A Dissertation Exploring the Issues Surrounding the Rapid Development of Information Appliances by Designers

Submitted for the Award of: PhD by Published Works

Awarding Body: University of Wales

Discipline: Product Design

By: Steve Gill, BA (Hons)

Date of Submission: 18th December 2008

Advisors: Prof. Alan Lewis and Dr Gareth Loudon

This research was undertaken under the auspices of the University of Wales Institute, Cardiff.
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td>3</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>3</td>
</tr>
<tr>
<td>CHAPTER 1 - ABSTRACT</td>
<td>4</td>
</tr>
<tr>
<td>CHAPTER 2 - INTRODUCTION</td>
<td>6</td>
</tr>
<tr>
<td>CHAPTER 3 - CONTRIBUTION TO NEW KNOWLEDGE</td>
<td>14</td>
</tr>
<tr>
<td>CHAPTER 4 – BACKGROUND</td>
<td>25</td>
</tr>
<tr>
<td>CHAPTER 5 – CURRENT PRACTICE AND APPLICATION</td>
<td>30</td>
</tr>
<tr>
<td>CHAPTER 6 - THE IE SYSTEM; ORIGINS AND FIRST WORKABLE MANIFESTATIONS</td>
<td>37</td>
</tr>
<tr>
<td>CHAPTER 7 – TRIALS AND EMPIRICAL PERFORMANCE MEASUREMENT</td>
<td>45</td>
</tr>
<tr>
<td>CHAPTER 8 – OTHER WORK: PAST, CURRENT AND FUTURE</td>
<td>49</td>
</tr>
<tr>
<td>TABLE 6: SUBMITTED WORKS</td>
<td>56</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>58</td>
</tr>
</tbody>
</table>
Declaration

This work has not previously been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

Signed  [Signature]  (candidate)

Date  18th March 2009

Statement 1

This work is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes and through explicit references. A full list of references is appended.

Signed  [Signature]  (candidate)

Date  18th March 2009

Statement 2

I hereby give consent for my work, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed  [Signature]  (candidate)

Date  18th March 2009
Chapter 1 - Abstract

This PhD by published works dissertation includes seven peer reviewed publications. The author uses selected papers to demonstrate the novelty of the work, summarising papers’ findings and illustrating as appropriate.

The Introduction explains the way in which the work has developed, its focus and the raison d’être for the order in which the papers are presented.

Contribution to New Knowledge briefly summarises the contribution of the outputs individually and collectively to the author’s chosen field.

The Background chapter explains the work’s origins, how the author became interested in the field, how he developed his initial interests into a research topic and the timescale of events. Two papers; The Virtual Environment in Design Projects (1999) and Designing a Learning Environment for Three Dimensional Thinkers (2000) are used as reference material.

In the Current Practice and Application chapter the work of other researchers relevant to the field of enquiry and the current practices of the design and manufacturing industry are discussed. References to papers included in this submission are cited as necessary.

The IE System; Origins and First Workable Manifestations chapter describes how the various elements of the system came together to form one coherent methodology. The chapter details how the work progressed from early manifestations and describes the development of the IE2 and IE3.
The Trials and Empirical Performance Measurement chapter uses material from two papers: The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance and Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time Balance. Through reference to these papers the author summarises the results of the various trials described in detail within them.

The dissertation concludes by describing the latest and future work with colleagues at Lancaster University and Sony-Ericsson. The IE4, IE5 and IE6 are described and the plans for the future research are discussed.
Chapter 2 - Introduction

The purpose of this dissertation is to present selected published research work carried out by the author since 1999 with a view to gaining a PhD by published works. The papers presented have been selected from the 23 peer reviewed publications the author has to his credit to date and they all fit within a general research theme revolving around an exploration of the role for industrial designers in a commercial and educational world increasingly dominated by ubiquitous computing. The earliest work concentrates on the manifold opportunities this technology brings while the main body deals with the problems of bringing design methodologies to bear on the products that utilise it, in particular so called information appliances. Commentators have continually criticised the poor design of such products (see Buxton (2001), Cooper (2004) or Loudon (2006)) but while this criticism is certainly justified, there is a general lack of serious, detailed and connected suggestions for industrial designer oriented methodologies that might be employed to solve the issue. Part of the problem is that these products are so remarkably complex that they require a far more holistic methodology and this has certainly been recognised. In the mid-nineties Thomas was already arguing for a systems approach (Thomas et al (1995)). In 2000 Hollan developed that concept further, arguing the case for distributed cognition (Hollan et al (2000)). How do we empower industrial designers to undertake these approaches? Before discussing that it might be sensible to define industrial design and to locate it within the product development process.

In the first half of the twentieth century, Holme reminded us that “Man does not exist for industry. Industry exists for man. The problem of today” (he continues) “is not to adapt man to industry but industry to man.”

---

1 Information appliances: "personal" digital devices designed to perform a specific activity. Examples include MP3 players, digital cameras and Personal Digital Assistants (PDAs).
Industrial Design means the conscious ordering and planning of production of material things to this end.” (Holme 1934) The International Council of Societies of Industrial Design (ICSID) no longer attempt to define industrial design. However, in 1963 their definition essentially expanded on Holmes’: "a creative activity whose aims are to determine the formal qualities of objects produced by industry. These formal qualities are not only the external features but are principally those structural and functional relationships which convert a system to a coherent unity both from the point of view of the producer and the user. Industrial design extends to embrace all the aspects of human environment, which are conditioned by industrial production." (ICSID 2009) While he doesn’t contradict either of the definitions above, Heskett takes a more utilitarian approach, defining industrial design as “a process of creation, invention, and definition separated from the means of production, involving an eventual synthesis of contributory and often conflicting factors into a concept of three-dimensional form, and its material reality, capable of multiple reproduction by mechanical means.” Heskett (1980) The Industrial Design Society of America (IDSA) brings the definition up to date without changing the sentiment of those above: “Industrial design (ID) is the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer.” (IDSA 2009)

It is therefore the industrial designer’s role to cohere a design solution that answers the needs of all stakeholders to create the finished item with which the user interacts. “Industrial designers are a special breed. They are part engineer, part marketer, part computer wizard. They must have excellent creative and technical skills. They must know about costs, materials and manufacturing processes. They apply humanistic principles to the process of mass production.” (Prescott, 2000) So the industrial
designer is expected to understand the user, their limitations, abilities, desires and frustrations. A good industrial designer will design products with an appropriate cognizance of their context of use.

Key to developing these understandings is the methods used. Typical tools include sketching, maquettes, soft models and rigs, all of which are used for iterative development in the early to middle sections of the development process. Other techniques towards the end of a design’s pre-production development include facsimile models, which look exactly like the real product but are non functional and facsimile prototypes which are close to indistinguishable from the finished item. Since the focus of the author’s research is on the early, rapid, iterative stage of the design process however, the most salient tools as far as this work is concerned are the first four: sketching, maquettes, soft models and rigs.

Sketching is the fastest method of recording and developing ideas, but industrial design is a three dimensional activity and even the most experienced designers need to trial their ideas in three dimensions. Lawson notes: “The drawing offers a reasonably accurate and reliable model of appearance but not necessarily of performance. Even the appearance of designs can be misleadingly presented by design drawings. The drawings which a designer chooses to make whilst designing tend to be highly codified and rarely connect with our direct experience of the final design” (Lawson, 1997). So for the development of form, proportion, aesthetics and structure designers supplement two dimensional sketch development with maquettes (scale models, generally of large products) or soft models, typically using card or modelling foam. Soft models often create the first opportunity for a user to interact with the product’s physicality, and this is a key component of the design process where a concept will frequently stand or fall. Ulrich and Eppinger note: “industrial designers build models of the most
promising concepts. Soft models are typically made in full scale using foam” (Ulrich and Eppinger, 1995). The other three dimensional development technique, the rig (sometimes also known as the prototype), is used to develop the mechanical aspects of a design. Rigs don’t always prototype the whole of the design and they sometimes won’t look like the design concept. Their function is to test concepts' mechanical properties, mechanisms or user interaction “prototypes are built to test and validate the design” (Kai et al 2008). For example a rig of a chair concept would be strong enough for users to sit on and would be adjustable so that the designer could swiftly act on observations regarding seat height, angle, comfort etc. but it wouldn't necessarily look like the finished article.

The author submits that the complex, organic nature of the systems approaches advocated by Thomas, Hollan and others mean that they can only be realistically achieved with fast and flexible developmental tools that enable iterative, prototype led design development (in other words a rig equivalent). Some might argue that this has been achieved, pointing out, for example, that by 1999 Moggridge was already publishing material about prototype-driven information appliance design (Moggridge (1999)) at IDEO. This is true to an extent, but IDEO are a multidisciplinary organisation with access to skills and facilities that are simply beyond the reach of most designers. Furthermore, even with the skills available at IDEO, the prototypes he presented as case studies were neither quickly nor easily made and so the goal of finding ways for designers to rapidly and iteratively develop prototypes of information appliances remains as relevant today as it was then. So a key aim of the author’s research has been to create an equivalent of the rig for the design of information appliances that will allow design concepts to be swiftly, iteratively tested, adjusted, accepted or rejected. The system the author has been engaged in developing offers a number of advantages
analogous to those offered by rigs. Within the information appliance design and development context it:

- Provides confidence in decision making processes for industrial and interaction designers by providing a method through which they are able to rapidly and iteratively design and develop low fidelity tangible prototypes. The reasons they can be confident lie in a series of empirical trials that prove that low fidelity prototypes that follow certain rules of physicality will give user trial results that closely match those of the real product (see Paper #7).

- Enables interaction design decisions to be validated through user testing, in context, at an early stage in the design process. It is at the fast and fluid early stages of a design process that many of the defining decisions are taken. The author argues that if the major building blocks are appropriately placed, the design is better founded to allow minor modifications as more detailed requirements become apparent later in the design process.

- Enables more explicit briefing of specialists: By empowering designers to swiftly and accurately try a number of solutions for a given problem these tools allow them to develop a more holistic understanding of user interaction with their designs. This in turn enables them be more explicit in their solutions and more certain about what aspects are vital to the design’s success. This informed viewpoint empowers the designer to negotiate appropriately within the overall project team.

A final note however: it is not the goal of the author’s research to create a single system for all information appliance prototyping. More than ten years ago Houde and Hill’s oft quoted paper “What do Prototypes
Prototype?” (Houde and Hill (1997)) advocated that a range of different prototypes should be employed according to the specific aspects of a design being explored. Nothing has happened in the intervening years to invalidate that argument and so what are being explored in this PhD submission are new methods that supplement and complement the ones already in existence. To be specific, the prototyping system presented here can be characterised as a designer led approach that can be undertaken at a variety of fidelities and which can be used as an augmentation to Experience Prototyping, Paper Prototyping and other ethnography-based techniques.

The target market, so to speak, of this research is the designers and developers of information appliances. Broadly speaking, the challenge the author (and in recent years the research team he leads) has addressed has been to understand the barriers faced by those implementing traditional design development techniques such as rigs in the development of information appliances. The problems these individuals face include (but are not limited to) the high level of electronics and software skills currently required to conduct adequate prototyping; the poor fit of most current solutions with the standard design process; and the slow speed at which meaningful prototypes can be created and/or modified. Using the knowledge he has gained of these issues, the author has led the development of techniques that might be used by designers in practice. The applied nature of this work is very important and seeing the techniques and knowledge implemented in industry (for example through a design consultancy Knowledge Transfer Partnership, or the implementation of key techniques and hardware by Sony Ericsson Smartphones) has provided strong motivation. Industry interest continues with recent connections established with Samsung Korea and with an increasing relationship with HP Labs in Bristol. HP’s work on experimental social information appliances such as Schminky
(Reid (2003)), *CitiTag* (Vogiazou et al (2004)) or even *Audiophoto Desk* (Frohlich (2004)) demonstrates a strong convergence of interest.

The author’s philosophy can be summarised as: “*carry out applied research, developing knowledge and techniques that will benefit the field of information appliance design and development in a tangible fashion and in the short to medium term*”.

The work here is not presented in chronological order of publication. Rather, the author has presented papers in an order that better represents the structure of a traditional PhD. For example, *Six Challenges Facing User-Oriented Industrial Design*, a publication written for the *Design Journal* and published in Spring 2009 is presented directly after the research background papers because it provides the reader with something which approximates a traditional literature review such as might be presented in a PhD thesis. Because it is a recently accepted work it also means that the literature reviewed is up to date. See Figure 1 for further information on the mappings between this submission and a traditional PhD thesis structure.
### Traditional PhD Structure

<table>
<thead>
<tr>
<th>Introduction and Overview</th>
<th>This Submission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Critical Literature Review</strong></td>
<td></td>
</tr>
<tr>
<td>Cultural bias</td>
<td></td>
</tr>
<tr>
<td>Social issues</td>
<td></td>
</tr>
<tr>
<td>Company politics</td>
<td></td>
</tr>
<tr>
<td>Prototyping approaches for information appliances</td>
<td></td>
</tr>
<tr>
<td>User testing methods for information appliances</td>
<td></td>
</tr>
<tr>
<td>Conclusions</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodology Overview</td>
</tr>
<tr>
<td>Equinox emulation testing</td>
</tr>
<tr>
<td>Process testing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
</tr>
<tr>
<td>Company B</td>
</tr>
<tr>
<td>Company C</td>
</tr>
<tr>
<td>Company D</td>
</tr>
<tr>
<td>Company X</td>
</tr>
<tr>
<td>Findings</td>
</tr>
<tr>
<td>Discussion</td>
</tr>
<tr>
<td>Conclusions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>User study overview</td>
</tr>
<tr>
<td>Equinox</td>
</tr>
<tr>
<td>Audi 24 Hr Project</td>
</tr>
<tr>
<td>Empirical approach</td>
</tr>
<tr>
<td>Qualitative approach</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analysis of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical analysis</td>
</tr>
<tr>
<td>Statistical analysis conclusions</td>
</tr>
<tr>
<td>Qualitative Analysis</td>
</tr>
<tr>
<td>Issues arising from the studies Discussion</td>
</tr>
<tr>
<td>Conclusions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>The role of information appliance development tools in the design process</td>
</tr>
<tr>
<td>Challenges for industry</td>
</tr>
<tr>
<td>Challenges for prototyping toolkits</td>
</tr>
<tr>
<td>Conclusions</td>
</tr>
<tr>
<td>Further work</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dissertation + Papers 1 &amp; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papers 3 &amp; 4</td>
</tr>
<tr>
<td>Papers 5 &amp; 7</td>
</tr>
<tr>
<td>Papers 3, 5 &amp; 6</td>
</tr>
<tr>
<td>Papers 4, 5 &amp; 7</td>
</tr>
<tr>
<td>Papers 3, 5, 6 &amp; 7</td>
</tr>
<tr>
<td>Dissertation + Papers 3, 4, 6 &amp; 7</td>
</tr>
</tbody>
</table>

---

**Figure 1:** Relationship between the structure of a traditional PhD and this submission
Chapter 3 - Contribution to New Knowledge

The author’s contributions to new knowledge lie in the crossover between computing technology and industrial design education and practice. His research hypothesis could be summarised as being that:

*The current design process for information appliances is flawed because it is missing physicality based tools such as adjustable rig equivalents in the rapid, iterative early stages.*

Although further detail appears below on a paper by paper basis, ‘headline’ contributions to new knowledge are claimed in five key areas:

1. The identification of a gap in the information appliance development process.

2. The creation of a well tested and iteratively developed, industrial designer-focused ‘systems’ approach to information appliance design.

