Creating diverse colour-changing effects on textiles

With the technological progress of materials science, the palette of colours with which to print on textiles has expanded beyond those with previously known properties and expressions to a new generation, with more advanced functionality and expressive properties. This new range of colours is characterised by their ability when printed on textiles to change colour in relation to external factors and internal programmes; for example, leuco dye-based thermochromic inks generally change colour in response to temperature fluctuations. This research explores the design properties and potentials of leuco dye-based thermochromic inks printed on textiles, with regard to creating a wider range of colour-changing effects for textile applications. The significance of this for textile design is related to the development of a methodology for designing dynamic surface patterns. The research was conducted by creating a series of design experiments using leuco dye-based thermochromic inks, which resulted in different recipes and methods, along with a pedagogical tool. The results highlighted the diverse colour-changing properties of leuco dye-based thermochromic inks, which have the potential to create more complex patterns on textiles. The outcome of this research proposes a foundation for textile designers with which to approach new ways of thinking and designing.
CREATING DIVERSE COLOUR-CHANGING EFFECTS ON TEXTILES

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ABSTRACT

With the technological progress of materials science, the palette of colours with which to print on textiles has expanded beyond those with previously known properties and expressions to a new generation, with more advanced functionality and expressive properties. This new range of colours is characterised by their ability when printed on textiles to change colour in relation to external factors and internal programmes; for example, leuco dye-based thermochromic inks generally change colour in response to temperature fluctuations. This research explores the design properties and potentials of leuco dye-based thermochromic inks printed on textiles, with regard to creating a wider range of colour-changing effects for textile applications. The significance of this for textile design is related to the development of a methodology for designing dynamic surface patterns. The research was conducted by creating a series of design experiments using leuco dye-based thermochromic inks, which resulted in different recipes and methods, along with a pedagogical tool. The results highlighted the diverse colour-changing properties of leuco dye-based thermochromic inks, which have the potential to create more complex patterns on textiles. The outcome of this research proposes a foundation for textile designers with which to approach new ways of thinking and designing.
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INTRODUCTION

For an extended period of time, materials scientists have had their attention turned away from structural materials, and towards the development of functional materials (Wang & Kang, 2013). These developments have attracted the interest of experimental textile designers, and have caused an inevitable movement in the textile design field towards the use of so-called ‘smart’ materials, a term which refers to materials with advanced functionality and the ability to sense and respond to one or more external factors and/or internal programmes (cf. Tao, 2001).

Smart materials introduce new possibilities for design practice, but their properties and capabilities bring with them a need to expand the range of design methods and techniques beyond those traditionally used in textile design, to develop ones that not only capture the inherent potential of smart textile materials, but also facilitate practical and theoretical development in design practice.

Leuco dye-based thermochromic inks are colouring agents which have been used for roughly a decade in the creation of interactive textile displays, but their full potential has not yet been fully realised or explored. There is thus a need for experimental textile researchers to develop methods with which to support ways of conceptualising and describing them in textile design practice.

For this purpose, this research focuses on the exploration of the design properties and potentials of leuco dye-based thermochromic inks when printed on textiles to create a wider range of colour-changing effects on textiles.

Structure

Chapter One consists largely of a literature review, providing an overview of current design practice related to the use of leuco dye-based thermochromic inks and associated technologies. It also identifies areas in which there is more work to be done.

Chapter Two describes the research programme as a framework for the exploration of the design properties of leuco dye-based thermochromic inks printed on textiles.

Chapter Three presents the practice-based research methodology used in this thesis. It discusses the context of experimental research in design from a
theoretical perspective, and provides a practical key to understanding the structure of the research in relation to design practice.

Chapter Four presents experiments and design examples which describe and define the leuco dye-based thermochromic inks as design materials, and posits a variety of the effects that leuco dye-based thermochromic inks could offer during design development.

Chapter Five presents a summary of the primary conclusions arrived at as a result of the design research findings, and presents recommendations for future work.

In addition to the above, this thesis also includes four appended articles. Each article supports a specific experiment and design example of Chapter Four.

List of publications

Appended papers


II. Kooroshnia, M., 2013. Demonstrating colour transitions of leuco dye-based thermochromic inks as a teaching approach in textile and fashion design, Proceedings of Nordic Design Research Conference 2013, June 2013, Copenhagen-Malmö, Denmark


Exhibitions

2014 (7-27 April) Let your body print your dress - Playful research of smart textiles, ArchInTex, Auckland, New Zealand.

2014 (21-15 February) Let your body print your dress - Playful research of smart textiles, ArchInTex, Vilnius, Lithuania.

2014 (6- 8 January) Let your body print your dress - Playful research of smart textiles, ArchInTex, Riga, Latvia.

2013 (14-27 November) Let your body print your dress - Playful research of smart textiles, ArchInTex, Ronse, Belgium.
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2013 (5-9 February) Smart textiles sample collections - Stockholm Furniture Fair, Sweden.


2011 (18-21 May) Mask - Milan Furniture Fair, Italy.


Workshops

2010-present, twice a year, three-day Thermochromic workshop, The Swedish School of Textiles, University of Borås, Sweden.

2014 (10-11 April), Thermochromic workshop, School of Art and Design, University of Auckland, New Zealand.

2013 (25-27 February), Thermochromic workshop, The Department of Design, Aalto University, Finland.

2012 (7-8 May), Thermochromic workshop, Bergen Academy of Art, Norway.
In 1909, Prague-based chemist Hans Meyer observed thermochromic behaviour in certain organic compounds; in 1954 and 1963, E. Harnik and G.M.J. Schmit, along with J.F.D. Mills and S.C. Nyburg, published several articles about thermochromism (Ritter, 2007, p. 80). In 1983, heat-sensitive encapsulated thermochromic inks were created by the Pilot Corporation of Japan, to be used primarily with plastics or textiles in commercial applications, e.g. thermochromic paints or wrapping materials (Kito et al., 1983). In the latter decades of the twentieth century, a number of products with thermochromic characteristics reached the market; these included a ‘mood ring’, thermochromic dyed clothing (which were in high demand at the beginning of the 1970s), a battery life indicator on Duracell batteries (Philips, 2000), a toothbrush, and a drinking vessel (Ritter, 2007, p. 87). At present, thermochromic inks are commercially available from several manufacturers, e.g. Zenit and LCR Hallcrest. The inks’ qualities, along with the availability of colours, vary slightly between different manufacturers.

There are two major types of thermochromic ink; liquid crystals, and leuco dyes. Liquid crystals react to small changes in temperature within a pre-formulated temperature response range, while leuco dyes are less sensitive to temperature fluctuations, more easily handled (Homola, 2003), and suitable for use as general indicators which display approximate temperatures (i.e. ‘cool’, ‘warm’, ‘hot’). The discussion presented here is limited to reversible, water-based leuco dye-based thermochromic inks.

The interactive properties of leuco dye-based thermochromic inks, which suggest new forms of communication and expression (Hallnäs et al., 2002; Worbin, 2010), have been explored by several researchers in the field of textile design. The Skin Stories (Berzina, 2004) is a practice-based multidisciplinary research project, in which the interactive and decorative potential of leuco dye-based thermochromic inks was investigated to create interactive textile surfaces for applications in home interiors. The leuco dye-based thermochromic inks, scents, and heat generated by electronic equipment or the human body were used to design various multisensory interactive surfaces that behave in a similar manner to human skin.

The interactive surfaces that resulted from the Electronic Textiles project (Orth, 2004) used woven electronic circuitry in combination with leuco dye-based thermochromic printed fabric to demonstrate the beautiful visual effects that may be achieved using
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thermochromic inks. Prototypes were created to challenge user perceptions about the static and dynamic relationships that exist between the compositional elements.

Other examples of interactive textiles include a piece created as a result of the Shimmering Flower project, consisting of a soft woven circuit board (produced on a Jacquard loom) which activates and controls thermochromic prints with individually addressable pixels in parts of the design (Berzowska, 2005), as well as two furniture pieces which are able to respond to the presence of a person by changing colour in response to body temperature, and retaining this colouring for several minutes after the person has left (BAN, 2007; also cf. Ritter, 2007).

In the Designing Dynamic Textile Patterns research project (Worbin, 2010), a series of examples were created which displayed the potential of leuco dye-based thermochromic inks for textile applications, and demonstrated ways of activating and controlling the printed patterns on these textiles. Through practice-based multidisciplinary research, Worbin combined traditional textile design processes and colour-changing and computational technologies to create and control dynamic textile patterns.

The AmbiKraf project used Peltier semiconductor modules to rapidly heat and cool thermochromic printed fabric, actively animating it (Peiris et al., 2010).

Furthermore, ‘An Investigation Of the Design Potential Of Thermochromic Textiles Used With Electronic Heat-profiling Circuitry’ (Robertson, 2011) discusses the design potential of thermochromic dye systems with regard to textiles activated by integrated electronic systems. Screen-printing and laser technology were combined with heat-profiling mechanisms as part of the experimental process to create a series of prototypes with complex and highly unusual colour-change effects which explored the aesthetic qualities of thermochromic dye systems (leuco dye-based and liquid crystal) when used in combination with heat-profiling circuitry.

While these research projects have provided successful examples of interactive textiles which may be activated and controlled, research into interactive digital textile displays has progressed relatively slowly due to a lack of exploration of the complete range of design possibilities afforded by leuco dye-based thermochromic inks, and because of a lack of documented information to guide textile designers regarding how these colours may be applied to textiles. Thus, these deficiencies have led to more emphasis being placed on initial prototypes and what they may be able to communicate, rather than on a more profound exploration of design properties.
With the technological progress of materials science, the palette of colours with which to print on textiles has expanded beyond those with known properties and expressions to a new generation, with more advanced functionality and expressional properties.

This new range of colours is characterised by their ability when printed on textiles to change colour in response to external factors and internal programmes. Often referred to as ‘smart colours’, these include thermochromic inks, photochromic inks, photoluminescent pigments, etc. They introduce new possibilities for textile design, and challenge current theory and practice by allowing designers to suggest certain perceptions, reactions, and activities through design.

