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Exploring Physicality in the Design Process

Devina Ramduny-Ellis, InfoLab21, Lancaster University, United Kingdom

Joanna Hare, PDR, University of Wales Institute, Cardiff, United Kingdom

Alan Dix, InfoLab21, Lancaster University, United Kingdom

Steve Gill, PDR, University of Wales Institute, Cardiff, United Kingdom

Abstract

The design process used in the development of many products we use daily and the nature of the products themselves are becoming increasingly digital. Although our whole world is turning ever more digital, our bodies and minds are naturally conceived to interact with the physical. Very often, in the design of user-targeted information appliances, the physical and digital processes are formulated separately and usually, due to cost factors, they are only brought together for user testing at the end of the development process. This not only makes major design changes more difficult but it can also significantly affect the users' level of acceptance of the product and their experience of use. It is therefore imperative that designers explore the relationship between the physical and the digital form early on in the development process, when one can rapidly work through different sets of ideas. The key to gaining crucial design information from products lies in the construction of meaningful prototypes. This paper specifically examines how physical materials are used during the early design stage and seeks to explore whether the inherent physical properties of these artefacts and the way that designers interpret and manipulate them have a significant impact on the design process. We present the findings of a case study based on information gathered during a design exercise. Detailed analysis of the recordings reveals far more subtle patterns of behaviour than expected. These include the ways in which groups move between abstract and concrete discussions, the way groups comply with or resist the materials they are given, and the complex interactions between the physicality of materials and the group dynamics. This understanding is contributing to ongoing research in the context of our wider agenda of explicating the fundamental role of physicality in the design of hybrid physical and digital artefacts.

Keywords

Physicality; Digitality; Product Design; Design Process; Prototyping; Materials

Traditional product design focused on purely physical artefacts designed using physical materials such as clay, wood or plastic foam. As humans we are fitted to live in a physical environment and the behaviour of stone and wood, water and metal appear 'natural' to us either through genetic make-up or early development. However, this is changing as the artefacts designed increasingly include digital elements, from MP3 players to electric drills, and in the design process itself, pencil sketches and clay models often give way to CAD.

It is in this context that we are seeking to explicate the properties of physical materials and physical artefacts and the way we understand and manipulate them, so that we can (i) better inform the design of hybrid digital/physical artefacts and (ii) understand the impact of changing tools and techniques on the design process.

Our previous work has considered properties of commercially available electronic and domestic products in order to uncover the ways in which designers have (maybe tacitly) exploited the physical nature and placement of controls such as knobs and buttons. Often quite subtle differences have a major influence on the naturalness of interaction for end-users (Ghazali & Dix, 2005), that is the extent to which the product exploits the user's automatic or subconscious reactions and behaviours. Another study of mobile phone prototypes showed that physical mock-ups of the interfaces can generate significantly more useful user feedback compared with purely on-screen interactive prototypes; whilst this was as expected, more surprisingly, even quite crude physical mock-ups were as useful as high fidelity ones (Gill et al., 2005).

In this paper, our focus is on physicality within the design process itself. We present the findings of a case study, based on information gathered during a design exercise we ran at the Second International Workshop on Physicality (Ramduny-Ellis et al., 2007) held at Lancaster University as part of the HCI 2007 conference. The objective of the exercise was to explore the role that physicality plays during the design process by setting a common design brief, and providing groups with different materials with which to solve it. Through doing this we hope to better understand the way tacit or explicit properties of these physical materials affect the process and outcomes of early design exploration.

The next section presents the motivation behind our work on understanding the fundamental role of physicality in product design. We then describe the case study in detail and walk through the design process of one of the teams. A detailed analysis of the video recordings of each team design activity revealed several recurrent themes and issues, which enabled us to unpick the rich interplay between materials, design brief, team makeup and dynamics. This thematic discussion is addressed in the final section.

Motivation

Human centred development of computer embedded products, and more specifically user targeted 'information appliances' (products embedded with computers such as mobile phones, digital cameras) are at the crossroads of a number of disciplines (Norman, 1998); therefore their development process can frequently be disjointed with the physical and digital interactions being designed in isolation. These physical and digital processes are often only combined for user testing near the end of the development process when major design changes are impossible. Baxter (2002), and Branham (2000) identified the need for new tools to overcome the problem.

In order to create an effective and a pleasurable experience for the user, designers need to ensure that the relationship between the physical and digital form is explored thoroughly at the early stages of the design process when ideas can be worked through quickly. Methods such as Experience Prototyping (Buchenau & Suri, 2000) and Paper prototyping (Snyder, 2003) go someway towards answering this issue, particularly in their inclusion of physicality; however, methods that retain their "quick and dirty" hands-on approach while incorporating more accurate simulation are still required. One of the problems facing designers in modern businesses is that the pressure to deliver to very tight deadlines and within tight profit margins means that physical prototypes are frequently not produced or are produced with limited functionality or at a low fidelity level. The ability to build meaningful prototypes without investing large sums of money and time is key to obtaining significant design information from product and user testing.

Increasingly, the products we use are a synthesis of digital and physical elements and, for the user, these become indistinguishable. As hybrid physical/digital products are developed, designers have to understand what is lost or confused by this added digitality – and so need to understand physicality more clearly than before.

