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Physicality in Design: an exploration

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ABSTRACT

Both the nature of many products and their process of creation are becoming increasingly digitally mediated. However, our bodies and minds are naturally conceived to interact with the physical, so crucial design information can be elicited by constructing meaningful prototypes. This paper examines how physical materials impact early design through a study that explores how groups with very different materials tackle a common design challenge. The inherent physical properties of the materials and the ways in which designers interpret and manipulate them give rise to subtle patterns of behaviour. 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 our research in explicating the fundamental role of physicality in the design of hybrid physical and digital artefacts.

KEYWORDS

Physicality; design process; prototyping

INTRODUCTION

Design has a long tradition of artistic engagement with, and manipulation of, materials as an intrinsic part of the design process. A material centric approach, exemplified by the artisan designer, has shaped our modern understanding of design (Pevsner, 1991; Raizman, 2004; Woodham, 1997). Potter (1969) describes the activities of the artisan designer as being driven by the manipulation of materials in workshops where they 'get their hands dirty'. Traditionally, product design has focused on artefacts designed using physical materials such as clay, wood, metal or plastic (Heskett, 1980). The human condition is made palpable by the material world it inhabits and meaning is taken from physical objects that colour our everyday lives (Dant, 1999; Woodward, 2007). We have a propensity for the physical materials we have experienced throughout our lives and understand the behaviour of stone and wood, water, and metal for example as being natural to us. However, this is changing as manmade artefacts increasingly include digital elements, from MP3 players to mobile phones, and in the design process itself, sketches and clay models are giving way to CAD and virtual representations.

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 firstly, better inform the design of hybrid digital/physical artefacts and secondly, understand the impact of changing tools and techniques on the design process.

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The authors' previous work has considered properties of commercially available electronic and domestic products in order to uncover the ways in which designers exploit the physical nature and placement of interface controls. 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 low fidelity mock-ups were as useful as high fidelity ones (Gill et al., 2005a).

In this paper, our focus is on the role of physicality within the design process. We investigate the manner in which material properties affect both the process and outcomes of design activity. Our study presents the findings of a design exercise based on using a variety of materials to explore a common design challenge, which was undertaken at the Second International Workshop on Physicality (Ramduny-Ellis et al., 2007). A detailed analysis of the design exercise identified several recurrent themes and issues regarding the rich interplay between materials, design brief, team makeup and dynamics. This thematic discussion is addressed in the latter stages of this paper. Understanding the fundamental role of physicality in product design has been a key motivation underpinning our research.

MOTIVATION

With advancements in technology, the form of objects is no longer driven by the technologies within them (Evans & Sommerville, 2007). Traditional modes of understanding for the product's expression of meaning no longer apply (Norman, 1998a; Vihma, 1995). 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, 1998b); therefore their development process can frequently be disjointed with the physical and digital elements being designed in isolation. These physical and digital processes are often only combined for user testing towards the end of the development process when major design changes are impractical. Baxter (2002) and Branham (2000) identify the need for new tools to overcome this 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 (Rakers, 2001). One of the ways that this could be achieved is by building prototypes, a true to life model of the design in progress, equipped with some properties. Ulrich and Eppinger (2003) define prototypes as an approximation of the product on one or more dimensions of interest, which serve as tools for leaning, communication, integration and milestones.

Prototyping techniques such as Experience Prototyping (Buchenau & Suri, 2000) and Paper Prototyping (Snyder, 2003) go some way towards exploring the physical and digital form, particularly in their inclusion of physicality. However, methods that retain their 'quick and dirty' hands-on approach while incorporating more accurate simulation

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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 results in physical prototypes being rarely produced or if they are built, often they have limited functionality. The ability to build meaningful prototypes without investing large amounts of time and money 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 discourse, 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).

There is much research activity looking into creating systems for the development of computer embedded products which are sympathetic to the designer's mindset and methods. These include Phidgets (Greenberg & Fitchett, 2001; Phidgets Inc.) Voodoo Dolls (Pierce et al., 1999), DTools (Hartman et al., 2005), Switcharoo (Avrahami & Hudson, 2002), Pin and Play (Villar 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 perspective.

