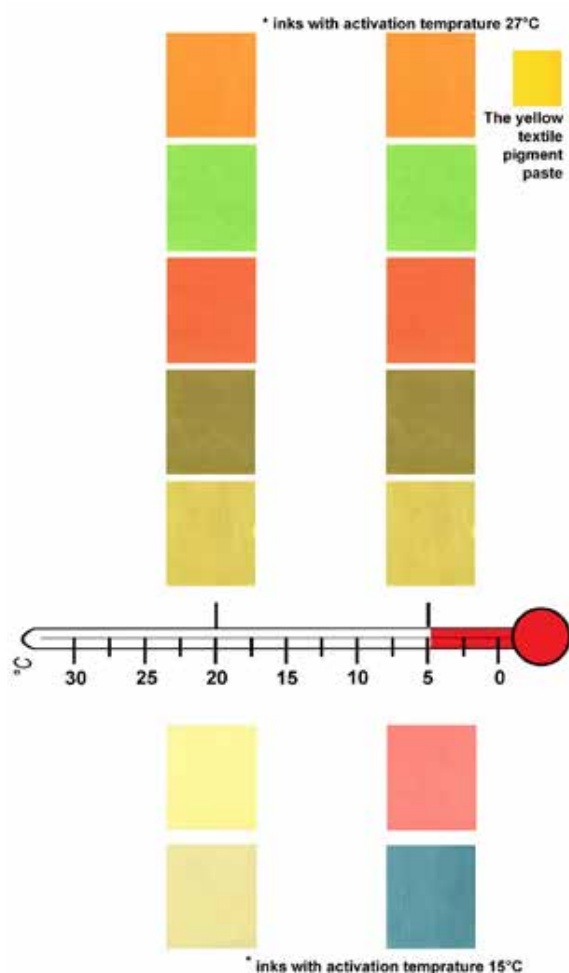


Figure 7. shows how the effect of cooling the printed fabrics produced by the inks with activation temperatures 15°C and 27°C look like compared with the one at 20°C. The effect of cooling the fabrics printed with the mixture of inks with activation temperatures of 27°C and 15°C and the yellow textile pigment paste. The effect of cooling the fabrics printed by the inks with activation temperature 27°C and yellow pigment was identical to those displayed at ambient temperature (20°C). However, cooling the fabrics printed with the blue and red inks with activation temperature 15°C and yellow pigment produced another color which is the actual color of the mixture.

The forth result is that by decreasing the temperature to a level equal to or lower than the activation temperature of the ink, the mixture of reversible leuco dye-based thermochromic ink and textile pigment printing paste always changes color to the actual color of the mixture.

Exercises

Deep learning was the central part of this approach. Therefore, a good strategy for creating and managing a high quality workshop environment was essential (Ginsberg, M.B. & Wlodkowski, 2009). My strategy was to give students exercises in order to experience the content. The exercises engaged the students in their design process. I started them off with easy exercises and followed up with increasingly challenging ones.

At the Swedish School of Textiles, University of Borås, thermochromic workshops are one part of the dyeing and printing course. The students were asked to bring two silk-screen frames (frame No.1 and frame No.2) on which the patterns were already exposed.

The first exercise was to work with leuco dye-based thermochromic inks with activation temperature 27°C. The white plain cotton-weaved fabric was given to the students. The students were then instructed to choose one warm color and one cold color from among the inks of an activation temperature of 27°C and then mix 3 grams of the chosen inks with 97 grams of the extender. They overprinted one of the patterns (frame No.1) with the chosen cold color and the other one (frame No.2) with the chosen warm color. In addition, in all exercises, they were required to wait until the printed fabrics were dry. Afterward, they heated up their printed fabrics to 30°C using a hair dryer or a heating pad in order to examine and observe the first result at the previous section (see Figure 8).



Figure 8. From top to bottom: sample of prints made with the turquoise and magenta inks with activation temperature 27°C at ambient temperature (20°C) and the effect of heating the printed fabric. Work by Bachelor Student Cecilia Krook, thermochromic workshop, 2012.

The second exercise was to work with the inks with activation temperature 15°C. The students were instructed to choose only one color of ink, either warm or cold. Two different recipes were given to them. One recipe was to mix 3 grams of the chosen ink with 97 grams of the extender (the first recipe) and the other one was to mix 1 gram of the chosen ink with 99 grams of the extender (the second recipe). After mixing the two recipes, they overprinted one of the patterns (frame No.1) with the first recipe and the other one (frame No.2) with the second recipe. At first, they heated up the printed fabrics to 30°C using a hair dryer or a heating pad to test the first result at the previous section. Then, they cooled the printed fabrics down to 8°C using a freezer, testing the third result at the previous section (see Figure 9).