Our concern with the nature of the physical world and our interaction with it is not new; it has been a concern for philosophers for many years, most notably Heidegger, and is the topic of ongoing debate, particularly related to issues of the embodied mind (Clark, 1998; Wheeler, 2005). For some within psychology, the traditional 'inside-to-outside' Cartesian conceptions of cognition have given way to an increasing acceptance of the importance of physical embodiment for cognition. This is explicit in frameworks such as distributed cognition (Hutchins, 1995), where the role of physical artefacts and multiple actors is seen as essential for 'cognition' to occur and also in the concept of situated action in Suchman's early work at Xerox (Suchman, 1987), which was seminal in bringing ethnographic approaches into interaction research and practice. Environmental psychologists such as Gibson have also explored this area and Gibson's concept of affordance, the ways in which an object is fitted for human action, has entered the vocabulary of interaction design (Gibson, 1979).

Whilst some of these have been applied in design settings, we feel that the range of properties covered does not fully encompass all that is important when using physical materials. For example, the temporal continuity of physical items is taken for granted. Furthermore, the focus is largely on the use of products, however the creative act of design involves a combination of imaginative and manipulative processes. To what extent is this creativity enhanced or inhibited by the physical nature of design materials?

There are a number of researchers looking into creating a suite of systems for the development of computer embedded products which are sympathetic to the designer's mindset and methods, such as Phidgets (Greenberg & Fitchett, 2001; Phidgets Inc.) Voodoo Dolls (Pierce et al., 1999), DTools (Hartman et al., 2005), Switcharoo (Avrahami & Hudson, 2002), Pin and Play (Villars et al., 2005) and Denim (Landay & Myers, 1995). However, these have tended to focus more on the electronics or programming base, whereas we are interested in such systems from a product design angle.

To that effect some of the authors have been involved in the development of low-tech keyboard emulation boxes called *IE Units* wedded to software building blocks (Gill et. al., 2005b). The *IE Units* allow rapid prototyping without the usual electronics or programming skills prerequisites and they have been used to empirically measure the performance of real products against physical and virtual prototypes.

The results show that the link between the physical act of holding a product and interaction was more marked than has previously been understood (Evans & Gill, 2006), thus highlighting the need for understanding the precise nature of physicality in the design process. This led to our recent work on physigrams – a diagrammatic notation based on a formal framework for mapping the relationship between physical devices and their corresponding physical actions (Dix et al., 2008) for designers' use.

Case Study

At the Physicality 2007 International Workshop, a design exercise was run in order to explore the influence of different design materials on early design and assess how their physical properties impact issues such as the number and novelty of design ideas and the kinds of designs produced.

Method

The approach taken was open and exploratory rather than controlled, reflecting the aim to uncover new behaviours rather than quantify known ones. A form of ethnographic observation was used that included both live observations and field notes and also video-recording to capture the design process and its outcomes for later review.

Participants were divided into teams of two or three people, and each team was given one kit of design materials to use, namely:

- paper and pencils,
- card and glue, or
- modelling clay, commonly known as plasticine.

Participants were only supposed to use their own materials. Beyond this they were not told how to use the materials, but in fact the materials implicitly suggested ways of use – for example, no team in the paper and pencil group chose to fold or mould the paper to make a model.

In normal design any or all of these materials would be used according to the preferences of the designer at a particular moment. However, in this exercise, teams of participants were given just one kind of material to work with. Thus we were performing something similar to a 'breaching experiment' (Garfinkel, 1967) which deliberately disrupts human activities in order to bring to light aspects that are tacit or taken for granted; although, in standard breaching experiment the conventions broken are social whereas here we are disrupting the ability to choose appropriate materials.

Materials

The materials were chosen to reflect traditional design practice and to cover a range of properties such as, two-dimensional vs. three-dimensional, manual vs. cerebral, malleable vs. constrained.

Pencil and paper are of course used extensively throughout the design process to sketch and work through ideas. Card and glue is an extension of this – allowing very quick rough '3D sketching' to give ideas some shape for discussion, though card can also be used for more refined models. Although "Blue foam" is the most common material used by product designers to create fast 3D models it was not used in this exercise because of the skills, tools and training required as well as accommodation issues (blue foam is very messy and produces fumes when cut with hot wires). Instead, modelling clay was chosen as it has a long history of use in the 3D design process by many designers 'according to the type of product and company practice' (Bordegoni & Cugini, 2005; Verlinden et al., 2001), most notably by the automotive industry (Rekimoto, 1996). It was felt that modelling clay provided the tactile 3D element that blue foam supplied without the need to train the participants.

Design brief and Setting

The brief was to design a hand-held device for producing light that can be turned off and on (see Figure 1). It deliberately kept the technical considerations to a minimum to encourage participants to reflect on the device in relation to the human body.

> This exercise looks at the physical design process and its effect on the physicality of the design concept.
>
> We have split you into 3 groups with the same design brief but with different design materials – one will have pencils and paper; the other paper, card, scissors and glue, and the third, plasticine.
>
> We will be recording the process and outcomes of this exercise for later review.
>
> At the end of the exercise we will invite each team to talk about their concept, the process they undertook and the pros/cons of the tools they used.
>
> The brief is to design hand-held device for producing light – it should be able to be turned off & on.

Figure 1. Design brief for participants

The participants were divided in three main groups (one for each material), and each group had 2-3 teams consisting of two or three people of mixed gender. Figure 2 shows the make-up of each group. Each group was given the same design brief but different materials to work with. The teams are labelled team A–H and the participants' names have been anonymised in the transcript fragments presented here[1].

The participants came from various disciplines ranging from computing, arts, design, sociology, philosophy, to human geography and architecture. We had eight teams in all; they were given forty minutes to work on the exercise and then invited to present their concepts and comment on the materials they had used. All the teams were based in the same large meeting room but each team worked independently.