3. A series of specific guidelines for all information appliance prototyping toolkits.

4. Empirical evidence that a three dimensional prototype of a handheld product is superior to a two dimensional prototype.

5. Early outline indications on the opportunities and limitations of low fidelity levels in tangible interactive prototypes backed by empirical evidence.
A series of research conclusions lie beneath those contributions. They are that:

1. There is a gap in the information appliance design and development process caused by a lack of tools and processes through which industrial designers can rapidly and iteratively “rig” interactive sketch prototypes. Filling this gap means finding a systems based solution that will fit seamlessly into the traditional design process and culture.

2. The IE System has been well tested and proven. The concept is sound but it must undergo iterative development to become more capable in a number of areas.

3. Toolkits for designing and developing information appliances need to enable low fidelity prototyping in between 1 and 2 hours.

4. Consideration should be given to developing plug-ins for existing software widely used in design practice such as Flash rather than developing products from scratch.

5. An ideal system would be capable of utilising at least 25 and preferably 50 ‘off the shelf’ control inputs.

6. Not all of those who design and prototype information appliances are industrial designers and not all computer embedded products are information appliances. Methodologies should therefore be flexible enough to accommodate different modes of use.

7. Scale may be more important than was previously realised because of the effects of physicality on interaction. It follows that a successful toolkit should be capable of prototyping information appliances at a
1:1 scale (many of the current prototyping methodologies at the time of writing have components which are oversized).

8. A handheld prototype is significantly better than an on screen prototype and reducing the fidelity of the handheld prototype does not significantly affect its effectiveness providing certain properties of its physicality are retained.

9. The point above regarding lowered fidelity levels for a tangible prototype remains true even when the fidelity of its graphic user interface is dramatically reduced.

Exemplification of contributions and conclusions can be found in each of the papers presented here: Paper # 1 identifies some of the issues facing design education; Paper # 2 covers information storage and retrieval methodologies (as a foundation aspect for the software aspects of the toolkits described below); Paper # 3 brings together research and case studies on the problems faced by designers; Paper #4 proposes a new design and development approach and toolkit; Paper # 5 tests the approach and toolkit proposed in Paper # 4 using a traditional design approach as a benchmark; Paper # 6 follows the toolkit’s employment in industry, leading to guidelines for all toolkits; and Paper # 7 presents empirical data proving the importance of 3D prototypes. Table 1 gives details of the areas covered by the papers (as opposed to their contribution to new knowledge).
Table 1: Areas Covered by the Papers in this Submission

More detail on the contribution to new knowledge of each paper in this submission follows below:

**Paper # 1: The Virtual Environment in Design Projects** (1999)

This paper was a very early piece of work, the author’s first peer reviewed publication. Its contribution lies principally in its identification of design education development issues, specifically those brought about by digital technologies in the industrial design field. Case studies are presented that suggest practical solutions to the challenges faced by industrial design at the time (and are still, to some extent faced with today). The issues that industrial design education would have to deal with are also laid out for the reader.

**Paper # 2: Designing a Learning Environment for Three Dimensional Thinkers** (2000)

Like *Paper #1*, this is an early piece of work. The paper’s contribution is based on a Virtual Learning Environment (VLE) concept designed, developed and implemented by the author and which encapsulates a 3D
designer focussed conceptualisation of information storage and retrieval. It also sought to help tackle some of the social issues facing design education. VLEs were by no means standard eight years ago, and the solution presented was (and remains) novel. It had a strong impact on both the programme where it was implemented (where staff and students still strongly favour it over the market leader, Blackboard) and also on the course of the author’s later research.

**Paper # 3: Six Challenges Facing User-Oriented Industrial Design (2009)**

In order to fully understand the needs of industry the author needs to have a holistic grasp of the problems and environment of those tasked with the design and development of information appliances. This paper is the result of a part of that process. Its contribution is that it brings together a lot of other disparate research into design issues such as cultural bias, company policy and social issues. It examines each of these within the narrow context of information appliance design and development, adding new primary research case studies which will give further insights to other researchers. Having done this, it proceeds to make a series of concrete proposals for the solution of each of the issues raised. These are intended to serve as guidelines for the author’s own research as well as that of the design and HCI research communities in general.


The significance of the work presented in this paper lies in its identification of a gap in the product development process, where design and development issues fall between two professions. Having identified this gap it also presents a suggested solution which, with incremental development has stood up to scrutiny over the intervening years.
Subsequent collaboration with the UK design industry revealed the detrimental effects of this gap and the lack of coordinated, multidisciplinary approach to tackling the problems behind it. The paper advocated an industrial designer-focused ‘systems’ approach that is a mixture of hardware, software and pen & paper techniques.

Other attempts at the time either concentrated on solving technical issues (Phidgets (Greenberg and Fitchett (2001)), Buck (Pering, C. (2002))) or low tech systems techniques (Wizard of Oz Maulsby et al (1993)), Experience Prototyping (Buchenau and Suri (2000)) and Paper Prototyping (Snyder (2003))). The technique presented here represented a new approach where modest technology was implemented in a flexible fashion through the coordinated use of hardware and software. There were three components to the technology side of this approach:

1. Hardware
2. Software
3. Virtual Learning Environment

Each part of the system was fairly modest in its level of novelty, but together they delivered significant benefits.

**Hardware**

The hardware was a product called an *IE Unit* that contained a keyboard chip, wired and presented in such a fashion that designers could easily and neatly utilise it. It was developed from a large, battery powered device containing an actual keyboard (see *Background* chapter (page 27)).

**Software**
Previously written programming code was made available through the VLE. Critically, it was presented by grouping strips of coding according to what functions each performed and by backing these up with online lecture notes and other tutorial support to help designers implement the code effectively and appropriately. This re-organising of the codes according to what they did, allied to improved support, proved critical in implementing the system effectively.

**Virtual Learning Environment (VLE)**

The VLE’s role in the *IE System* has been critical in making it usable by facilitating the software component via ‘building blocks’ of code and other support mechanisms available in a single place and accessible off site. The VLE was developed by the author before such environments had become standard in higher education and so its impact has to be judged against the standards in 2000 rather than 2008/2009. It was utilised by making programming code and support material in the form of templates, tutorials and lecture notes available to design students over the internet.

Since this paper was published the field has progressed. Stanford’s *DTools* (Hartman *et al* (2005)) addresses some issues and the author’s research team, in conjunction with Lancaster University, are developing faster more flexible systems based on ad hoc networking systems. In 2003 however, the work broke new ground and led directly to the system’s adoption by *Sony Ericsson Smartphones*.

**Paper # 5: The Traditional Design Process Versus a New Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance (2005)**

This work was based on a case study centred on an exercise in designing and prototyping an information appliance in 24 hours. The exercise was
carried out simultaneously in Cardiff and London with industry, academic and student involvement at both locations. The team in Cardiff used the *IE System*, integrating it into the design process with implementation in the conceptualisation, development, production and client presentation phases, while the London team used more traditional methods.

The importance of the work’s contribution lies in the fact that by comparing the two processes and the results it is able to make conclusions that shed light on the potential advantages and pitfalls in utilising new techniques, particularly within tight time constraints. While the *IE System* was used in this case, it will not be difficult for other researchers to extrapolate useful generic lessons on the implementation of design development techniques for information appliances.

**Paper # 6: Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology (2008)**

This paper reflects on a selection of the author’s interactions with the design industry over the last few years. In doing so it contributes to new knowledge by drawing from the various implementations of the *IE System* in various environments a series of specific guidelines for all prototyping toolkits. A selective summary of findings includes the following:

1. Toolkits for designing and developing information appliances need to enable low fidelity prototyping in between 1 and 2 hours.

2. Consideration should be given to developing plug-ins for existing software widely used in design practice such as *Flash* rather than developing products from scratch.
3. An ideal system would be capable of utilising at least 25 and preferably 50 ‘off the shelf’ control inputs.

4. Not all of those who design and prototype information appliances are industrial designers and not all computer embedded products are information appliances. Methodologies should therefore be flexible enough to accommodate different modes of use.

5. Scale may be more important than was previously realised because of the effects of physicality on interaction. It follows that a successful toolkit should be capable of prototyping information appliances at a 1:1 scale (many of the current prototyping methodologies at the time of writing have components which are oversized).


One of the core assumptions driving the author’s research as well as that of others in this field is that a three dimensional prototype of a handheld product is superior to a two dimensional prototype. Surprisingly however this hypothesis has never been fully tested and that is what this research set out to achieve. A series of tests were carried out. There were several significant results:

- a handheld prototype is significantly better than an on screen prototype

- dropping the fidelity of the handheld prototype does not significantly affect its effectiveness
• even when the fidelity of the Graphic User Interface triggers is dramatically reduced, the prototype continues to outperform a high fidelity screen-based prototype

• physical buttons make a significant difference to a user’s interaction with a product

Peer reviewers found that this paper delivered substantial new knowledge when they unanimously accepted it for publication in 2008. Favourable comments were received on the thoroughness, experimental quality and the variety of tests undertaken, one noting that the “Statistical analysis made the results and interpretation strong and convincing.”

In summary, the seven selected papers presented here have been chosen from the author’s list of peer reviewed works because together they were judged to “tell the story” of his line of research best, and because together they cover the ground of a traditional PhD. These papers’ contributions to new knowledge include:

• the identification of a gap in the product development process and a method to plug it

• the creation of a product designer-focused ‘systems’ approach to information appliance design through the flexible application of modest technology

• the potential advantages and pitfalls in utilising new development techniques for information appliances
• case studies of design industry implementations leading to specific guidelines for all information appliance prototyping toolkits and

• definitive empirical evidence that a three dimensional prototype of a handheld product is superior to a two dimensional prototype

The way in which the author’s line of research began is covered in the next chapter.
Chapter 4 – Background

Table 2 briefly outlines the papers most pertinent to this chapter, their subject and why they are relevant.

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Subject</th>
<th>Chapter 4 Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>The Virtual Environment in Design Projects</em></td>
<td>The way computers are used in product design education</td>
<td>Author’s first publication, demonstrating the roots of the research theme he explores in this dissertation.</td>
</tr>
<tr>
<td></td>
<td>(Peer reviewed international conference paper)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><em>Designing a Learning Environment for Three Dimensional Thinkers</em></td>
<td>Designing a 2D Virtual Learning Environment using 3D thinking</td>
<td>The Virtual Learning Environment described in this paper was key to the development of the <em>IE System</em> because it provided a key tool for organizing support material vital to the system’s implementation.</td>
</tr>
<tr>
<td></td>
<td>(peer reviewed international conference paper)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 2: Papers with most direct relevance to Chapter 4*

This chapter explains the history of how the author’s involvement in his chosen field of research evolved. His progress from a general interest in the possibilities presented to design by computing, to the development of online support and hardware design is mapped *en route*.

The origins of this line of research lie in three events:

1. 1990: Whilst an undergraduate student at *University of Northumbria*, the author is exposed to *Alias Studio* which gives him an early interest in the possibilities for digital technologies in industrial design practice.

2. 1992: The author attends a keynote talk by Bill Moggridge at which Moggridge demonstrates an early form of IDEO virtual prototyping for information appliances.
3. 1998: As Programme Director of the BA Industrial Design programme the author is faced with a strategic decision regarding the direction of a Level 2 undergraduate module entitled Information Ergonomics. The previous tutor had concentrated on paper based prototyping techniques and storyboarding. The author wished to investigate the possibilities for more sophisticated interactive prototyping.

It was in this context that the author co-wrote his first research paper, Paper #1 entitled The Virtual Environment in Design Projects which can be found in the Appendices. The roots of all the research that followed can be found in this first publication which explores the potential for computing technologies in design education. At this point the author was yet to completely isolate information appliances and their interaction as his area of main interest and so the paper concerns itself with general CAD/CAM as well as interaction design issues. Interestingly this early work confidently predicted that the way forward lay in developing methods for incorporating virtual interfaces on virtual three dimensional CAD models, a route which nearly all the author’s subsequent work, including his most recent interests on the importance of physicality in product interaction (see Paper #7, Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time Balance) would prove to be fallacious. He was not alone in wrongly predicting the future however; blue chip industry experts at the time were confidently predicting seamless connectivity between devices (Väänänen-Vainio-Mattila, and Ruusta (2000)) which, one might argue, the consumer is still awaiting nearly ten years on.

Faced with a review of the industrial design programme’s approach to interactive product design prototyping, the author began to look at
existing solutions. At the time *Macromedia Director* was the programme of choice for this type of prototyping with *Macromedia Flash* rapidly gaining in popularity. The author investigated the possibilities presented by these as well as a freeware programme called *Dazzler*. He concluded that, with a year group of 35 and a four week module delivery window, all three programmes were too complex to be ideal vehicles (the reader should recall that a decade ago most students were far less computer literate than they are now). The solution he chose was to use a programme which was designed for another purpose entirely.

It occurred to the author that the slide metaphor employed by *PowerPoint* was analogous to a state transition chart’s description of the states of an information appliance. Furthermore, by using *PowerPoint*’s shape hyperlinking feature it was very easy to move from “state” to “state”. A technique for rapidly building on-screen prototypes employing sound, animation, menu systems etc. was quickly assembled over the next few weeks, and shortly thereafter combined with a method of mapping sketch state transitions to the *PowerPoint* prototype to form a complete design prototyping methodology.

A new member of staff, TJ Nam had just joined the team. Nam saw the potential for the *Visual Basic for Applications* (VBA) embedded in *PowerPoint* to increase the power and flexibility of the system, including its ability to be triggered via keyboard strokes. Nam had a technician build a modified keyboard (see *Figure 2*) that would allow prototypes to be connected to it, triggering on screen changes in the *PowerPoint* slide show via keyboard activated commands in *PowerPoint*’s VBA code. The new system allowed undergraduate product design students to produce interactive prototypes, which was very unusual for the time (possibly unique in the UK for Batchelor of Arts students). There was a high failure rate in the module however. Students were required to develop an
understanding of programming theory and many of them struggled. It was recognised early on that students would need access to electronic data such as lecture notes and VBA coding. A comprehensive approach was required that could offer peer to peer communication as well as providing ‘out of hours’ tutorial notes and other support.