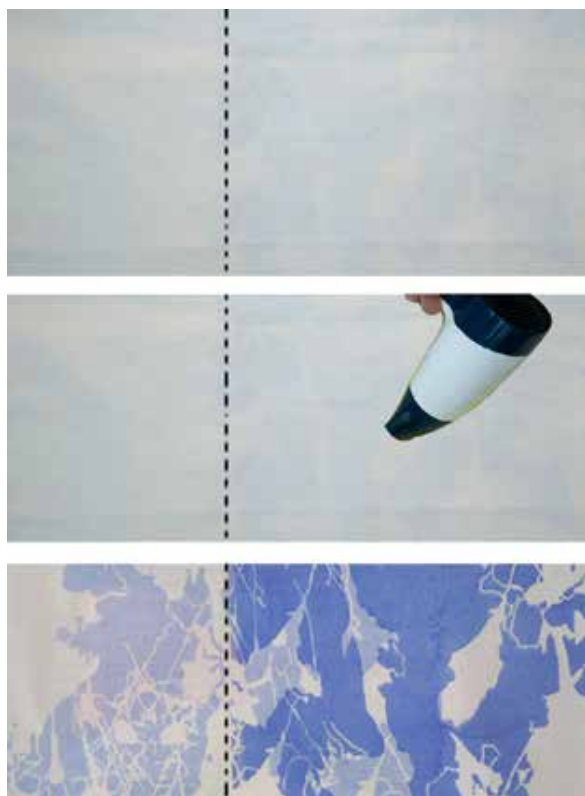


Figure 9. From top to bottom: sample of prints made with the blue ink with activation temperature 15°C at ambient temperature (20°C) and the effect of heating and cooling the printed fabric. Left to right: 1 gram of ink and 3 grams of ink, both with activation temperature 15°C. Work by Bachelor Student Therese Amus Gidlöf, thermochromic workshop, 2012.

The third exercise was to mix the inks with activation temperature 27°C with the textile pigment paste. The students were instructed to use a textile pigment printing paste of their own choosing and to mix it with the inks chosen in the first exercise. They then overprinted one of the patterns (frame No.1) with the mixture of the ink

of a cold color and the pigment paste and the other one (frame No.2) with the mixture of the ink with a warm color and the pigment paste. After doing this, they heated up the printed fabrics to explore the result of the second exercise at the previous section (see Figure 10).

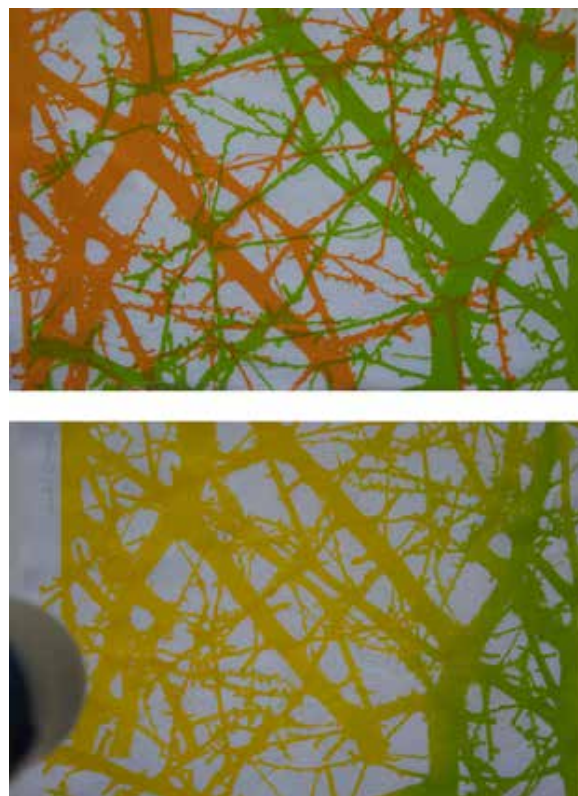


Figure 10. From top to bottom: sample of prints made with the mixture of yellow pigment and orange and blue inks with activation temperature 27°C at ambient temperature (20°C), and the effect of heating the printed fabric. Work by Master Student Justien De Bus, thermochromic workshop, 2012.

