But how, Donald, tell us *how* ?

ON THE CREATION OF MEANING IN INTERACTION DESIGN THROUGH FEEDFORWARD AND INHERENT FEEDBACK

Tom Djajadiningrat, Kees Overbeeke & Stephan Wensveen
ID-StudioLab, Faculty of Industrial Design Engineering, Delft University of Technology
Landbergstraat 15, 2628CE Delft, The Netherlands

In recent years, affordances have been hailed by the interaction design community as the key to solving usability problems. Most interpretations see affordances as 'inviting the user to the right action'. In this paper we argue that the essence of usability in electronic products lies not in communicating the necessary action and instead shift our attention to feedforward and inherent feedback. With feedforward we mean communication of the purpose of an action. This is essentially a matter of creating meaning and we discuss two approaches to do so. With inherent feedback we try to strengthen the coupling between the action and the feedback. The sensory richness and action potential of physical objects can act as carriers of meaning in interaction. We thus see tangible interaction as indispensable in realizing feedforward and inherent feedback. We illustrate our ideas with examples from our teaching and research.

Keywords: usability, feedforward, feedback, meaning, expressiveness

INTRODUCTION

Usability of consumer electronics devices remains a difficult problem to solve. Ever since Norman (1988) introduced the term affordance—a term coined by the perception psychologist Gibson (1979)—into the HCI community, it has been viewed as a concept which may hold the key to improved usability. Whilst there are many interpretations of affordance, most of these interpretations have in common that an affordance invites the user to a particular action. Norman illustrates how many of our everyday objects afford the wrong action or afford no action at all. Examples include push doors that need pulling and knobless taps which simply baffle the user.

Whilst these illustrations of the term affordance prove to be highly inspiring and useful in the design of products which have a single, expectable function, they appear to have their limits in the design of electronic products which are characterized by their multi-faceted and often novel functionality. Though the buttons on an electronic product may afford pushability, the sliders slideability etc. this only partly helps in improving the usability of these products. In our opinion, the essence of usability lies not in communicating the necessary action. Instead we argue for attention to two other aspects of interaction. The first is communicating the purpose of the action. This communication of the purpose of an action we call feedforward. The second is strengthening the coupling between the action and the feedback, leading to what we name inherent feedback.

The following model may clarify our reasoning (figure 1). We distinguish between information before the user carries out the action (pre-action), and after the user carries out the action (post-action). These phases correspond with feedforward and feedback. Feedforward informs the user about what the result of his action will be. Inviting the appropriate action is a prerequisite for feedforward but it is not sufficient. The product also needs to communicate what the user can expect. Feedback informs the user about the action that is carried out, shows that the product is responding, indicates progress, confirms navigation etc. We plead for designing

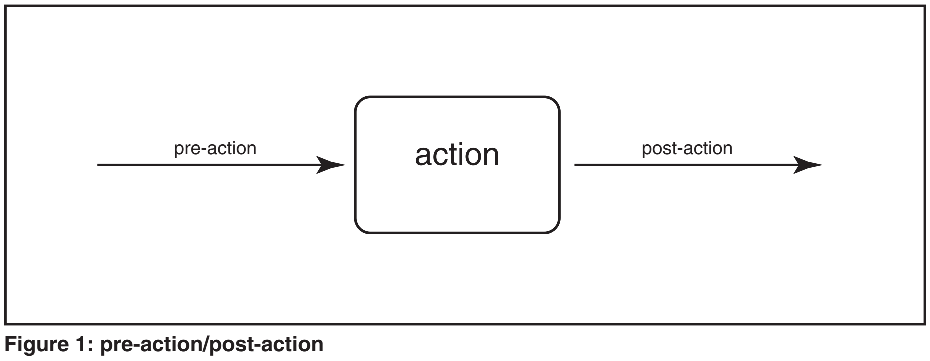


Figure 1: pre-action/post-action

Figure 2: Natural Mapping
An extreme example of natural mapping: the layout of this railway control panel maps directly onto the physical layout of the railway tracks themselves. The idea can be applied to anything in which spatial layout is meaningful, be it cooking rings, room lighting, car mirrors etc. Yet the settings of electronic products and computers are often abstract and do not naturally have spatial meaning. Natural mapping thus fails in the area where we need it most desperately: in making the abstract intuitive in use.

products in such a way that they feature what we call inherent feedback; the user should experience the feedback as a natural consequence of his actions.