Group	Team	Team members
Card and Glue	A	E^{+}, C*, L^{+}
	B	F*, L^{+}, R*
Plasticine	C	G*, R*, B^{+}
	D	H^{+}, A^{+}
	E	J*, B^{+}, C*
Paper and Pencils	F	A*, B^{+}
	G	D*, E^{+}
	H	H*, F*, G^{+}

<u>Key</u>

* male

$^{+}$ female

[1] Note the anonymised names are not unique across groups, if there is any ambiguity as to the current group we will refer to a participant as, for example, B>F meaning participant 'F' in team B.

Figure 2. Allocation of teams to groups

Initial Observations

The teams varied significantly in terms of their level of exploration. Some teams focused on a single design idea and produced a single prototype, whilst others explored various design ideas and produced a number of prototypes. However, there was no simple relationship between the groups that used particular materials and them being more prolific or more focused in terms of process and output. Indeed in each group there was at least one focused team and one more exploratory team.

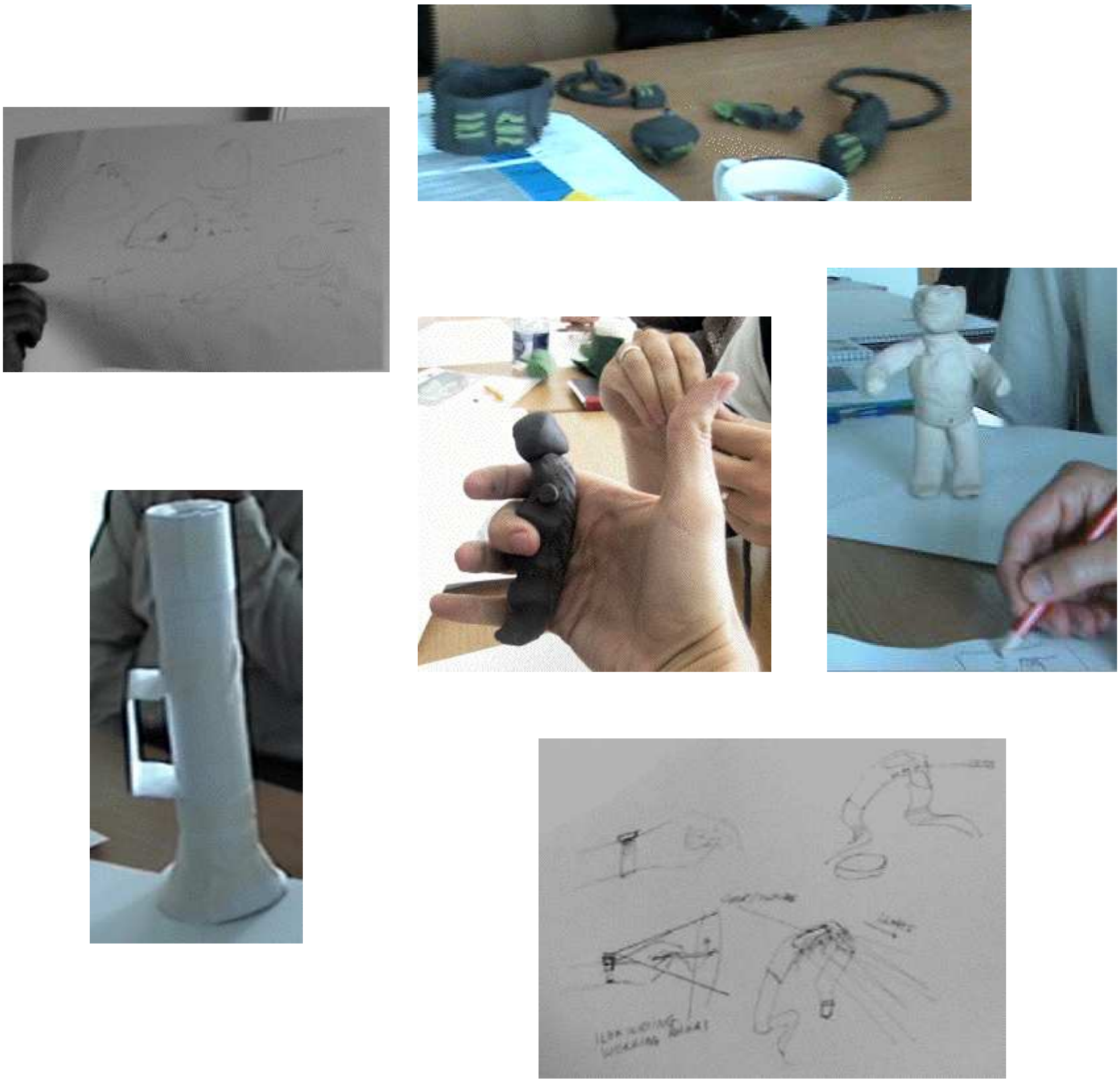

Figure 3. Sample of prototypes

Participants came up with a variety of designs, from fairly traditional functional torches, to a child's bedtime cuddly toy that glowed when stroked. Figure 3 shows some of the prototypes that the participants produced during the design session. We expected that richer materials would lead to more varied designs, however the end picture was far more complex. One team ended up spending most of their time in discussion rather than using the materials as a means to explore designs, and defied the instructions that they should not write things down. It was only at the very end that they used the plasticine to implement an already complete design idea. Another team that only had paper and pencil to work with was most prolific in terms of the number of design ideas they produced. In other cases, the nature of the materials drove the design, so one of the teams working with card ended up producing a card shape design of a torch.

However, while there was not a simple message such as "physicality helps creativity", detailed analysis of the video recordings reveals more subtle patterns of behaviour: including the way groups move between abstract and concrete discussions, the way different groups either comply with or resist the materials they are given, and the complex interactions between the physicality of materials and group dynamics.

Interactions within a team

We will now walk through a single team's interactions step by step. This will give some idea of the way these teams behaved and also begin to highlight issues, which we will discuss more thematically in the final part of the paper.

