Thermal Cards: From Classical Chinese Poetry to Designerly Lenses on Thermal-Affective Technology

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ABSTRACT

A “warm” smile? A “cold” rage? Thermal and emotional experiences are often tightly connected. In recent years HCI has investigated opportunities for thermal technologies to enrich user experience. However, our vocabulary for these experiences has remained limited and inexpressive: “hot”, “cold”, “warm”, “cool”. This limits our ability to describe and conceptualise experience, and impedes the exploration of design features for thermal and affective interaction. Our pictorial offers resources to enrich language and clarify the design space for thermal and affective technologies. We expand a recently developed theoretical framework based on Chinese classical poetry to present six lenses on thermal and affective experience. The pictorial also functions as a deck of design cards with a design exemplar. Together these resources can help researchers and designers conceptualise thermal experience, explore parameters for experiential design, and design technologies for rich thermal and affective experience.

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Authors Keywords

Thermal interaction; affect, emotion; experiential quality; design cards; design principle; cross-culture; Chinese poetry

CSS Concepts

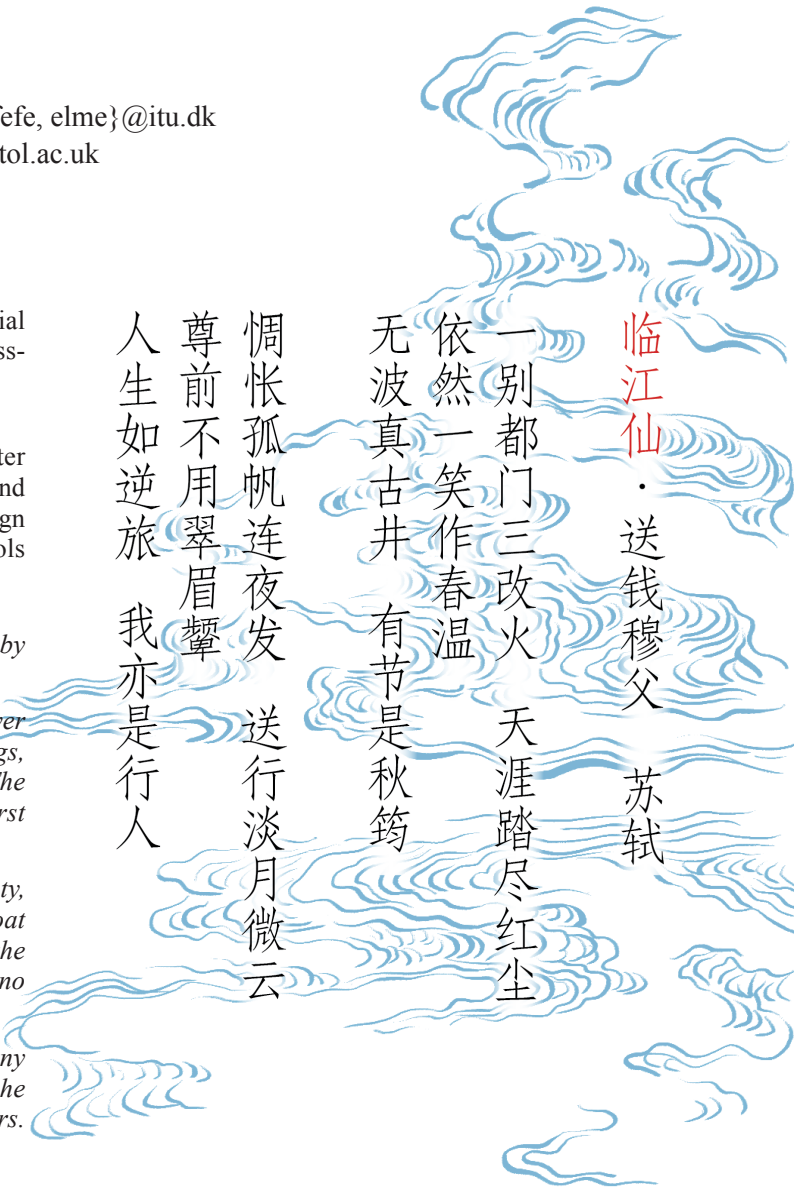
• Human-centered computing~Human computer interaction (HCI)~HCI theory, concepts and models~Interaction design~Interaction design theory, concepts and paradigms~Systems and tools for interaction design

Right: a poem by Su Shi: To the Tune “Immortal by the River”, Farewell to Qian Mufu

Su Shi and a close friend have been separated over years, through passing of many winters and springs, but find themselves together for a brief time. The smile of the friend makes Su Shi aware for the first time that the spring’s warmth has arrived.

The two friends are quickly pulled apart by duty, and Su Shi accompanies his friend to the boat which will take them away. They bid farewell in the chill moonlight. Su Shi regrets that he can travel no further.

Only the pale moon and the thin clouds accompany the friend on his journey. Su Shi reflects that he cannot frown for long. He is one of life’s travellers. This is his lot.



INTRODUCTION

Developments in multisensory technology enrich our interactive and affective experiences, from haptics [9] to olfaction [4]. In recent years, researchers have increasingly investigated the potential of thermal experience to support immersive, aesthetic and affective experiences [6].

Incorporating thermal modalities into technology brings both opportunities and challenges. Our everyday thermal experiences are often resonant, meaningful and emotive: from the stress relief of a hot bath, to the way sadness can feel externalised in a cold grey day. Thermal technologies present the opportunity to extend the embodied emotional range of interface design to address such experiences. At the same time however, we often lack language to analyse and express such experience, limiting our ability to analyse and specify experiences. Our experience of thermal qualities often remains implicit and difficult to articulate in language [6]. In contrast to the richness of thermal-affective experience, our everyday vocabulary for thermal terms is often sparse, and limited --- restricted to simple intensity terms like "warm/hot" and "cold/cool" [6].