The authors have developed low-tech keyboard emulation boxes (*IE Units*) which link to software building blocks (Gill et. al., 2005b). The *IE Units* allow rapid prototyping without the usual electronics or programming prerequisites and 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 (Gill et al, 2008), 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 for designers' use (Dix et al., 2009). Having recognised that physicality is important in devices and prototypes, this paper looks at how the physicality of design materials may affect the design itself.

CASE STUDY

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At the Physicality 2007 International Workshop held at Lancaster University, a design exercise was undertaken to explore the influence of a variety of materials in the initial stages of the design activity and assess how their physical properties impact issues such as the number and novelty of design ideas and the kinds of designs produced.

Method

Our approach was open and exploratory rather than controlled, reflecting the aim to understand new behaviours rather than quantify known ones. Ethnographic observation was used that included both live observations with field notes and also video-recording to capture the design process and its outcomes for detailed review.

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

- paper and pencils
- card and glue
- modelling clay (commonly known as plasticine)

Participants were instructed to use the allocated materials as detailed above but beyond this they were not told how to use the materials. In practice the materials 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; as expected they produced sketches of their design. In everyday design practice, any or all of these materials would be used according to the preferences of the designer and the nature of the design problem. However, in this exercise, participants were restricted just one kind of material. 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 workshop attendees were a mixture of designers and technologists, artists and architects, psychologists and philosophers. We opted for materials that are accessible for a wide range of people and which did not require any specialised skills. The choice of materials also reflects traditional design practice and covers 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 for sketching, a process by which the designer works on the design problem by exploring various ideas and experiment with different approaches.

Card and glue is an extension of this – allowing very quick rough '3D sketching' to give ideas some shape for discussion, although card can also be used for more refined models.

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The most common material used by product designers to create fast 3D models is 'blue foam', however 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). Modelling clay provided the tactile 3D element of blue foam without the need to train the participants to use specialist equipment.

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). Technical considerations were deliberately kept to a minimum with the intention of encouraging participants to reflect on the device in relation to the human body.

Figure 1

Participants were divided in three groups, one for each material. Each group had two to three teams consisting of two or three people. 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.

The participants came from various disciplines including computing, arts, design, sociology, philosophy, 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.

Figure 2

Initial Observations

Video recordings from three camcorders and photographs were taken during the design exercise of both the individual teams and the final presentations. As there were more teams than video cameras, we chose to rove between teams within a design material group and have a series of shorter recordings showing periods of group interactions rather than continuous end-to-end video of single teams. The trade-off between breadth of coverage of different teams and depth for a single one does not appear to have a simple answer, but in this case the more exploratory nature of the study suggested the former. The following discussions show that the periods of videoing were sufficient to capture significant events in full.

The level of exploration varied significantly between teams. Some teams focussed on a single design idea and produced a single prototype, whilst others explored various design ideas and generated a number of prototypes. However, there was no clear relationship between the groups that used particular materials and those being more

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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.

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 exercise. 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 cylindrical prototype.

Figure 3

However, it is not possible to identify a direct relationship between the type of material used and the approach each team adopted. Detailed analysis of the video recordings reveals subtle patterns of behaviour including: the way groups move between abstract and concrete discussions, the way different groups either comply with or work against the materials they are given, and the complex interactions between the physicality of materials and group dynamics.

INTERACTIONS WITHIN A TEAM

We will now examine one team's interactions step by step to provide an understanding of team behaviour and also begin to highlight issues, which we will discuss more thematically in the latter 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, teams A and B, both in terms of the way the members collaborated and in the type of prototypes 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 are denoted as A1, A2 and A3. The team members spent a substantial time discussing their design concept and exploring various alternatives with the materials they were given. They began with an 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 A2 later confirmed in the presentation session.

A2: 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.

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A2: … 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. A1 starts by naturally rolling the card into a cylindrical shape, but A3 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.

A2: Something that illuminates like a keyhole

A3: It can be any light, a strobe light ... an instant strobe light

A1: A head torch?

A3: What about something rechargeable, that's not very heavy?