Figure 2: The original, keyboard-based unit

In 2000 the author built and launched a Virtual Learning Environment (VLE) for the then School of Product & Engineering Design called the Virtual School. The Virtual School showed great promise for supporting complex modules such as Information Ergonomics because it made sharing “copy and paste” items such as programme code easy and available across the internet on a 24/7 basis. It also allowed students to re-access lecture notes on complex subject matter to ensure that they understood particular points. The Virtual School made a significant impact on the viability of what was to become the IE System. The thinking behind it is described in greater detail in Paper #2 Designing a Learning Environment for Three Dimensional Thinkers (2000) which can be found in the Appendices. Its development was influenced by Leeds University’s Nathan Boddington Building VLE (Leeds University (2008)) which employed the analogy of a building and University of Northumbria’s Open Folio online repository (University of Northumbria
which sought to exploit digital technology to support the designer’s culture. At first, however, it did not significantly improve the pass rate of the *Information Ergonomics* module because it was not being properly or fully utilised.

Following Nam’s departure in 2001 the author elected to restructure the entire delivery mechanism, from the VLE support to the hardware element. For more detail see *Chapter 6*. 
Chapter 5 – Current Practice and Application

Table 3 briefly outlines the papers most pertinent to this chapter, their subject and why they are relevant.

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Subject</th>
<th>Chapter 5 Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Six Challenges Facing User-Oriented Industrial Design</td>
<td>The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by PAIPR as well as on literature.</td>
<td>The paper covers some of the ground of a literature review, examining the work of others in the field. It also played a major role in helping the author’s understanding of the issues faced by industry in relation to the design of information appliances. Understanding these challenges is critical to researchers seeking fit for purpose applied solutions.</td>
</tr>
<tr>
<td>6</td>
<td>Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology</td>
<td>The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by the author as well as on literature.</td>
<td>This publication covers more literature review groundwork, adding to the work described in Paper #3. It also presents case studies of the IE System’s implementation in real world design and development scenarios. These were key tools in developing and refining the research path undertaken.</td>
</tr>
<tr>
<td>7</td>
<td>Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time Balance</td>
<td>Conclusions about the value of low fidelity tangible prototypes versus the traditional methods of developing information appliance early prototypes on a touch screen. Presents empirical data that proves the value of the IE System.</td>
<td>The paper points to a key finding of major interest to design practitioners. The findings directly imply that a prototype’s scale is of critical importance to its fitness for purpose in user testing. One of the reasons that this is a key finding is because it makes tools that focus on “smart components” dramatically less attractive.</td>
</tr>
</tbody>
</table>

Table 3: Papers with most direct relevance to Chapter 5

One of the core philosophies behind all of the author’s research is that it should seek to develop new methodologies that can be usefully applied.
by practitioners. To develop a contribution that is both unique and useful, it follows that a thorough understanding of the work of others in the research field wedded to an up to date knowledge of industry practice is extremely important. This chapter describes work that has sought to provide context and direction to the overall research effort. In doing so, it will briefly describe and categorise other key research in the immediate field. It will follow this with a discussion on the generic issues raised by the approaches of other researchers. Two journal papers that describe this work in more depth will be referenced for a more thorough overview, and another will be cited because its findings are particularly pertinent to this chapter.

Research on methodologies for the design and rapid development of information appliances generally falls into one of two camps: low technology solutions and high technology solutions.

**Low technology solutions** are generally paper or scenario based. Examples include *Paper Prototyping* ((Snyder, 2003) which uses paper, card, and other ‘soft’ materials to build prototypes. Human operators make physical changes to product states according to the user’s interaction with the ‘product’), *Wizard of Oz* ((Maulsby et al 1993) which involves human operators simulating sophisticated machine responses such as voice or text recognition) or *Experience Prototyping* ((Buchenau & Suri, 2000) an ethnographic approach that uses improvisation and low tech. props).

Low technology solutions (which generally offer methodologies best suited to industrial design practices) are generally the work of HCI designers, with notable exception of *Experience Prototyping* which is a technique developed by IDEO. Their advantages are that they are fast and flexible, offering ways to test ideas at an early stage. They tend to
be good for identifying problems with menu systems, symbols, screen layout etc. but not very good for more detailed information such as product interactions within a single device state, or interactions which tend to happen quickly such as sending a text message.

**High technology solutions** generally rely to some degree on designers possessing some form of electronics and/or programming skills. Examples include *Augmented Reality* (Nam & Woohan (2003)) which uses a combination of real and virtual simulations, with the product’s “screen” simulated via a tracking data projector; *Phidgets* (Greenberg & Fitchett (2001)) which are a series of electronic building blocks that can be programmed and controlled through a software interface; *Switcheroos* (Avrahimi & Hudson (2002)), which uses switchable passive RFID tags triggering Java code linked to *Director*; The *Buck Method* (Pering, (2002)) which involves using an existing *Palm Pilot* wired to a PC; and the *Calder Toolkit* (Lee et al (2004)) plus VoodooIo (Villar et al (2007)) which both involve prototyping via ad hoc networks.

High technology solutions are typically offered by software or electronics engineering research groups who, unlike most designers, are comfortable with programming environments and electronic circuitry. This tends to be evident in their solutions, although attempts have been made to remove software programming, notably by the *DTools* group (Hartmann et al (2005)). *DTools* uses “smart” components combined with a drag and drop state transition software tool.

High technology solutions generally create more realistic simulations than low technology solutions but to a greater or lesser extent they generally do so at the expense of prototyping speed and, just as importantly, the expertise required to prototype them is not usually within the skills of an average designer. Paper #3: *Six Challenges Facing*
User-Oriented Industrial Design and Paper #6: Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology both give more detailed overviews of the research mentioned above as well as others.

A less obvious issue is one of scale. Nearly all high technology solutions rely on “smart” components which combine control inputs with some type of circuitry. The fact that “off the shelf” controls are not an option with these systems means that most prototypes will make significant compromises on accuracy of scale, “feel” and control placement. Paper #7, Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time Balance covers empirical tests which prove the importance in prototyping these facets of a design. See Chapter 7 for more details.

Regarding the development of knowledge concerning industry practice, Papers #3 and #7 also focus on an exploration of the issues faced by designers in industry: Six Challenges Facing User-Oriented Industrial Design holistically examines the problems faced by designers of information appliances. Drawing on ethnographic studies and a review of existing literature, it concentrates on large scale issues, specifically:

- **cultural bias** (designers from one cultural group designing for another without sufficient understanding of the differences in their world view)

- **breaking with convention** (inappropriate abandonment of conventional control mappings, signage, colour or other established standards)

- **social context** (failure to appreciate the importance of a product’s context of use and its ability to affect usability)
• *ingrained thinking* (inability to reconsider a product’s modes of use as technology empowers the user e.g. digital camera as an ad hoc photo album and editor enabled by playback screen which doubles as a viewfinder, versus a chemical camera which must be held to the eye)

• *company size and structure* (company is too small and so subject to market forces or company is too big with one part dominant over the other which in effect replicates the “company is too small” problem)

• *company politics*

The purpose of Paper #3 in the overall research thrust is to gain an understanding of some of the key issues that contextualise the business environment in which any toolkit is implemented. It has become clear that the ability to effectively implement a methodology is often dependent on the modes of operation employed by those responsible for its use. The mode of operation itself is heavily influenced by the business context, thus the importance of this line of enquiry to the author’s work and to others in directing future information appliance design and development toolkits.

Paper #6, *Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology*, is a closely focused case study-based paper which follows a number of industry implementations of the *IE System*. Its purpose is to seek conclusions on which to base future development of the *IE System* and other toolkits with the same purpose. Four case studies of the *IE System*’s implementations are used: the *Audi 24 Hour Product Project*, *Sony-Ericsson*, *Samsung Design*
Europe and Alloy Total Product Design. The paper makes seven conclusions, most of them specifically intended as guideline material for future research. Five of these conclusions were aimed at information appliance design toolkit characteristics. In summary, they recommended that the ideal toolkit should be:

- easily learned and making low fidelity prototyping possible in between 1 and 2 hours with no prerequisite electronics or programming knowledge
- capable of 25 - 50 varied “off the shelf” control input types, including touch screen and analogue controls such as dials and sliders
- capable of wireless connectivity
- usable by a range of disciplines other than industrial design and in a range of situations other than the standard design consultancy set up
- be capable of prototyping information appliances at a 1:1 scale

Of the two remaining conclusions, one pointed to a strand of research which should be followed up in later work, namely that the exact circumstances where inclusion of a screen is critical be the subject of a detailed enquiry. The last conclusion (suggesting that design courses need to train students to prototype information appliances as part of their standard curriculum) was for external consumption.

The importance of these papers within the general scheme of the author’s research is that together they provide a frame of reference for
all the other work. Between them they provide a more holistic understanding of both the wider strategic issues and the narrower, more specific operational problems faced by design teams tasked with design development and testing of information appliances. Taken together with the first two papers with their literature reviews of the work of others, the author submits that he has demonstrated a good understanding of the current state of the art.
Chapter 6 - The IE System; Origins and First Workable Manifestations

Table 4 briefly outlines the papers most pertinent to this chapter, their subject and why they are relevant.

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Subject</th>
<th>Chapter 6 Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Developing Information Appliance Design Tools for Designers</td>
<td>Presents the IE System including the IE 1 Unit and the PowerPoint/VBA method of programming presented as building blocks of code in a Virtual Learning Environment.</td>
<td>This is the first paper that presents the IE System. As such it presents the reader with all the elements in their initial form: the theory about design process, use of codes presented by function, the hardware component and the integrated design methodology taking the practitioner from sketch state transition to working prototype.</td>
</tr>
<tr>
<td>5</td>
<td>The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance</td>
<td>Uses the case study of the Audi 24 hour Product Project to compare and contrast the work of the UWIC/Alloy team with that of the Nottingham Trent/PDD team. An analysis is made of the ways each team used their time and conclusions drawn about the IE System’s usefulness and deployment.</td>
<td>The case studies described led directly to the modifications to the system embodied in both the IE2 and IE3 hardware platforms.</td>
</tr>
</tbody>
</table>

Table 4: Papers with most direct relevance to Chapter 6

Chapter 4 describes the background to the author’s research into information appliances. This chapter concerns itself with how the IE System’s various elements came together from those early interests to form one coherent methodology. It will detail how the work progressed from early work undertaken with Nam into the development of the IE1,

In recent years information appliance design and development using prototyping methods has become a well developed research field. Unfortunately however, much of this work is not carried out by or with industrial designers. Much of the reasoning behind the author’s research approach is that in order to address the problems many design teams face in the development of information appliances, toolkits need to be developed which fit well with design practice. In practice, this means amongst other things that information appliances require the equivalent of a rig. Industrial designers are taught at university to use functional mock ups, or rigs in order to test components of their design concepts. If a designer is tasked with the design of a chair for example, he or she will sketch a design on paper, perhaps progressing to a small “soft” model after a time. When the design has become developed enough they will build a rig. The rig is an entirely functional apparatus. Its raison d’être is to allow the designer to test various aspects of their design. It will probably be built so that it can be adjusted quickly, allowing changes to be swiftly incorporated. Having been through an entire design process that includes full rig development and testing, a designer can be confident that the finished article will function as it has been designed to. Despite various attempts (see Chapter 5 above), a satisfactory rig equivalent remains beyond the reach of most design teams developing information appliances. The evolution of the IE System represents an attempt to create a fast, flexible rig equivalent.

In 2001 the IE System as it was shortly to be called was still a Learning and Teaching focussed methodology designed to support the Information Ergonomics module. The work done at this point was to make it practical enough for students to use at Level 2, and this turned out to be good
discipline in evolving a methodology for designers to learn and implement easily. The initial aim however was simple: increase the module pass rate to an acceptable level. The author elected to achieve this by restructuring the entire prototyping system that had so far been developed. The changes included:

1. **Changes to the VLE support**: All the programming code that had previously been written was rearranged and presented by its function. Simple “cut and paste” instructions were added and coupled to comprehensive, step by step lectures and tutorial notes. The concept was to allow students to use code without having to really understand it. Instead, strips of code were copied according to what the designer wished to achieve.

2. **Integration of the state transition element of the design process**: Students had previously been taught about state transition charts but were left to decide how they might utilise the knowledge. This aspect was now simplified and rationalised to become part of a coherent design process. Students were taught to use *Post-IT* notes to create flexible sketch transition charts. These were then mapped to *PowerPoint* slides representing product states so that the finished state transition chart represented a layout diagram for the design and construction of the *PowerPoint* prototype.

3. **Development of the hardware component**: The keyboard-based unit shown in *Figure 2, Chapter 4* had proved effective in some ways but had several drawbacks: it was too big, not very reliable, required frequent changes of battery, looked unprofessional, was vulnerable to damage and was not portable in any practical sense. The author configured a new unit utilising a
keyboard chip wired to a socket and housed in a tough and compact housing (see Figure 3 below)

![Image](image_url)

**Figure 3: The first IE Unit**

Together these changes transformed student performance on the *Information Ergonomics* module eventually bringing it to its current state where the pass rate percentage is typically in the mid to high 90s. The system as it existed at this point was described in *Paper #4: Developing Information Appliance Design Tools for Designers*, which analyses the issues facing design teams in developing information appliances in the age of ubiquitous computing. In it the author advocates an industrial designer-focused ‘systems’ approach that is a mixture of hardware, software and pen & paper techniques. This is a good model for a ‘designer friendly’ process that might typically start with mind mapping activities such as those advocated by De Bono (1990) or Van Gundy (1988) and which would ideally aim to employ ethnographic research techniques such as those advocated by Sacher and Loudon (2002) or Kankainen (2003) to pick up on user need by observing what Suri called ‘thoughtless acts’ (Suri + IDEO, (2005)). Other attempts mentioned in *Chapter 5* above have either concentrated on solving technical issues (e.g. *Switcheroos, Phidgets, Buck*) or low technology systems techniques such as *Wizard of Oz, Experience Prototyping* or *Paper Prototyping*. As mentioned above, the field has progressed since this paper was
published, but in 2003 the work broke new ground and even at the time of writing the system as described still enjoys many advantages. Among the most important of these are:

- its ability to work with a wide range of standard software (including, theoretically, the shareware DTools software)
- its ability to use ‘off the shelf’ components
- its proven usability (over 200 prototypes at varying levels of fidelity produced in as little as 12 hours by Level 2 BA students and up)

Around 2003, shortly after the publication of Paper #4, the author began to explore the potential for the IE System in industry. This exploration eventually led to the purchase of IE Units by Alloy Total Product Design, Samsung Design Europe and Kinneir Dufort. It also led to strong interest and sustained collaboration with Sony-Ericsson.