To address this issue recent work has turned to Chinese classical Ci poetry to identify principles and language patterns used to describe and evoke thermal and affective experience [6]. Ci poetry is renowned for its rich first-person accounts of situated, embodied, first person experience [6]. Feng et al. conducted a grounded theory analysis of thermal experience in 154 Ci poems, building on the results to develop a framework to guide the design of thermal experience. That framework conceptualised the different experiential qualities of thermal experience, the interactions of these qualities with affective experience, and the role of senses beyond just direct thermal touch in creating thermal experience. The framework identified vocabulary and concepts, and applied these to the analysis of existing work.

However, this leaves a space for "designerly-oriented" principles [12] which can effectively support the use of the framework for developing new designs. In this pictorial we translate Feng et al's framework, drawing on ideas from Stolterman about how design theory can prepare designers for action [12]. We develop key elements into a set of easily referenced "design cards". In this translation, we curated key elements which have been less represented in previous design research. These elements were interpreted through our design practice and formulated into design principles. We then selected poetic extracts from the original paper that illustrate ideas and serve as sources of inspiration. Translating the framework in this way frees the design concepts from the linear presentation of a standard paper format, allowing designers to find their own path. Designers can easily select and cross-reference between cards to support ideation, or use them to structure discussion and co-design. We then describe a design exemplar which illustrates our own application of the lenses in design. Finally we relate our approach to Stolterman's ideas about design rationality and the avoidance of rigid guidance [12], and discuss the particular importance of this for thermal-affective design. To our knowledge this is the first paper to attempt to bridge between thermal affective experience and design knowledge in this way.

HOW TO READ THIS PICTORIAL

After this introduction, below, we provide a map of the document. From pages 3 to 9 we present 6 design cards, beginning with an overview of the design card section on page 3. The cards themselves, on pages 4 to 9, present six lenses on thermal-affective experience and design. Each page includes an explanation, inspirations for articulating experiential aspects, and related design principles. Each card is marked by a different colour, which we use to link the lenses across the pictorial. Readers can read the cards in sequence or begin with any card relevant to their interests. Where deeper engagement is desired on any lens, more detail is available in [6]. The cards are followed, on page 10, by a design case which demonstrates the use of the design cards, and finally reflections on the design cards on page 12.

A NOTE ON THE TEXTS

For illustration and inspiration, this pictorial includes extracts from Classical Chinese poems in Chinese and their English translation. Each has an ID link to the full poems attached in the auxiliary material package.

OVERVIEW - SIX LENSES FOR THERMAL AFFECTIVE DESIGN

Thermal cues:

1/6

...are multisensory

Thermal experience is not just about touch! We see heat haze over hot tarmac, smell decaying leaves in autumn, and wood smoke in the winter air. How do the different senses contribute to thermal experience? We discuss five design parameters that can help explore the sensory space of thermal design.

2/6

...have material qualities

Cold, hard steel feels different from soft white snow. Sitting in a hot bath is different from lying in the sun. The quality, meaning, and emotional resonance of a thermal cue is influenced by its material quality. We discuss four design parameters that can help designers consider the role of materiality in thermal design.

3/6

...have temporal aspects

Think of the sharp shock you feel when stepping into cold water, compared to swimming int the same water a few minutes later. Imagine the coolness of a summer evening contrasting with memories of the day's heat. Changes in thermal experiences carry meaning. We discuss four design parameters to help designers work with thermal change over time.

4/6

...can be perceived to have agency

Winter winds are "biting", iciness "penetrates" warm clothes, and fierce summer heat saps our strength. Thermal cues can give an implicit feeling of agency: dominating, soothing, active or passive. Attention to thermal agency could help designers communicate urgency, energy, or calm, or help ensure the acceptability of thermal gadgets in everyday life.

5/6

...interact with emotions

Temperatures don't map neatly to emotions. Depending on the context cold may feel depressing or invigorating, heat can be associated with anger, energy or comfort. We discuss ways that designers can think about the thermal cues as they invoke and augment emotion, and support mindfulness or reflection.

6/6

...contribute to aesthetics

How can we understand the aesthetic contribution of thermal experience? This section brings together ideas from the other five lenses to address aesthetic experience. We give examples mapping descriptions of aesthetic experience to design principles.

THERMAL CUES ARE MULTISENSORY

When designing thermal cues, our thoughts may immediately jump to thermal-haptic modalities. However, thermal perception can involve multiple senses: visual (e.g. "warm" colours), auditory (bright or "warm" timbres), or olfactory (cold menthol or spicy scents), to name just three. Feng et al. found that, in some cases, haptic sensation may play a small, or even absent, role in thermal perception [6]. Often other senses take the lead in conveying thermal experience. This card explores those possibilities.

Haptic
Different body areas perceive differently. Texture, pressure, friction influence quality of thermal cue.

Visual
Luminance, colour (saturation and hue), and visual symbollism express thermal qualities.

Ofactory
Heat drives scent diffusion (the sea smells stronger in summer). Menthol "smells cold", some spices "smell warm".

Auditory
Cicadas are associated with warmth, howling winds with the cold, etc.

Interoceptive
Thermal perception within body, influenced by drink, food, exercise, etc.

Gustatory
Chilli feels hot, bitternes can seem cold, tea tastes cool (to many Chinese!)

SOURCE OF INSPIRATION

This extract [from To the tune: the return of Mr Ruan] (ID1) illustrates how multiple senses can come together to create a single episode of thermal experience.