To design a dynamic pattern on a textile, a textile designer requires basic knowledge regarding how to use thermochromic inks to achieve different colour-changing effects, as well as an understanding of how different methods, approaches, and procedures can affect design decisions. Experimental textile researchers play a key role in exploring the design properties and possibilities of these colours, and seek to enlarge the body of knowledge related to understanding, describing, and working with these smart colours in connection with textiles.

The research programme of this thesis is; to explore the design properties and potentials of leuco dye-based thermochromic inks when used on textiles, to facilitate the understanding and design of dynamic surface patterns in the context of textile design.

The programme is formulated based on my previous experiments with leuco dye-based thermochromic inks, obtained during my Master’s studies at the Swedish School of Textiles, University of Borås.

The programme provides a foundation and framework for experimentation, and directs actions towards a goal. It outlines a specific perspective for interpreting the design experiments, and forms a basis for constructing a theoretical foundation.
Objectives

I. Explore the design properties of leuco dye-based thermochromic inks to provide basic printing paste recipes for use with textiles; described in Experiment I and Paper I.

II. Formulate a method for creating a temperature-sensitive colour mixture to expand the range of available designs possibilities, revealing latent colours and patterns; described in Experiment II and Paper IV.

III: Formulate a method for printing a dynamic surface pattern on a textile in order to promote diverse colour-changing effects; described in Experiment III and Paper IV.

IV. Explore an approach to explaining the behaviour of leuco dye-based thermochromic inks to students in the field of Textile Design, to facilitate the understanding and design of dynamic surface patterns for various temperatures/environmental conditions; described in Experiment IV and Paper II.

Fig.3. A thermochromic print after heating, before heating the image is a dark grey.
Experimental Research in Design

Research through design involves a researcher who is also a professional designer developing a theoretical contribution with which to advance knowledge in the design field in question (Hallnäs & Redström, 2006, p. 133); this contribution should be of use to other researchers and practitioners in the field. This form of research has been discussed and developed during the last two decades (Durling et al., 2002; Frayling, 1993), and is today known as ‘practice-’ or ‘experimental-based’ design research (Frayling, 1997). Hallnäs and Redström (2006, pp. 133-140) state that experimental research in design may consist of many things, including testing a design or a probe, an exploration, or the presentation of a notion. This thesis focuses on experimental research as a means of exploring and investigating the expressive qualities of a design material, in order to expand the boundaries of design space and develop the design field.

With this approach to experimental research, ‘design’ is usually the creation of an artefact (Hatchuel & Weil, 2009) through a process of exploration and discovery (Jones, 1992, p. ix). These explorations generate new design possibilities, skills, and “initiate change in man-made things” (Jones, 1992, p. 6).

In short, the process begins with an initial interest, followed by the generation of ideas and methods with which to develop a concept and, finally, a model/prototype. The process is not a predictable one due to the shaping actions of subjectivity, intuition, tradition, and training in design thinking, which reformulate working ideas in such a way that the creative design process is enhanced through experimentation (Kimbell, 2009).

Through the creative design process, designers reflect upon the methods used by revising, developing, rejecting, or returning to them (Schön, 1995). This method of reflection in action creates dialogues between the designer’s internal mental process, their external expression, and representation in sketches. As Santiago Calatrava describes how he designs in the Design mind book written by Lawson (1994): “to start with you see the thing in your mind and it does not exist on paper and then you start making simple sketches and organizing things and then you start doing layer after layer […] it is very much a dialogue”.

The design process must be systematic in order to indicate how a designer has formulated his/her design programme, understood and structured the design procedures, and
generated a suggestive proposal. The systematic design process suggests methodologies or structured approaches that should lead designers towards a good design in an efficient manner (cf. Cross, 2006).

The experimental design research is pursued within a systematic design process of doing and rationalising, with a strong basis in logical foundations, resulting in the generation of both tacit and explicit design knowledge. It focuses on conceptual and methodological contributions (Cross, 2001). In experimental design research, the researcher becomes a reflective practitioner and critical investigator, combining his/her skills with experiences gained during the design process and his/her critical and analytical faculties so as to formulate new questions for future exploration. Thus, experimentation and reflection, as contemporary conceptions of generative thinking and traditional notions of evaluative conceptualisation, re-define our understanding of things so as to move beyond existing approaches.

In experimental design research, ideas are examined, developed, and evaluated through a series of experimentations, and new forms of expression are created as a result of these explorations. The design experiment therefore demonstrates the development of design processes in terms of the decisions which have been made and, crucially, how they have been made; thus, they become tools for interpretation and constructing theory.

As Chadarevian and Hopwood (2004, p. 433) note, the experience of creating design experiments is in itself valuable for the development of a deeper understanding in relation to the research programme.

The design experiments carry explicit and implicit content (cf. Stappers, 2007), which may generate new knowledge and insights. The explicit aspect is the design experiment itself (cf. Biggs, 2006), which facilitates communication and the generation of tacit knowledge, while the implicit requires some form of linguistic expression in order to be made comprehensible and so as to aid in the generation of explicit knowledge with which to satisfy the research community and audience.

The design research text is an interpretation of the investigations pursued and conclusions drawn during the research process; from the creative design stage, through to the concretisation of design examples and construction of a result. It describes the expression achieved during the process of material exploration.

The outcome of the research is a suggestion in the form of design methods for further innovations in practice (Hallnäs, 2010). The outcome is thus a development of pre-existing design methodology for the purpose of generating, developing, and discussing concepts so as to construct a foundation for further innovation in the design field (cf. Jones, 1992, p. xi; Biggs, 2004; Hallnäs, 2010).
Design research method

This research was carried out following the principle of experimental exploration. The research programme was formulated to explore the design properties and potentials of leuco dye-based thermochromic inks, and to document them as design materials in order to achieve an improved understanding and design approach for creating dynamic surface patterns.

The research programme created a frame for the experiments. These were undertaken in the context of textile design and using textile printing techniques, with particular reference to hand-screen printing.

Themes and ideas were generated through literature studies and sketching ideas brought into practice. Within the programme, fabric samples were developed to suggest alternative ways of achieving colour-changing effects on textiles. At each stage, fabric samples, as the results of each experimental process, were gathered and interpreted to form a foundation for the next stage. The collection of fabric samples demonstrated the development of the research process in terms of how and why experiences, observations, reflections, and decisions were made through experimentation with the leuco dye-based thermochromic inks. At the same time, the interpretation of the collection formed a theoretical foundation.
In order to meet the goals of the stated research programme, a series of practical experiments which used leuco dye-based thermochromic inks on textiles were carried out.

In all of the experiments, surface patterns were designed in order to assist the exploration of the design properties and potentials of leuco dye-based thermochromic inks through their artistic expressions.

The primary inspirations when designing with the leuco dye-based thermochromic inks were Persian designs; this was due to a personal interest and cultural background, and focused particularly on the plasterworks of palaces, flower and bird (Rose and nightingale) paintings, and arabesque patterns.

However, while colour was at the core of the research, colour selection was not always based on the design, but often dictated by market availability.

**Experiment I**

This experiment explored the design properties of leuco dye-based thermochromic inks in order to formulate printing paste recipes; these function as fundamental knowledge, and expand on how leuco dye-based thermochromic inks can be used with textiles.

Two leuco-dye based thermochromic inks of the same colour (blue) but different activation temperatures (27°C and 15°C) were used to demonstrate the properties of a single colour of thermochromic ink when applied to textiles.

Both blue inks were mixed with an acrylic-based extender in different proportions, producing differing shades of blue at ambient temperature (20°C). Although numerous shades of blue were possible, this experiment sought to investigate six shades for each thermochromic ink, and so tones which clearly differed from one another were chosen.

The blue shades produced by both inks were tested at equal to or below 15°C and at or above 27°C in order to explore the design properties of leuco dye-based thermochromic ink at different temperatures. An ice bag was used to cool the printed fabrics, and an iron was used to warm them.
First, fabric samples which displayed different colours at ambient temperature, at
equal to or more than 27°C, and at equal to or less than 15°C were constructed. These
demonstrated and allowed comparisons of the effects of cooling and heating the
printed blue shades produced by the thermochromic inks.

Following this, yellow textile pigment paste was mixed with the blue shades of the
previous experimental stage to explore more colour-changing effects.

The same methods of cooling and heating were used to explore the design potentials
of the mixture at different temperatures (see Fig 5 & 6 & 7).

Next, two more fabric samples of differing colours at the three different temperatures
(ambient, equal to or more than 27°C, and equal to or less than 15°C) were
constructed. They demonstrated the effect of cooling and heating the printed green
shades produced by the mixing of the yellow textile pigment paste and blue inks with
activation temperatures of 27°C and 15°C (see also Paper I).

Tests were conducted with different fabrics, including 100% cellulosic cotton, 50:50
cotton/polyester, and 100% polyester fabrics. It was observed that the most desirable
printing effect was achieved by printing inks on cellulosic fabric, as this allowed the
structure of the fabric to be seen through the print.

Fig.5. (opposite) A colour atlas which is used to demonstrate the
colour transition of leuco dye-based thermochromic inks in
combination with textile pigment pastes.
EXPERIMENT I

Fig. 6. A selection of entries from the colour atlas showing that an increase of temperature to a level equal to or above the activation temperature of the ink, the colour of the mixture of reversible leuco dye-based thermochromic ink and pigment always changes to that of the mixed pigment, though slightly lighter.

Fig. 7. A selection of entries from the colour atlas showing that an increase of temperature to a level equal to or above the activation temperature of the ink, the colour of the mixture of reversible leuco dye-based thermochromic ink and pigment always changes to that of the mixed pigment, though slightly lighter. With a decrease of temperature to a level equal to or lower than the activation temperature of the ink, the colour of the mixture always changes to its full colour.
Result

This approach resulted in recipes for print formulation, and provides designers with valuable knowledge regarding how leuco dye-based thermochromic inks can be used on textiles (see also Paper I).

The recipes can be utilised as a guide for the purpose of designing dynamic textile surface patterns. For instance, a 1:99 ratio of ink (15°C) to binder resulted in a white colour at ambient temperature (20°C), and light blue at equal to or less than 15°C. This could be used to hide or reveal surface patterns (see Fig 8).