The team under consideration here is team A, which was supplied with a range of card sizes (A4, A3 and A0 rolls), a glue stick, masking tape and a pair of scissors alongside the design brief. It is interesting to note that there were some remarkable differences between the two teams in the card and glue group (see Figure 2), both in terms of the way the members collaborated and in the type of prototypes they produced. Also, the participants from both teams employed a lot of gestures during the discussion to demonstrate the ideas they were trying to get across.

The participants in team A were `E', `C' and `L'. The team members initially spent a substantial time discussing the design concept and exploring various alternatives with the materials they were given. They started with the obvious idea of a torch as a hand-held device that can be switched on and off, but they soon moved away from that concept, as `C' later confirmed in the presentation session.

> A>C: *we started with the obvious torch, you just press a button to light... we thought that was very boring …*

They narrowed their design focus by thinking of a possible scenario that they may need such a device for.

> A>C: *… we thought about what you need light for, we came up with the very plausible scenario of you wanting to read under your blanket without disturbing or being disturbed*

They went on to explore the shape of the device. `E' starts by naturally rolling the card into a cylindrical shape, but `L' suggests, *"what if it can be a handheld device, that is really flat and you can unfold and keep in your pocket".*

The type of light source was the next issue that was discussed.

> A>C: *something that illuminates like a keyhole*

> A>L: *It can be any light, a strobe light ... an instant strobe light*

A>E: *a head torch?*

A>L: *what about something rechargeable, that's not very heavy*

The team members carried on with their discussion until their ideas started getting clearer. They then proceeded to make some prototypes from the materials they were given and ended up producing three main prototypes, one based on each team member's design concept. However, there was some degree of collaboration between the team members during the model-making process, as described below. Their aim was to produce a reading light that is inconspicuous and more importantly, does not look like a traditional reading light.

Prototype 1

'C' starts by rolling up an A4 size card and taping it with some masking tape to make a tube. 'E' is quick to point out the issue with using a straight tube in a tent.

A>E: *In a tent, the problem is that with a straight tube light (demonstrates using the glue stick) the angle is wrong, what you want is a torch that bends as an upside down u shape on the top (demonstrates using gestures)*

'E' proceeds to make a prototype (see Figure 4) by using an A4 size card (4a), she cuts angles off with the pair of scissors (4b) and uses the masking tape to join the edges (4c). She cuts open the end to show where the light shines out from (4d). She later improves the design by adding another piece onto the end (4e).

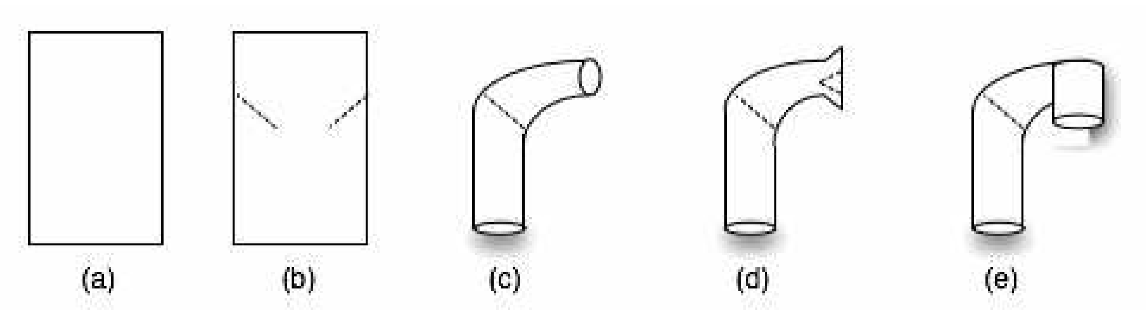

Figure 4. Various stages of prototype 1

During the presentation, 'E' describes her thoughts behind her prototype as follows:

A>E: *a lamp, the same idea as reading in a tent or reading under the blanket, you are able to hold it in the hand, you want the light to only go on the book, but not on the cover, so you don't get caught by your parents… and then it would be good if it's heavy at the bottom so it doesn't, so you don't need to hold it*

Prototype 2

'C' rolls out an A4 size card into a thin tube to produce a reading light that can be attached to the outside of book, which he demonstrates by folding a piece of card to represent the book (see Figure 5). 'L' suggests having a flexible light at the top so one can easily point to different places on the page but 'C' remarks that, "*a 'V' shaped is better for shedding even light across the whole page*". 'C' adds, "*it is better to stick it outside the card otherwise you can't flip the pages of the book*".

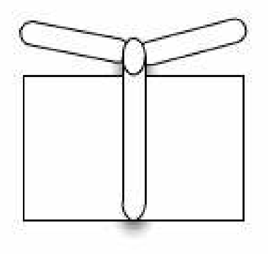

Figure 5. Example prototype 2

They then engage in a discussion as to where the batteries should be fitted. 'C' suggests, "*on the flat side (showing the book spine)*", hence the need for "*flat batteries*".

'C' later describes his prototype as follows:

> A>C: *a book reading lamp for underneath your blanket, you basically hold it behind your book, and there is a little switch here (imaginary one)… you move it up and down, it shines light on your page, you can flip the pages without the light being in your way, and you can hold it in one hand and hold up the blanket with the other hand*

Prototype 3

'L' scrunches a piece of card to demonstrate an 'ergonomic handheld' shape that can be shone onto things. She engages her team members by suggesting:

> A>L: *imagine if it is made out of rubbery material (holding the scrunched up paper) that you can squeeze and the best thing is that it doesn't look like a torch, so if you get caught you don't have a torch, you have a stress ball or something!*

'E' suggests, "*a teddy bear on the wrist*", 'L' embraces that idea.