Olfactory
Incense diffuses readily in hot air

Auditory
The sound of seasonal insects is dampened by the dense summer foliage of the trees

"Green scholar tree and tall willows swallow the sound of the new-hatched cicadas, a humid fragrance blows among the (musical) strings. Incense flows under the green window screen and the sound of Weiqi (Go stones) rouses a daytime sleeper. Light rain passes, lotus leaves unfold, pomegranate blossoms waver in the air…"

绿槐高柳咽新蝉　薰风初入弦
碧纱窗下水沉烟　棋声惊昼眠
微雨过　小荷翻　榴花开欲然
玉盆纤手弄清泉　琼珠碎却圆

Visual
Heat-haze is a causal consequence of summer heat (an "indexical" cue), here it distorts the view of seasonal flowers

DESIGN PRINCIPLES

Consider harmony and reinforcement among the senses
Cues can be used in a congruent or harmonious way across different sensory modalities: e.g. red-hues, spicy scents and warmth in contact with the skin. This can create an integrated or even synergistic thermal experience: coherent and potentially amplified or immersive.

Use contrast between the senses
Contrast between sensory modalities can also be powerful: the scent of burning incense on a cold day, or the sensation of a cold drink on a hot day. Such contrasts can sharpen awareness of thermal experiences, or create aesthetic tension.

Substitute or replace experience across senses
Often, thermal haptic devices are not accessible or convenient. In such cases thermal information can still be conveyed via other senses. Users' past experiences can be leveraged to construct rich thermal experiences via sight, sound, scent, and taste.

Consider both internal and external thermal experience
Awareness of thermal qualities in the body may influence our experience of thermal qualities in the world around us. Think of thermal states induced by food and drink, or physical activities. These internal thermal experiences may be congruent with, or contrast with thermal cues from the technology (see above) and may influence the overall thermal experience.

Consider associations across senses
Psychologists have found that different senses connect and influence each other in many ways [14-16]. Examples include the association of vanilla scents with warmth, or cucumber scents with coolness. Such correspondences offer opportunities for harmony, reinforcement, contrast and substitution.

CROSS SENSORY EXAMPLES

Visual colour and brightness: Higher temperatures are often associated with higher level of saturation or brightness.
Taste: Intense coldness may be associated with a bitter taste.
Perception of mass: Extremes of temperature, both cold and hot, can carry a sense of heaviness.
Sense of motion: A coldness may be associated with the sense of falling (e.g. in the stomach in response to an unpleasant surprise).

MATERIAL QUALITY

Radiant warmth from sunlight or fire is experienced very differently than the enveloping, liquid warmth of a bath. The sun strikes us from one direction and can change quickly (e.g. as clouds pass). The warmth of a bath surrounds us and changes slowly. Equally, it feels different to touch a cold metal bar, soft snow or a wool scarf, even when these materials are at the same temperature.

Designers should consider how material qualities affect the sensation and meaning of thermal cues. Both the materiality of the thermal source, and the way materials (e.g. fabrics) mediate the transfer of heat. This is important not only when designing and implementing thermal cues, but also when communicating them [6]. Material qualities are concrete and familiar and can help users to articulate their experience, or define their thermal preferences.

This page presents design principles and material qualities which help conceptualise, design, implement and communicate the material nuances in thermal experience.

DESIGN PRINCIPLES

Directionality

Where does the thermal cue originate, and how does it project? Radiant warmth, or cool air arrive from a particular direction and may reach on particular parts of the body.

Enveloping thermal cues can create an immersive sensation. Moving thermal cues across the body can create flowing sensations and a sense of activity. Since direction, immersion, and movement can give a sense of "activity", or "dominance", directionality may influence **perceived agency** 4/6.

Thermal conductivity

Different materials conduct heat in different ways. Air conducts heat less strongly than water. A cold cue will be transmitted very quickly through metal, while wool will slow and diffuse it. Attention to conductivity in the materials which generate and mediate thermal cues opens up design space for thermal dynamics. For example, designers may use active mediating layers, which inflate with air [e.g., 5] to change the degree of insulation. This principle applies to the design of both haptic and **multisensory** thermal cues 1/6.

Texture

Material texture influences the contact area with the skin. Coldness may feel less intense when mediated via a coarse texture than by a fine texture. Designers can choose or fabricate particular textures to mediate thermal cues. Textures can even be updated in real-time to create evolving experiences, via shape-change technology for example [5]. Manipulating texture may also influence other haptic experiential dimensions, such as perceived friction or pressure [5], which may create harmonies or contrasts 1/6.

Stiffness/Softness

Think how, on a winter's day, soft snow can feel more pleasant than a shard of ice, and think of the different actions each affords. The softness and texture of the material mediate the contact of the thermal source with the body, and also the affordances for interacting with the thermal source.

Beyond designing with materials of different softnesses, designers may manipulate the firmness of a material over time: for example, using soft robotics techniques [1].

SOURCE OF INSPIRATION

Feng et al. noted how some Chinese thermal vocabulary expresses material quality [6]

暖 **"Nuan": *radiant* warmth.**
"The sun's warmth (暖 nuan) on the mulberry creates a cascade of light" (ID2).

日暖桑麻光似泼

温 **"Wen": *enveloping, flowing* warmth.**
"With spring rain the last of iciness fades, warm (温 wen) wind comes to cold ashes" (ID3).

春雨消残冻　温风到冷灰

In other poems material qualities are conveyed by phrases rather than individual characters

Cold is mediated by the wind...
"Eager for signs of spring, flowers are hard to find and the west wind retains winter's chill" (ID4).

春意看花难　西风留旧寒

Or by fabric...
"The coldness penetrates the garment and sleeves" (ID5)

冷透人衣袂

TEMPORAL ASPECTS

Thermal experiences in everyday life are not static, but evolve over time. The shock of cold as we jump into a swimming pool is very different from reaching the same temperature over the course of several minutes. Feng et al found that in descriptions of thermal experience, memories of previous states contextualised each new thermal experience [6], pointing to the potential for experiences to contrast and accumulate over time.

Further, temperatures, and thermal preferences change over course of the day, and over seasons. How can technologies take this into account?

SOURCE OF INSPIRATION

"Dreaming, drunk with my wine cup,

Startled by the lake wind which brings a chill to my seat." (ID6).

醉梦尊前

惊起湖风入坐寒

"Changed into my thin robes, I taste the fresh green ant wine.