The team members carried on with their discussion until their ideas began to develop. They proceeded to make prototypes 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 (Team A)

A2 starts by rolling up a piece of card (A4 size) and taping it with some masking tape to make a tube. A1 is quick to point out the issue with using a straight tube in a tent.

A1: 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).

A1 proceeds to make a prototype (see Figure 4) by using another A4 size card (see figure 4a), she cuts angles off with the pair of scissors (figure 4b) and uses the masking tape to join the edges (figure 4c). She cuts open the end to show where the light shines out from (figure 4d). She later improves the design by adding another piece onto the end (figure 4e).

Figure 4

During the presentation, A1 describes her thoughts behind her prototype as follows:

A1: 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.

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Prototype 2 (Team A)

A2 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). A3 suggests having a flexible light at the top so one can easily point to different places on the page but A2 remarks that '*a "V" shaped is better for shedding even light across the whole page*'.

A2 adds '*it is better to stick it outside the card otherwise you can't flip the pages of the book*'.

Figure 5

They then engage in a discussion as to where the batteries should be fitted. A2 suggests '*on the flat side (showing the book spine) … we need flat batteries*'.

A2 later describes his prototype as follows:

A2: 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 (Team A)

A3 scrunches a piece of card to demonstrate an 'ergonomic handheld' shape that can be shone onto things. She engages her team members by suggesting:

A3: 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!

A1 suggests '*a teddy bear on the wrist*' and A3 embraces that idea.

A3: 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.

A3 starts by making a pattern for the teddy bear. A1 and A2 join in with their own teddy bear models made from different size cards. A1 cuts out a fairly large flat teddy bear. A2 instead uses the ergonomic shape that A3 made earlier as a mould and adds layers to it, resulting in an amorphous hand-held shape.

A3 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

Looking at the end result (see Figure 6), A3 remarks '*it is quite a big teddy lamp!*'.

A2 calls it '*iTeddy*'.

A1 adds a belly button to her flat teddy model and suggests '*this can be pushed, like that (holding the teddy up)*'.

A3 sticks a button on her 3D teddy model too but A2 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*'.

A3 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)*'.

A3 later explains the thoughts behind her design:

A3: 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 shows a selection of the prototypes produced by Team A.

Figure 7

THEMATIC ANALYSIS

After the event, the videos were transcribed by one of the authors who had been present during the study. The video was then informally analysed with the aid of the transcription by another author who had not been present during the design exercise, thus allowing a degree of distance from the data. The aim was to pick up any trends or patterns from the data gathered. The transcription included both the words spoken and descriptions of the artefacts being prototyped, sketching, gestures etc. The dialogue and descriptions in the previous sections are excerpts from this transcript.

The transcripts were then subjected to a systematic in-depth iterative analysis. The analysis began with a small number of known themes and issues, principally physicality itself and its influence on creativity in the designs produced. This was used to pump prime iterative passes over the data using dialectic re-coding (Dix, 2008). This involves coding the data according to the known categories, but not doing so in order to 'gather evidence' for pre-judged themes, but instead subjecting them to critique. We looked for two main kinds of tensions (the dialectic) between the themes and the data:

(i) gaps in coding - apparently important events or statements that did not fit within the thematic scheme

(ii) inadequate coding - where there is a way of coding the data, but it appears to be incomplete in its description of the data

The first leads to the identification of new themes, many of which had not been considered. The second leads to refinement or modification of existing themes.

This process combines an inductive data-driven qualitative analysis with an explicit recognition that we had pre-existing expectations and intentions when approaching the data gathering and data analysis.

This is similar to the Strussian School of grounded theory (Strauss and Corbin, 1990) and indeed dialectic re-coding was first proposed as a way of validating the results of grounded theory or other qualitative analysis methods.

Even within Team A, we can identify a wide variety of behaviours: from designs driven by the physical properties of the materials, for instance when A2 rolls up a piece card in prototype 1 and 'finds' a classic cylindrical torch shape, to more abstract discussions of properties:

A3: What about something rechargeable…

There were also some underlying tendencies, 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 unpick the rich interplay between materials, design brief, team makeup and dynamics.