In 2004 the IE System was deployed in an exercise sponsored by the Audi Design Foundation called the Audi 24 Hour Product Design Challenge. Papers #5 and #6 describe this exercise and the results in more detail, and this is discussed in the next chapter. However, the experience of deploying the system in this exercise in conjunction with Samsung and Sony-Ericsson’s feedback from live trials highlighted certain weaknesses and this had ramifications on the further development of the IE System’s hardware. The principle weaknesses in the hardware (as opposed to weaknesses in its deployment) were identified as being that:
• the cable was too big, interfering with handling and so potentially affecting usability data gained from prototype testing

• it was not capable of handling enough control inputs

• it could not handle most “off the shelf” rotary dials

• where a contact was held closed, the unit sent a keyboard signal repeatedly, causing unintended state transitions on the prototype

The IE 2 Unit was designed in response to these issues which it solved by:

• employing a cable of around 1/3 the width of the original

• increasing the number of control inputs from 13 to 24

• employing a “common ground” wiring protocol that allowed “off the shelf” rotary switches to be used

• using a new keyboard chip that did not send repeat signals when a contact was held closed
In 2005 the author participated in a consultancy project led by a colleague to design a pain and wound assessment appliance. The IE2 (see Figure 4) was used to prototype and test product concepts that included a camera element which required a USB connection. The person tasked with developing these prototypes was a PhD student whose research topic involved him in developing techniques for in context testing of information appliance prototypes. A group mind mapping session eventually resulted in the design of the IE3 in 2006 which replaced the PS2 keyboard connectors of the IE1 and IE2 with a USB connector. The IE3 had the following advantages over the IE2:

- USB connection to the computer meant that laptops, which were no longer being produced with PS2 ports again became usable by the IE System. It also allowed the IE3 to be plugged in after a machine had been turned on.

- The connection to the PC could be made from either the back or the front of the IE3, enabling the unit to be stored in the user’s pocket to improve its usability in in context user tests.
• The unit provides other USB connectors at its front face, effectively behaving as a USB hub. The advantage in this case is that, by allowing connections of cameras or other USB devices operating on the prototype to connect close to other connecting points, the ‘umbilical’ connecting the prototype to the PC via the IE Unit, is kept in a single compact line, which greatly enhances usability.

Figure 5: The IE3

The Intellectual Property deployed in the IE3 is now the subject of a pending patent. It is the last of the IE Units planned in this configuration and while the IE4, which is already working in prototype form is an evolution of the theme, the IE5, the subject of its own IPR application is a very different system. Both the IE4 and the IE5 are described in more detail in Chapter 8.
Chapter 7 – Trials and Empirical Performance Measurement

Table 5 briefly outlines the papers most pertinent to this chapter, their subject and why they are relevant.

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Subject</th>
<th>Chapter 7 Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance</td>
<td>Uses the case study of the Audi 24 hour Product Project to compare and contrast the work of the UWIC/Alloy team with that of the Nottingham Trent/PDD team. An analysis is made of the ways each team used their time and conclusions drawn about the IE System’s usefulness and deployment.</td>
<td>Comparison trial between the two design methodologies employed in the exercise helped to develop knowledge about at which stage in the design process the deployment of prototyping systems are best suited.</td>
</tr>
<tr>
<td>7</td>
<td>Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time Balance</td>
<td>Conclusions about the value of low fidelity tangible prototypes versus the traditional methods of developing information appliance early prototypes on a touch screen. Presents empirical data that proves the value of the IE System.</td>
<td>This paper proves that for handheld information appliances, a tangible interactive prototype delivers far more realistic user test results than a touch screen. This validates key theoretical drivers behind the IE System’s development.</td>
</tr>
</tbody>
</table>

This chapter will describe work carried out in assessing the IE System’s performance. In doing so it will reference two papers:

- Paper #5 *The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance*. This paper compares the performance of
the team using the *IE System* against that of a second team using different methods, operating at the same time to the same brief.

- **Paper #7 Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time Balance.** This paper presents the results of three separate experiments to compare the quality of user testing data gathered by the *IE System* against data gathered from tests of both a real product and a screen based prototype.

**Paper #5** is focused on analysing and comparing implementation strategies with a view to extrapolating generic lessons that might be learned both for the further development of the *IE System* and for other methods of the same ilk. The research described in **Paper #5** is essentially qualitative, focussing on how the teams spent their time and how the results may have been affected by the processes which gave birth to them. **Paper #7** on the other hand takes an almost exclusively empirical approach, its primary aim being to quantify the differences in effectiveness between tactile and non tactile information appliance interaction.

**Paper #5**

*Chapter 6* briefly described the *Audi 24 Hour Product Challenge* project that was sponsored by the *Audi Design Foundation*. The project was run simultaneously at the *National Centre for Product Design & Development Research* (PDR) and PDD, London. **Paper #5** describes and compares the approaches of the two design teams. Both methodologies are described in detail and then a comparison of their approaches is made, analysing how time was spent by each team on certain types of activity (research & concept generation, development work, implementation etc.). The paper critically evaluates the teams’ design outputs and summarises the
lessons learned for both the further development of the \textit{IE System} and the ways in which it should or should not be implemented. As mentioned above, the lessons learned in the exercise and described in this paper, in conjunction with Samsung and Sony-Ericsson’s feedback from live trials, led directly to the \textit{IE2} and shaped the Intellectual Property leading to patents pending for the \textit{IE3}, \textit{IE4} & \textit{IE5}. Of equal importance were the lessons drawn out in the conclusions of \textit{Paper #5} which led to questions on the implementation of the system in the exercise. The paper essentially concludes that the system worked well but was, in some ways at least, inappropriately deployed.

\textbf{Paper #7}

This paper documents a series of three comparative user trials of an information appliance. The first set of tests compared the real product with a prototype mocked up using the \textit{IE System} and a screen based prototype. Two further trials repeated the experiment with reduced fidelity levels in the \textit{IE} prototype in an effort to determine the importance of physicality in information appliance interaction.

The resulting empirical data proves that the \textit{IE System} (and therefore any other system that produces physical prototypes at the right size and scale) produces a more accurate representation of hand held products than a screen-based software prototype. This result completely contradicts Sharp et al (1996), probably because the product in Sharp’s case (a microwave) was so well suited to a touchscreen simulation. A critical additional finding however, was that the superiority of the handheld prototype in the user tests continued even its fidelity levels were significantly reduced, thereby proving the importance of physicality (and, by direct implication scale) on user experience and perception.

The original tests that eventually provided the key material for this paper
were also the source of material for an invited keynote by the author at the 1st International Workshop on Physicality. The resulting discussions helped broaden an existing relationship (see Chapter 8, below) with Lancaster University’s 5* rated computing department. This eventually resulted in major joint funding under the AHRC/EPSRC funded Design for the 21st Century programme.
Chapter 8 – Other Work: Past, Current and Future

This chapter concludes the dissertation by describing activity not mentioned in the published outputs including work which is at an early stage or that is planned. It will concentrate on five areas:

1. Work with Lancaster University on the RAPID and DEPtH projects
2. DENIM + Pin & Play Evolution work
3. Sony-Ericsson
4. The IE 4, IE5 and IE6
5. Future gazing

Work with Lancaster University on RAPID and DEPtH

In 2004 the author began collaboration with Professor Hans Gellerson from Lancaster University’s computing department. The collaboration originated in a conference conversation revolving around the possibilities of combining the Pin & Play (later renamed VoodooIO) concept with the IE System. This initial discussion has developed into a long term relationship. Initially Lancaster and the author submitted two £1m EPSRC bids (called RAPID) both of which were short-listed. Although neither was ultimately successful, both partners recognised the merits of collaboration and this has continued to develop. In 2005, problems with the manufacture and performance of the Pin & Play networking substrate were solved by a temporary member of the author’s research group. Following this, Lancaster employed PDR to manufacture the substrate in quantity. In around 2006, one of Gellerson’s research students, Nicolas Villar (now working at Microsoft Research) developed a Flash plugin which allowed Pin & Play to output ASCII codes like the IE System. The result of this work is described below under DENIM + Pin & Play Evolution. In 2007 the author and Gellerson began co-supervision of a PhD student investigating the potential for super fast prototyping of
information appliances. This work, 12 months old at the time of writing, has already resulted in a patent application and is briefly mentioned below under *IE4, IE5 and IE6*. A second PhD student, also co-supervised with Gellerson has just begun his studies with the author’s group. The concept behind this work is described below under *Future Gazing*. A third bid with Lancaster following the theme of super fast prototyping techniques is in the early stages of planning at the time of writing.

In 2006 the author’s work with Gellerson and Villar led to an invitation to give a keynote address at the *1st International Workshop on Physicality*. This in turn led to his involvement, as co-investigator with Professor Alan Dix in a major funding bid called *Design for Physicality (DEPtH)* to the AHRC/EPSRC funded *Design for the 21st Century* programme. The success of this bid has resulted in a two year study on the effects of physicality on design of and interaction with products, with a particular emphasis, in the author’s case, on information appliances. Research outputs from DEPtH have so far included:

- two workshops for industry and academia, with a third planned in early 2009
- two publications in conference/workshop proceedings
- one journal article accepted for publication with a second conditionally accepted
- joint editorship of a journal special issue with a second planned

A book chapter in the second *Design for the 21st Century* book has been agreed, and the author will commence writing a jointly written book on the subject of Physicality with Professor Dix in November 2008. The success of the project and the working relationship developed with Lancaster has already resulted in an outline plan for a three year EPSRC project bid using the same team structure as DEPtH.
DENIM + *Pin & Play* Evolution

In 2004 the author and a colleague discussed the potential for DENIM as a software component of the *IE System*. DENIM (see Newman *et al.*, 2003) is a system that allows the designers of web pages to very swiftly create designs from state transition sketches. The system exploits touch screens (or interactive whiteboards) and gesture recognition to allow for a very flexible and swift sketch-based prototyping system for designing webpage connectivity. The author employed a programmer to modify DENIM, which was open source at the time, to allow it to be triggered via keyboard events and therefore by the *IE System*. Unfortunately, though the system worked, it remained untested until 2006 when one of the author’s PhD students, Alex Woolley, spotted the opportunity to link it with *Pin & Play* to form an experimental prototyping methodology. A demonstration of this can be viewed by following this link: [http://uk.youtube.com/watch?v=Yl0oYl8S-bU](http://uk.youtube.com/watch?v=Yl0oYl8S-bU). In 2007, an MSc product design student, Ian Culverhouse adopted the system in the development of a digital camera. The lessons learned are the subjects of a paper being authored at the time of writing but while the system showed promise, it was also clear that a complete re-work would have to be carried out of both hardware and software elements in order to make a system robust, flexible or fast enough for use in industry.

*Sony-Ericsson*

The relationship with *Sony-Ericsson* mentioned above and in some of the outputs is still in being. In 2007 members of the Smartphone interface design team participated in the 2nd *International Workshop on Physicality* and in July 2008 they were also involved in another DEPtH workshop examining the role of physicality in the design process. *Sony-Ericsson* Smartphones remain committed to the adoption of the *IE System* in their design and development processes, and the author and a colleague
recently received invitations to present to Sony Ericsson’s other interface design development centre as well as their industrial design department, both in Lund, Sweden. The first production Smartphone in the development of which the IE System was implemented is the Sony Ericsson P1i (see Figure 6)

Figure 6: Sony Ericsson P1i (source: http://findgadgets.blogspot.com/2007_08_01_archive.html)

The challenge for future collaborations with Sony Ericsson will be to persuade more of the organisation of the merits of employing very rapid development methodologies early in the design process. The key to this is integration of the system in more than one department. In turn the key to “selling” that point is likely to hinge upon the creation of faster more flexible systems such as those being planned around the IE4, IE5 and IE6.

IE4, IE5 and IE6

The IE4 and the IE5 are both working as “test bed demonstrators” at the time of writing while the IE6 exists only as a concept. As mentioned above, the IE4 and IE5 are both the subject of patent applications and so their details can be discussed. Unfortunately, for IPR reasons the IE6 can
only be described in outline terms. A brief description of each unit follows:

- **IE4**: A very small **IE Unit** approximately the size of a USB memory stick. The IE4 is designed to be accommodated inside soft or facsimile models and communicate ASCII codes wirelessly to a computer. The system will work with “off the shelf” components though it will likely also be produced with a number of pre-wired control inputs for speed and ease. In this configuration it will require no tools to assemble. The unit is working reliably in prototype form and the author has successfully bid for funding to develop it into a robust and practical unit for use by designers. This work is scheduled to start in November 2008.

- **IE5**: The product of a group mind mapping exercise by the author and others, followed by further innovations by Culverhouse. The origins of the IE5 can also be traced (less directly) to the DENIM + **Pin & Play** Evolution work and the short listed EPSRC bid with Lancaster. It is a passive RFID based system able to communicate ASCII codes wirelessly with a computer over an estimated range of 100 metres. Like all IE Units to date it will work with ‘off the shelf’ components. However, like the IE4 it will be produced with a number of pre-wired control inputs, the use of which will release the user from the necessity to use any kind of tools. The IE5 does not require control inputs to be wired at all, and consequently they can simply be moved around on the prototype. This aspect of the system means that prototyping can be completed very quickly indeed. It also means that the resultant prototype is likely to be flexible enough to be used as what Kankainen referred to as a “low fidelity UE probe” for user led interface development using context scenarios and role play (Kankainen (2003)).
has progressed as far as a proof of concept breadboard demonstrator and is likely to take around 24 months of development by Culverhouse (now a PhD student) as part of his research into super fast prototyping techniques.

- **IE6**: In common with other technology-based prototyping systems the **IE4** and **IE5** are both primarily configured to allow lab-based user testing. One of the authors’ interests has been in the field of in context testing. This has been the line of research taken by one of his research students, Alex Woolley. Woolley’s work has led to a greater understanding of the influence of context on interaction and hence to a greater drive to solve the complex problems associated with developing techniques that allow rapidly designed and developed prototypes to be tested in their context of use. As mentioned above, the **IE6** exists only as a concept, but the aim is for it to fulfil the functions of the **IE4** and **IE5** in a fully mobile manner and in a range of settings.

**Future gazing**

The **IE System** has thus far attracted favourable interest from industry and can be described as forward looking inasmuch as its development has always been guided by a desire to increase flexibility and speed in the design process applied to information appliances. However, the type of prototyping it accommodates has thus far been essentially retrospective in that the system is designed to accommodate control inputs that are already commonly used rather than helping designers to experiment with new interaction paradigms. This issue was brought to a head by the rapid increase in industry demand for methods of rapidly prototyping and testing products with multi touch screens, largely brought about by the launch of the **Apple iPhone**. It occurred to the author that a strand of research was required that would take a more
proactive attitude to the process of developing appropriate design and development systems. As a result he applied for and was awarded bursary funding for a PhD student to investigate upcoming technologies and to forecast the types of interactions they were likely to support. This work has just commenced at the time of writing in October 2008 and is intended to begin a new, blue sky strand to the existing research theme.