Fig. 8. The sample produced shows a dynamic surface pattern created by inks with activation temperatures of 27°C (at a ratio of 25:75) and 15°C (at a ratio of 1:99). From left to right: the printed fabric at ambient temperature, cooled, and heated.
Experiment II

This experiment sought to explore methods of creating a temperature-sensitive multi-colour mixture.

The results of the initial experiments formed a basis for the development of more complex colour-changing effects which were intended to conceal or reveal more than one colour at once.

Temperature-sensitive colour mixtures are generally made by mixing a leuco dye-based thermochromic ink with a base colour and a textile pigment paste. Based on the first experiment, the colour of the mixture changes to a transitional one as a result of an increase in temperature. For instance, a mixture of blue leuco dye-based thermochromic ink with an activation temperature of 27°C and a yellow textile pigment paste results in a green temperature-sensitive colour mixture below 27°C and yellow at or above 27°C.

An attempt was made to conceal one colour of the surface pattern. For this, one textile pigment paste and one leuco dye-based thermochromic ink with similar base colours were chosen. Both were mixed with extender in separate mixing cups until they looked alike. They were then printed on the fabric and left to dry (for more on mixing colouring agents, see Worbin, 2010, p. 83).

In order to conceal and reveal two latent colours of the surface pattern, there was a need to make two temperature-sensitive colour mixtures. The first was made by mixing a leuco dye-based thermochromic ink of colour A and a textile pigment paste of colour B. The resulting temperature-sensitive colour mixture was colour C below the activation temperature of the leuco dye-based thermochromic ink and a transitional colour B at or above the activation temperature. The second temperature-sensitive colour mixture was formed by mixing a leuco dye-based thermochromic ink of colour B and a textile pigment paste of colour A, resulting in colour D below the activation temperature of the leuco dye-based thermochromic inks and a transitional colour A above it. For the third temperature-sensitive mixture, a leuco dye-based thermochromic ink of colour A was mixed with another temperature-sensitive compound of colour C and a textile pigment paste of colour B, resulting in colour E below the activation temperature of the leuco dye-based thermochromic inks and three different transitional colours at or above the activation temperature of the inks. For instance, to hide and reveal blue (colour A), magenta (colour B), and yellow (colour C), temperature-sensitive colour mixtures were made in the following order: The first temperature-sensitive colour mixture was made by mixing blue (colour A) and magenta (colour B) leuco dye-based thermochromic inks with an activation temperature of 27°C and yellow (colour C) textile pigment paste. The first mixture resulted in brown-greyish (colour D) below 27°C and yellow (colour C) at or above 27°C. The second temperature-sensitive colour mixture was formed by mixing yellow (colour C) and blue (colour A) leuco dye-based thermochromic inks and magenta (colour B) textile pigment paste, and was brown-greyish below 27°C and magenta at or above 27°C. The third temperature-sensitive colour mixture was made by mixing yellow (colour C) and magenta (colour B) inks with an activation temperature of 27°C and blue (colour A) textile pigment paste. The third temperature-sensitive colour mixture was made by mixing magenta leuco dye-based thermochromic ink (colour B) with an activation temperature of 27°C and blue textile pigment paste (colour A), and was violet (colour C) below 27°C and blue (colour A) at or above 27°C. It is noted that for both, the colour mixing must be done in such a way as to ensure that both temperature-sensitive mixtures have similar colours when below the activation temperature of the ink (see Fig 9 & 10 & 11).
EXPERIMENT II

mixture resulted in brown-greyish (colour D) below 27°C and blue (colour A) at or above 27°C.

The same principle was then used to prepare six temperature-sensitive colour mixtures (see Fig 12 to 15).

A screen-printed pattern was produced, and involved printing each temperature-sensitive colour mixture next to the other ones. As the temperature was raised, the temperature-sensitive colour mixtures activated and started to change, from brown-greyish to four different colours (see Fig 16).

The transformative visual qualities were one of the most interesting results of this stage of the research, and provided the idea to create patterns which were altered through colour-changing (see Fig 17).

It should be noted that this experiment did not provide the precise printing paste recipes as the first experiment due to a lack of a thermochromic database with which to measure the dynamic colour samples with a spectrophotometer.
Fig. 10 & 11 (opposite). A selection of entries from the colour atlas that shows that two different temperature-sensitive colour mixtures can have the same colour at ambient temperature, but each will show a different colour when heated.
Fig. 12 & 13 (opposite). Two of the five possible temperature-sensitive colour mixtures that will display the same colour at ambient temperature, but different colours when heated. The same principle can be used to prepare a total of five different temperature-sensitive colour mixtures, each displaying a different colour when heated.
Fig. 14 & 15 (opposite). Each mixture must have the same colours, one of which should be a pigment, the others thermochromic. As an example, both mixtures presented here display dark brown-grayish at ambient temperature, but the first mixture has a magenta pigment, producing magenta when heated, and the second mixture has a cyan pigment, producing a cyan when heated.
EXPERIMENT II

Result

This approach resulted in a method of mixing colours for formulating a temperature-sensitive colour mixture consisting of multiple colours. It expanded the available range of possibilities for designing dynamic surface patterns in terms of revealing latent colours and designs.

The method illustrated the possibilities offered by utilising a common background colour below the activation temperature of the inks which, when heated, generated a multi-coloured background at or above the activation temperature. In contrast to the prior method, which used thermochromic inks to create a multi-coloured pattern that became transparent when heated, the approach discussed above offers the opposite transition, i.e. from a single-coloured (plain) background to one with several colours (see also paper IV).

With reference to Experiment I, the temperature-sensitive colour mixtures can be made using leuco dye-based thermochromic inks with activation temperatures lower than ambient temperature, e.g. 15°C. They thus become visible when exposed to a change in temperature; i.e. the temperature-sensitive colour mixtures are slightly coloured in a heated state, and more coloured when cooled.
In this experiment, the temperature-sensitive colour mixtures were mixed with an ink which had one activation temperature (27°C). Alternatively, the activation temperature of the inks in each temperature-sensitive colour mixture may differ from the others (for more on mixing colouring agents, see Berzin, 2004, p. 183).

Fig. 17. This sample shows the possibilities of revealing latent colours and designs. Here a printed fabric was produced with five temperature-sensitive colour mixtures with activation temperature 31°C and at a ratio of 25:75, shown at ambient temperature and then heated.
EXPERIMENT III

Experiment III

This experiment explored a method of printing a complex dynamic surface pattern on textiles.

The results of Experiment II suggested the potential of layering temperature-sensitive colour mixtures in order to create another colour-change effect on textiles.

In the paper printing industry, offset lithography is one of the most common flat techniques for printing full-colour images or photographs, and involves a series of steps, or transformations, to generate a quality colour reproduction. Two graphic techniques are required to prepare an image for four-colour printing. One is a system in which a full-colour image is separated into four different colours (colour separation), while the other involves translating each colour layer to halftone. The process of colour separation is started by separating the original image into cyan, magenta, yellow, and black layers, abbreviated as CMYK. After this, each single-colour layer is converted to halftone, as the printing press cannot vary the amount of ink applied to particular areas of the image; thus, halftone represents lighter shades as tiny dots. During the colour printing process, the halftone layers are printed in succession; inks are printed on top of each other so as to produce different hues. Green thus results from printing yellow and cyan inks on top of one another. The halftone grids (dots) run at different angles to give the impression of infinite colours, in a kind of optical illusion.

This experiment was based on the offset method of printing, as well as the method of forming a temperature-sensitive colour mixture comprising multiple colour mixtures, as was described in Experiment II.

A full colour pattern, inspired by Persian patterns featuring flowers and birds, was designed. Using Photoshop it was changed to CMYK mode, and then each channel was converted to halftone (Image > Mode > Bitmap > Halftone method). Each halftone colour channel or layer was then exposed on a silk-screen frame and hand-screen printed.

Colour preparation was performed as for Experiment II. The first of four temperature-sensitive colour mixtures was made by mixing magenta, yellow, and black leuco dye-based thermochromic inks with a cyan textile pigment paste, resulting in a dark greyish violet below 27°C and cyan at or above this temperature. The second temperature-sensitive colour mixture was formed by mixing cyan, yellow, and black leuco dye-based thermochromic inks with magenta textile pigment paste, giving dark greyish violet below 27°C and magenta at or above. The third and fourth mixtures were made following the same principle, but with yellow and black textile pigment pastes, respectively. All four temperature-sensitive colour compositions looked similar at or below the activation temperature of the inks.

Screen-printed patterns were produced, with the first layer consisting of cyan textile pigment. An angle of 60 degrees was used for the halftone screen, and additional layers, consisting of magenta and yellow textile pigments (at angles of 110 and 120 degrees, respectively) were printed; this was then overprinted with a layer of black textile pigment at an angle of 30 degrees. When the temperature was increased, the temperature-sensitive colour mixtures were activated, and started to change from dark greyish violet to vibrant colours (see Fig 18).

To determine the correct fabric for the development of the design, tests were conducted with different fabrics and thicknesses, including different types of woven cotton and polyester. The results were all fairly similar, meaning that, for this particular method, it is possible to achieve sharp, defined forms on most fabrics.

Result

This approach resulted in a textile printing method which combined the offset method of printing and the method of forming a temperature-sensitive colour mixture comprising multiple colours.

This method demonstrated that it was possible to create a wider range of colour-changing effects through layering different temperature-sensitive colour mixtures.

Thus, it allowed for more complex dynamic surface patterns on textiles, in which the colour of the pattern changed from one colour, possibly, with different shades to continuous tones (see also Paper IV).
Digital printing methods can produce similar printing effects, as was demonstrated in this experiment without any restriction of colour profiles, but they cannot yet process the leuco dye-based thermochromic inks. This method, then, offers a new method for obtaining a similar effect to digital printing through the use of leuco dye-based thermochromic inks.

Fig.18. A printed sample showing the wide range of possible colours. The fabric was produced with four temperature-sensitive colour mixtures with activation temperatures 27°C and at a ratio of 25:75 ratio.
Experiment IV

This experiment proposed a pedagogical tool for teaching the behaviour of leuco dye-based thermochromic inks to students of textile design.