> A>L: *oh yes a teddy bear, so the light comes out of its eyes ... how do you make that ... ok I try to build that one now.*

'L' starts by making a pattern for the teddy bear. 'E' and 'C' join in with their own teddy bear models made from different size cards. 'E' cuts out a fairly large flat teddy bear. 'C' instead uses the ergonomic shape that 'L' made earlier as a mould and adds layers to it, resulting in an amorphous hand-held shape.

'L' however works towards making a medium size 3D teddy bear model. She makes the 3D body shape from two layers of cards cut-outs and stick the cut-out angles together to produce a 3D effect. She adds some scrunched up card as stuffing between the layers. She then proceeds to make a 3D head shape with some stuffing in between. Before joining the head to the body, L adds some flat arms and secures everything with the masking tape.

Figure 6. Prototype 3

Looking at the end result (see Figure 6), 'L' remarks, "*it is quite a big teddy lamp!*"; 'C' calls it "*iTeddy*".

'E' adds a belly button to her flat teddy model and suggests, "*this can be pushed, like that (holding the teddy up)*".

'L' sticks a button on her 3D teddy model too but 'C' remarks '*I don't think we need the button, in a way, you can just squeeze it (demonstrates using the model) to switch it on*". 'L' agrees and removes the button and says, "*keep it as a conceptual sketch ... and how its gonna look, the light is gonna come out (squeezing the teddy)*"

'L' later explains the thoughts behind her design:

> A>L: *when I was little I used to take my microscope lamp to read, it wasn't easy to switch off. So I thought of something that was hand shaped that you could squeeze... and then we did this one (showing the teddy bear) and then thought it would be cool, if your parents actually catch you and you don't have a lamp in your hands, so you have like a teddy bear... you just press the teddy and the light shines …we thought a book and it would be a good supplement for a children's magazine.*

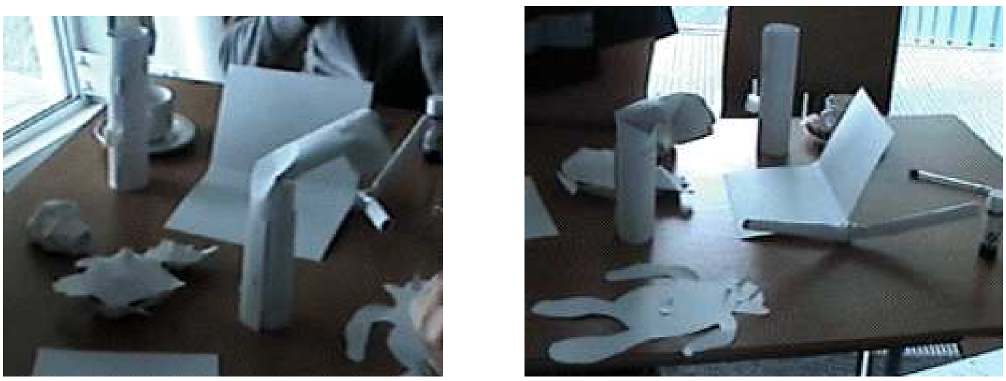

Figure 7. Some prototypes made by Team A

Figure 7 shows a selection of the prototypes that Team A produced.

Thematic Analysis

The initial ethnographic observations and field notes carried out on site were later supplemented by a detailed transcription of the video recordings. Our data highlighted several issues and through an in-depth iterative analysis, we identified individual topics and activities as well as a number of recurrent themes.

Even within this one team, we can see a wide variety of behaviours: from designs driven by the physical properties of the materials, for instance when 'C' rolls up a piece card in prototype 1 and 'finds' a classic cylindrical torch shape, to more abstract discussions of properties:

A>L: *what about something rechargeable …*

There were also some underlying trends, for example, the groups with paper and pencil tended to produce more fragments of ideas, but not necessarily more finished design concepts. However, the picture is typically more complex, and the themes have helped us to unpick the rich interplay between materials, design brief, team makeup and dynamics.

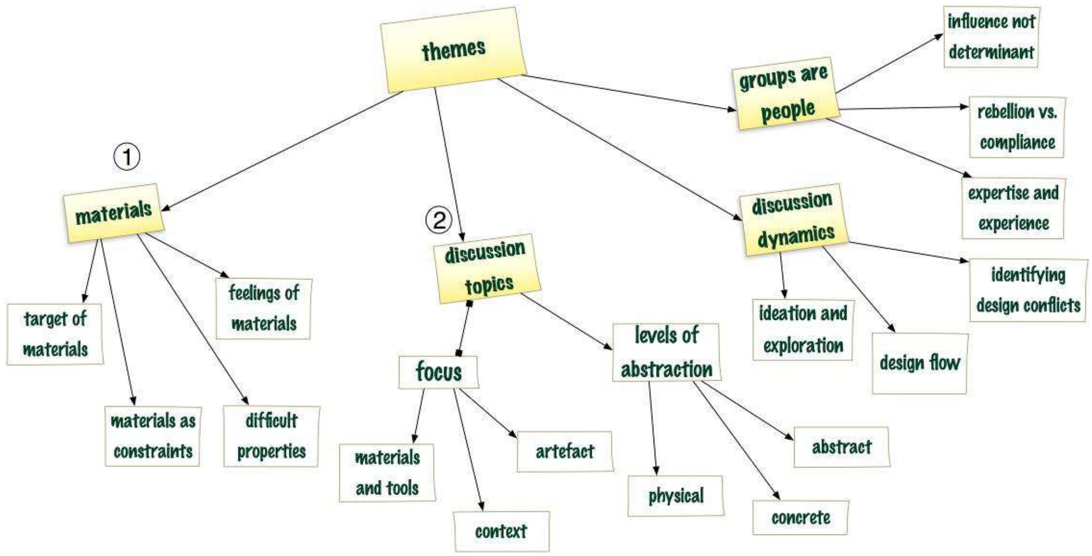

Figure 8. Breakdown of themes

We have categorised the themes into four main classes (see Figure 8):

① those relating specifically to what the materials give to the teams;

② those concerned with the topic of the design discussions;

③ those relating to the flow or dynamics of that design discussion; and finally

④ those relating to the personal and interpersonal factors within the group.