In time there comes a moment of wind,

a moment of rain,

a moment of cold." (ID7)

薄衣初试 绿蚁新尝

渐一番风

一番雨

一番凉

DESIGN PRINCIPLES

Change

Designers can look beyond momentary and static cues to consider how thermal experiences unfold and change in time. Sharp transitions are experienced differently than slow ones: they draw attention to themselves and may feel more "active" (**Perceived agency** 4/6) than cues that change slowly. Designers can control rate of change of transition between temperatures by specifying control ramps, or by using materials to mediate the change (**Material quality** 2/6).

Duration

A related parameter to consider is the time scale over which a thermal cue is sustained. The perceived strength and impact of thermal cues will be affected by familiarity and acclimatisation: A new, or changing thermal cue will feel different than one the user has adapted to, and so short durations will have a different effect than long durations. Different durations may have different affective connotations, and so may imply different kinds of agency (**Perceived agency** 4/6), issues which may be important in augmenting communication, for example [7].

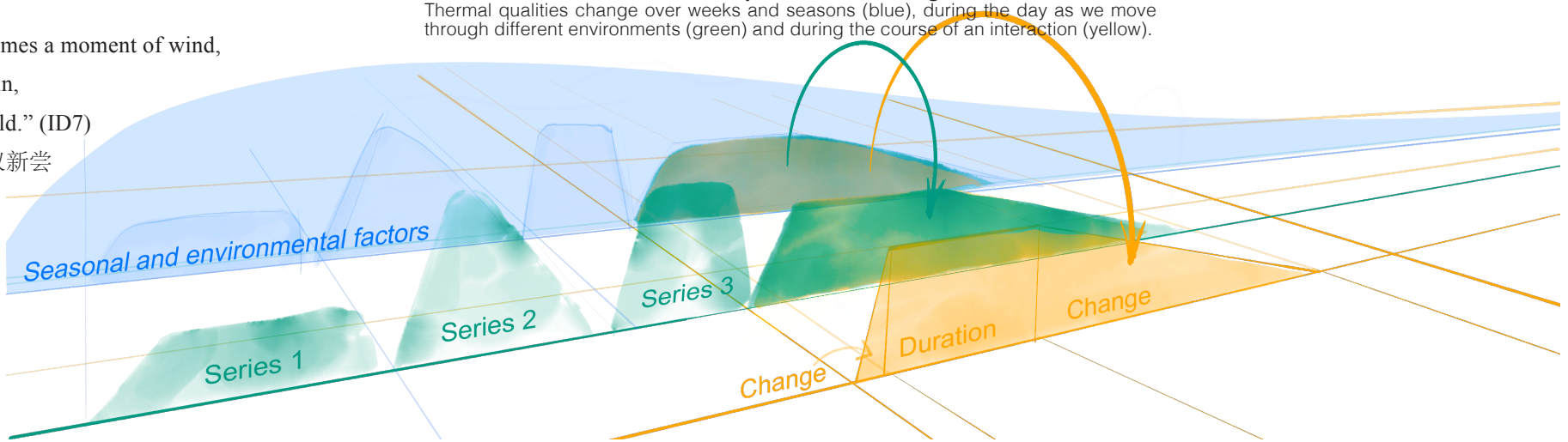
Seasonal and environmental factors

Reliability testing of technologies requires strict control of the environment. However, thermal technologies will be used in far more unpredictable and changeable conditions which may influence the perception of thermal cues. Some such issues are predictable: a warm cue that provided comfort during testing in a cool room may feel oppressive on a hot summer's day. Other effects are harder to anticipate: in very cold conditions, even body temperature stimuli can create a burning sensation (the "thermal grill" illusion [11]). This creates paradoxical effects, e.g. rubbing hands in cold snow can create a sense of warmth. How can your design fit into such experiences in the wider environment?

Series of thermal cues

Successions of thermal cues can accumulate in memory over time, allowing designers to work with contrast and synergy, to create more complex overall thermal experiences. For example, a cold blast of air, dampness, and a slowly growing ambient chill may evoke the mood of autumn (**Sensory Features** 1/6). Designers can take into account the role of memory and anticipation, and consider the effect of their designs at

Nested timescales of thermal experience with design
Thermal qualities change over weeks and seasons (blue), during the day as we move through different environments (green) and during the course of an interaction (yellow).



PERCEIVED AGENCY

4/6

In the poems analysed by Feng et al., many thermal qualities take on the appearance of agency [6]. Cold can seem aggressive (“the coldness penetrates the garment and sleeves”) or playful (“the satisfying breeze teases our sleeves”). At an intuitive level, people readily project imagined intentions and characters onto the world [3,13]. The association of thermal qualities with energy and metabolism perhaps makes this particularly natural in the case of thermal experience. This perception of agency may emerge from qualities discussed on the other cards. As such, perceived agency also offers a possible frame for coordinating these different lenses on thermal experience.

“I experience this thermal cue as …”

Active
“The spring rain dissipates the last of iciness” (ID8)

春雨消残冻

Pervasive
“Cold crows pack the sparse fences, competing to enjoy the jade blossoms of the cold plum tree” (ID9)

寒雀满疏篱 争抱寒柯看玉蕤

Intrusive
“Coldness penetrates the fabric of my robes” (ID10)

冷透人衣袂

Emerging
“An outline of warm wind appears through the fine cold mist ” (ID11)

嫩寒初透东风影

Lingering
“Eager for signs of spring, flowers are hard to find and the west wind retains winter’s chill” (ID12)

春意看花难 西风留旧寒

Aggresive
“A few cup of light wine, how could they resist (the chill), night arrives with a squall” (ID13)

三杯两盏淡酒 怎敌他 晚来风急

Diffuse
“pale moon by the west pavilion, chillness flows from it’s halo” (ID14)

西楼淡月凉生晕

Interruptive
“the pre-dawn wind beyond the curtain, dreams blow away without a trace”

帘外五更风 吹梦无踪 (ID15)

Dominant
“moonlight flies, lighting the ground straight as an arrow, coldness soaks the emerald autumn sky” (ID16)

桂魄飞来 光射处 冷浸一天秋碧

Passive
“the new season’s chill lingers on the pillow, dreams won’t come” (ID17)

一枕初寒梦不成

DESIGN PRINCIPLES

Thermal contrast
Larger, more noticeable thermal contrasts and sharp onsets or changes (**Temporal quality** 3/6) can appear active. For example, designers might use different temperature intensities in succession, or at different locations on the body.