In the remainder of this paper we first discuss what aspects are of importance in feedforward. Secondly, we discuss the issues in inherent feedback. Finally, we discuss the relevance of tangible interaction in the context of feedforward and inherent feedback. We are especially interested in the sensory richness and action potential of physical objects as carriers of meaning in interaction. We argue that the creation of meaning in interaction is the key to making abstract concepts in consumer electronics accessible. As educators and researchers in industrial design this is of much concern to us; shaping meaning in the appearance of and interaction with physical objects is an essential task for designers.

FEEDFORWARD

If a product is to communicate its various functions, then its controls should be differentiated both in appearance and in action. Currently, controls of electronic products look highly similar and require the same actions (Norman, 1998, page 94). If all controls look the same and feel the same, the product can never communicate its functions. So how can we make the controls communicate their purpose? If operation of a control has directly perceivable consequences in the real world, then Norman's natural mapping offers a solution. The way product components are laid out spatially can help the user in understanding their purpose. Figure 2 shows an extreme example of this: the layout of this railway control panel maps directly onto the physical layout of the railway tracks themselves. The idea can be applied to anything in which spatial layout is meaningful, be it cooking rings, room lighting, car mirrors etc. Yet the settings of electronic products and computers are often abstract and do not naturally have spatial meaning. Natural mapping thus fails in the area where we need it most desperately: in making the abstract intuitive in use. In short, it does not suffice to make controls differentiated in appearance and action, the crux of the problem lies in the creation of meaningful appearance and actions. So what are our options in the creation of meaning?

THE CREATION OF MEANING

We see both appearance and action as carriers of meaning. The way a control looks and the action that it requires express something about the control's purpose. In general there are two ways to approach this expressiveness. These are the semantic approach and the direct approach. We outline them side by side in figure 3. Although they are seldom made explicit, we feel that they underlie many interaction concepts.

The first approach starts from semantics and cognition. The basic idea is that using the knowledge and experience of the user the

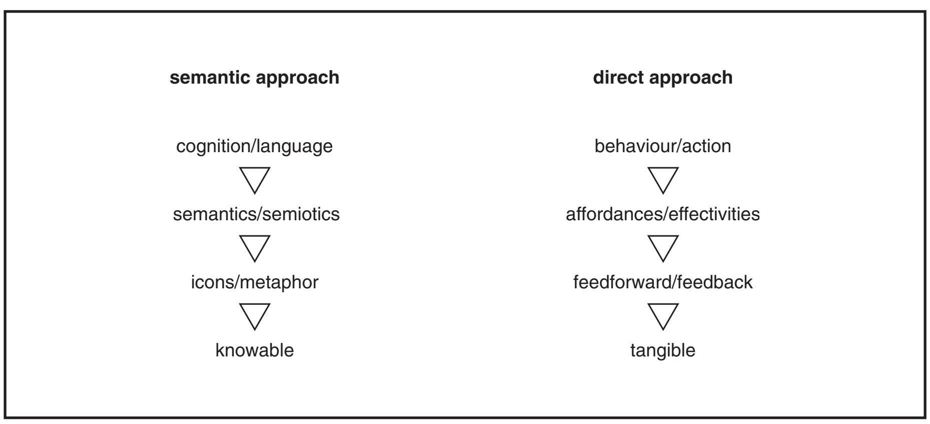
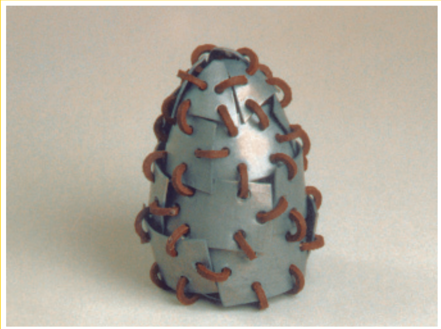


Figure 3:
Two approaches to creating meaning in interaction design



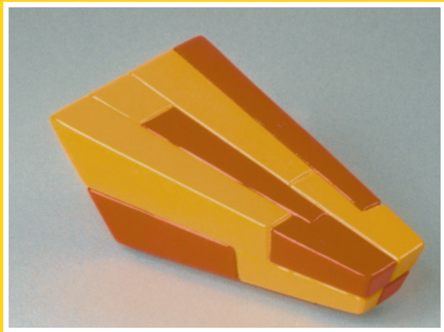
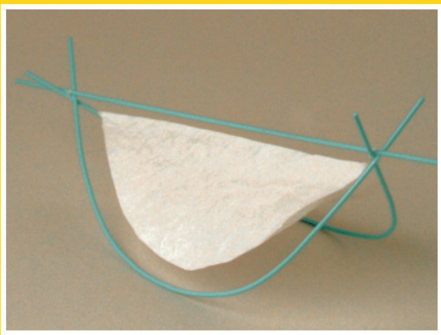