As a Master’s student at the Swedish School of Textiles at the University of Borås, I participated in workshops on liquid crystals, photochromic inks, and leuco dye-based thermochromic inks. All of the workshops began with the lecturer giving an oral presentation on the topic, followed by some experimental work without any specific direction. Consequently, following and interpreting the content, which was mainly related to colour transition, through verbal communication alone was difficult for me, and so I was not able to predict the actual colour transitions through experiments. In these workshops, a systematic teaching approach to provide support in learning new skills was lacking, as was the existence of a good plan to respect the needs, desires, and requirements of learners. Thus, when I was asked to hold the Thermochromic Workshop, I decided to offer a hands-on experience which demonstrated the colour transition of leuco dye-based thermochromic inks at various temperatures so as to help students achieve a better understanding of this phenomenon.

For this purpose, the experiment began with two collections of colour-samples; one with only the leuco dye-based thermochromic inks in blue, magenta, orange, turquoise, and black, each with an activation temperature of either 27°C or 15°C, and the other with a mixture of leuco dye-based thermochromic inks and yellow textile pigment paste. The colour samples were then measured with a spectrophotometer at three different temperatures; at ambient temperature (20°C), after heating (above 27°C), and after cooling (below 15°C). The measurements were then translated to colour swatches, printed using the textile pigment printing pastes. As a result, the colour swatches produced made it possible to effectively demonstrate the colour transition of the leuco dye-based thermochromic inks at different temperatures.

A printed thermometer was placed on the table of the printing lab in order to illustrate three different temperatures. The right side of the thermometer was used to display the effects produced by inks with an activation temperature of 27°C, and the left side displayed the effects produced by inks with an activation temperature of 15°C.

The colour swatches were placed on the table so as to display and compare the effects produced by either the inks with activation temperatures of 27°C or 15°C, or the mixture of the inks and yellow textile pigment paste at ambient temperature, after heating, and after cooling.

As it was important for me to provide the students with a thorough understanding, my strategy was to give them exercises in order for them to experience the phenomenon themselves. I began with easy exercises and followed up with increasingly challenging ones (see also Paper II).

Result

A pedagogical tool for teaching the behaviour of leuco dye-based thermochromic inks to students in textile design was the result of this experiment.

The printed colour swatches successfully demonstrated the colour transitions of leuco dye-based thermochromic inks at different temperatures. The exercises created opportunities for students to learn colour transition principles in a quick and easy way, facilitating the design of dynamic patterns from the start, without experiencing the usual, steep learning curve.

The pedagogical tool seems to be an efficient one, enabling students to integrate their new knowledge of the behaviour of thermochromic inks with what they already knew about conventional pigments in relation to the design of a surface pattern. Moreover, it allowed them to work on their ideas using their design skills, and assisted in developing their ability to predict the consequence of their design decisions in terms of where and how to apply dynamic colours in relation to other design elements when designing dynamic surface-patterns.
Experimental examples

This stage of the research did not attempt to define any specific applications; rather, the intention was to explore and demonstrate ways of understanding and working with leuco dye-based thermochromic inks. Thus, two artefacts were created to demonstrate the results achieved through Experiments I to III, as well as to explore the variety of effects that leuco dye-based thermochromic inks can offer during design development.

Design example I; Mask

This design example was exhibited in various locations; the Museum of Textile History in Borås, Sweden (2011), Milan Furniture Fair, Italy (2011), and the Ambience Conference, Borås, Sweden (2011).

A series of masks was designed, with the intention of testing the colour-changing effects offered by the recipes and methods of the previous experiments. Inspiration was taken from the H1N1 swine flu pandemic; at this time, as countries verged on panic, people were afraid of contracting the virus, and some wanted to wear masks to protect themselves from the illness.

The collection consisted of a series of different prints and three different shapes of mask; the traditional surgical style, a wrap-around-scarf, and a full-face sinus mask.

Surface patterns inspired by Persian designs were produced on nonwoven 100% polyester fabrics, screen-printed with a mixture of leuco dye-based thermochromic inks with an activation temperature of 31°C and textile pigment pastes, following the recipes and methods that resulted from Experiments I to III.

In order to observe the colour-changing effect of the masks, a model was asked to wear them. The model was given no other instructions than that to wear the masks and breathe normally.

A series of photographs were taken, the analysis of which indicated several interesting aspects. The difference in terms of the heat source was very apparent in the colour-change results; from using an iron in the previous experiments to body temperature in this one. The heat generated by the iron was high, meaning that the change in colour happened fast and the colour-changing effect had two states; one expression (colour) before, and another after. Here, however, it was observed that the temperatures generated by breathing or skin contact were comparatively cooler, creating a gradual movement of colour (see Fig 20 & 21).

However, while the rate of the change in colour was generally slow, the magenta leuco dye-based thermochromic ink changed more quickly than other thermochromic ink colours and took much longer to return to its original colour. The reason for this is most likely the constitution of the microencapsulated particle.

This constant change in colour created an unusual sense of life on the mask.
Fig. 20 and 21 A series of photos showing that the temperatures generated by breathing or skin contact create a gradual movement of colour.
Design example II: Let your body print your dress

This design example was undertaken in collaboration with Laura Clausen. It was exhibited in various locations; Playful Research in Smart Textiles, ArchInTex, in TiO3 Ronse, Belgium (2013), the Art Academy of Latvia (2014), the Vilnius Academy of Arts, Lithuania (2014), and the School of Art and Design, University of Auckland, New Zealand (2014).

The design process was initiated by testing colour-changing effects using the recipes and methods developed during the previous experiments in relation to body temperature, as thermochromic inks are applied to textiles and may be activated by the heat of a human body.

A recipe, consisting of 25% leuco dye-based thermochromic inks with an activation temperature of 31°C and 75% binder, as was described in Experiment I, was selected in order to provide a good textile-printing effect with maximum colour intensity at ambient temperature (20°C).

To determine the correct fabric for use in the development of the garments, tests were conducted with different fabrics and thicknesses, including woven and knitted cotton, silk, wool, and silk organza.

A series of random and controlled garments were created. In the first series of tests, very basic versions of a dress and trousers, with a minimum of seams and curves, simple sleeves, and straight silhouettes, were chosen for making the garments. The cutting patterns were applied to the plain satin-cotton fabric and covered by a mixture of black leuco dye-based thermochromic ink and yellow conventional textile pigment paste.

In the second series of experiments, the garments were based on the principles detailed in the design of the first garments, but with more width and a greater distance between the garment and the body. In addition, four straps were attached so as to allow adjustments to be made to the garments at certain points by tying them differently.

In the third series of experiments, two garments were created with prints consisting of block shapes, using black conventional textile pigment and a black leuco dye-based thermochromic dynamic print. The first of these was a long cotton dress, made with a straight-edged black shape on the left side and a long black dynamic print on the right. The reason for choosing this cutting pattern was to extend the colour-changing effect over a larger area, as well as to create a greater contrast between colour and form based on a clear shift in print along the length of the body. The second was a silk organza dress, printed entirely with black leuco dye-based thermochromic ink except for around the chest and crotch.

In the fourth series, two intricate dynamic patterns were created in order to illustrate the expressive potential of leuco dye-based thermochromic ink in terms of revealing and concealing patterns and colours. One pattern was inspired by trees and tattoos, and the other consisted of four colours and was inspired by Persian designs. The surface patterns were applied using the textile printing method used during Experiment III.

Two models were asked to wear them, and a series of photographs were taken. An analysis of these indicated that the interaction between the garments and the wearers’ bodies created patterns which were unique but wild, messy, uncontrolled, impossible to reproduce, and temporary.

The patterns that were observed resulted from body temperature and movement in terms of arm bending, walking, and turning.

The interaction between the garments and the wearers’ bodies created gradual movement of colour.

One result was achieved through continued interaction between body temperature and the prints. Pattern shadows were left on the surface of the fabric as an imprint of the last interaction.

The prints reacted to body temperature very quickly, especially at those parts of the garment that were in direct contact with the body, e.g. torso, shoulders. In the second series, looser straps resulted in the body shape becoming less apparent, as the decrease in contact between the body and the dynamic prints led to restricted colour-changing.

The results varied based on the individual’s body shape, temperature, and movement (see Fig 22 to 27).
Using silk-organza fabric in the production of the last garment greatly changed the effect of body temperature on the dynamic prints, which were rendered transparent in the blink of an eye, leaving only the three black blocks. Thus, although the body generates heat slower than, for example, a clothes iron, the thickness of the fabric still has to be considered when designing dynamic patterns for textiles (see also Paper III).
EXPERIMENTAL EXAMPLES

Discussion

‘Mask’ and ‘Let your body print your dress’ were informative regarding the aesthetic qualities achievable through the use of thermochromic inks, and led to a greater understanding of the colour-changing effect.

The observations of the colour-changing effects of both examples indicated that the use of thermochromic inks offers a gradual colour palette which textile designers have not previously had access to. It allows changes in colour, not only from A to B to A, but from A to Z to A (and to all of the letters in between) (Nilsson et al., 2011), and thus adds an unusual depth of colour (see Fig 28 to 30).

In addition, the observations offered the opportunity to design a unique dynamic print which would reflect the texture of the layer underneath through the colour-changing effect (see Fig 31).

In terms of design, the gradual change of colour, together with the pattern shadows, could potentially be developed to create more complex, multiple colour-change effects using thermochromic inks (see Fig 32).

Fig.28-30. (pages 79-81) The interaction between the garments and the body creates a gradual colour palette.
Fig. 31. The texture of the layer underneath—here, the model’s underwear—is shown on the garment.

Fig. 32. Over time, the interaction between the body and the print can create pattern shadows on the surface of the fabric as an imprint of the previous sustained body position.


DISCUSSION

This thesis is the record of an experimental research programme which set out to explore the design properties and potentials of leuco dye-based thermochromic inks when printed on textiles, in order to create a wider range of colour-changing effects. The significance of this for textile design is related to the development of a methodology for designing dynamic surface patterns.

The experiments resulted in multiple recipes, methods, and a pedagogical tool. The results highlight the different colour-changing properties of leuco dye-based thermochromic inks, which have the potential to create more complex patterns on textiles. These could be applied by textile designers during different phases of the design process as new ways of designing dynamic patterns for textiles.