Figure 8

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

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

2. those concerned with the topic of the design discussions;

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

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.) to draw out issues related to the physical properties of the materials during the early design phase.

THEME 1: DESIGN MATERIALS

Target of materials: Prototype / design / product

Some of the materials given to the groups were intended to be used for prototyping: card and plasticine for example, whilst others, such as paper and pencil although used

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during the design process are not evident in the prototype itself (except insofar as the design sketches are on paper).

None of the teams given only paper and pencil used these materials to create a paper model by folding, tearing etc., despite having ample paper to draw on and use for prototyping. It can be identified that once participants regarded the paper as an object for drawing on (design material), it became unlikely that they would see it as a material for construction. This convention was seen despite many other forms of challenging behaviour, thus suggesting that it is a 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,

C1: '… 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 materials included scissors, masking tape, etc and 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 larger ones using the point as a pivot. Furthermore, materials were often drawn in from the environment in addition to those supplied. 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 have demonstrated the importance of shared artefacts in coordinating actions (Heath & Luff, 1992). Likewise, in our study the design materials are used to manage sharing and provide shared focus. For example, in Team F, members F1 and F2 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 that limits or holds back development. 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), A3 did not let the card, an essentially two-dimensional material hinder her design for a 3D teddy bear

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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:

A2: Yes, I mean, I think we were lacking some pen to scribble.

A3: Or plasticine!

And Team B:

B2: 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:

H2: I think… the sketching, or the pencil and paper were ok for the initial communication of ideas and... summarising what we thought was right…

H3: Yeah, 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'.

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 replicate with physical prototypes. This included the weight of objects (hard with card), softness (hard with plasticine), the light itself.

F1: How do we produce light?... is a spark a light?

We 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

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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'*.

Feeling 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 toward material properties. 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 while 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, C1 starts playing with the plasticine and says '*Oh yeah, well we really enjoyed the plasticine! Yeah, that was fun*'.

In contrast, card suggested more formal/serious designs:

B3: 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 …

THEME 2: DISCUSSION TOPICS

The topics that were discussed by the teams during the design exercise 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:

B3: …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 objects in the environment (such as the water bottle mentioned previously) to augment their design or to demonstrate or stimulate ideas:

G1: So the idea was a watch with light... so the concept was this watch (showing his wristwatch), putting some lamps inside the clock/the watch, by sensors, touching it you can make it work.

And even their own bodies:

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H2: yeah sure... you are just cupping the light... (demonstrates two different ways of cupping using his hands) ...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:

C1: Yeah 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):

B3: 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:

F1: … 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:

H3: 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.

H2: (sketching on paper) I think if you look at the fire, there's a couple of things that 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

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It is evident that the discussion topics were concerned with the artefacts that are being designed:

F2: We started with the obvious torch

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

A2: 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:

E2: 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 can 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.

Most of those teams with physical materials apt for prototyping 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:

C1: 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*'.

Figure 9

CONCLUSION

Our study has demonstrated that a simple design brief combined with low fidelity materials can generate a wealth of information, thus reaffirming the importance of producing low fidelity prototypes at an early stage in the design. As Rettig (1994) remarks, 'lo-fi prototyping require little more in the way of implementation skills other

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than the ones learned in kindergarten'. The participants from our study were not all 'natural designers'; they came from different disciplines and as the materials they were given did not require detailed skills, they could focus entirely on the features of the design itself.

Our research focus was to explore the role that the physicality of materials plays in the design process. The results do not support 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. 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.

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, used paper and pencil. This ability to move against the natural affordance of physical materials was dependent on the characters of individuals and/or teams.

Here are some of the key themes from our analysis:

Physicality and teams – Paper and pencil were firmly regarded as sketching or drawing material, unlike card and clay, which were treated as modelling materials. Like Kingsley et al. study (2005), we found the modelling teams had more fun, felt happier with their end design and more committed to the goals of the group, however, we did not specifically measure for these. Also, as the actual building process started, the level of interaction between members of the modelling team members did slow down especially with the teams that produced more than one prototype as each one started making on their own design. Similarly, we found that with the paper and pencil teams, the drawing was mainly done by one person, allowing or compelling the team members to continue building their relationship through gaze rather than focussing on their own activity.