Figure 4: Expressiveness of form

In this exercise, students had to make hand-sized sculptures which were expressive on three dimensions. Each dimension had two opposite poles. The first dimension was number (few-many), the second dimension was accessibility (accessible-inaccessible) and the third dimension was one of the following: weight (light-heavy), age (old-new), size (small-large), robustness (fragile-sturdy) and speed (slow-fast).

Each student had to create a pair of objects which coincided on two dimensions and which were opposites on a third dimension. The two resulting objects therefore were similar in some respects, yet also were different. Note how form has many expressive aspects including shape, direction, proportion, colour, material and texture. The first four rows on this page show a selection of these pairs of objects. See whether you can guess on which two dimensions the student intended the objects to express the same and on which dimension the objects were to be opposite poles. The answers are given below.


Answer:
row 1: many/inaccessible/sturdy-fragile
row 2: many/inaccessible/slow-fast
row 3: few/inaccessible/light-heavy
row 4: few/accessible/old-new
You may have noticed that the dimensions weight, size and robustness are interrelated and require subtle manipulation of form to express well.


Sometimes students had a hard time creating a pair of objects, but still managed to succeed in expressing one of the poles. These two unrelated objects were made by different students to express:
left: few/accessible/fast
right: few/accessible/heavy

product can communicate information using symbols and signs. (Krippendorff & Butter, 1984; Aldersey-Williams et al., 1990). The approach is characterized by reliance on metaphor in which the functionality of the new product is compared to an existing concept or product that the user is familiar with ("This product is like a ....", "this functionality resembles..."). Often this leads to the use of iconography and representation. In the semantic approach the appearance of the product and its controls become signs, communicating their meaning through reference. Products resulting from this approach—be it hardware or software—often use control panels labelled with icons or may even be icons in themselves.

The second approach—the direct approach—takes behaviour and action as its starting point. Here the basic idea is that meaning is created in the interaction. Affordances only have relevance in relation to what we can perceive and what we can do with our body: our effectivities. In this approach respect for perceptual and bodily skills is highly important and tangible interaction is therefore a logical conclusion.

What appeals to us in the direct approach is the sensory richness and action-potential of physical objects as carriers of meaning in interaction. Because they address all the senses, physical objects offer more room for expressiveness than screen-based elements. A physical object has the richness of the material world: next to its visual appearance it has weight, material, texture, sound etc. Moreover, all these characteristics are naturally linked, an issue which we will get back to later.

Figure 4 shows the results of a students' exercise initiated by Bill Gaver when he was a visiting lecturer in our department. Inspired also by a paper by Houde & Salomon (1993) in which the richness of our physical world is contrasted with graphical user interfaces, students had to exploit the expressiveness of physical objects in the creation of meaning. They had to make a pair of objects which had to coincide on two dimensions whilst being opposite poles on a third dimension.

Figure 5 shows an alarm clock from a students' exercise. The alarm clock consists of two parts, a base station and an alarm ball. The alarm ball is used to set the wake up time and consists of a display strip flanked by two rotating semi-spheres. The size of the ball and the way it matches the recess in the base station afford picking up and the two halves afford rotation. But more importantly, the positioning of the halves adjacent to the hour digits and the minute digits, informs the user of what he will adjust. The further the user moves or throws the alarm ball from the base station, the louder, the more aggressive and the more insistent the waking sound will be in the morning. The closer the alarm ball is placed to the base station, the softer and more gentle the waking sound will be. Here it is both the appearance and the actions that are carriers of meaning. Throwing the ball to the other side of the room is a different action from placing it just to the side of the base station and can thus have different consequences. This is also consistent with the actions the user has to carry out to silence the alarm clock. The further the alarm ball is away from the base station, the more of an effort he has to make to find it, to pick it up and to place it over the speaker to muffle the sound. Here again the fit of the alarm ball to the recess and the idea of covering the loudspeaker inform the user of the consequences of his action.
While tangible interaction has the promise of making the most of the user's perceptual-motor skills, we feel that many examples do not