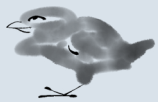
Proximity of thermal delivery
Thermal cues delivered via wearables or devices close to the body may be more supportive of illusions of active agency. Cues closer to the body allow for sharper contrasts, faster changes, and make it easier for the user to perceive discrete events and changes.

Thermal dynamics
When objects change in ways that don’t follow inertial laws, this can cause people to perceive intentional agency behind the change [3,13]. This principle might be used in the design of thermal cues, by controlling how cues rise, persist or fade away, in ways which mark them out from passive objects obeying physical laws. By coordinating change at different sites, designers may even create a sense of spatial movement to create very rich illusions of agency (**Temporal quality** 3/6).

Material aspect
Physical and mechanical features of materials mediate the delivery of thermal cues, which may define the character of thermal agencies. The same cold stimulus, for example, may feel less intrusive when mediated by soft fabric rather than a metal plate. Cues might also be combined with deformation of shape or texture to deliver a sense of active agency. (**Material quality** 2/6).

Multisensory features 1/6
Designers can explore consistent or inconsistent cues over multiple senses to investigate their impact on sense of agency. Congruent cues can create reinforcing synergies [6] which may make a thermal cue more pervasive and dominating. For example, heat pulses on the skin may be combined with reddish light, vanilla scents, and spicy flavours. Inconsistent multisensory cues, such as cold stimuli combined with warm scents and red colours, may be surprising and “unnatural”.

Are there circumstances when this kind of violation functions like the breaking of inertial laws, provoking attribution of intention? (see Thermal Dynamics, left)



INTERACTION WITH EMOTIONS

SOURCE OF INSPIRATION

"Warm rain then sun and breeze break the frozenness. Willow eyes and plum-blossom cheeks, I already feel the vitalisation of the spring heart." (ID18)

暖雨晴风初破冻 柳眼梅腮 已觉春心动 — **Warm - Vitality**

"Looking back I bid farewell to spring and turn to drink. The east wind breaks the thousand lines of my tears." (ID19)

回首送春拚一醉 东风吹破千行泪 — **Warm - Sadness**

"The strength of wine gradually disappears and the wind is soft, sou-sou *[a mimetic word for chill, fast wind]*, my broken hat is melancholy, too much in love to abandon my head."

酒力渐消风力软 飕飕 破帽多情却恋头 (ID20) — **Cold - Humour**

"The incense and the drunkenness fade away, leaving unmotivated grumpiness. The cold west wind hurries and speeds the fall of the paulownia leaves. Leaves falling, autumn falling too, loneliness grows." (ID21)

断香残酒情怀恶 西风催衬梧桐落
梧桐落 又还秋色 又还寂寞 — **Cold - Grumpiness and loneliness**

Thermal experience influences emotion, and emotion influences perception of thermal cues [6]. Commonly researchers have associated warmth with positive affect, cold with negative affect; yet there are cases when such simple associations break down: both warmth and coolness have been associated with positive experience [2,8,10]. Thermal-affect interaction is complex and context-dependent [6] offering a rich, but complex design space.

DESIGN PRINCIPLES

Different kinds of associations

Feng et al. suggest that simple associations between particular thermal and affective states may not be reliable [6]. Associations seem rather to change in response to situations and contexts. Examples on the left provide sources of inspiration.

Direction of the thermal-affect interaction

Do the thermal cues and the related experience influence the user's affective state? Does the user's affective state influence how they tolerate, perceive and interpret thermal experience?

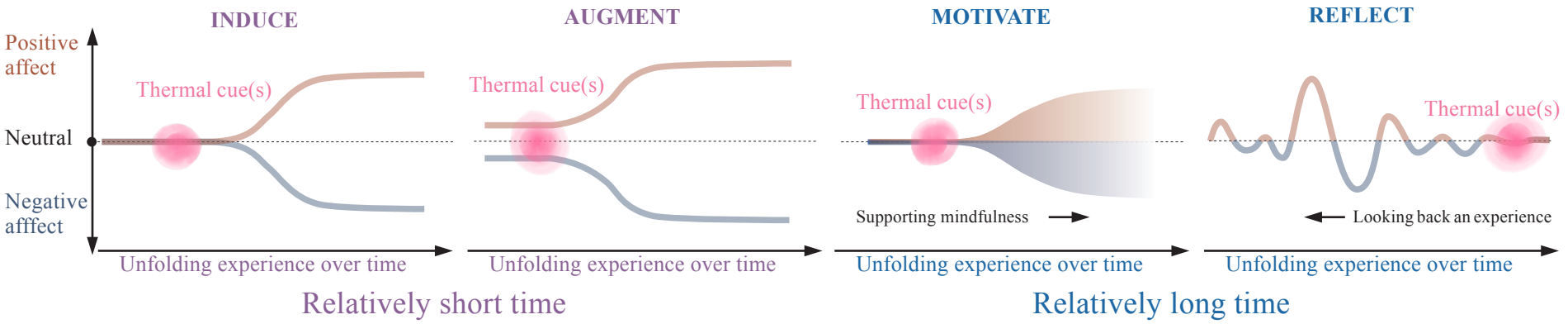
Types of thermal-affect interaction (Depicted in the figure below)

INDUCE: thermal cues can induce affect. E.g., a sudden cold cue on a summer day may induce surprise or alertness. Persistent warmth may induce lethargy.