Additionally, two design examples have demonstrated some of the aesthetic qualities that are possible through working with the recipes and methods detailed. They have suggested that a difference in heating source creates a gradual movement of colour, and affords the opportunity to create a unique dynamic print which would reflect the texture of the layer underneath through the colour-changing effect. In addition, they have indicated the flexibility of the colour-changing effects and shown that they can be used in multiple contexts.

The recipes and methods lead a textile designer along, step by step, and explain the process thoroughly and in detail; the literature review demonstrated that there is a distinct lack of technical information regarding how to use leuco dye-based thermochromic inks in design, and this means that designers often have to take a trial-and-error approach when using thermochromic inks.

The recipes and methods can be combined with other technologies to develop multi-disciplinary projects and innovative concepts.

The leuco dye-based thermochromic inks have a limited lifespan when compared to traditional dyes. In addition to this, they are damaged by environmental stimuli such as long exposure to UV light. This may be considered as barriers in a design process, it may, in trun, be considered as design potentials.

Albers (1975) has suggested an approach to studying and teaching colour, based on learning by direct perception rather than through theories or colour systems. Moreover, Collis and Wilson (2012) and Green (2010) have argued for the advantages
DISCUSSION

of using colour systems for rapid communication and the understanding of visual displays. Their approaches, terminologies, colour systems, and colour-coding are not adapted to deal with smart and dynamic colours and their properties; hence, there is a lack of proper linguistic terminology for discussing colour-changing under differing temperatures or conditions. Consequently, throughout the technical stages of the experiments, attention was focused on the development of a visual vocabulary by demonstrating the expressions and effects of colour transition, thus sidestepping the absence of a proper vocabulary. The next step of the research will focus on a contribution to the development of a conceptual language for colour-changing effects.

The development of a methodology for designing a dynamic pattern for textiles will be accomplished through the development of a conceptual language for colour-changing effects, which will eventually provide the basis for knowledge transformation and collaborative work between disciplines. In both a pedagogical and a collaborative work context, the development of a conceptual language involves the development of colour theory, as it requires bringing clarity to colour communication through the establishment of a new system that may accurately predict the behaviours of thermochromic inks in relation to temperature and time.

Just as it is said that a sheet of paper defines a drawing, the drawing defines an object, the object defines a space, the space defines a building, the building defines a city, etc., it is hoped that this research has constructed a foundation for textile designers with which to move towards new ways of thinking and designing, and further innovation in textile design.
REFERENCES


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PUBLICATIONS

Appended papers


Exhibition

LEUCO DYE-BASED THERMOCROMIC INKS: RECIPES AS A GUIDE FOR DESIGNING TEXTILE SURFACES

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Abstract

Although there has been some research on the use of leuco dye-based thermochromic inks in textile and fashion design, there is still a lack of research on how these inks can be used on textiles to create complex and dynamic patterns through textile printing. This paper provides information on the properties of leuco dye-based thermochromic inks to facilitate the understanding and designing of dynamic surface-patterns, and demonstrates the color transitions of thermochromic inks at different temperatures. A practice-based design method was chosen to investigate two different reversible and water-based blue inks with activation temperatures of 27°C and 15°C. The result showed scales comprising the recipes that were used as a guide for designing textile surfaces. This paper contributes to making the color-changing process understandable and demonstrating the actual effects of leuco dye-based thermochromic inks at different temperatures for textile and fashion design. This facilitates designers to achieve more advanced textile surface patterns.

Keywords: leuco dye-based thermochromic inks, textile pigment paste, fashion design, printing technique, color-change, smart materials

Introduction

In recent years, there has been growing interest in the use of leuco dye-based thermochromic inks as smart materials in textile and fashion design. Fabric displays have been created for new forms of communication and expression such as the Reach [1], and the Ambikraft [2] projects. In those, leuco dye-based thermochromic printed fabrics were combined with technology to create interactive textile displays allowing us to reconsider relationships between human behaviors and the surrounding environments. Furthermore, in the research theses Skin Stories [3], and Designing Dynamic Textile Patterns [4] thermochromic printed fabrics have been combined with technology to explore ways to control and develop dynamic textile expressions. However, most of this research has focused on combining thermochromic printed fabric with computational technology and exploring ways of heating or cooling the thermochromic printed fabric. There is a lack of documented information on how thermochromic inks can be used on textiles. This paper aims to provide information on the properties of leuco dye-based thermochromic inks to facilitate the understanding and designing of dynamic patterns. Textile dynamic patterns are described by Worbin (2010) as “a textile pattern that reacts to environmental stimuli and always returns to a given initial expression” [4].

Leuco dye-based thermochromic inks

Leuco dye-based thermochromic inks are specialized dynamic inks that change color when exposed to different temperatures, i.e., below their activation temperature they are colored and above their activation temperature they are clear or slightly colored. They are usually blended with some other pigments (non-heat sensitive pigment) change from one color to another [5]. The activation temperature is defined as the temperature above which the ink has almost achieved its final clear or light color end point. The color starts to fade at approximately 4°C below the activation temperature and will be in between colors within the activation temperature range. Leuco dye-based thermochromic inks [6] can be made to change color at temperatures ranging from -15°C to 60°C. The ink’s temperature can be chosen when it is ordered.

There are some important factors, which should be considered before starting to work with leuco dye-based thermochromic inks: the ambient temperature (20°C), 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. Temperature sensitivity of the chosen inks were 27°C and 15°C. The inks were reversible and water-based. Therefore, the most desirable printing effect was achieved by printing them on cellulose fabric. White plain cotton-woven fabric was used as a background. The method used was silk-screen printing and the size of the silk-screen mesh was 43 threads per centimeter.

1 Zeniti company in Sweden

A single color of leuco dye-based thermochromic ink with activation temperatures 27°C and 15°C

The thermochromic ink was mixed with binder to attach the ink onto fabric. 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” [7]. In this experiment, binder was acrylic-based extender. Both inks were mixed with extender in different proportions that produced different shades of blue at ambient temperature (20°C).

Although numerous shades of blue were possible, this paper was limited to investigate six shades for each thermochromic ink with activation temperatures 27°C and 15°C (See figures 1 & 2). As shown in figure 2, the recipe consisting of 25% ink and 75% extender provided a good textile-printing effect with maximum color intensity at ambient temperature (See figure 3).

Figure 1: From left to right shows the blue shade produced by the thermochromic ink with activation temperatures 27°C, and 15°C at ambient temperature (20°C).

Figure 2: shows the mixing and printing the ink with activation temperatures 27°C, 15°C, with the extender in different proportions produced different blue shades at ambient temperature (20°C).

Since thermochromic inks are specialized dynamic inks that change color with exposure to different temperatures, the produced blue shades (with activation temperatures 27°C and 15°C) were tested at 15°C or less, and also at 27°C or more in order to explore the design potentials of leuco dye-based thermochromic ink at different temperatures. An ice bag was used to cool the thermochromic printed fabrics down to 15°C and below. An iron was used to warm the thermochromic printed fabrics up to 27°C and above. The effect of cooling the printed blue shade produced by the ink with activation temperature 27°C was identical to the blue shade at ambient temperature (20°C). Whereas, the effect of the printed blue shade produced by the ink at an activation temperature 15°C was a dark blue shade compared with the one at ambient temperature (20°C) (See figures 4, 5, 6 & 7).

From the textile design perspective this experiment highlighted one particular aspect. Reversible leuco dye-based thermochromatic ink is not available in white. However, as shown in the last row of figure 5, the mixture of 1% of 15°C thermochromic ink with 99% extender resulted in white at ambient temperature (20°C) and light blue at equal or less than 15°C. This possibility can be used to reveal hidden designed surface patterns (See figure 7).

The effect of heating the printed blue shade produced by the ink with activation temperature 27°C was a light gray-yellowish shade compared with the blue shade at ambient temperature (20°C). Whereas, the effect of the printed blue shade produced by the ink at an activation temperature 15°C was a light gray shade. This is because the leuco dye-based thermochromic inks are always clear or slightly colored above their activation temperature (See figures 9, 10, 11 & 12).
Adding a textile pigment paste to leuco dye-based thermochromic with activation temperature 27°C and 15°C

A particular amount of yellow textile pigment paste was mixed with the used blue shades in previous experiment with the same activation temperatures. The color combinations created different green shades at ambient temperature (20°C). The green shade produced by the mixture of ink with activation temperature 27°C was darker than the green shade produced by the mixture of ink with activation temperature 15°C (See figures 12, 13 & 14).

The same methods of cooling and heating were used to explore more design potentials of mixture of leuco dye-based thermochromic ink and a textile pigment paste at different temperatures. Thus the mixtures were examined at 15°C or less and also at 27°C or more.

The effect of cooling the printed green shade produced by the yellow textile pigment paste and the blue ink with activation temperature 27°C was identical to the green shade at ambient temperature (20°C). However, the green shade produced by the yellow textile pigment paste and the blue ink with activation temperature 15°C was a darker green shade compared with the one at ambient temperature (20°C). Based on thermochromic ink’s characteristic the cause of this difference was that the actual color of blue ink (15°C) appeared at 15°C or less causing the color combination to get darker. Therefore, the green shade changed color to a dark green shade (See figures 15, 16, 17 & 18).

The effect of heating both green shades produced by the blue ink with activation temperatures 27°C and 15°C and the yellow pigment paste resulted in a slightly lighter yellow that of the yellow pigment paste. Based on thermochromic ink’s characteristic the mixture of leuco dye-based thermochromic ink and textile pigment paste always changes to the color of the mixed pigment paste, only slightly lighter (See figures 19, 20, 21 & 22).
The effect of cooling the printed fabric was 25% ink+75% extender+4% pigment. At ambient temperature (20°C), cooling with ice-bag and the effect of cooling.

The chosen recipe was 10% ink+90% extender+4% pigment.

Figure 15: From left to right, and top to bottom shows the printed green shade produced by the mixture of inks with activation temperatures 27°C, 15°C and the yellow at ambient temperature (20°C), cooling with ice-bag and the effect of cooling.

Figure 17: The effect of cooling the printed fabric produced by the mixing of blue ink with activation temperature 27°C and yellow pigment. The chosen recipe was 25% ink+75% extender+4% pigment.