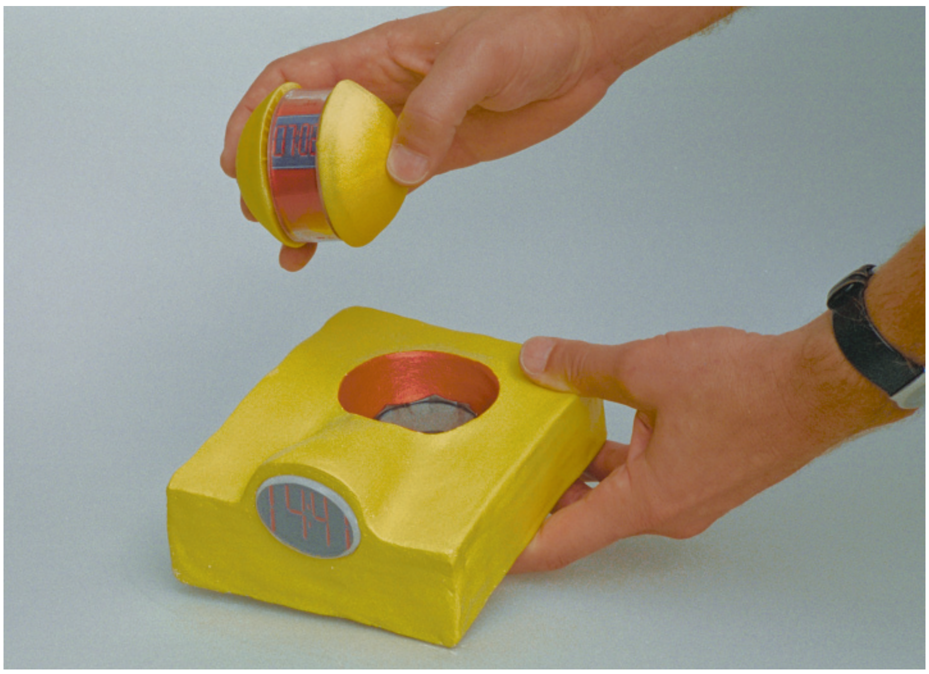


Figure 5: An alarm clock
If the left hemisphere of the alarm ball is turned while holding the display strip, the hours of the waking time are adjusted (top left). If the right hemisphere is rotated, the minutes are adjusted (bottom left). The alarm clock can sense the distance between the base station and the alarm ball (above). The further the alarm ball is placed away, the more insistent the sound will be in the morning.The user's actions thus become carriers of meaning and influence the alarm clock’s behaviour (design: De Groot and Van de Velden).

make the most of the expressiveness of physical objects. In fact, many tangible designs implement a kind of natural mapping or fall back onto a semantic approach. For example, Urp (Underkoffler et al., 1999) makes use of natural mapping of model buildings onto the prospective buildings. Architectural planning is something that lends itself very well to natural mapping since those elements which are to be controlled and visualized—buildings, shadows, reflections—have spatial meaning in our physical world. An example of how tangible interaction can fall back into a semantic approach is the concept of phicons, physical icons. A phicon does not so much have meaning in itself, but draws upon metaphor and has meaning only with respect to a referent. Figure 6 shows a non-electronic example of what we would consider a phicon. If this object were electronically augmented, one could argue that it has many desirable interaction qualities: it is movable and thus its spatial location and orientation can have all the advantages associated with natural mapping, it clearly invites the right actions (rolling and opening the lid) and it has iconic meaning as a rubbish container which allows us to get rid of stuff during a hotel breakfast. Our objection is that the object was not designed to have meaning for itself. This limits the designer's possibilities, both conceptually and aesthetically.

INHERENT FEEDBACK

The importance of feedback is generally understood and appreciated, Yet in many electronic products the coupling between action and feedback is 'loose'. There seems to be no relationship between the action, its purpose and the feedback. In interaction design it is sometimes suggested that 'any feedback will do'. For example, in a typical electronic product scenario, pressing a button causes a display element to turn on and the product to beep. This kind of coupling is arbitrary. There is no relationship between the appearance of the control, the action and the feedback. This limits the value of the feedback as we can expose by working backwards from the feedback to the action. The feedback offered could have been caused by any control and by any action. In information psychology there is a term called inherent feedback. With inherent feedback we address the issue of the relationship between the feedback and the action. Usually associated with the realm of the mechanical, in inherent feedback there is a tight coupling between action and feedback. The feedback is a natural consequence of the action. For example, a pair of scissors gives visual, auditory and haptic feedback during cutting which is a direct consequence of the user's action. It is this feel of direct consequence that we now try to realize in electronic products too. For electronic products to offer inherent feedback they have to be designed from the ground up with appearance, actions and feedback in mind. Inherent feedback cannot be added as an afterthought. It is exactly the 'sticking on' of feedback that we object to.