In conclusion, the author has been research active at a level which is normally considered post doctoral for many years. He has a good funding record that includes major research council funding and has worked closely with 5* rated researchers. He has five research students and is Director of Studies for three of them. His first PhD student is about to complete exactly on schedule. He has 23 peer reviewed conference and journal publications to date and has a further 5 (3 journal, 2 conference) either pending review or being authored at the time of writing. He is due to commence work on a book proposal that will be co-authored with Prof. Alan Dix, a world class researcher. His research has followed a consistent theme since its beginnings in the late 1990s and its future is assured by the commercial and academic interest that has attended it, particularly in recent years. A summary of the work submitted is included in Table 6 below.
### Table 6: Submitted Works

<table>
<thead>
<tr>
<th>Paper</th>
<th>Subject</th>
<th>Process</th>
<th>Where published</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Virtual Environment in Design Projects</td>
<td>The way computers are used in product design education</td>
<td>Abstract submission reviewed by editors. Peer review of full paper following acceptance</td>
</tr>
<tr>
<td>2</td>
<td>Designing a Learning Environment for Three Dimensional Thinkers</td>
<td>Designing a 2D Virtual Learning Environment using 3D thinking</td>
<td>Abstract submission reviewed by editors. Peer review of full paper following acceptance</td>
</tr>
<tr>
<td>3</td>
<td>Six Challenges Facing User-Oriented Industrial Design</td>
<td>The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by PAIPR as well as on literature.</td>
<td>Full paper submission followed by double blind peer review</td>
</tr>
<tr>
<td>4</td>
<td>Developing Information Appliance Design Tools for Designers</td>
<td>Presents the IE System including the IE 1 Unit and the PowerPoint/VBA method of programming presented as building blocks of code in a VLE.</td>
<td>Full paper submission followed by peer review</td>
</tr>
<tr>
<td>5</td>
<td>The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information</td>
<td>Uses the case study of the Audi 24 hour Product Project to compare and contrast the work of the UWIC/Alloy team with that of the Nottingham Trent/PDD team. An analysis is made of the ways each team used their time and conclusions drawn</td>
<td>Abstract submission reviewed by editors. Peer review of full paper following acceptance</td>
</tr>
<tr>
<td><strong>Appliance</strong></td>
<td><strong>about the <strong>IE</strong> System's usefulness and deployment.</strong></td>
<td><strong>6 Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology</strong></td>
<td><strong>The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by the author as well as on literature.</strong></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>7 Paper 8: Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time balance</strong></td>
<td><strong>Conclusions about the value of low fidelity tangible prototypes versus the traditional methods of developing information appliance early prototypes on a touch screen. Presents empirical data that proves the value of the IE System.</strong></td>
<td><strong>Full paper submission followed by double blind peer review</strong></td>
<td><strong>Peer reviewed international journal paper in <em>Tangible and Embedded Interaction</em>, a special issue of the <em>International Journal of Arts and Technology</em>, 2009 ISSN 1754 - 8853 (print), 1754 - 8861 (online)</strong></td>
</tr>
</tbody>
</table>
References


Appendices 1, 2 and 3:

Publications, Authors’ Statements and Brief Author’s CV
Appendix 1: Submitted Papers
<table>
<thead>
<tr>
<th>Paper</th>
<th>Subject</th>
<th>Process</th>
<th>Where published</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>The Virtual Environment in Design Projects</em></td>
<td>The way computers are used in product design education</td>
<td>Peer reviewed international conference proceedings for the 12th International Conference on Design and Technology Educational Research (IDATER), Loughborough University, 1999 ISBN 1899291407</td>
</tr>
<tr>
<td>2</td>
<td><em>Designing a Learning Environment for Three Dimensional Thinkers</em></td>
<td>Designing a 2D Virtual Learning Environment using 3D thinking</td>
<td>Peer reviewed international conference proceedings for the Design Plus Research Conference, Politecnico di Milano, 2000</td>
</tr>
<tr>
<td>3</td>
<td><em>Six Challenges Facing User-Oriented Industrial Design</em></td>
<td>The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by PAIPR as well as on literature.</td>
<td>Peer reviewed international journal paper in the <em>Design Journal</em>, Spring Issue, (12.1) Berg, Oxford, 2009 ISSN 1460-6925 (print) 1756-3062 (online)</td>
</tr>
<tr>
<td>4</td>
<td><em>Developing Information Appliance Design Tools for Designers</em></td>
<td>Presents the IE System including the IE 1 Unit and the PowerPoint/VBA method of programming presented as building blocks of code in a VLE.</td>
<td>Peer reviewed international journal paper in <em>Personal and Ubiquitous Computing</em> (7.3-4), Springer, London, 2003, ISSN 1617-4909 (print) 1617-4917 (online)</td>
</tr>
<tr>
<td>5</td>
<td><em>The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of</em></td>
<td>Uses the case study of the Audi 24 hour Product Project to compare and contrast the work of the UWIC/Alloy team with that of the Nottingham Trent/PDD team. An analysis is made of</td>
<td>Chapter of peer reviewed book of international conference proceedings for the 2005 Human Oriented Interface and Telematics Conference (HOIT), York University, published by Springer, 2005 ISBN 0387251782, 9780387251783</td>
</tr>
<tr>
<td><strong>6</strong></td>
<td><strong>Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology</strong></td>
<td>The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by the author as well as on literature.</td>
<td>Full paper submission followed by double blind peer review</td>
</tr>
<tr>
<td><strong>7</strong></td>
<td><strong>Paper 8: Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time balance</strong></td>
<td>Conclusions about the value of low fidelity tangible prototypes versus the traditional methods of developing information appliance early prototypes on a touch screen. Presents empirical data that proves the value of the IE System.</td>
<td>Full paper submission followed by double blind peer review</td>
</tr>
</tbody>
</table>
Paper 1: The Virtual Environment in Design Projects

By James Fathers and Steve Gill

Published in the proceedings of the 12th International Conference on Design and Technology Educational Research (IDATER), Loughborough University, 1999 ISBN 1899291407

Subject: The use of computers in product design education

Reason for inclusion: The roots of all the subsequent research can be found in this paper.
The Virtual Environment in Design Projects

By: James Fathers & Steve Gill

School of Product and Engineering Design

University of Wales Institute Cardiff.

Keywords

CAD/CAM

Computer-supported design

Design methods

Information Ergonomics

Design Education
The Virtual Environment in Design Projects.

Traditionally design projects for students have been based around conventional sketching methods, soft models and marker renderings. As we enter the 'Information Age', it is important that designers are taught to address matters such as Graphical User Interfaces, the design of controls for technology based products.

In this paper we report on:

A) Systems-based design projects where matters of Information Ergonomics and GUI's are addressed.

B) The use of 3D CAD models as a way of presenting a final design project.

C) True virtual prototyping and evaluation. This area is currently in the research stage where a 3D CAD model of a product is tested for usability exclusively in the virtual environment.

Key words: CAD/ CAM, Computer supported Design, Design methods, Information Ergonomics, Design education

Introduction

Many would argue that the ‘Apple Mackintosh’ has eroded the skills base of those engaged in the field of Graphic Design. A casual observer of the appointments pages will have noticed that advertisements for Graphic Designer have gradually been replaced by Graphic Designer/Mac operator. As a profession, Graphic Design has been quick to meet the threat and move itself onwards, embracing Multi-media (tightening their embrace on the ‘Mac’) and acquiring new skills.

In our own field of Industrial/Product design, solid and surface modeling software programs such as I-DEAS Master Series and Pro-Engineer could deplete the usefulness of traditional Industrial/Product Design skills such as rendering, model making and even technical drawing. However if this challenge is addressed, design graduates can be equipped to maximise the benefits of both traditional and computer-based disciplines.

Overview:
In this paper, we explore how best to educate designers so that they can respond to this challenge and be comfortable with a development process that is a marriage between technology-led design and traditional skills. There are a number of advantages that traditional techniques enjoy over the CAD model. Amongst these are the ability to appreciate scale, the resolution of detail, the sensation of touch and of weight and the sheer convincing reality. However there are significant advantages in using computers as a design tool: alterations to colour, scale, overall finish and graphics can be made easily, as can detail changes to mouldings and structures. Data can be produced which will indicate the likely success or otherwise of components as production parts and how they will perform under stress.

CAD can be used as a powerful design tool, to simulate both form and function in a virtual environment. This information can be easily modified to generate a number of iterations. The increased level of information available then aids the process of convergence, to a final solution. The final design solution can then be performance tested for both form and function.

Our Response:

There are two models that we are currently utilising to address the issues discussed above:

- Computer based Systems Design projects utilising Graphical User Interfaces
- Using solid modeling CAD to produce virtual models, replacing or complementing traditional workshop-based model making techniques.

A further development of these models is currently being researched and will filter through to the curriculum in the near future. This utilises a combination of CAD models & Graphical User Interfaces to create ‘Virtual Prototypes.’

Section A

Systems based Projects
One of the features of UWIC’s BA (Hon’s) Industrial Design degree is that of the two major projects undertaken in the final year. The first one is based, not on a single product, but a system of products.

The work that the students produce fall into three main categories:

Products interacting at consumer level to create a system (e.g. ‘Lego’ bricks)

Products interacting at national or international level to create a system (e.g. Inner-city transport)

Products interacting with computer software to create a system (e.g. an Electronic Passport)

Inevitably, a high percentage of projects tend to look at hardware/software interaction and this in turn often means that the traditional Industrial/Product design activities tend to be displaced in favour of Graphical User Interface design based on Information Ergonomics.

When the Systems project was first introduced, the results of student’s endeavours tended to be displayed using pages of paper with screen images, flow charts etc. Not surprisingly this lacked the impact of the real product. More recently students have begun to use software such as ‘Corel Draw’, ‘Macromedia Director’ and ‘Dazzler’ to produce more realistic results.

In recent projects, the use of touch screens have enabled students to further blur the line between real & virtual product design. Our students can now design a product (system or otherwise) & produce an on-screen visualisation. The combination of software animation techniques and touch screen technology make it possible to create virtual products in an undergraduate environment. Users can then interact with these prototypes in much the same way as the real product. In this way we are able to view, with far greater clarity, the quality of work that the student has undertaken. Likewise the student is able to “test” the product much more effectively and deliver a design of greater depth & subtlety than before. Information Ergonomics issues can be explored using the multi-media model, far more effectively than the old display chart method. Sound can be added, for example, so that a switch will make a satisfactory click when it is activated; to reassure the user that the operation is completed.
Sound gives the designer another tool with which to influence the user’s interactive experience. As well as the traditional mechanical noises mentioned above, there are a number of software sounds which have universal meaning: alarms, fault warning notes, correct answer-tones etc. have become common currency, bridging barriers of language, race and culture. There are also universally accepted visual cues which are used most effectively in multimedia applications. Industrial / Product design graduates who are conversant with these languages will have a better chance of success in an increasingly competitive sector of the job market.

**Case studies**

Below are three case studies of recent student work which illustrate the issues discussed in the previous section. As each group of students address this type of design project we learn a little more and discover ways to improve this type of project.

1. **A Navigation System** (The halfway method)

A good example of a systems project explained using this new media is a navigational aide for pilots of large ships. The student in question had identified through research that there were a number of flaws with existing navigational aides and had been able to point to a number of maritime disasters, which highlighted the scale of the problem.
This particular example is a good case of a student opting to make a display which is not fully interactive. The object of the exercise is to display design prowess rather than computer programming skills. Time spent designing the complex mechanics of user interaction is likely to be at the expense of proper examination of the design of the Graphic User Interface itself. For this reason we encourage the use of a less interactive computer model in cases where the complexity of the system would distract form the core activities of the project.

This student elected to use the computer as a tool to explain the system more fully and more satisfactorily than more traditional display methods. The viewer is invited to press the start button and the display commences. A number of pre-programmed scenarios using sound, light, colour, movement, numerical and graphical data are displayed. Various features are displayed in a pre-determined order ensuring the viewer leaves with a full impression of the systems capabilities. Experience has shown that it is far easier to convince visitors of a given systems viability by this method when it appears to “work” before their eyes rather than asking for a leap of imagination from flow chart and story board information to interactive product.

2. In-store Guide (The interactive model)

In contrast to the model above, the work of this student shows what can be achieved when a more modest system is undertaken. In this example the student has identified a problem with information management in large department stores. Large stores tend to employ staff with knowledge of specific services within the overall shop (e.g. the butchers, film processing labs, delicatessen etc.) When shoppers are unable to locate specific products within the store which often happens, then these specialised staff are unable to help and the customer is forced to look elsewhere for an answer to their query.
The concept for her system was therefore simple: design a user-friendly in-store information guide which helps customers find products when the right staff can’t be located.

In this model the software “product” is interactive, and with the use of a touch screen an extremely realistic analysis of the Graphic User Interface’s usefulness can be undertaken.

It is interesting to note, that unlike the previous example which was designed using Corel Draw & Macromedia Director, this project was implemented using ‘Dazzler’- a shareware package that the student received taped to the front of a magazine(!)

Section B

Spectacles Design

A study of the impact of CAD and Rapid Prototyping on design realisation.

The 1st years of both the BA Industrial Design & BSc Product Design & Manufacture degrees at UWIC annually participate in a live project with Norville Optics Ltd, Gloucester. The best results of this collaboration are submitted to a national design competition run by the Worshipful Company of Spectacle Makers.

As part of the project, Norville help with the construction of prototype frames for those students whose designs are within the scope of their manufacturing capabilities. Those students who have produced designs outside the scope of Norville’s facilities are obliged to build their prototypes by hand, in our modelmaking workshops and in their spare time.
This case study is an excellent illustration of CAD and Rapid Prototyping supplementing traditional model making facilities.

The problem this particular student encountered was that his design was complex. Technical drawings highlighted an almost complete absence of reference points or even straight lines. When he attempted to make the frames in our workshop he found the task beyond his skills and our facilities. The student had then to look for alternative ways to make his spectacle frames.

I-DEAS allows complex free form shapes to be modelled relatively easily and like any CAD system it can create mirror images of components so only half of any symmetrical model need be built. This particular model took around two weeks to complete. At this point it was given to the Design Engineering Research Centre (DERC) who used the data to manufacture the frame components using their Stereo Lithography facility. The completed components were returned to the student who went back to the model making workshop to finish, colour & assemble them using traditional techniques.