Figure 18: The effect of cooling the printed fabric produced by the mixture of red ink with activation temperature 15°C and yellow pigment. The chosen recipe was 10% ink+90% extender+4% pigment.

Figure 19: From left to right, and top to bottom shows the printed green shade produced by the inks with activation temperatures 27°C, 15°C and the yellow at ambient temperature (20°C), heating with iron and the effect of heating.

Figure 21: The effect of heating the printed fabric produced by the mixing of blue ink with activation temperature 27°C and yellow pigment. The chosen recipe was 25% ink+75% extender+4% pigment.

Figure 22: The effect of heating the printed fabric produced by the mixture of red ink with activation temperature 15°C and yellow pigment. The chosen recipe was 10% ink+90% extender+4% pigment.

Figure 20: shows and compares the effect of heating the printed green shades produced by the blue thermochromic ink at activation temperatures 27°C, 15°C and yellow textile pigment paste.

Figure 16: shows and compares the effect of cooling the printed green shades produced by the blue thermochromic ink at activation temperatures 27°C, 15°C and yellow textile pigment paste.

Table 1: Heat and cool results of heating and cooling the printed fabric with different recipes

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Discussion and conclusion

This paper has aimed to provide printing paste recipes in order to provide fundamental knowledge of how leuco dye-based thermochromic inks can be used on textiles. The figures presented, consisting of scales at three different temperatures (at ambient temperature, at equal or more than 27°C and at equal or less than 15°C). Each scale has shown a recipe as a guide for designing dynamic textile surface patterns. These recipes are reliable references for any types of leuco dye-based thermochromic inks such as water-based or UV cured. This paper has also demonstrated the actual effects of leuco dye-based thermochromic with the aim to help designers achieve more advanced textile surface patterns (figure 23).

Finding the exact color of printed fabric using thermochromic ink in Photoshop, and matching the color theory vocabulary to describe color of printed fabric were the main limitation of this experiment. One suggestion for further studies would be a technical investigation in Photoshop to make a color index of leuco dye-based thermochromic inks transition.

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References:
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. Collins and Wilson (2012) discuss an investigation in to 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 (Wlodkowski, 1999), and adopt it to my own way of thinking about planning (Ginsburg & 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.
chosen inks was 27°C and 15°C. 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.

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-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), light black (17-0613 TCX), magenta (17-2250 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 Figure 2).

![Figure 1.](image)

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-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), light black (17-0613 TCX), magenta (17-2250 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 Figure 2).

Figure 2. shows how the effect of printed fabrics produced by the mixture of 3gr of ink with activation temperature 15°C and 27°C with 97gr of extender look like at ambient temperature (20°C). 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°C).

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 (11-2509 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 compared 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: greenish-orange (16-0540 TCX), grayish-orange (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).
The activation 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 (12-6752 TCX) (see Figure 5).

The third result is that by decreasing the temperature to a level equal to or lower than 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. The result of cooling the fabric 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 5. shows how the effect of cooling the printed fabrics produced by the mixture of inks with activation temperatures 27°C and 15°C look like compared with the one at 20°C. The effect of cooling (at 30°C) the fabrics printed with the mixture of the inks with activation temperatures 25°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) look like at ambient temperature (20°C). From bottom to top: the result of mixing the blue and red inks with activation temperature 15°C and blue, magenta, turquoise and orange inks with activation temperature 27°C and the yellow textile pigment paste at ambient temperature (20°C).

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).

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.

Figure 7. shows the effect of cooling the printed fabrics produced by the inks with activation temperatures 27°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 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 produced the dark blue and dark red (18-4045 TCX) and yellow fabric (15-1920 TCX) (see Figure 7).

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.
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).

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).

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).

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).
Previous approaches Albers (1975) and Collis and Wilson (2012) reveal that essential knowledge regarding (Ginsberg & Wlodkowski, 2009). students had hands on practice with high degree of designed created active learning environments where textile designers. The length of workshop and plan thermochromic ink in a proper color systems. are designing dynamic surface-patterns (Drew, 2004) & the properties of thermochromic inks supported by learning (Sork, 1997). exercises created opportunities for students to craft an understanding of the design potential of using leuco dye thermochromic inks through experimentation and individual exploration. 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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PAPER III

Performative interactions between body and dress: thermochromic print in fashion

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Introduction

In 1991, the Generra Sportswear Company of Seattle released a new line of clothing called “Hypercolour”, which consisted mainly of T-shirts and shorts that changed colour when in proximity to heat (Wieland Nogaki, 1992). Although they were initially in high demand, the company went bankrupt after a year due to mismanagement and fading demand, the latter probably explained by the fact that the colour effect could be permanently damaged, particularly when the clothing was washed in higher temperatures than recommended, ironed, bleached, or tumble-dried. Regardless of the initial success of the clothing line, the Hypercolour T-shirts opened up a new space for exploration in the field of interactive garments.

Several researchers have explored different methods for activating and controlling interactive garments. A project known as Reach (Jacobs & Worbin, 2005) is a significant example of the application of thermochromic inks in the area of wearable everyday objects. This project was designed to investigate methods of self-expression in terms of personal ways of expressing one’s personality in public spaces through direct physical interaction as well as through the sensing of social context; through this work, the researchers proposed and explored alternative forms of social communication.

Later, a related project, entitled Costumes (Bondesson et al., 2006), consisted of three interactive garments worn by dancers and a thermochromic printed wall. This project in the context of a performance explored the expressive capabilities of interactive textiles through the relationships between body and space; here, dancers wore interactive dresses equipped to send out a radio signal that changed with their body movements. The receiver was placed in a thermochromic printed tapestry hanging from a wall, and the changing signal caused changes of colour in the tapestry; thus, the choreographed body movements of the dancers affected the visual expression of the wall in real time.

Another project, entitled Repetition (Damireouc, Lundstedt, Persson, & Satomi, 2012), was also designed to explore relationships between body and space as a method of remediating, in an interactive way, the wearer’s body movements. The interactive wall hanging incorporated electronics that react to the tactile interaction provided by a dancer who wore a garment printed with thermochromic ink. After coming into contact with the heat-conducting threads, which were knitted into the textile wall, the interactive garment changed colour according to the movement of the body.

Subsequently, the design project Utslack (Lubbers, 2013) was an interactive lace lingerie garment, which combined an old bobbin lace technique and printed thermochromic thread. The interactive garment promoted physical contact, interaction, and awareness between individuals through changing colour, as electrically conductive threads in the garment produced heat as a result of one person touching the wearer.

While the aforementioned researchers and their projects have presented a range of combinations according to digital prints and technology and created interactive garments
which prompt reconsideration of the extant relationships between human behaviour and the surrounding environment, these researchers did not consider the role of the body and those cultural conceptions that may be utilised in an inter-active manner with a dynamic printed garment or the world as a whole. Thus, this project addresses the gap between fashion and technology by taking the early nineties and the digital approaches described here. It explores possibilities of expressing one’s personality in more ways, that is, how to integrate dynamic prints into the construction of the garment in order to improve its interactive qualities. Specifically, the paper reports on the use of dynamic prints in garments as well as ways of adapting cutting patterns to the dynamic printing methods. Moreover, in exploiting the interactive quality of a garment, focus is placed on the performative aspects of the garment, which is the function that establishes the interaction between the wearer and the garment; hence, performativity as such is derived from Austin’s (1957) speech act theory, that is, as the function of an object to induce a bodily reaction based on its form and matter. Thus, in this particular case, the performative function of the garment implies the wearer’s ability to perform an action upon the wearer through the behaviour of the dynamic prints in combination with the construction of the garment. Thus, ‘performative’ and ‘performativity’ are here used in their broad sense and not limited to or focused on the reiterative power of political or gender discourses (cf. Butler, 1993).

Design process

The design process was initiated by testing how dynamic prints produced with leuco dye-based thermochromic inks behaved in relation to body temperature; as thermochromic inks are applied on textiles and activated by heat and the human body, which is almost always covered in clothes, they behave like a heat source. A recipe consisting of 25% ink and 75% binder was selected (Kooroshnia, 2013) in order to provide a good textilising-printing effect with maximum colour intensity at ambient temperature. The printing method used was silk-screen printing. To determine the correct fabric for use in the designs, which is in keeping with the use of different fabrics and thicknesses, including woven and knitted cotton, silk, wool, and silk organza. Different colour combinations were also tested to find out which combinations most clearly demonstrated the colour transitions and created bright and visible dynamic prints, as well as to reveal dynamic colour changes in the pattern, which remained latent until activated. The colours were mixed and printed on fabrics in such a way as to exhibit very dark colours at ambient temperatures (20°C), and bright colours after interacting with the body. Based on the hypothesis that dynamic prints respond to and expose specific, intimate parts of the body (relating to stereotypical cultural conceptions of being naked), two dresses with different degrees of defined nude body representations were designed. The goal of the designs was to cause the wearer to enact performative bodily gestures, instead of to communicate certain symbolic aspects of cultural value such as class, gender, and social attitudes (cf. Davis, 1992; Kaiser, 1997), which may be considered the primary goals of clothing in terms of fashion (cf. Goffman, 1959; Simmel, 1904) or in the form of social expression of human conditions (cf. Crank, 1994; Wilson, 1965).

The concept of nudity was chosen because, as Lamp (2010, para. 86) argued, ‘no society exists that would consider a person clothed if the genitals are exposed, regardless of how thoroughly the rest of the body is enclosed in parkas and snow pants and gloves.’ Moreover, ‘most societies in the twenty-first century find complete nudity in public inappropriate.’ The critical aspect of Lamp’s argument in relation to the research is that ‘all concepts of nudity include fundamentally the exposure of the genitals and then, for some, other parts of the body as well’ (2010, para. 86). Thus, clothing is a means of exploring the notion of being dressed or undressed, depending on the garment’s relation to the body (cf. Barnard, 2002). Privacy or shyness, on the other hand, relates to the gestures and acts of the wearer as they react to and counteract the experience of sensations related to nudity.