The fourth exercise was to mix the inks with activation temperature 15°C with the textile pigment paste. The students were instructed to use a textile pigment color of their own choosing and mix it with both recipes from the second exercise. They overprinted one of the patterns (frame No.1) with a mixture of the first recipe and the chosen pigment paste and the other one (frame No.2) with a mixture of the second recipe and the chosen pigment paste. They heated up the printed fabrics to observe the second result at the previous section. Afterward, they cooled the printed fabrics to examine and analyze the fourth result at the previous section (see Figure 11).

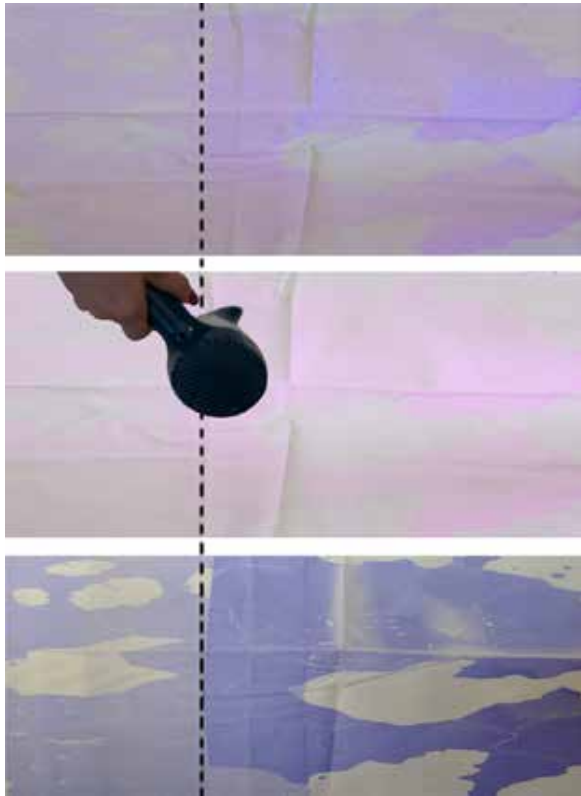


Figure 11. From top to bottom: sample of prints made with the blue ink with activation temperature 15°C and magenta pigment paste at ambient temperature (20°C), the effect of heating and cooling the printed fabric. Left to right: 1 gram of ink and 3 grams of ink, both with activation temperature of 15°C. Work by Bachelor Student Annika Björk, thermochromic workshop, 2012.

At this point, the students had had enough experience working with the inks with activation temperatures 27°C and 15°C. They were in a situation that challenged their previous conceptions about color. The situation created a forum for open discussion of the exercises and so they were instructed to bring all samples of printed fabrics for discussion. Afterward, I showed them some examples of dynamic patterns used in textile applications.

The last exercise was an assessment exercise based on the process (what they had learned so far). The exercise was to design a dynamic surface pattern that would give the audience different information or produce different expressions at different temperatures. Textile dynamic pattern is described by Worbin (2010) as “a textile pattern that reacts to environmental stimuli and always returns to a given initial expression”. The point of this exercise was to give the students a chance to construct their own meaning (Biggs, 2003) & (Wlodkowski, 2008), when learning the properties of thermochromic inks (see Figure 12 & 13).

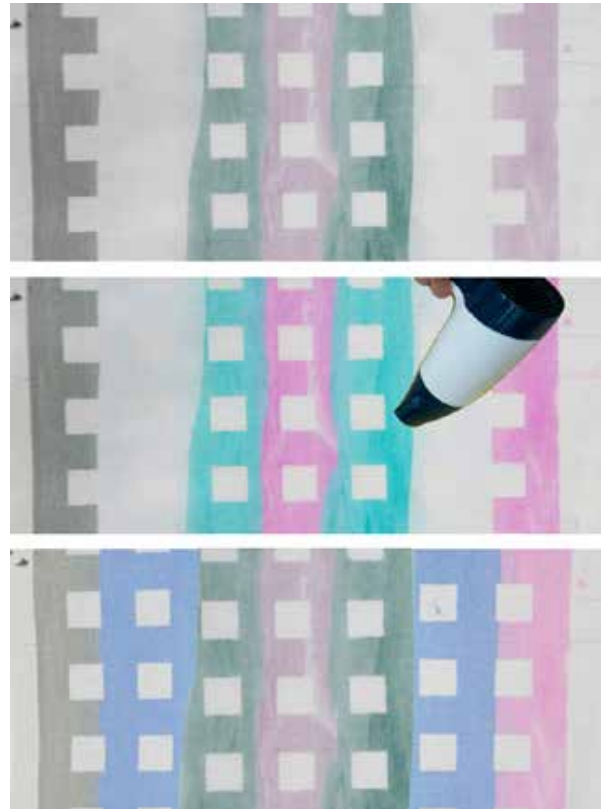


Figure 12. From top to bottom: sample of prints made with the inks with activation temperatures 15°C and 27°C and pigment paste at ambient temperature (20°C) and the effect of heating and cooling the printed fabric. Work by Master Student Matilda Andersson, thermochromic workshop, 2011.