Rapid Prototyping is still a relatively rare process in the area of undergraduate projects. However, we feel that it is important to engage in a small number of case study projects for use as examples of new practice in more generic manufacturing process or model making courses.

The DERC is part of the Faculty, which also includes the school of PDE. They are equipped with both Stereo Lithography and Laminated Object Manufacture facilities and students are able to have access to these facilities, by arrangement, for more advanced projects.
Section C

Future Developments

Combining CAD models and GUI’s

The next step in the evolution of the virtual design must be to combine CAD models and computerised Graphic User Interfaces.

Packages such as ‘Macromedia Director’ & ‘Corel Draw’ can be made to work with I-DEAS to produce virtual models that provide interaction at a realistic level. In this way we will be able to create products, which can be viewed from any angle, weighed, analysed for stress and optimised for production.

Assessments will be possible on the structure, best finishes and so on. In addition we will be able to assess the user interaction on an entirely new level.

Prototyping in the virtual environment.

In recent years a new prototyping technique has emerged which uses interactive computer simulations of products to test the usability of new designs with the intended users. This enables prototypes of interactive products to be produced quickly, and then used to evaluate the product without the need for expensive proprietary hardware. However, there are concerns that these virtual prototypes do not accurately represent the final product.

If a highly interactive prototype is required and the product’s mechanical functions (e.g. doors opening/closing, sliders etc.) are not too complex, then a virtual simulation of the product maybe appropriate (Sharp et al., 1996). The benefits of using virtual simulation prototypes are usually associated with greater flexibility for making modifications, quicker construction times and reduced development costs (Cambridge Consultants Limited, 1997: Emultek, 1997b). Until recently there was a lack of rigorous empirical work to support many of the current ideas on integrating virtual prototypes into successful new product development. Sharp has however conducted controlled user trials which address these areas of concern. The study
consisted of a domestic electronic product and a virtual simulation of the same, with which interaction was conducted via a touch screen. The subjects were asked to attempt a number of tasks on both the virtual and the real products. Their responses were logged and comparisons were made. The main conclusion was that for this type of product there was little or no difference in user response between a virtual and a real prototype.

We will be reporting this work in another forum. (Sharp et al., Ph.D. Thesis 1997 & Private Communication).

We intend that this new work on virtual prototyping will influence curriculum development on our design courses in the near future. Students will need to be conversant with the methods of product development that are being used in leading companies, and be competent in the application of the appropriate blend of traditional and technology based skills for each design problem.
References:


(Word Count 2365)
Paper 2: Designing a Learning Environment for Three Dimensional Thinkers

By Steve Gill and Tim Coward

Published in the proceedings of the Design Plus Research conference, Politecnico di Milano, 2000

Subject: Designing a 2D Virtual Learning Environment (VLE) using 3D thinking

Reason for inclusion: The Virtual School VLE was integral to making the IE System functional

Abstract (added post publication for the purposes of submission as part of a PhD by published works)

This paper examines the ways in which the three dimensional design and world views of the industrial designer can be utilised within a two dimensional interactive space through the use of spatial analogies. The paper begins by examining current approaches before presenting a case study based on the implementation of a Virtual Learning Environment (VLE) called the Virtual School. The Virtual School makes use of spatial analogies, sound and graphic output to support student learning and improve engagement. It also shortens the “learning curve” for new students by making the real and VLE worlds mutually enforcing. The paper concludes by speculating on possible future developments.
Designing a Learning Environment for Three Dimensional Thinkers

Steve Gill, Course Director, BA (Hons) Industrial Design

Tim Coward, Head of School of Art & Design

University of Wales Institute, Cardiff
Western Avenue
Cardiff
UK
CF5 2YB

Tel: +44 (0) 29 2041 6732
Fax: +44 (0) 29 2041 6645
E-mail: sjgill@uwic.ac.uk / tcoward@uwic.ac.uk
Introduction

It could easily be argued that multi-media is currently “owned” by graphic designers. There are an increasing number of industrial designers, however, who use multi-media in ways that a graphic designer would not.

Graphic designers and Industrial designers come from distinct design cultures, which affect both groups’ ways of thinking. The conceptual model for a graphics product tends to be two-dimensional while the three-dimensional nature and context of an industrial product's point of use together with the added elements of users and modes of use, tend towards three-dimensional, often time-based, conceptual models.

Both models have their pros and cons.

It would be fair to say that Industrial Designers view design in a very different light to their counterparts in 2D disciplines. They are accustomed to designing in three dimensions; they study modelmaking, ergonomics and the presentation of three-dimensional design concepts in two-dimensional form. They use abstract models & diagrams to structure & re-examine problems & to test possible solutions. They are accustomed to building rigs and soft
models to test & develop their theories. The ability to view a concept from various angles and to **touch** it is very important.

It would be equally fair to say that it would be difficult to over-estimate the contribution of Graphic Design to the creation of the dynamic web environment that we see at the beginning of the 21st century.

Industrial Design has a contribution to make however. Among the advantages of Industrial Designers’ approach is that they can use skills learned in subjects like Information Ergonomics, Rig Building and Modelmaking to produce "three-dimensional" environments that better immerse the user in the designer's virtual reality.

Although there are those in the field who have been using multi-media for some time, there are many industrial designers who have yet to realise the full potential of the tools available. One of the reasons for this is that the current state of technology offers little encouragement.

Industrial designers edging their way into web-based design are in an excellent position to benefit from the advances & developments made by graphic web designers over the years. But is it necessary to ask why they have not made a greater contribution before now? The answer lies in the rate of technological progress. As early as 1973 one of the authors was involved...
in examining ways in which 3D designers could use computers\textsuperscript{1}. It was almost another twenty years, in the late 1980s before the advent of computers powerful enough to facilitate useable 3D CAD finally made it a viable proposition for professional designers.

In the year 2000, software houses are developing products that allow objects to be viewed in three dimensions over the Web. The power is now available to allow Industrial Designers to explore the skills they have learned in traditional areas and bring them to bear on web design & multimedia. Unfortunately we are still in the early stages of this process. The limiting factor now is the technology linking the World Wide Web rather than the power of the computers attached to it. All web-based design is limited in what it can achieve because of the consideration given to the speed that information can be sent down a conventional phone line (2.8kps on average). The problems are worsened when another spatial dimension is added.

In this paper we discuss a web-based environment designed by Industrial Designers. We look in particular at how that environment that uses many of the major principles of Information Ergonomics, taught as a matter of course to under-graduate Industrial Design students.

\textsuperscript{1} Computer Modelling Techniques, Science Research Council, Department of Design Research, Royal College of Art, London, 1973-74

International symposium on the dimensions of industrial design research May 18-20, 2000 Politecnico di Milano, Italy
The expanding role of the Industrial Designer

Many would argue that the ‘Apple Macintosh’ has been a mixed blessing for Graphic Design. A casual observer of the appointments pages in the Design Press will have noticed that advertisements for "Graphic Designer" have gradually been replaced by "Graphic Designer/Mac operator" and sometimes even "Mac Operator". As a profession, Graphic Design has been quick to meet the threat and move itself onwards, embracing Multi-media and acquiring new skills.

In our own field of Industrial Design, solid and surface modelling software programmes such as I-DEAS Master Series, Pro-Engineer, Alias Wavefront and 3D Studio deplete the usefulness of traditional skills such as rendering, model making and even technical drawing.

Like Graphic Design, Industrial Design has been faced with the necessity to embrace CAD and exploit the potential for further technology-led opportunities. One of the areas that might benefit from Industrial Designers’ traditional skills is the field of multi-media.
The Cardiff Model

One of the ways in which we have chosen to stretch the boundaries of Industrial Design at Cardiff is through the medium of Systems Design. We define a System as a number of products that operate together, no single element of which will work on its own. Lego bricks, for instance, are a System; although each brick is a product in its own right, it performs no useful function without a number of others. A tram is a product but it can't perform a useful function without a number of other trams, a network of rails, tram stops etc.

A high percentage of Systems projects, chosen by the students, tend to look at the way hardware & software interact to form a system. This in turn often means that the traditional Industrial design activities tend to be displaced in favour of Graphical User Interface (GUI) design, based on Information Ergonomics.

When the Systems project was first introduced, the results of students’ endeavours tended to be displayed communicated using pages of paper with screen images, flow charts etc. Not surprisingly this lacked the impact of a real product. More recently students have begun to use software such as Corel Draw, Director and PowerPoint to produce more realistic results.

Touch screens have enabled us to further blur the line between real & virtual product design. Our students can now design a product (system or otherwise)
& produce an on-screen visualisation. The combination of software animation techniques and touch screen technology make it possible to create virtual products in an undergraduate environment. Users can then interact with the virtual prototype in a manner that approaches more nearly the experience of interaction with the real product. In this way we are able to view, with far greater clarity, the quality of work that the student has undertaken. Likewise the student is able to test the product much more effectively and deliver a design of greater depth & subtlety than before.

Industrial Designers employ tactile skills naturally. Much of the qualitative assessment of a product is by quality of touch, weight, warmth & finish. Many of these aspects can be explored through traditional techniques: weighted rigs, soft models, facsimile models etc. Multi-media models open up other areas. One of those that can be explored far more effectively, using the new tools available, is Information Ergonomics.

Sound can be added, for example, so that a switch will make a satisfactory click when it is activated; reassuring the user that the operation is completed; another tool with which to affect the user’s interactive experience.

This "psychology of sounds" is not new; it has always been part of the industrial designer's stock in trade, but it has been difficult to produce the results pre-production without very sophisticated and expensive facsimile models.
Industrial Design graduates who are conversant with these languages & other Information Ergonomics related issues will have a better chance of success in an increasingly competitive sector of the job market.
Multi-media design by three-dimensional Designers

In this section we explore the difference between 3D & 2D design approaches.

As any Industrial Designer will tell you, the most efficient way of designing an effective, useable, GUI is to make it's use *instinctive* to the user. In this case the definition of *instinctive* is a method of use that triggers a meaning learned & so often reinforced during the individual’s life that they no longer have to think about it. One of the basic methods of instinctive languages commonly used in GUI design is the *spatial analogy*.

Spatial analogies are an excellent example of the value of three-dimensional thinking for good interface design.
Example 1: A two-dimensional space analogy

Picture the layout of a computer keyboard. As the reader will know, modern computer keyboards have a collection of buttons with arrows on them that allow the user to move a cursor or an object anywhere in 2 dimensions. See Figure 1

The keyboard sits horizontally on the desk so that the arrow on the isolated key is pointing away from the user. The user is looking at a vertical screen and knows that although the arrow is pointing away from them, if it is pressed the selected item on screen will move up. The user knows this will happen because this type of spatial analogy and its transposition from

Figure 1: computer keyboard direction keys

International symposium on the dimensions of industrial design research
May 18-20, 2000 Politecnico di Milano, Italy
horizontal to vertical is a convention and over time it has been so reinforced in his or her mind that it has become *instinctive*.

*So:* a forward pointing arrow means *up*.

**Example 2: A three-dimensional spatial analogy**

Picture the same keys displayed in *figure 1* being used on the same computer keyboard as the controls of an aircraft running flight simulator software.

We know from the two-dimensional spatial analogy that the forward arrow can either mean forward (in its horizontal mode) or *up* (in its vertical mode).

If the user wished to make the aircraft go *down*, which key would they press? Surprisingly, the answer is the *forward* arrow. To explain why, we must move from two to three dimensions.
If the bottom face of the cube in figure 2 represents the plane on which the keyboard resides and the back face represents the plane on which the screen resides, let us look at the scene from the left-hand face of the cube.

This face has a diagram of an aircraft control column on it. When the forward arrow is pushed, the users mental model is of a control column being pushed in the way shown in the illustration.
So why was the control column designed the way it was? This is another example of a spatial analogy.

The reason control columns work the way they do is because they are an excellent example of a sophisticated three-dimensional spatial analogy and are therefore used instinctively. *(See figure 3)*

![Figure 3: Joystick spatial analogy](image)

If one were to place a model of the aircraft on the pivot of the control column, the model would faithfully reproduce the spatial movement of the aircraft. The mind employs this mental model in order to control the
machine. It is an exemplar of good three-dimensional design ergonomic practice.

**Case study: A multi media product by an Industrial Designer**

Since December last year, we in Cardiff have been involved in the design of a new Virtual Learning & Communication Environment (VL&CE) for use by both staff & students.

For a number of years, like those in universities the world over, we have had access to excellent on-line learning materials, databases, e-mail, staff web space etc. With the possible exception of e-mail, these are so far under-utilised.

There are a number of excellent VLEs available already: “The Nathan Boddington Building” at Leeds University to name but one.

The Nathan Boddington model allows students to work in seminar groups, sit tests on the World Wide Web, belong to seminar groups, retrieve lecture notes, etc. It is a very sophisticated model and is utilised by academics and students across the university.

The Cardiff model aims to emulate many of these functions, but we are also attempting to
Create a social environment that connects staff & students with other parts of the university

Harmonise the VL&CE with the real world environment.

Tackle the social aspects of learning

Make information retrievable by the individuals with moderate to poor IT skills

In this section we examine the design of a multi-media learning environment by an Industrial Designer and discuss the Design principles that it brings into play.

The first problem the designers were faced with at the start of this project was how to make students and staff want to interact with the environment we were creating. Three major principles were agreed upon.

1. The learning curve should be short and flat (instinctive)
2. The system should be entertaining to use
3. The system should be mutually reinforcing of real world information the users already have
4. Information should be easily located and retrieved
5. The System should facilitate better communication between staff and students in all areas of the University
1. Shortening the Learning curve

One of the first decisions the designer had to make was how to shorten the learning curve. A fundamental principle adopted to do this was to equate the environment to a product. While there are a number of people in the western world who are still computer illiterate, the chances of a student reaching university without having used a range of consumer products was thought slight. Consumer products embody a number of basic man-machine interface rules and the concept was that these could be used to help the user feel more at ease in the virtual environment. Thus areas where text appears have been displayed as screens, buttons have been set into surfaces, and instrumentation has been designed to reflect the appearance of real world products. Other product icons used are more symbolic. An example of these is the doors. With the exception of the map page each "room" has a number of doors that allow the user to exit. These have been included because of their real world connotation and appear as symbols within the symbolic (virtual) product.

Another method used to shorten the learning curve was to use a spatial analogy that both students and staff were already familiar with. That way creating a conceptual model of the virtual world in the mind of the user would be easier because it used information they already held.

It was therefore determined that the University campus should be used as the spatial model for the project. Sites would equate to rooms, each room connected to the others in the same manner as they were in the real world and
each given their real function. In this way (it was intended) students would be able to get the information or person they needed by simply asking themselves where they would look in the real-world model.