We will briefly discuss the first two of these themes (① and ②) as they explicitly bring out issues related to the physical properties of the materials during the early design stage. We also support this discussion with excerpts from the transcripts.

Materials

Target of materials: prototype – design – product

Some of the materials given to the groups were clearly intended to be used as a part of the prototype itself: card, plasticine, whilst others, such as the paper and pencil, are used during the design process, but are not evident in the prototype itself (except insofar as the design sketches are on paper.)

It was interesting to note that none of the teams given only paper and pencil used this to create a paper model by folding, tearing etc., despite having ample paper to draw on and to play with. It seems that once participants regarded the paper as a thing for drawing on (design material), it became impossible to see it as a raw material for construction. This conservatism was seen despite many other forms of challenging or subversive behaviour, thus suggesting that it is a very hard mindset to change.

Occasionally, the discussion turned to the actual materials that would be used on the product assuming the design were realised, for example,

> C>G: *"… and LumaTed is made from luminous material -"Philips Lumalight", with a sort of translucent material, that can light up in different colours, and you interact with it by stroking, so it will have a set of capacitor sensors that will allow you to stoke it in different ways and the more you stroke it the brighter it gets...*

This group even went on to give LumaTed a price. However, few groups explicitly differentiated the prototype material from the production material, probably exacerbating some team's tendency to be 'trapped' by the materials (see discussion below).

The design materials included things like the scissors for cutting, but these were sometimes used in unexpected ways. For example, team B considered using a roll of masking tape to draw smaller circles, and the scissors as a compass to draw wider ones using the point as a pivot. Furthermore, materials were often drawn in from the environment. Team D used a water bottle extensively both to inspire their design and eventually as part of their prototype (that is both as a design material and a prototype material). Another team rolled plasticine on the rough walls in an attempt to produce textured surfaces.

Ethnographies of group activities in other domains have demonstrated the importance of shared artefacts in coordinating actions; for example, the large common display in Heath and Luff's (1992) analysis of the London Underground. In our study we too found that the physical nature of the design materials is used to manage sharing and provide shared focus. For example, in Team F, members 'A' and 'B' started sketching ideas on separate sheets of paper, but rapidly switched to using the same sheet of paper, thus using the paper as a shared artefact to maintain collaboration and generate design ideas.

Materials as constraints

Constraints can sometimes be seen as a bad thing: limiting, holding back. However, psychological research on creativity and problem solving has often found that constraints can inspire creative designs (Ormerod, 2002), partly because they focus the design and partly because they sometimes prevent the 'obvious' solutions.

As we saw earlier during the production of Prototype 3 (Figure 6), L was did not let the card, an essentially two-dimensional material, hinder her design for a 3D teddy bear model. In fact her ability to produce such a refined model most likely reflects her background in fashion design.

However, most of the other participants often referred to the fact that they would have preferred one of the other materials, sometimes during specific parts of the design process. Some wanted pens to sketch with or other set of materials to use, for instance with Team A:

> A>C: *yes, I mean, I think we were lacking some pen to scribble*
>
> A>L: *or plasticine!*

and Team B:

> B>L: *I think to sketch out an initial design probably would've been handy, or a way to, sort of, come up with some ideas*

Similarly, Team H were frustrated that they have not been given clay to try out their ideas:

> *H>F: I think… the sketching, or the pencil and paper were ok for the initial communication of ideas and... summarising what we thought was right…*
>
> *H>G: Yeh, it would've been good to have something that we could actually mould and actually get more feeling about the actual prototype we came up*

Noticeably there was a greater tendency to ask for clay than card. This may reflect its greater malleability, for example Team A admitted during their presentation that they found the card "*difficult to bend to the shapes that our minds had formed in our head*" and Team F *"… tried to look at some sort of more organic bioforms, shapes, but paper is not a very good medium for doing that…*". The popularity of the clay may well also be because it was regarded as being more 'fun' (see later).

Teams also responded more subtly to their materials: the majority of card-based prototypes were formed from cylinders and other rollable shapes. However, this material did not totally determine the design, as we saw Prototype 3 (Figure 6) included scrunching up the paper, making it in effect more like the clay.

Difficult properties

Some properties that were mentioned during design discussions were difficult to recreate in *any* physical prototypes. This included the weight of objects (hard with card), softness (hard with plasticine), the light itself.

> F>A: *how do we produce light?... is a spark a light? …*

It is interesting to note that only the teams using paper and pencil discussed energy and 'light' at length. This is perhaps related to the fact that they engaged in more abstract discussions and that whilst weight, energy and light are very physical in one sense, they are also somewhat ethereal properties. But even this was not a universal rule as Team E used a cone of paper to " *simulate light*".

Feelings of materials

Whilst the materials did not determine team behaviour, the fact that plasticine was a child's toy certainly seemed to influence the teams' attitudes. The teams using plasticine appeared to operate in a more playful and sometimes wacky manner; for example, at one point team E produced a Petri dish. Team C spent a period discussing ideas, but all the while each holding a piece of plasticine, kneading and playing with it, but not using it to make anything. Even during the discussion stage, C>G starts playing with the plasticine and says "*Oh yeh, well we really enjoyed the plasticine! And yeh that was fun*".