AUGMENT: thermal cues can augment existing affect. A warm cue may enhance the perception of intimacy in messages between loved ones, for example

MOTIVATE: thermal cues can motivate a mindset toward the present or future, e.g., a comforting warm space may support a meditative, calm, mindset. A cool space may motivate clarity.

REFLECT: thermal cues can provoke reflection upon the past, e.g., a warm campfire in the evening may supports reflection on the memories and moods of the day.



AESTHETICS

In their analysis of thermal experience in poetry, Feng et al. identified examples where metaphor and metonym are used to capture intangible, aesthetic, and affective experiences [6]. Such language offers a rich resource for experience-design. This card demonstrates how the six lenses in this pictorial can help designers move from descriptions of aesthetic experience to design principles. We translate poems into brief plain language explanations, then connect aspects of the experiences described to one possible approach to implementation, via principles found on the other design cards.

Source of inspiration

metaphor

"Spring water flowing into the strings, and frost falling on the notes (of the plucked string instrument)" (ID22)

春水流弦霜入拨

The frosted strings of a plucked instrument indicate a percussive, sudden and momentary sensation of cold. In the poem, this alternates with imagery of warm, flowing spring water, suggesting an aesthetic experience characterised by the contrast between sharp, cold, moments within a more persistent, slower, fluid, warmth.

"Snow flakes flowing in the midst of a fire-ocean, bringing coolness" (ID23)

雪飞炎海变清凉

Another poem about musical experience. While the larger fire ocean suggests an overall impression of heat, the author ends the scene with the character 凉 indicating liquid coolness. Again we see a contrast between a larger warmth, closing on a final, penetrating cold.

metonymy [1]

"Abundant measures of Hu Po and Lü Yi fragrance the air

Reaching my sorrowful gut they stir the sense of late spring" (ID24)

浓斟琥珀香浮蚁

一到愁肠 别有阳春意

The fragrance of the wine in the air combines with the sensation of warmth it creates in the body, evoking a sense of late spring warmth. The, aesthetic experience lies in the entanglement of interoception, multisensory perception and environmental awareness. The perception of the season becomes entangled with bodily sensation, as warmth in the body connects to the seasonal warmth in the world.

"No need to see my frosted temples to know I am ageing

While in you I still see apricot blossom" (ID25)

霜鬓不需催我老

杏花依旧驻君颜

Visual thermal cues are often connected to ageing and the passing of time, carrying strong affective connotations. The white frost of autumn stands as a metonym for both coldness, and the whitening of temple hair in the autumn of a person's life. Contrasting with this the apricot blossom stands as a metonym for both the warmth of spring and the blossoming of adulthood. Metonyms here connect embodied and sensory experience to narrative meaning.

[1] In a metonym a concept or thing is evoked by something closely associated with it. In "the pen is mightier than the sword": the pen is a metonym for literacy.

Thermal contrast unfolding 1/6 3/6
Manipulating thermal contrast either sequentially or simultaneously to augment musical or visual events.

Material quality 2/6
Fluid, enveloping cues which may move over the body, combined with sharp cues from rigid, more spatially static cues to create a polyphonic contrast.

Perceived agency 4/6 1/6
Combining congruent thermal cues across senses to support a sense of domination, movement of cues to give a sense of activity.

Material quality 2/6
Directionality of the radiant heat, contrasting with enveloping cool cues.

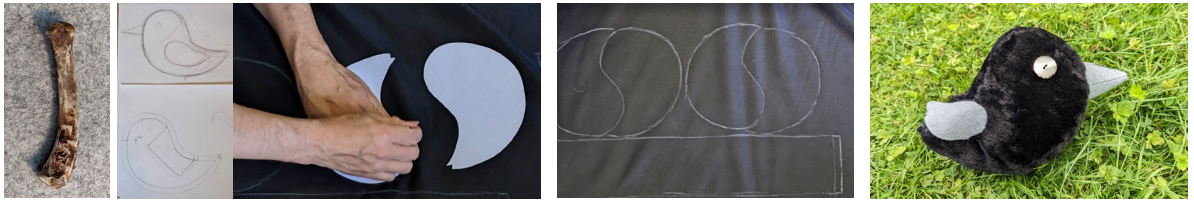
Multisensory features 1/6
Multisensory synergy across scent, internal warmth and external warmth.

Interaction with emotions 5/6
A sense of holism and extension of the self into the world. Perhaps through high amplitude, congruent cues, symbollic imagery?

Material quality 2/6
The rough texture of frost, and the softer texture of blossom.

Unfold in time 3/6 5/6
Thermal experience over long time scales: static seasonal imagery, combined with the cycling of seasonal cues.

DESIGN EXEMPLAR



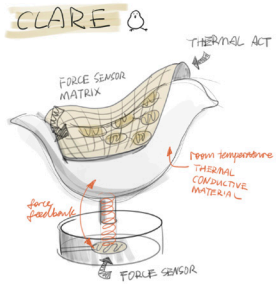
An interactive companion crow

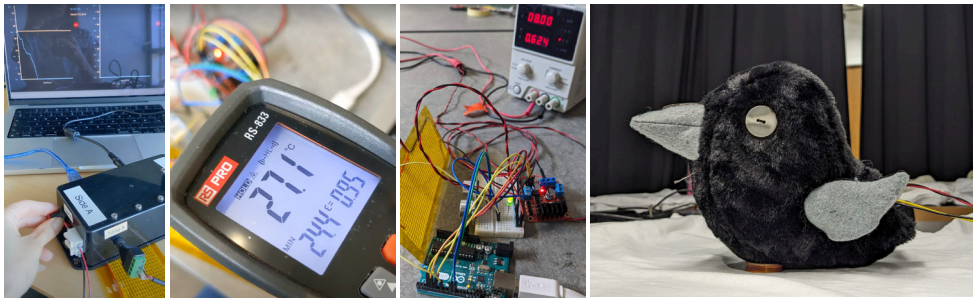
In this section we demonstrate one way of using the design cards in this pictorial by documenting the design of an interactive "companion crow": a personalised tangible gadget to support emotional regulation and reflection. This demonstrates how the cards can help designers reflect on particular circumstances rather than prescribing particular approaches: "prepared for action" rather than "guided in action" [12].