Figure 6: A non-electronic phicon

We have identified a number of issues in strengthening the inherency of the feedback. We illustrate these issues by the example of a programmable heating controller (Figure 7). Programmability of consumer electronics is a renowned problem which manifests itself in many forms: videorecorders, microwave ovens, heating controllers etc.

Programming the heating controller is done by three types of components: a single wallmounted FloorPlan, a TimeRule and several TempSticks (Figure 7a). There is one TempStick per room, and the TempSticks are related to the rooms through natural mapping on the FloorPlan.The reasoning behind this example is that each room (living room, bathroom, bedroom, garage etc.) has a particular comfort temperature. To adjust a room’s comfort temperature, its TempStick can be slid vertically through a hole in the horizontally placed FloorPlan. The length of the TempStick which protrudes above the floor plan thus indicates the comfort temperature. The basic idea behind a programmable heating controller is to lower the temperature when the user is asleep or away from home. In our example we assume a fixed fallback temperature, that is, the temperature is lowered by a fixed amount from the comfort temperature. In the remainder of this explanation we concentrate on setting the day program for a single room.
When the TimeRule is slid through a TempStick, a time interval on the rule is visible through the window of the TempStick. There are two modes. In recording mode, the user can adjust the day program of a TempStick (Figure 7b). In playback mode, the user can inspect this program (Figure 7c). Switching between the modes is done by means of a record button at the end of the TimeRule (Figure 7d and 7e).
When the time rule is slid through the TempStick with a pressed record button, a day program for a room can be input by means of the springloaded fallback button on top of the TempStick. Pressing it activates the fallback, that is, the programmed temperature is adjusted downwards from the comfort temperature (Figure 7f). Releasing it causes the programmed temperature to equal the comfort temperature (Figure 7g). When the fallback button is

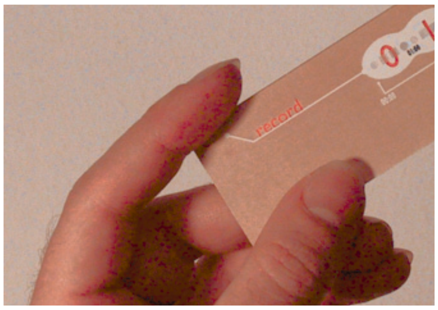
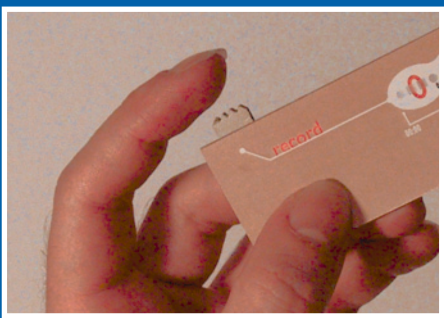


Figure 7d above: Pressing the record button at the end of the TimeRule allows the user to program a TempStick.
Figure 7e below: Releasing the record button lets the user inspect the program of a TempStick.



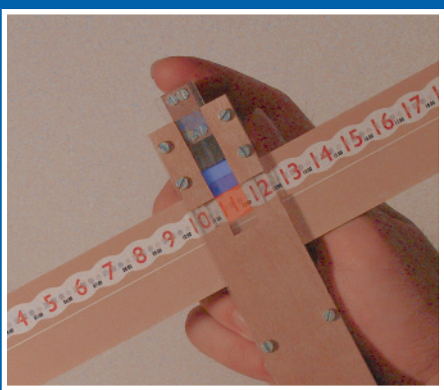
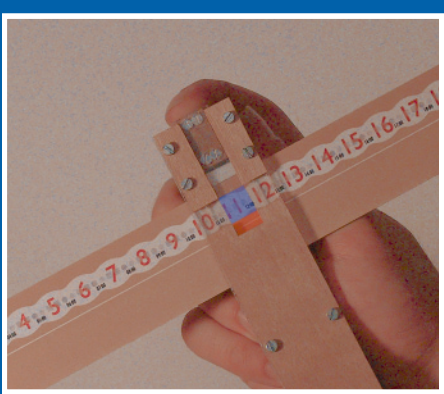


Figure 7f above: A released fallback button on the TempStick in record mode maintains the preferred comfort temperature (above), Figure 7g below: A pressed fallback button programs a drop in temperature (below). Note the sliding red and blue filter.