In respect to the above notions, dynamic prints were placed near to specified body parts in order to enhance, control, and integrate the changing effects which occurred during the performative photography sessions. In order to observe the colour-changing effect on the garments and the performative qualities of the dresses, two models were asked to wear them in a semi-public space. Observations of the models wearing the garments in a semi-public place conducted by a male observer. The models were given no other instructions than that they were to wear the dresses during a photography that would last for around 15 minutes per dress. During the photographing session, the models only occasionally received instructions regarding their facial expressions, but were continuously given instructions regarding movement and posture. In the semi-public space, the garments reacted in any way expose the wearer’s genitals or any other parts related to nudity, such as, for example, conscious reactions related to nudity or any other obvious motive (see Figure 3).

An analysis of the photographs from the perspective of the models presented above, especially considering the fact that all concepts of nudity include exposure of the genitals or other parts related to nudity such as, for example, reactions related to nudity or any other obvious motive (see Figure 3). Whereas the focus in the first two series of dresses was largely on forms, pattern cutting, and dynamic prints, the design of the final two series of dresses centred on defined decision in relation to nudity the dresses in these two series were created with prints consisting of black shapes, using black conventional textile pigment and dynamic print produced by black leuco dye-based thermochromic ink. The aim of this series was to break up the blotchy shapes and create an ambiguous but defined focus on the area of the
Figure 1. The interaction between the garments and the wearer’s body, displaying the patterns which were unique but wild, messy, uncontrolled, impossible to reproduce, and temporary.

chest and bottom of the dress through a close but not skinny fit of the dress. The first of these dresses was a long cotton dress made with a straight-edged black shape on the left side and a long black dynamic print on the right. The reason for choosing this cutting pattern was to extend the colour-changing effect over a larger area, as well as to create a greater contrast between colour and form based on a clearer shift in print alongside the whole of the body, including the seat and chest, and thereby partially outlining the surface of the body underneath, and adding further contrast and emphasis by making the other half of the dress in a non-dynamic black fabric (see Figure 3).

Throughout the 15-minute-long photographing of this dress (Figure 3), the model orchestrated her movements so that, rather than trying to avoid exposing body parts, she appeared to embrace such occurrences and increased the dress’s articulation of the outline of her body, drawing further attention to the bottom of the dress and to the chest through her postures. Whether the performance was a reaction to an unspoken expectation or a natural act was, however, difficult to ascertain (Figure 3).

The second of these dresses was a silk organza dress, printed with black leuco dye-based thermochromic ink, except for the areas around the chest and crotch, which were printed with black block shapes, which did not disappear entirely when activated by heat thus framed the areas of the dress covering the seat, crotch, and chest. By wearing the garment, the body temperature caused the dynamic prints to disappear in the blink of an eye, leaving only the three black blocks. Thus, although the body was fully covered, it appeared to be naked, offering an interesting interplay between what was on display and what was hidden (see Figure 4).

For the duration of the photographing of this dress the model attempted to adjust her posture, mainly by turning her back against the photographer and male observer for most of the time during the session and keeping her pose very straight and upright so as not to increase the changes...
in the dynamic print. On several occasions, when she was asked to face the photographer, the model either covered or kept one or both her hands close to her crotch (see Figure 4).

Discussion and conclusions

This research project explored several possibilities for developing items of clothing that may also function as interactive tools through using dynamic print in the design and construction of garments. It focused on the shape of the body and its temperature zones. Body temperature was a dynamic, rather than stable, design variable that provided challenges for us, while simultaneously offering a foundation for a new area of wearable communication. In this research project, design decisions were made after analysing the photos taken of the garments developed for the research.

The initial tests indicated that the interactive garments reacted to body temperature very quickly, particularly in parts of the garments that had direct contact with parts of the body. The results revealed a unique expressiveness in each garment due to the individual’s distinct body shape and temperature that in turn highlighted the role of body parts in the garments that had direct contact with parts of the body. The results revealed a unique expressiveness in each garment due to the individual’s distinct body shape and temperature that in turn highlighted the role of body parts in the garments that had direct contact with parts of the body. The interaction between garment and the body has not only created chaotic and impermanent patterns, but has led to what may be regarded as a new engagement with clothing.

As with any research project, this project has a limitation. The mixtures of thermochromic inks with conventional textile pigment paste always changed from a dark colour to a bright one, a limitation to design capabilities. The technological applications of color chemistry and construction of garments. It focused on the shape of the body and its temperature zones. Body temperature was a dynamic, rather than stable, design variable that provided challenges for us, while simultaneously offering a foundation for a new area of wearable communication. In this research project, design decisions were made after analysing the photos taken of the garments developed for the research.

For these reasons, the concept of fashion may be understood in the dynamic print. On several occasions, when she was asked to face the photographer, the model either covered or kept one or both her hands close to her crotch (see Figure 4).

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EXPLORING THE RELATION BETWEEN TIME-BASED TEXTILE PATTERNS AND DIGITAL ENVIRONMENTS

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Abstract

Presently, digital sketching environments have come to be used as a complement to the traditional manufacturing techniques for textiles; the research presented here looks into the area of time-based patterns and their relation to digital tools and textile structural techniques. Thus, the aim of this work is to expand on the existing methods used by designers, and to explore ways for capturing and expressing the complexity and temporality of pattern changes in textiles. Furthermore, our result sketches a method for using dynamic colors to design complex surface patterns for textiles by utilizing methods that facilitate the hiding and/or revealing of multiple colors and shapes on the printed surface of the textile; this method is discussed in connection to the different expressions that can be achieved by using knitting as media for print.

Keywords: leuco-dye based thermochromic inks, dynamic surface design, time-based textile patterns

1 Introduction

In textile design, the relationship between the material and the graphical drawing is quintessential to the definition of the surface pattern. The design of surface patterns for textiles has traditionally been supported by a range of manufacturing techniques, e.g., screen-printing or structural techniques such as Jacquard knitting or weaving; thus, the material itself has come to play an important role in the definition of the expression together with colors and forms. Accordingly, these established methods have allowed the designer to explore the synergy between the surface pattern and the character of the material texture in the design process. As computer software has come to be used as a complement to the traditional manufacturing techniques in the design process for knits and weaves, a wide range of digital environments that support the design process of surface patterns has emerged. These environments are capable of creating either static (e.g. Adobe Photoshop and Corel Draw) or dynamic forms (e.g. Processing and Java). It is possible that digital tools may not just introduce new aesthetics but a different way of sketching complex patterns by introducing digital elements such as pixels and vectors as design fundamentals [1]. In structural techniques for the design of surface patterns, i.e. Jacquard weaving and knitting, bitmap images have become mediators between the digital environment and the physical world, facilitating the translation of digital images into textile constructions; thus, the manner in which digital elements, such as the pixel, are defined become fundamental to the translation of the depth of the pattern expression. Compared to the solid, monochromatic fields produced by screen printing, the ability to define the properties of individual pixels in digital printing allows for the creation of a different kind of surface expressions, which are based on gradation and an unlimited range of colors. Examples of artistic works explore the design potential of digital pattern design and which proposes ways to manipulate a surface expression in order to create illusions in the perception of the surface pattern in space are, or enhance the sensuality of the material by creating an illusion of depth and volume[2, 3].

Moreover, the research presented here looks into the area of time-based patterns and their relation to digital tools and textile manufacturing techniques, aiming to explore methods for capturing and expressing the complexity and temporality of pattern changes in textiles. In so doing, a new area for textile design explorations is framed.

2 Designing dynamic surface patterns for textiles

In addition to existing digital methods for surface design, new techniques for coloring textiles, such as printing with thermochromic inks, contribute with rich variables to the design of dynamic expressions in physical textiles, compared to conventional textile materials, which have static expressions, thermochromic inks are able to change between multiple states; thus providing a range of different expressions in textiles. Leuco dye-based thermochromic inks have the ability to change color in response to temperature variations; these changes are reversible, which allows for repeated changes from state A to state B and then back to state A again [4]. In the search of a conductive textile medium on which to print thermochromic inks, some research projects have taken to exploring different ways of combining structural textile techniques, such as weaving, with the aim of finding a method for controlling and composing with the temporal and spatial activation of the dynamic printed patterns. Dynamic Double Wove[5] and Shimmering Flavour[6] are two experimental projects which investigate the interactive potential of printing with leuco dye-based thermochromic ink on textiles; the inks were used in combination with woven structures. This project discusses the complexity of designing dynamic surface patterns and proposes a method for relating the gradual changes in temperature to the changes in color and shades when designing time-based expressions for textiles [cf. 7]. The research projects mentioned above all consider weaving only as the role as a structural fabrication technique for conductive textile materials to print the patterns on, and as no other printing methods besides conventional screen-printing were used, however, these methods are limiting the depth that can be achieved in the surface expressions by using dynamic colors. Although the contributions made by these research projects improve on the understanding of the aesthetic qualities achievable through the use of leuco dye-based thermochromic inks in combination with heat-profiling circuitry, a great deal of work remains to be done on the aesthetical possibilities inherent in textile structural techniques and how to relating them to the printing process, i.e. proposing methods in which the conductive textile structure is considered as part of the design process and in which the depth of the printed pattern is included in the sketching. The research project presented here takes as its point of departure the vast complexity of the surface patterns possible to design using digital printing techniques, and focuses on exploring mixed methods as synergies between physical and digital media i.e. to create new ways to design dynamic textiles. Thus, the aim of this work is to expand on the existing methods used by designers translate complex time-based patterns into textile surface expressions by utilizing methods that facilitate the hiding and/or revealing of multiple colors and shapes on the printed surface of the textile. Furthermore, our result sketches a method for using dynamic colors to design complex surface patterns for textiles, which will be discussed in connection to the different expressions that can be achieved by using knitting as media for print.

3 Methods

Since the project explores the relation between programmable textiles (supporting and activating media) and thermochromic prints (reactive media), the design experiments presented here involved three layers of exploration:

1. methods of knitting patterns which allow the conductive circuits to be hidden from the surface of the textile, based on inlay techniques and knitted on a single or double bed machine;
2. a method of forming temperature sensitive color mixtures using leuco dye-based thermochromic inks;
3. a method of printing a dynamic surface-pattern on textiles using Offset method of printing with temperature sensitive color mixtures;

In this research project, reversible and water-based leuco dye-based thermochromic inks, with an activation temperature of 31°C were used. A recipe consisting of 25% ink and 75% binder was selected [8] in order to provide a good textile-printing effect with maximum color intensity at the ambient temperature. The printing method used was traditional hand silk screen printing, and the size of the silk-screen mesh was 43 threads per centimeter. For the first series of experiments, black thermochromic ink was mixed with orange textile pigment paste.