In contrast, card suggested more formal/serious designs:

> B>R: *In terms of our process it was very much orientated to what we thought we could do with the materials we'd been given …we feel that it was good for making something that was solid, if you drop it, it probably won't break, but more than that it's not very expressive …*

Discussion topics

The topics that were discussed by the teams were based on different levels of abstractions (from physical, concrete to abstract) and focus (on the artefact, the context and the materials). Some teams spent more time in one or other kind of discussion, but also each team moved between kinds, at one moment discussing concrete design ideas, at another, more abstract discussion of requirements.

Level of abstraction: physical – concrete – abstract

Some of the discussion focused around the physical nature of the materials and models that were in their hands. For example, team B focused on making a torch that was as realistic as possible:

> B>R: *… most of our process was about making a model that looks relatively realistic, or at least as realistic as we could get.*

They also used physical things in the environment (such as the water bottle mentioned previously) to augment their design or to demonstrate or stimulate ideas:

> G>D: *So the idea was a watch with light... so the concept was this watch (showing his watch on his wrist), putting some lamps inside the clock/the watch, by sensors, touching it you can make it work*

and even their own bodies:

> H>F: *yeh sure... you are just cupping the light... (demonstrates two different ways of cupping using his hands)*

> H>F: *...I think it would be great... for warming light... (rubbing hands together)…*

Note, team H was in the paper and pencil group, so had no obvious prototyping material to create this sort of physical focus for their discussion.

At other times, the discussion was still quite specific, talking about a particular design or scenario of use, but without having it physically to hand. For example, team C were refining the shape of their teddy bear:

> C>G: *Yeh to show... we have a version... when the child grabs, cuddles it, it will come on, that's one situation, or strokes it... we have yours where it's at the end of the bed and we have to look for it, so we have to ask it, call its name and it'll come on …*

Finally, there were times when the discussion was at a more abstract level discussing general ideas, properties or dimensions. For example team H discussed ideas of "*discrete feedback*" and needing some form of "*discrete interaction*" and Team B considered the '*primitives*' afforded by their material (card):

> B>R: *we've got a circle (holding the masking tape) so we can use that to create a precise circle, we can mark it with that but we can score the card, so those are the primitives…*

There was a tendency for the paper and pencil group to have more abstract discussions, but this is far from being their preserve and many teams engaged in some form of more abstract discussion. What was evident was that at the point at which discussions became more abstract the teams with prototyping materials 'stepped back' from the materials … and one plasticine team even 'cheated' and used paper and pen!

Despite this 'stepping back', this is not to suggest that these different levels of abstraction are independent discussions. On the contrary, there is a constant interplay where more abstract discussions lead back to concrete design suggestions:

> F>A: *… produces light and there are implications with that… it has a battery, it has a bulb – that's the normal way to produce light, although they could have one of those, err, wind up ones...*

or lead to physical design solutions:

> H> G: *I guess if you're looking for discrete… what you need is some sort of discrete interaction like clapping …*

and even physical on concrete considerations prompt generalisations.

> H>F: *(sketching on paper) I think if you look at the fire, there's a couple of things that, err, you can read from the physicality of the fire.. if you place more logs on the fire, you can see how long the fire might eventually burn... and if the fire dims, you see the flames going down, you see that you have to put more on the fire...*

Focus: artefact – context – materials and tools

From the quotes and examples we have seen so far it is evident that the discussion topics sometimes focused on the artefacts that are being designed:

> F>C: *we started with the obvious torch*

sometimes on the context in which the artefact would be used:

> A>C: *… we thought about what you need light for, we came up with the very plausible scenario of you wanting to read under your blanket without disturbing or being disturbed*

and sometimes on the materials, tools or process of design itself:

> E>B: *…we used all kinds of tools, we split a pen apart and used the top and cut with this and used round things as forms and used the paper to simulate light and we borrowed some of the green plasticine from the other group...*

Each of these could be discussed at each level of abstraction as exemplified in Figure 9. We have seen several instances of these, such as in team A's prototype 2, they not only made the reading light, but they also used a folded piece of card to simulate a book: a physical model of the context.

Some parts of the picture are more common than others; for example, most of those teams with physical materials spent a considerable amount of time manipulating the physical artefacts. However, as previously noted, the abstract parts of this space are not the preserve of the paper and pencil group only, indeed team C, in the plasticine group, at one point raised the following:

> C>G:*… And we decided to focus it on children. And it seemed reasonable in that case to try to make it into some kind of night light, something that will help children when they're feeling frightened at night. And so from that we got a set of properties that we thought we would want to express through this, we wanted to help children feel safe and secure at night, it would be something that would be easy to interact with when they're kind of in that semi-wakeful state, something that would be soft, or warm, smooth, stable, robust... and out of all that came "LumaTed" ...*

The above excerpt illustrates the flow of the discussion which starts off in abstract context "*focus on children*", moves to concrete artefact "*night light*", then back to abstract context "*feeling frightened at night*", to abstract artefact "*set of properties*", and eventually back to more refined concrete artefact "*LumaTed*".

Focus / Level of Abstraction	artefact	context	materials/ tools
physical	holding torch	making book	rolling the card
concrete	mentions torch	scenario	scissors as compass
abstract	need to be rigid	requirements	'primitives'

Figure 9. Level of Abstraction vs. Focus of discussion topics

Conclusion

Our case study showed that a minimal design brief with fairly low-tech materials can in fact generate a wealth of information, thus reaffirming the importance of producing low fidelity prototypes at an early stage in the design. Although we set out to explore the role that physicality plays in the design process, the results defy simplistic conclusions such as "physicality promotes creativity", or even the opposite.