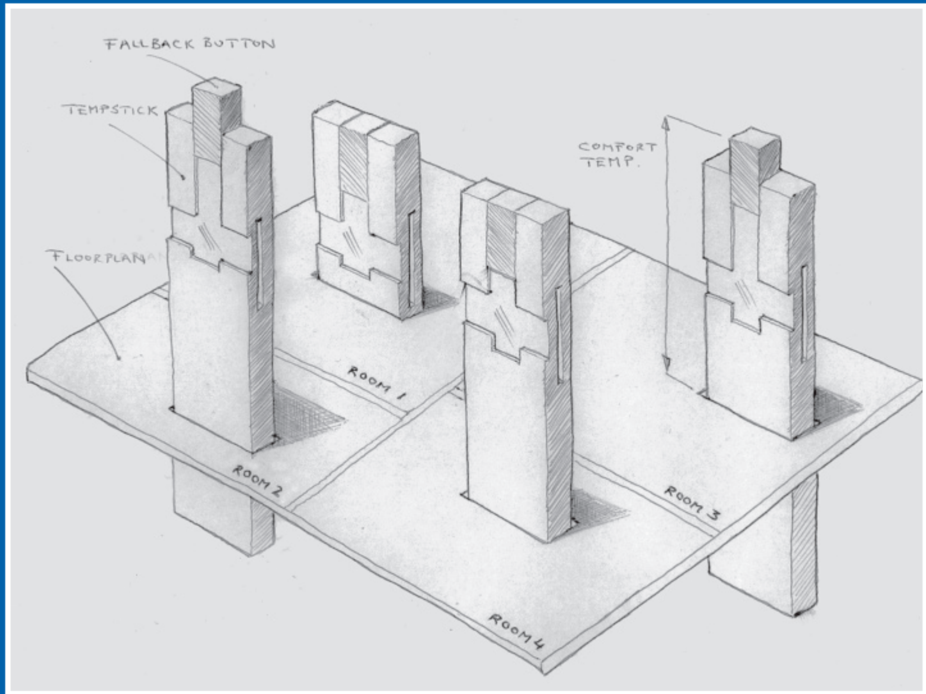


Figure 7a: TempSticks in the wallmounted FloorPlan of a four room apartment. The height of a TempStick above the FloorPlan indicates the comfort temperature. The fallback buttons move in sync with the programs: up for the comfort, down for the fallback temperature. In rooms 2 and 3 the temperature is at the comfort temperature whilst in rooms 1 and 4 the fallback temperature is active (design: J.P. Djajadiningrat).

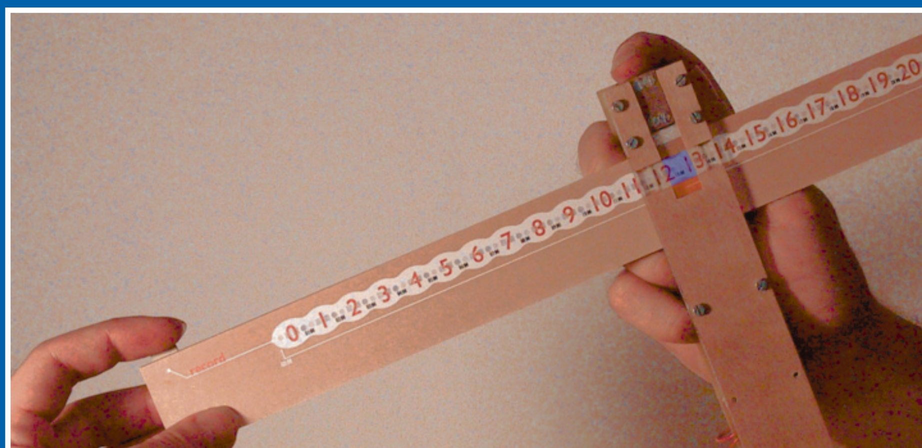


Figure 7b: When the TimeRule is slid through the TempStick in record mode, pressing and releasing the springloaded fallback button on the TempStick inputs the program.