1. Methods of knitting patterns which allow the conductive circuits to be hidden from the surface of the textile, based on inlay techniques and knitted on a single or double bed machine;
2. Printing was explored in relation to three different types of knitted structures:

1. Single bed knit: The first structure was a single jersey cotton fabric with conductive yarns inserted into every sixth wale using loops and floats as shown in the picture below. As the textile was heated, the first visible change appeared after 5 seconds as the loops created a clear shape on the printed layer. After 20 seconds of heating, the floats on the...
back of the textile structure became visible, changing the color of the whole print, as the shape of the wale was mirrored by the pattern created by the heat. After 30 seconds maximum diffusion of the pattern was achieved in the shape of the conductive wale (see Figure 1).

Figure 1 Single Jersey structure showing (from left to right) the colour change after 5, 20 and 30 seconds

1.2 Double bed rib: The second structure was a full rib knitted in cotton with the conductive yarn knitted in every sixth loop on the front bed and as a tack stitch in every third loop on the back bed. When the textile was heated, the first visible change took place after five seconds as the loops became visible as diffuse dots on the printed face. After 20 seconds of heating, the floats between the beds became visible, changing the color of the whole print, as the shape of the conductive wale was mirrored by the pattern created by the heat. After 30 seconds the conductive wale was fully heated mirroring the tack stitches from the back bed to the printed front of the surface, at which point the pattern took on the diffuse form of a straight line (see Figure 2).

Figure 2 Double bed rib structure showing (from left to right) the colour change after 5, 20 and 30 seconds

1.3 Jacquard net structure (1X2): This type of structure allowed the conductive threads to be embedded only in the front side of the knitted fabric, thus enabling the textile material to be heated so as to form specific patterns, and by adjusting the density of the conductive loops in specific places in these patterns it was also possible to vary the textures of the material. After 5 seconds of heating, the shapes of the pattern became visible, and after 20 seconds, the floats between these shapes became visible as the heat changes the color of the whole print; in this way, the textile surface is divided into areas with different visual textures. After 30 seconds of heating maximum diffusion of the pattern was achieved, at which point the printed layer displayed the diffuse form of a straight line (see Figure 3).

Figure 3 Double bed rib structure showing (from left to right) the colour change after 5, 20 and 30 seconds

During the conducting of these experiments, it was observed that the area around the interface between the knitted material and the printed layer reacted to the heat emitted by the conductive yarn. The shape of this area was circular due to the shape of the stitches, and its radius depended on the length of the stitches; the color change introduced an offset radius of up to 4 millimeters around each stitch. The precision with which the surface pattern embedded in surface of the knitted fabric was translated by the heat depended on the distance between the loops of conductive yarn which came in direct contact with the printed layer, and also on the amount of heat applied. In order to achieve a pixelated expression, the heat has to be planned so as to turn on/off at five-second intervals, and for an organized expression, the distance between the loops has to exceed the size of the offset circle around each stitch. For the exact shape of a whole wale of knit to be transferred to the printed surface by the heat, the conductive threads have to stay activated for 20 seconds; if the activation time exceeds 30 seconds, the knitted line becomes completely diffused. The times stated here are primarily included to facilitate comparisons between the examples, as the exact times vary with the amount of current used.


The results of the experiments presented above highlighted the need to expand on designers’ possibilities to create more innovative dynamic surface patterns than offered by existing methods, and to do so by utilizing a technique where multiple colors and patterns are hidden and/or revealed. Thus, further experiments were conducted to accomplish this.

In order to hide and reveal more than one latent color of the surface pattern, there was a need of forming temperature sensitive color mixtures. For hiding and revealing each color, temperature sensitive color mixtures had to be prepared. The first of five temperature sensitive color mixture was made by mixing magenta, yellow, orange and black leuco dye-based thermochromic inks with a cyan textile pigment paste, resulting in a dark grey below 31°C and cyan at or above this temperature. The second mixture was formed by mixing cyan, yellow, orange and black leuco dye-based thermochromic inks with magenta textile pigment paste, giving dark grey below 31°C and magenta at or above and so on. All five temperature-sensitive color compositions looked similar at or below 31°C, and produce five different color transitions above 31°C.

The work illustrates the possibilities of having one common background color below the activation temperature of inks, which if heated, generates a multi-colored background at equal or above the activation temperature of the inks. In contrast to the existing methods available to designers, in which thermochromic inks are used to provide multi-colored patterns which become transparent when heated, the examples in this paper illustrate how to design dynamic patterns which display a single color at temperatures below the activation temperature, and a multi-colored at higher temperatures (see Figure 4).

Figure 4 Pictures showing one common background color below the activation temperature of inks, which if heated, generates a multi-colored background


In the paper printing industry, the offset litho printing method is one of the most commonly flat printing techniques used for printing full-color images or photos; it is performed in a series of steps starting with process of color separation, during which the image is decomposed into the four process colors (CMYK), and translating each color layer to halftone. A Persian inspired, full-color surface pattern was digitally designed and prepared for four-color printing in Photoshop using the Channels window; this included creating four halftones by selecting each channel in turn and exporting the result as a bitmap image. Based on the principles of CMYK color separation, four temperature-sensitive color mixtures were prepared. The four temperature-sensitive color mixture resulted in a gray-brownish color below 31°C and cyan, magenta, yellow, and black above 31°C. The layers were printed in succession from light to dark colors, which means the temperature sensitive color mixture made by black pigment was printed last, i.e. over all the others (see Figure 5).

Figure 5 Pictures showing (from left to right) the printed pattern on white plain cotton-wove at ambient temperature (20°C) and the effect of heating

When trying to find the lower limits of printable details, an experiment was made several times on a knitted without a successful result, i.e. when the prints were heated up the color changes did not turn out as planned. When trying out the same print on a more compact weave, it was not only clear that the more compact textile gave a higher resolution when it came to details in terms of millimeters and inches, which one can assume; the weave also gave a higher resolution in the color changes. In fig 6, for instance, one can see a difference in color of the two fighting animals, whereas there is no difference of the animals color in the less compact knit. The reason was that an accurate overlapping of print on knitted layer was not possible to be achieved with a looser knitted structure (see Figure 6).
4 Expressions

The complexity of a design process of a printed pattern increases when time is added as a design variable. Colors are no longer static or limited to binary changes between A to B to A; rather, in our design experiments, they change from A to 2 and then back to A again with any number of steps in between, and the speed of these changes vary as it is determined by whether the conductive yarn is heating up or cooling down. The complexity increases even further when these parameters are taken together with those representing material properties, to the point where it becomes exceedingly difficult to predict the exact outcome of a design process [7]. Thus, the conducted experiments take into consideration all variables relevant to the understanding of the final pattern expression, even those representing material properties such as the character of the yarns, stitch length, and the structural properties of the textile material. Three overlapping layers of information, i.e., knit, ink, and print, have been identified, and the method is discussed in relation to the basic expressions that can be achieved by using knitted materials as printing media. Consequently, two types of surface pattern expressions are presented. In the first type, the expression of the knitted material defines the foreground of the dynamic surface pattern, with the printed area as the background; the surface reveals a visual textual expression based on knitted forms as the one of the printed layer transforms as the result of exposure to heat. Thus, the structure of the knitted material adds to the expression of the printed layer, and the diffusion of heat over time creates the possibility to design new time-based expressions, e.g. revealing the knitted structure in order to create the illusion of a three-dimensional texture or the emergence of an unexpected textual pattern of colors (see Figure 7).

For the second type of surface pattern expressions, the expression of the print defines the foreground, creating a complex pattern, and the knitted structure forms the background; as the knitted structure is heated, the surface reveals multiple colors and shapes within the initial pattern (see Figure 8).

5 Discussion

The increased involvement of computation in the design process brings two questions to mind: How does it influence the textile expressions designers create? Is it even fruitful to consider the idea that it may give rise to certain aesthetics? Digitally printed textiles or three-dimensionally printed garments do in fact materialize intricate design expressions, based on complex design variables and the relationships between them; these expressions carry a distinct depth, sharpness, and accuracy regarding details which result from the digital parts of the design process. As Figures 7 and 8 illustrate, textiles add to the digital a strong material expression based on the structural techniques used. Consequently, the introduction of computational properties may also be regarded from different angle; for example, the same raster principle used to enhance the expression of depth in digital printing can be applied to hand silk screen printing with thermochromic inks (a type of ink which is still incompatible with digital printing). In the same manner, a knitted structure can be regarded as a set of pixels, although the type of stitch used is not a binary parameter as there is also a third possibility: the tuck. Moreover, a textile material knitted on a flat bed or double bed machine and printed with thermochromic inks is able to alter between multiple colors and visual textures; thus, such a "pixel" would not only need to contain information about the surface structure of the material but color values as well. When combining two layers, e.g. a printed layer (with variables such as color changes and printing method) and a knitted material (type of structure) they will together define the qualities of the digital unit (see Figure 9). The digital environment may be a meeting point between different design methods where the pixel becomes the fundamental unit for the communication of the pattern design, and from which the pixel takes the step into the physical space in the form of a stitch. In this perspective, the smallest element used to design a pattern intended for printing does not only contain information about color, but also about the conductive structure of the textile material; thus, it becomes the bearer of the very idea that determines the visual appearance and the dynamics of the final product.

References

EXHIBITION

Kooroshnia, M., 2011, MaskProceeding of Ambience11, November, Borås, Sweden
Mask

This collection of masks is designed to give an aesthetic warning if the wearer is running a fever or the concentration of allergens in the air exceeds a certain threshold. The pattern printed with thermochromic ink changes color when the exhale exceeds 37°C.

The collection comprises a series of different prints and three different shapes of masks: a traditional surgical style, a wrap-around scarf, and a full-face sinus mask. The latter also senses temperature increases of the forehead as well as around the mouth.

The idea is to create a stylish early-warning system at least for other people if not for the wearer.

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Images (top row): (left) ambient temperature 30°C; (right) after breathing. Note page: (left) ambient temperature 20°C; (right) after breathing. Photos: Jan Berg