Our in-depth thematic analysis however reveals dimensions along which general trends can be seen. For example, the tendency for the teams with paper and pencil (typically) to engage in more abstract discussion, is probably one of the reasons for the greater number of (often fragmentary) design ideas. But again this is not as simple a story as stating that teams with prototyping materials tended to do such and such things. Although we have focussed on the materials and discussion topics, we cannot ignore the effects that the flow or dynamics of the discussion, and the personal and interpersonal factors within a group have on the design process.

The way that materials were utilised was partially a consequence of preconceptions brought into play by the backgrounds of the participants. So even within a single group, card is treated as if it were clay (crumpled to conform with the shape of a clenched hand), as an essentially two dimensional material (forming a bear as a cut out) and finally as a textile (forming a three dimensional teddy). So while the materials supplied may influence the output, it was also clear that the experience the user brought to the table partially influenced the design.

Individuals within groups and the way they worked together, would often mean they defied the restrictions or paths suggested by their materials – including rebelling completely, as with the plasticine team who, against the rules, got paper and pencil. This ability to move against the natural tendencies of physical materials seems very dependent on the characters of individuals and teams.

For practicing designers, but even more so for students, this does prompt questions as to how to maximise the benefits of specific physical materials in prompting new ideas, whilst also at appropriate moments during design activity, to 'escape' the practical and cognitive limitations they create. We do not answer this question here, but believe that the rich understanding of the design process we have produced is a step towards this.

Much of the more theoretical understanding of physical artefacts is focused on objects that concretely achieve physical goals: for Heidegger the way a hammer is 'ready to hand' in the act of joining wood with nails, or for Gibson, the way a rock if of suitable size 'affords' sitting upon. In the case of objects in a 'natural' (pre-technological) environment, Gibson argues that if we are well adapted to the environment, then our perceptions are tuned so that the affordances are immediately perceived; we are creatures tuned for action. However, as soon as we consider technological objects, things become more complex. Even turning a door handle needs to be considered as a sequentially unfolding chain of learnt associations and skills, as well as more immediate visual and haptic perceptions (Gaver, 1991). Similarly, 'ready to hand', while frequently misquoted, is not a matter of 'walk up and use' but is the product of culture and skill.

In this paper, we have looked at materials in design - that is physical objects that are for essentially *cognitive* tasks. What a material 'affords' under such circumstances is even more finely dependent on the past knowledge and skills of those using them (e.g. fashion designer vs. sculptor); and yet the material is not entirely open, without influence, like a piece of wood being carved, it has a grain, a set of uses that are easier than others, that fall more readily to hand or mind. Building an adequate practical and theoretical understanding of such a nuanced and context sensitive area is no easy task, and one we have by no means accomplished, but is, we believe, a valuable goal.

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Devina Ramduny-Ellis

A researcher in the Computing Department at Lancaster University in UK. She started her research in the area of Human Computer Interaction and Computer Supported Collaborative Work and was awarded her PhD in May 2003 for her work on developing architectural frameworks for enhancing temporal interface behaviour for distributed collaborative users. Her research interests ranges from devising methods for work analysis and interaction properties, modelling techniques and interface design, to computing infrastructure and employing empirical field studies involving ethnographic and other qualitative techniques to inform novel designs and prototypes. She has worked in several research projects within an academic environment, which covered a wide range of areas including ubiquitous computing, dependability, decision management and interfaces and infrastructure. She has over 25 publications and she is currently managing and working on the DEPtH: Designing for Physicality AHRC/EPSRC funded project. She has been

actively involved in starting up a multi-disciplinary community in physicality through the Physicality 2006 and Physicality 2007 International Workshops.

Joanna Hare

Jo graduated in 2004 from De Montfort University, Leicester with a BSc. honours degree in Industrial Design, during which she completed a placement year working within BMW's Design and Development building in Munich. After graduating, Jo worked for Exmoor Plastics, a medical device manufacturing company in Taunton, in conjunction with PDR as part of the Knowledge Transfer Partnership (KTP) scheme. The KTP project focused on increasing the company's productivity by decreasing product development time. New procedures were successfully implemented that defined and selected new project proposals to take forward. Jo is currently working within the PAIPR research group on Design for Physicality (DEPtH), an AHRC/EPSRC funded project under the Design for the 21st Century programme.

Alan Dix

A Professor in the Department of Computing at Lancaster University in the UK. He was a mathematician by training, and mathematics is still his first love, but he has worked in Human-Computer Interaction since 1984, has published over 300 articles and is author of a key textbook in the area. He has worked in several universities, agricultural engineering research, local government and hi-tech start-ups. His interests are eclectic: formalisation and design, physicality and digitality, the economics of information, structure and creativity and the modelling of dreams. Recently he and a colleague have developed technology for autonomous pixels that can be configured in turn any surface or space into a two or three dimensional display.

Steve Gill

A product designer with 15 years experience in industry and academia. He is Director of Research of the Cardiff School of Art & Design and Director of the Programme for Advanced Interactive Prototype Research (PAIPR) within The National Centre for Product Design & Development Research (PDR). He has designed or product managed around 50 products to market and has published 20 academic journal and conference papers. Steve has a range of research interests related to product design and development including the rapid design development of information appliances, the role of physicality in the design process and the implications for product design development of testing early information appliance prototypes within their context of use. He works closely with academic partners such as the University of Lancaster and those in blue chip industry such as UIQ and Sony-Ericsson (whose Smartphone division have altered their interface design strategy to implement his research work through a working partnership).