A campus map therefore forms the opening page (see figure 4) of what has tentatively been named the *Virtual School*. A number of convenient conventions have been used. For instance, the real scale of the campus has been entirely abandoned. Building plans have been simplified and re-sized and unused spaces reduced dramatically (a concept first devised by graphic designer Harry Beck in 1933 and used on the well-known London Underground map). Other conventions have been dropped too. The map does not align with the viewer's viewpoint, nor is there any association between "Up" & "North".

The user navigates by pointing the mouse over the areas where he or she expects to find rooms. When a room highlights, then he or she clicks the mouse to travel there. A room index exists to back up this system.
**Figure 4: Virtual School opening page**

The user can now travel where he or she wants. If for instance they wanted to contact a member of staff, the most obvious place to do so would be that staff member's staff-room. *See figure 5*
2. Making the Environment enjoyable to use

Another basic principle the designer was keen to adopt was that the environment should be stimulating to use. Aside from the creation of a product simulation mentioned above, there are a number of ways in which this goal has been addressed. A good example of this is the e-mail facility. If a user wishes to e-mail someone within the VLCE they move the mouse over that person's image on the screen. The person then turns towards the user, and speaks, asking to be e-mailed. The user has only then to press the mouse button and an e-mail window will appear. The extra effort required to create the necessary rollovers and sound bytes, not to mention the extra webspace occupied by such functions has to be balanced with the undoubted pleasure.
students get from using a device with this level of feedback. The project must firstly and foremostly be concerned with encouraging students to utilise the resources contained in the new environment.

In other areas too, deliberate sacrifices have been made in order to maintain an entertaining environment. In order that the user will always know his or her location within the VLCE a navigator has been provided that resides in the lower left hand side of the screen. The most efficient manner of presenting this information would probably be as a simple text message. A dial was chosen however because of its connotations of quality & solidity and to add to the "quirkiness" of the environment.

Still more effort has gone into maintaining the illusion that the user is using a product rather than a web page. When a user wishes to leave a "room" he clicks on the appropriate "door" The door will then obligingly open before the user proceeds to their chosen destination. Lights illuminate, buttons depress and screens light up with their messages; all adding to the illusion of a real three-dimensional product-based environment.

3. Making the Environment mutually enforcing

The system is mutually reinforcing in number of ways. The first of these is that it is "face-based", meaning simply that people can be contacted if you know any two of the following:

- Where they work
• Their name

• What they look like.

Students and staff can learn to associate names either through real-world contact or through the virtual environment. This and the fact that they can also learn that person's location, through either medium, form one of the basic principles of the VLCE.

Other mutual reinforcing principles include real world "hints" such as the mimicry of symbols used in the real world in the virtual environment. A good example of one of these is the "1" in the top right hand corner of the 1st year studio "room" (see figure 6). The same symbol appears in the same position of the real 1st year noticeboard. The presence of this in conjunction with the drawing pins on the corners of the notices is designed to act as a clue to the space's use.
4. Information should be easily located and retrieved

In order to make it easy for users to retrieve information, the system allows webmasters to filter that information before it reaches the user. For example, in the real-world model, Industrial Design 1\textsuperscript{st} year students share their studio with the 2\textsuperscript{nd} year. Although they share the same physical space they are following a programme of lectures, visits, etc. that is entirely different from those in the higher year. In order to remove extraneous information each student is asked to login before entering the Virtual Environment. This allows the system to give them only the information relevant to them. A first year entering the Main studio (see figure 6) will see different information.
from that seen by a second year but will have all the same services available to them.

The same system allows for better access to useful web addresses, databases, search engines, on-line learning materials etc.

6. Facilitating better communication

The last of the fundamental goals of the VLCE was that it should facilitate better communication between students and academic staff, and that it should provide a vehicle to link various components of the university and make them available to their customers.

One of the areas addressed was the services of the Campus nurse. A new building had recently been opened at Cardiff and the nurse had been moved into it as part of a drive to provide students with improved facilities and service. Unfortunately it was noted that the number of students making use of the service actually declined when it was moved to a higher profile area. The reason turned out to be that students were frequently embarrassed to be seen, visiting the nurse, in this more public environment.

This was an area then that the VLCE could tackle (see figure 7): students could get in touch with the nurse easily and virtually anonymously. If the required advice could not be dispensed by e-mail then an appointment could
be made, but the difficulty of the first approach was softened by the method in which it could be made. Information about the services available is also included in the "room" and this further aids the communication aspect.

![Nurses Room](image)

*Figure 7: Virtual School Nurses room*

### 3. Future Developments

The Virtual School project is presently in its prototype form. Its present functions have been detailed above. There are a number of developments planned for the future however.

Design students at Cardiff already have a great deal of web support: Project briefs are available on-line, PowerPoint presentations can be downloaded...
from the web as can a number of other resources. The Virtual School, when it comes on line will become the portal for all these functions and (it is planned) a great deal more besides.

Analysis of the prototype has demonstrated that the face-based geographical model works well and a number of the planned developments are based on this facet. There are already projects underway at universities such as Northumbria and Brunel (See Nam, T & Wright, D. (2000) Observations of team design process and the impact of collaborative technologies, Proceedings of Co-Designing 2000, Coventry, UK) looking into collaborative working using the web. This work may have a direct bearing in this arena and it is one of the areas the team is keen to explore.

Some of the limitations of the Web have been detailed above, but software from Macromedia, Apple and JulyNet Co are providing methods with which to explore 3d objects from a number of 2D images. There are a number of uses we are currently investigating for this type of platform.
Bibliography

Nam, T & Wright, D. (2000) Observations of team design process and the impact of collaborative technologies,
Proceedings of Co-Designing 2000, Coventry, UK

Computer Modelling Techniques, Science Research Council, Department of Design Research, Royal College of Art, London, l973-74


Open folio: http://www.openfolio.com/

A Framework for Pedagogical Evaluation of Virtual Learning Environments:
http://www.jtap.ac.uk/reports/htm/jtap-041.html

The Nathan Boddington Building:
http://www.tlsu.leeds.ac.uk/nathanbodington.html
Biographical Notes:

Steve Gill  BA (Hons) Industrial Design; Course Leader, Industrial Design, School of Product & Engineering Design University of Wales Institute, Cardiff, Wales, UK. Professional experience includes Industrial Designer; Product Manager; Tutor and Course Director for First Degrees in Industrial Design and tutor for Masters Degree course. University of Wales Moderator for BA Industrial Design course at Fundacion San Valero, Zaragoza, Spain; member of course validation and review panels in UK and Spain. Principal areas of interest are: Product Interaction, Information Ergonomics, Multimedia design for Industrial & Product Designers.

Tim Coward  MDesRCA in Industrial Design, by Research; Fellow of the Chartered Society of Designers; Head of the Cardiff School of Art and Design, University of Wales Institute, Cardiff, Wales, UK. Professional experience includes: Research Fellow in Department of Design Research at Royal College of Art, London; Tutor and Course Director for First Degrees in Industrial Design; and tutor for Masters Degree course. Supervisor for Research Degrees in Design; External Examiner for BA and MA Design courses and Research Degrees in wide range of institutions; member of course validation and review panels in UK Universities and Colleges; moderator for overseas design courses. Chair and member of executive National Association for Three-Dimensional Design Education; member of executive Design Education Association. Principal areas of interest are: design methods, research methods; cultural factors in design education.
Paper 3: Six Challenges Facing User-Oriented Industrial Design

By Steve Gill

Published in the Design Journal, Spring Issue, (12.1) Berg, Oxford, 2009 ISSN 1460-6925 (print) 1756-3062 (online)

Subject: The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances.

Reason for inclusion: The scope of the paper is fairly broad. In part it serves the function of a literature review
Six Challenges Facing User-oriented Industrial Design

Steve Gill
National Centre for Product Design and Development Research (PDR), University of Wales Institute, Cardiff (UWIC)

ABSTRACT Much has been written about the need to address the requirements of the user when designing information appliances (mobile phones, MP3 players, personal digital assistants (PDAs) and so on), but less is written about the challenges designers face in bringing this about. Using case studies, this paper will examine six of the problems facing design teams in consultancies, Small- to Medium-sized Enterprises (SMEs) and multinationals tasked with the design of complex computer embedded products. A case study of the successful implementation of a technology-based product is presented. The factors that make it an example of good practice and the ways in which the designers have overcome the six challenges
are examined. In conclusion, the challenges for the successful design and development of information appliances are summarized and ways in which they might be addressed discussed.

KEYWORDS: industrial design, product design, design management, design issues, information appliance, computer-embedded product, innovation

Introduction

Modern products are increasingly likely to be computers. Bill Buxton (2004) summarized the situation succinctly. In a keynote address to the Second International Conference on Appliance Design regarding users’ perceptions of modern products he stated: ‘A PC is a computer you type into, a mobile phone is a computer you put your ear to and a digital camera is a computer you look into’. Increasingly, the product is actually the user interface while what we perceive of as the product is actually just packaging it. Products of this nature (MP3 players, global positioning system (GPS) devices and so forth) are frequently referred to as information appliances. In 2002, the global sales total of communications-based information appliances was 94 million units. In 2008 more than 546 million device sales are forecast, while Web-based information appliances were forecast for a twentyfold increase from less than 0.5 million units to over 10 million in the same period (ETForecasts, 2003).

Much has been written about the faults in the way the design and manufacturing community approach this developing and increasingly important area of design (see, for example, Cooper, 2004; Norman, 1999). The specific problem of developing processes via which to design information appliances was identified some years ago (for example, Buxton 2001; Houde and Hill, 1997; Lee et al., 2004; Thomas et al., 1995) and a number of tools and techniques are either available or in development, a selection of which are briefly described below:

- The Buck Method (Perring, 2002) involves using an existing product wired to a PC;
- Paper Prototyping (Snyder, 2003) uses paper, card and other ‘soft’ materials to build prototypes. Human operators make physical changes to product states according to the user’s interaction with the ‘product’;
- Experience Prototyping (Buchenau and Suri, 2000) is an ethnographic approach that uses improvisation and low technology props;
- Wizard of Oz simulations (Maulsby et al., 1993) involves human operators simulating sophisticated machine responses;
Six Challenges Facing User-oriented Industrial Design

- Augmented Reality (Nam and Woohan, 2003) uses a combination of real and virtual simulations;
- DTools (Hartmann et al., 2005, and widely regarded as the best rapid hardware/software development tool so far) uses ‘smart’ components combined with a state transition software tool;
- the Calder Toolkit (Lee et al., 2004) involves prototyping via \textit{ad hoc} networks;
- the IE System (Gill, S., 2003): a flexible system of hardware and software linking a prototype to a PC. For further details on some of these techniques and others, see Gill, S. \textit{et al} (2005).

It is also worth noting that in two-dimensional design there have been some interesting developments such as DENIM (Newman \textit{et al}, 2003) which allows designers of Web pages very swiftly to create designs from sketches using gesture recognition. Similar approaches may yet be useful for the development of information appliances.

As can be seen from the small sample above, a lot of research is being carried out, attempting to find ways for designers to overcome the problems of designing computer-embedded products. Why then is so much still written about unsatisfactory information appliances? (for example, Kim, 2005; Nielsen, 2004).

Designers do not operate in a professional vacuum. This paper will demonstrate that the context of their operation is as important to the problems facing the design development of information appliances as the day-to-day design and prototyping issues themselves. Specifically, the paper seeks, through case studies, examples and discussion to explore the problems faced by designers and industry, the hurdles to be surmounted and the further work needed in order to achieve that.

**Challenges 1–4 (Social Factors)**

There can be a temptation to regard the facilities, expertise, problems and methodology for designing information appliances as common to all design teams. Papers such as Pering (2002) and Mohageg and Bergman (2000) only deal with how information appliances are designed in a particular setup (Handspring and Sun Microsystems respectively), while Avrahami and Hudson (2002), Greenberg and Fitchett (2001), Hartmann \textit{et al} (2005), Lee \textit{et al} (2004) and Nam and Woohan (2003) appear all to assume a similar set of problems for all designers. The author’s own previous work (Gill, S., 2003) briefly acknowledges only two basic scenarios for information appliance design.

Research commissioned by the National Centre for Product Design & Development Research (PDR) at the University of Wales Institute, Cardiff (UWIC) has found a range of different design environments in which information appliances are developed. Not \textit{all} designer teams face \textit{all} the challenges listed in this paper; they occur according to company structure, the skill sets available, the...
time given to the project and even the financial circumstances of the company designing the product.

**Challenge 1: Cultural bias**

In countries like South Korea and Japan, consumers are happy to take time to deal with technology. In their paper examining the success in Japan of *iMode*, a mobile internet system, Barnes and Huff (2003) noted that ‘Modern Japanese culture is well known for its enthusiasm for electronic devices, especially among its youth.’ The result is that devices designed for the Japanese, Korean or Taiwanese markets tend to have a lot of functions, often at the expense of usability issues. Moggridge (2006) notes ‘(iMode had) interactions that, though not easy to learn, were mastered by teenagers as well as adults with enough patience’. In the West, there has been a backlash against function-heavy products. Barnes and Huff note that in 2003, Japanese consumers were subscribing to *iMode* at a rate of 15,000 per day, and that between June 2002 and May 2003 *iMode* in Taiwan reached 900,000 subscriptions. In contrast, they note ‘European versions of *iMode* became available to German and Dutch markets in early 2002 and France in November 2002, but have struggled to convince customers to subscribe.’ This enjoyment of technology carries over into machines for use by the general public; Figure 1 contrasts UK and Japanese ticket machines, and Moggridge (2006) cites an example of an *iMode*-operated drinks dispenser with a very complex, involved and distributed interface (dispenser, mobile phone, *iMode*, content provider).

Lee *et al* (2007) further examines the uptake of mobile internet through a post-adoption study in the Far East. They attribute Korean,
Hong Kong and Taiwanese attitudes to information technology as being due to the ‘cultural lens’ through which those cultures view it. Among other findings is the intriguing suggestion that a willingness to share is one of the possible social contributors to mobile internet being more successful in collectivist cultures (see below). Marcus (2002) examines the ways different cultures view colours, symbols, words and layouts, suggesting methods for ensuring cross-cultural acceptance in user interface design. Shen et al (2006) lends a Chinese perspective to the debate, arguing that many standardized interfaces create problems for some cultures. The paper discusses the almost universal use of Western metaphors, representations, colour associations and navigational logic and notes issues such as the Japanese preference for not pictorially representing body parts or actions, a very common approach in the West. Khaled et al (2006) examines Persuasive Technology and how it might be cross-culturally implemented. They suggest that one of the keys to understanding cultural differences lies in understanding the collectivist nature of many Eastern cultures versus the individualist nature of the West. They note, for example, that in the individualist Western culture the predominant negative motivational force is guilt, while in the collectivist culture the equivalent negative motivator is shame.