In this project we sought to investigate the design of a personalised emotional regulation device, via an autobiographical design approach. The high level design hypothesis was that emotional regulation can be supported by combining interaction and sensory feedback strategies with sources of personal meaning and emotional resonance. We used the cards for inspiration, to clarify the design space, and to structure discussion. In this way the cards scaffolded our ability to respond creatively and with specificity to a particular design case.

Design Ideation

Two designers (the first author leading, in conversation with her partner) began by each engaging independently with prototypes of the cards presented above. The first author was the target user for the device. They used the design principles and extracts on the cards to clarify their reflections on their needs, and to consider the possible roles the device might take in their emotional experience. They also paid attention to ideas and images on the cards that felt resonant.





From card 5/6 **(interaction with emotions)**, they felt that the device should induce positive emotions in the moment, while also supporting reflection which she expected to be more effective for longer term emotional coping.

The "Cold crows" on card 4/6 **(perceived agency)**, connected to our personal experience with local crows and jackdaws (first two figures on the top-left). During an unsettled and stressful period we developed the habit of spending some time each day with these birds, visiting the same park daily, in all weathers, to feed the crows a few peanuts. Our relationship with the crows foregrounded the weather. On wet, windy days, the crows remained distant. On icy days the "cold crows" fluffed their feathers and one pair often remained close together, seemingly to share body heat. On hot days, crows would often open their wings and stand with beaks open to cool themselves.

In each case, the encounter with the crows created a small bubble of emotional warmth in the day. We connected this to the layering of thermal timescales described on card 3/6 **(temporal qualities)**. Over time the crows began to approach quite close to demand peanuts. Once one brought the first author a gift (a chicken bone, top-center), stepping back to wait for them to take it. Rarely a crow would approach close enough for the first author to feel its physical warmth.

Discussing this both designers felt that the form of a crow could help motivate a calm and reflective mindset 5/6, pointing back to the events of the year, both stressful and comforting. We discussed the soft material quality 2/6 of the feathers, and the exchange of living warmth and care 4/6. This led to the intention to develop a soft companion crow, which could receive care, and return a living sense of warmth.

Sketching

After initial discussions, the first author made a range of initial sketches, imagining forms and interaction modalities which afford caring interactions and the sharing of warmth. They visited a fabric shop to select materials (see material off-cuts on page 10). Thinking back to the cards, she considered how these materials would impact thermal quality, both in tactile qualities 2/6 and in influencing the diffusion and rate of change 3/6 of temperature. They selected a thick plush black fur as the thermal delivery surface, to encourage slow thermal change, expecting this would encourage slower interactions and calm reflection. A firmer contrasting grey felt was chosen for potential interactive surfaces on the beak and wings, locations where we had read that crows sometimes appreciated touch.

Prototyping and refinement

The final form of the crow was sketched and then transferred to fabric cutting patterns. It was designed to allow sensors and actuators to be placed in multiple locations allowing exploration of options: the head and back, where the crow could be petted, the bottom of the crow where it could be held, and the wings back, and beaks where it could be stroked. The first author conducted rapid prototyping with electronics to investigate interaction approaches and possibilities for multisensory thermal cues 1/6.

They investigated interaction with proximity sensors, conductive touch surfaces, light, warmth, vibration, and motion of the wings. After testing multiple options, they felt that direct touch was the interaction modality that felt most expressive of care. In particular, touch on the beak paired with warmth on the back of the crow encouraged a cradling interaction and engaged both hands. This discouraged distraction by other devices, and supported centering in the thermal-affective experience.

Considering the possibilities for multisensory interaction on card 1/6, red light feedback was considered for its potential to reinforce the perception of warmth. However this did not feel natural to the character of the crow. It also drew visual attention, rather than leaving the visual sense free for memory and reflection. Warm scents were also ruled out due to the temporal character 3/6 of scent diffusion on an absorbant fabric. It lingered longer than the anticipated time frames of interaction, disconnecting it from the perception of intentionality 4/6. Instead a thermal pad on the back of the crow, beneath its fur, was paired with a vibration motor to give a sense of living warmth, and responsive agency. Overall the interaction was designed to encourage slow, focused interaction which would lower arousal and create space for reflection 5/6, connecting to the experiences and time frame 3/6 which the crow embodied for the first author. Vibration and warmth were designed to rise slowly in response to continued, slow, stroking input on the beak or back.

REFLECTION

Our approach in designing these cards was guided by Stolterman's reflections on the nature of design practice [12]. Stolterman articulates the need for design research to help designers be "prepared for action", rather than "guided in action" [12, pg. 61]. This is to say that design research should provide "tools for reflection" which allow designers to continuously develop and adapt to circumstances rather than detailed but rigid prescriptions.

We feel that this focus on preparedness, rather than guidance, may be particularly important in thermal-affective design, since, here, strict principles may be particularly likely to break down. As Feng et al. note, thermal-affective experience is complex and highly contextual [6]. Where some previous work has sought direct mappings (e.g. cold = sad), Feng et al. found evidence both in their corpus and in other research that everyday interactions between thermal and affective experience are far more varied and context dependent [6]. It is also important to note that thermal technologies are not easily isolated from their context - in a warm room we cannot simply turn our head to focus on a cold stimulus as we could with sight. Adding to this complexity, our own bodies are themselves both sources of heat, and involved in a constant process of metabolism and thermo-regulation.