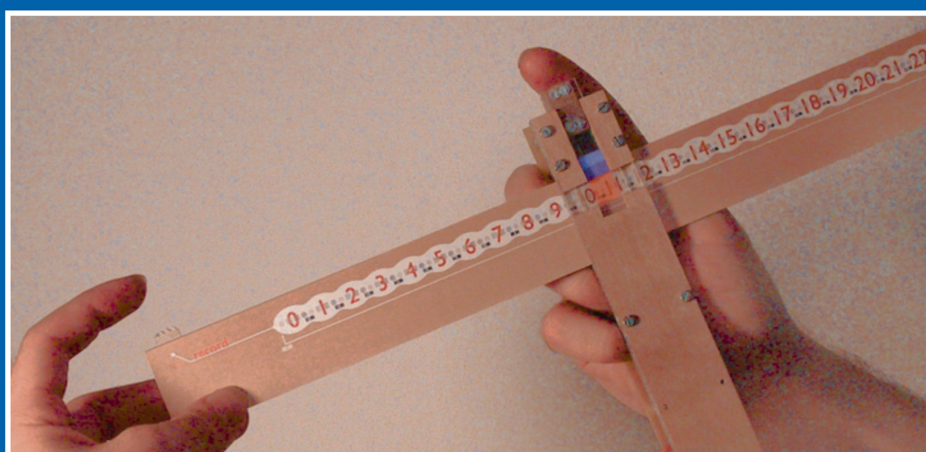


Figure 7c: When the TimeRule is slid through the TempStick in play mode, the user can see and feel the fallback button move up and down.

pressed and the programmed temperature is decreased, a blue colour filter slides int view in front of the TimeRule. When the fallback button is released, a red colour filter slides into view.
To understand the playback mode it is important to note that the springloaded fallback button on top of the TempStick is solenoid powered. When the user slides the TimeRule through the TempStick without pressing the record button and resting his finger lightly on the fallback button, he can see and feel the fallback button move up and down in accordance with the program in the TempStick. Note how familiar interaction topics such as two-handed input and multi-modality form an integral part of this concept.
Clearly this concept has a number of shortcomings from an industrial design point of view. Amongst these are issues with its physical ergonomics (the operation of controls on TempStick and TimeRule), its functionality (the lack of a week program) and its complexity in terms of production. What we tried to focus on, however, is inherent feedback. We think the following issues are of importance in strengthening the inherency of the feedback in this example.

1. Unity of Location
The action of the user and the feedback of the product occur in the same location.
In this example, the user presses the button on top of the TempStick to activate the fallback and the product operates the same button as a display of the fallback. Input and output thus become co-located (Underkoffler et al., 1999). Because input and output occur in the same spot and because the physical elements involved are both controls and displays the inherency of the feedback is strengthened.

2. Unity of Direction
The direction of the product's feedback is the same as the action of the user.
As the user presses and releases the button on top of the TempStick, the feedback of the coloured filter that is visible in the window moves in the same direction. If feedback includes movement, be it on a display or of physical components, this movement could conceivably be different in direction from the action of the user. Such deviation in direction weakens the inherency of the feedback.

3. Unity of Modality
The modality of the product's feedback is the same as the modality of the user's action.
Here the user exerts force and creates movement and the product responds through force feedback and the creation of movement. In many products there is a discrepancy between the input modality and the output.

4. Unity of Time
The product's feedback and the user's action coincide in time.
This one should need little explanation. If there is too much of a delay between action and feedback they are no longer seen as related.

We are currently working on versions of the heating controller concept which purposely break with one or more of these four points, to get a better feel for the consequences for inherent feedback.

CONCLUSION
Ullmer and Ishii (2000) point to the fact that a fundamental challenge is to answer the question: what makes for good tangible interface design? We think that feedforward and inherent feedback are two criteria for quality in tangibility. The sensory richness and action-potential of physical objects in relationship to our perceptual-motor skills can help designers fulfill these criteria in ways that graphical user interfaces can not. Though we have mainly spoken about the usability aspects of tangible interaction, the aesthetic consequences.for industrial design deserve attention too. As feedforward and inherent feedback do not lend themselves to be added to existing forms, attention to these concepts may have far reaching effects for the look and feel of our future electronic products. Physical objects that appeal to all our senses and fit our bodily skills may ultimately not only be more usable but also be more aesthetically appealing in interaction.

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