Physicality and user experience – We cannot overlook that the fact that the way that materials were utilised was partially a consequence of preconceptions brought into play by the backgrounds of the participants. 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 activity.

Physicality and level of abstraction – Typically the tendency for the teams with paper and pencil was to engage in more abstract discussion as they had no physical focus, thus contributing to the greater number of (often fragmentary) design ideas. When some of the teams in card and modelling clay groups did discuss abstract properties, they had to step back from the material and some even cheated by writing on paper. On the whole, the card and modelling clay groups were more inclined to discuss the physical artefact

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they were designing, the context it would be put to use and how to work with the materials.

For practicing designers, but even more so for students, the findings from our research do 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, nor can we make any sweeping statements as to the impact of our findings on the way we might design things in the future, but we believe that the rich understanding of the design process we have produced is a step towards this.

Based on Ulrich and Eppinger (2003) classification of prototypes, in our design exercise, card and modelling clay were used to produce physical prototypes (tangible artefacts that approximate the product) while paper generated more abstract prototypes (where the products are more analysed rather than built). But they were all low fidelity prototyping materials that are versatile and accessible; as a result, they can be very useful for early exploration of design concepts in a short space of time. They allow the team to try out lots more ideas and are driven by the experience and behaviour that the people bring to the table. In terms of purpose for building prototypes, whilst Ulrich and Eppinger begin with 'Learning', this is expressed in terms of learning about the suitability or potential of an already part-formulated design concept. In contrast our groups had a playful and open brief and their purpose was largely exploratory, closer to Gedenryd's (1998) notion of design as inquiry. Also while Ulrich and Eppinger suggest that only physical prototypes can be 'comprehensive', the importance of context of use highlighted in the last section, questions this comprehensiveness, which is perhaps more about the final artefact in isolation, not the artefact in context.

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; indeed Ilyenkov (1977) regarded ideals (ideas) as embodied relationally in the activities of creating and using artefacts.

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.

Philosophers of embodiment such as Clark (1998) and Gallagher (2005), and Gedenryd's (1998) application of this strand of thinking to design go some way towards this. However, some of our results, notably the way the teams turned to discussion or paper and pencil for more abstract 'stepping back' or Team A's ‘shapes that our minds had formed in our head’, seems to contradict Gedenryd's claim that ‘designers go out of their way to avoid intramental thinking’. This may be because our participants were academics, used to talking (!), and maybe having a rich repertoire of concrete examples that could be drawn upon mentally. In contrast, Gedenryd's focal transcripts concern tutor–novice dialogue, where the tutor may be being concrete for the benefit of the novice. However, looking afresh at even these transcripts (ibid. p.82, drawn from Schön (1983)) reveals a more mixed picture, as the pivotal action of the tutor, Quist, is to notice that the novice, Petra, has become stuck in detailed design and so step back to reformulate the problem. The outcome of this stepping back is presented concretely in sketches representing an alternative approach, but the stepping back itself is conveyed in words.

Looking forward, future empirical studies could focus on practising product designers, observing a longer exercise over which participants could get more involved in the process and tools they are using. Rather than limiting them to a single prototyping material, a combination could be offered at different stages of design to observe which are chosen, how they are used, and indeed when they are not used at all. More interventionist experiments could control the order the materials are made available to groups, maybe presenting materials deliberately in the 'wrong' order, for example, first modelling clay followed by pencils then card and glue.

In summary, the data resists simplistic assumptions. Choice of material clearly has an impact, but the individual skills and background of the participants are equally important. Materials can constrain people, but they can also inspire creative design, hence the need for physical modelling to be part of the design curriculum and students’ awareness of and willingness to use these techniques need to be cultivated in an age of CAD. But equally, less tangible expression in discussion and plain old lists seems to allow breadth of exploration. A full theoretic approach needs to take this richness into account, not just the embodied interplay between mind and environment, but also recognising that parsimony (Clark, 1998) cuts two ways with the balance between mental/verbal and manual/physical 'cognition' dynamically adapting to suit the situation.

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