We argue then that the design of effective thermal technologies will rely on context sensitivity, adaptivity and preparation for diverse use contexts. To design for such circumstances it seems particularly important to focus on what Stolterman calls "design rationality" [12, pg. 61]. This is the ability to adapt to the design possibilities present in a situation in a flexible but structured and disciplined way, and to act out of good "design judgement": a sensibility which is heightened by training and by the acquisition of a repertoire of lenses, skills and perspectives.

Following Stolterman's suggestions, in the design of our cards, we have focused on describing "tools for reflection" [12, pg. 61]: concepts, lenses and relationships between properties which can be repurposed in multiple ways to scaffold designers' own ideas. We avoid making normative statements, or suggesting clear, universal, mappings from thermal ranges to emotional valences. Rather we aim to sensitise designers to the ways in which thermal and affective qualities may interact, and to scaffold the movement from experiential qualities to design. As in Stolterman's description of Shön's approach, we aim to describe practices and intellectual tools rather than "prescribing the process on any detailed level" [12, pg. 61].

In our design exemplar, we illustrate how the design cards can be incorporated into a design process in a supportive but not prescriptive manner. The exemplar is not intended to serve as empirical evidence of the effectiveness of the cards. Rather it serves to illustrate one, quite specific, way the cards can be used - intentionally too specific to serve as a general rule. Our exemplar shows how the cards can be used flexibly, and how they can be appropriated to serve particular needs; the design process did not involve reference to every card, and there is much in the design process which is not found in the cards (the focus on tactile modalities, and on autobiographical detail, for example).

We anticipate a range of potential applications. For example, they could facilitate communication between designers, users, and engineers; they could serve as a reference for analysing user experiences. Researchers and practitioners might use them to support design reasoning: developing design briefs and portfolios, and structuring co-design sessions, and much else besides. We hope our fellow designers will appropriate the cards to a far wider range of use cases.

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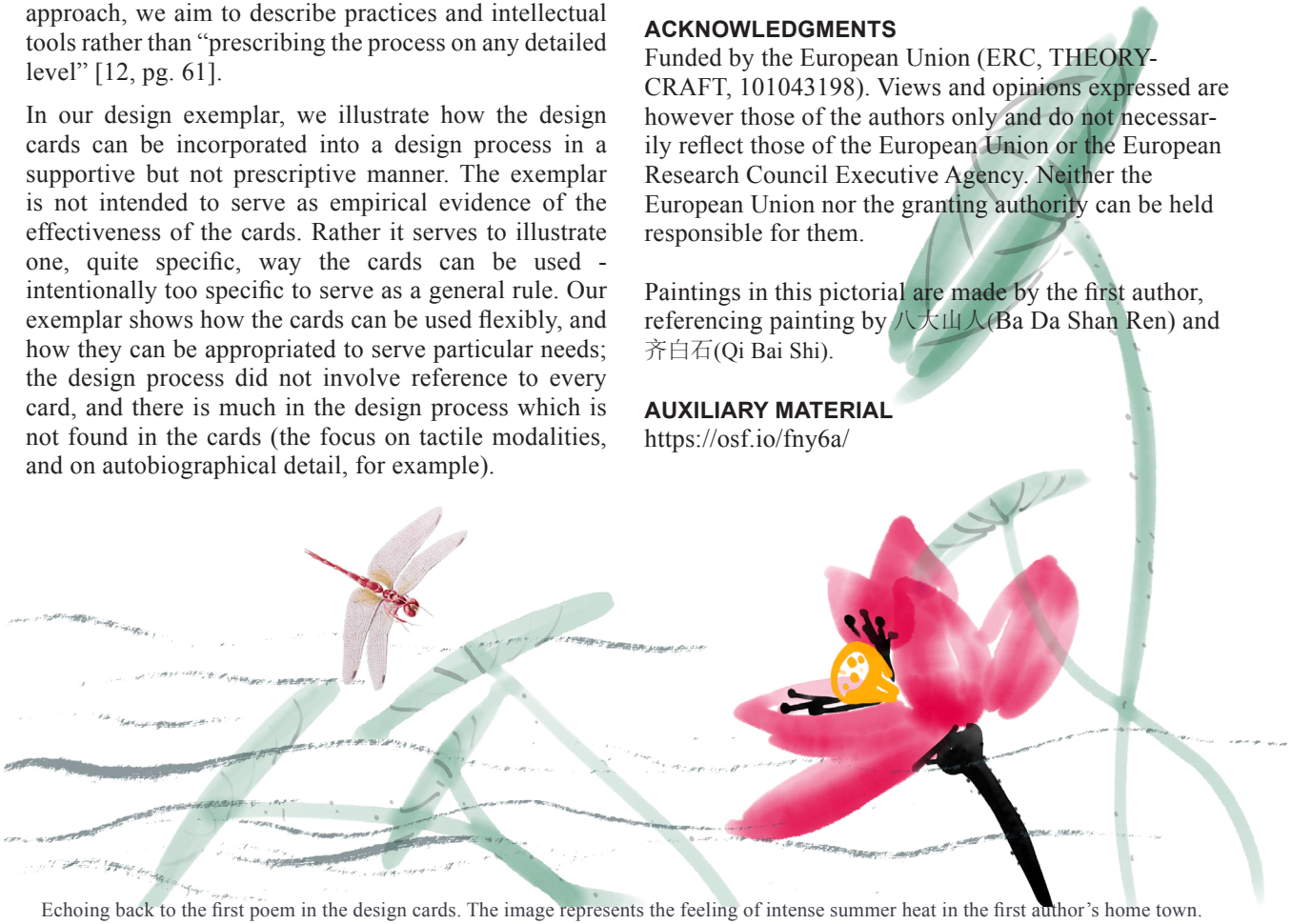
Paintings in this pictorial are made by the first author, referencing painting by 八大山人(Ba Da Shan Ren) and 齐白石(Qi Bai Shi).

AUXILIARY MATERIAL

https://osf.io/fny6a/



Echoing back to the first poem in the design cards. The image represents the feeling of intense summer heat in the first author's home town.

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