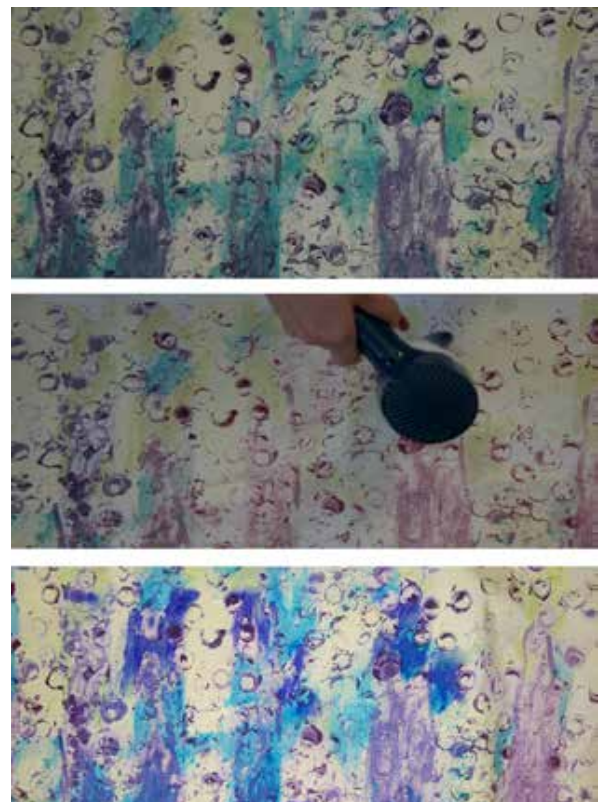


Figure 13. From top to bottom: sample of prints made with the inks with activation temperatures 15°C and 27°C and pigment paste at ambient temperature (20°C) and the effect of heating and cooling the printed fabric. Work by Bachelor Student Johanna Samuelsson, thermochromic workshop, 2012.

DISCUSSION/ CONCLUSION

The aim of this paper has been to share a systematic approach of teaching the behavior of leuco dye-based thermochromic inks in Textile and Fashion Design. It has focused on demonstrating the color transition of the thermochromic inks to facilitate the understanding and designing of dynamic surface-patterns at three different temperatures: the ambient temperature (non-heated state of e.g. the printing lab); a heated state, i.e. a temperature above the activation temperature of the ink; and a cold state, i.e. a temperature below the activation temperature of the ink.

Printed color-swatches made with the textile pigment printing pastes and exercises made up the core of the approach. The printed color-swatches effectively demonstrated the color transitions of leuco dye-based thermochromic inks at different temperatures. The exercises created opportunities for students to craft an understanding of the design potential of using leuco dye thermochromic inks through experimentation and individual exploration.

This approach has been applied as a three days workshop at both Bachelor and Master level, as well as textile designers. The length of workshop and plan designed created active learning environments where students had hands on practice with high degree of learning (Sork, 1997).

The samples made by the students in the final exercise has indicated that the approach creates a new way for me as a lecturer to convey thermochromic knowledge to the students and also creates a unique set of fundamental skills for students to learn color transition principles in a more quick and easy way for designing dynamic patterns through the experimental workshop. The approach seems to be an efficient approach allowing students to develop their ideas through pushing the properties of thermochromic inks supported by design skill and predicting color transition while they are designing dynamic surface-patterns (Drew, 2004) & (Ginsberg & Wlodkowski, 2009).

Previous approaches Albers (1975) and Collis and Wilson (2012) reveal that essential knowledge regarding color within a particular context can be achieved through experiential learning, materiality and experimental processes. By entering smart colors such as leuco dye-based thermochromic ink into textile and fashion area, the design process has been directed towards a new face of design, which needs new approaches. One suggestion for further studies would be more investigation on how to use the leuco dye-based thermochromic ink in textile digital printing, and how to describe color transition of leuco dye-based thermochromic ink in a proper color systems.

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