Designers from one culture designing for another sometimes fail to understand these cultural differences and assume certain consumer knowledge, taste or habits are universal. When this turns out to not be the case, products can fail (as in the case of iMode in Europe). ‘What makes it doubly hard to differentiate the innate from the acquired is the fact that, as people grow up, everyone around them shares the same patterns’ (Hall, 1976).

The differences in the way different cultures perceive products and technology has been well understood for some time, and so large companies often have design offices in different parts of the world as a means of accounting for these factors (Trompenaars, 1997). In theory, this should deal with the problem, but in fact these arrangements can fall foul of the very cultural differences they set out to address. PDR commissioned an ethnographic research company to investigate issues facing design teams dealing with information appliances. The study was commissioned to develop improved approaches to the issue including new tools. Some of the case studies uncovered by the research are used here to illustrate six challenges faced by the design industry. The following is an excerpt from one of the interviews. Companies’ and employees’ names have been replaced by the titles ‘A’, ‘B’, ‘C’ and so on, to protect their identity (individuals have agreed to their inclusion in this paper on that basis).

Mr X is a designer in Company A which is a well-known multinational concern with a design office in Europe to create products for that market. Mr X: ‘We spend months working on a design that has been
painstakingly researched and developed for European tastes; when the final proposal is sent to Company A headquarters they make arbitrary changes and launch it in another market altogether. In other words, although the design office has been set up in order to advise headquarters on European tastes, they are not allowed to make the final decisions. These decisions, including those on culturally biased tastes, are made by senior managers from a different culture than the intended users of the appliance. The situation is compounded by a culture within the home company of deference to seniority, even when those in more junior posts are better placed to make decisions.

**Challenge 2: Breaking with convention**

Interaction requires two key components. One is the controls, through which people can manipulate access to digital information and computations. Also it’s very important to have external representations that people can perceive, to understand the results of the computations (Hiroshi Ishii in Moggridge, 2006).

There are many conventions that users rely on to help them ‘navigate’ products (what Norman (1998) refers to as ‘natural mapping’). The semantics and grammar of many signs have become ingrained with associations only partially based on their original meanings. One example is the triangular symbol found on audio and video devices, the history of which can be traced to the reel-to-reel tape recorder where it denoted the direction of the tape’s travel. Today it has come to mean ‘Play’ on a wide variety of devices from DVD players to solid-state MP3 devices. Its original meaning has been lost, but by convention it has acquired a powerful and ubiquitous communicative ability. Designers working towards the right solution for an individual product sometimes fail to understand the significance of conventions such as these, particularly when they are in the process of evolving.

As we grow up, we associate certain shapes, symbols, colours, textures, materials and sounds with given functions, so much so that when we interact with a well-designed product we speak about having a ‘natural’ sense of how it should be used. If there was such a natural sense and we had been brought up isolated from the industrialized world, we would be as able to use it as someone who had used this type of object all his or her life. There is nothing natural about it, however. Rather, there is a direct link between cognition and culture (Gill, G., 1993; Hollan et al, 2000) and by understanding us as users, the designer has made use of accepted metaphors and norms, borrowing imagery, shapes, textures, symbols and so forth to help us interact using pre-learned knowledge. Goldstein et al (2003) argue that complex devices with multiple functions prevent the use of previously acquired source metaphors (in other words
Six Challenges Facing User-oriented Industrial Design

conventions). They note that ‘a novice users’ previous knowledge plays a major role when interacting with a new multipurpose device for the first time. In order to bridge the gap between the known and the unknown context, the use of metaphors as knowledge carriers have been frequently employed by human computer interaction (HCI) designers.’ They go on to discuss how, for example, a digital camera function in a personal digital assistant (PDA) forces the user to use computer conventions to interact with the camera, breaking the contextual link with the user’s source metaphors. For more on the methods used to design exactly this type of product see Fernandez (2004). This paper spells out some of the problems, amongst them the isolation of the industrial design and software design teams (see below). What really adds complexity to the issue of conventions, however (as briefly touched on by Goldstein above), is the issue of context.

Fifteen years ago Robinson (1993) noted that ‘Computer systems and applications that mediate work between people are increasingly discovered to be used in ways that were not anticipated by their designers.’ He goes on to note a simple illustration of a hotel key rack that, incidentally to its original purpose, serves as an indicator of which guests are currently in residence. While a key rack could be misused, it was predictable for designers and users. Furthermore, its potential uses were dependent on its ‘physical properties, local conventions and rules, and situated activities’. Robinson proposed that this was a model on which computer-based interactions ought to be based. Vyas and Dix (2007) argue that as well as previously understood issues such as distributed cognition affecting product users, the materiality and embodiment of their context are equally important factors. Introducing the concept of ‘Artefact Ecologies’, they note: ‘One of the central aims behind designing tangible and embedded interfaces is to allow users to interact with them in a natural way that is grounded in everyday mundane experiences. This poses two main challenges for designers. First is to understand what ways the users naturally interact in their mundane experiences. And the second is to introduce a technology that supports (or improves) their experience.’ Dix (2006) discusses the impact of physicality on users and, in some ways, Magnusson (2006) continues the theme of physicality, discussing the affordances required of computer-screen-based musical instruments for use by musicians whose understanding of their instrument lies partly in embodied action. He also notes that one of the potential problems with computing-based musical instruments (as with information appliances) is ‘unnatural mappings’. He notes: ‘the control device and the sound source are arbitrarily related, unlike in acoustic instruments’.

This lack of any physical link between action and response is one of the reasons such care needs to be taken with information appliances since the user is all the more dependent on the informed and careful use of conventions by the designer. Some of the
problems of convention and context became apparent recently when researchers from PDR conducted tests on a *BT Equinox*. The Equinox is a landline phone with some of the same functionality (for example, colour screen, texting) as a mobile phone. Although the red and green phone button convention has been ‘borrowed’ from mobile phones for answering and ending a call, the ‘Power’ control has been placed at the top left of the product. There are three immediate and contradictory issues of convention here.

1. It is a common convention on products to have the power switch on the left hand side, often away from other control inputs (Hi Fi separates, DVD players, washing machines).
2. It is common for mobile phones to have a power switch. There is no absolutely established convention but many phones (Nokias for example) use the red phone key for the ‘Power’ control.
3. Conventional landline phones do not usually have a ‘Power’ control at all.

PDR conducted a series of empirical tests on the Equinox based on a methodology developed by Molich and Dumas (2006). Tasks were chosen to include common functions including Power On and Power Off. The programme was critically trialled on six participants to check for errors before implementing the main body of tests. Modifications were made to the software, hardware and methods of testing and recording data as a consequence of these. A total of 80 participants from the University of Wales, Institute Cardiff (UWIC), took part (62% female), ranging in age from 18 to 30 years. They all had at least one year’s experience using mobile phones with an average experience of seven years. They sent an average of six text messages a day, suggesting good familiarity with ‘typical’ phone interfaces. Each participant was given an instruction sheet to read and they were allowed to ask questions if they were unsure of the procedure. They were then given one minute to familiarize themselves with the interface before the tasks commenced. The trials were also videoed with sound (see Figure 2) and users were encouraged to ‘think aloud’ if they wished. Comments were noted as were actions or errors of specific interest.

One of the most notable issues that users had was that they were repeatedly confused by the placing of the power switch. This was because although the designers had made a series of choices that followed convention, the context in which they had used them (a landline phone with the functionality of a mobile) was confusing because the predominant characteristics of the phone as perceived by users were that of a mobile. Consequently they tried to implement the wrong source metaphors and when asked to switch the phone on they automatically pressed the red phone button without looking for the ‘Power’ symbol. Many of them tried the same thing repeatedly and some failed to switch the phone on at all.
Six Challenges Facing User-oriented Industrial Design

The development of designs which successfully employ ‘natural mapping’ require designers to be fully cognizant of which conventions should be employed where. Tests need to take place at an early stage in a product’s development to determine how the user views the product. It is not enough to follow a series of conventions; rather the designer needs to know (and know early) which conventions users are expecting to follow. As mentioned elsewhere in this paper, the tools to allow designers to very rapidly explore these issues at an early point in the design process do not exist in a satisfactory form.

Challenge 3: Social context

‘In attempting to design a system to “fit” the end user, behavioural issues must be considered and understood. Given the limitations of the analytical tools available, and our inability to adequately predict system performance in “real-world” situations, it is unlikely that the first implementation of any user interface is going to function as well as it could or should. Under these circumstances, an alternative is to take an iterative approach to design: keep trying until you get it right’ (for more, see Schrage, 2000). ‘However, two problems become immediately obvious. First, how do you know when you have got it “right”, and why it is “right”. Second, how can such an iterative approach be made practically and economically feasible?’ (Buxton and Sniderman, 1980).

When 3G phones were first launched one of their key Unique Selling Points (USPs) was that they had cameras. The cameras were mounted on the same side as the screen to allow video conferencing. Later ethnographic research (Loudon et al, 2002) showed that users wanted cameras to take photos of other people and objects and so later models (many of them not 3G) place the camera on the other side of the phone.

Figure 2
BT Equinox undergoing user trials.
face of the product. Manufacturers had failed to understand the social context of phone camera use.

Most commercial design tends to be carried out in a studio or office environment. There are a number of reasons why this is the case, not least among them confidentiality issues and the fact that the environment is equipped for that purpose. Nevertheless, products are frequently designed and tested well outside their context of use and as the example of the camera phone illustrates, this can lead to problems once they are in production. Experience Prototyping, as mentioned in the Introduction, is one way to tackle the problem of simulating the context of use environment without leaving the office or design studio. Augmented Reality (for testing rather than prototyping) is another, as are the techniques used in Project Maypole (Kankainen, 2003) where end users (children in this case) were brought into the design environment and involved in the product development process. A third method is the use of video collages, sound, pictures and so forth gathered, filtered, edited and presented by ethnographers to help the design team understand a product’s context of use (Keller and Stappers, 2001).

Unfortunately, design teams are frequently not in a position to undertake context of use testing or simulation either because of company structures or financial and time pressures (see Challenge 5 below), so are forced instead to work in isolation from either the end user, other parties involved in the design or both. The result is that designs are frequently conceived, designed, developed and launched with no real understanding of the users’ requirements.

**Challenge 4: Ingrained thinking**

Just a few years ago, a camera was a mechanical and optical instrument with a chemical film. Little by little the computer chips invaded. First it was automatic exposure, then autofocus and red-eye removal; now digital memory is replacing film. We still think of it as a camera, though, dedicated simply to the task of capturing images, but it is not just a camera anymore. It’s a camera, an album, and a way of editing and choosing. Somehow the design expression has to support all of these things (Moggridge, 1999).

From early on in their history, cameras have had viewfinders that necessitate the user placing their eye to them. As the digital camera came of age, it became apparent that users frequently ignored the viewfinders and used the screen. Ingrained thinking by designers, manufacturers and users led to a slow transition from optical to digital viewfinder/viewing screens that allow more camera angles and facilitate effective picture browsing (see Figure 3). Tripsas and Gavetti (2000) describe a case study of Polaroid’s response to the problems of digital technology dominance, citing the mindset of managers
who, since they ‘are boundedly rational, must rely on simplified representations of the world in order to process information. These imperfect representations form the basis for the development of the mental models and strategic beliefs that drive managerial decisions. They influence the manner in which managers frame problems and thus how they search for solutions’ (Simon, 1955). What they found was that while Polaroid had the technology and the personnel to make the changes required, their view of the photography market was too ingrained to allow their products to flourish. Kodak took a different approach, asking IDEO to ‘make sense of digital camera interactions’ for them. IDEO were early pioneers of a change in traditional design methodologies. They recognized that designers of information appliances should start by ‘designing interactions’ rather than products or interfaces. In an interview with Bill Moggridge (2006), Matt Hunter describes how the brief from Kodak led them to re-look at the possibilities offered by the technologies and conduct ethnographic research in order to point at the types of functionality required. The output was an oversized interactive prototype which embodied a number of suggested interactive possibilities for Kodak to utilize in future products. Kodak quickly developed a strong market position on the back of this work which was carried out by a multidisciplinary team looking at an issue laterally.

Designers are trained to think laterally. Methods such as *Six Thinking Hats* (De Bono, 1990) and *Techniques of Structured Problem Solving* (Van Gundy, 1988) are commonly taught in universities. There are many examples of designers displaying this ability to ‘think out of the box’ (for example, Gaver and Martin, 2000). Unfortunately

---

**Figure 3**

Camera on the left retains standard viewfinder. Model on the right uses the increasingly popular large screen format with no conventional viewfinder.
the realities of design as a commercial practice are that there is frequently not enough value placed on innovation in any fundamental sense (that is, not a willingness to pay or to wait for it). Thus, early on in the evolution of the digital camera, standards were borrowed from chemical film cameras without fully understanding the change in its function brought about by the technology that enabled it to exist (hence Kodak hiring IDEO).

Again, this situation is exacerbated by the lack of prototyping tools available to designers without access to multidisciplinary skills and further still by ingrained thinking within their immediate environment. Even now, the designers interviewed by PDR did not have access to the skills required to output prototypes of the type IDEO produced for Kodak in 1995.

A researcher commissioned by the PDR interviewed Mr Y, also a designer within Company A. Mr Y was asked about his views on usability testing. He stated: ‘Usability testing should provide validation, as designers should be able to know what a user wants.’ Dr Z noted a similar trend in Company B (another multinational brand): ‘The New Product Manager called us in and told us that he wanted us to conduct user research into the design of a new product. However he already had strong views on the design including the type of screen, its input devices, its capabilities and so on and insisted on us using his ideas. When we did the research we found that the needs of the target users didn’t really match the design ideas of the New Product Manager.’

Challenges 5 and 6 (Commercial Organizations)

Design is a commercial activity and design departments do not exist in isolation, even in design consultancies. The structure of an organization has the potential to greatly influence design output. This issue is not unique to information appliances, but given their complex nature and need for effective cross-disciplinary cooperation, they are particularly vulnerable to issues of organization.

Challenge 5: Company size and structure

There are three main sectors within which information appliances are generally designed: design consultancies, Small to Medium-sized Enterprises (SMEs) within the manufacturing sector and multinational companies. The opportunities and the challenges facing each of these will be discussed and illustrated through case studies.

The company is too small

Researchers working for PDR spoke to the design and development employees of six UK-based companies. All agreed that the ideal way to approach the design of a product is to get in-depth market and user analysis before proceeding towards concept generation. Unfortunately, in the case of small companies, they faced growing pressures to get products to market within very tight time and cost
The Design Journal

Six Challenges Facing User-oriented Industrial Design

constraints. In general terms, the smaller the company, the less able it is to turn work away and the less able also to influence a client’s decisions. In the words of a senior manager of Company C, a medium-sized design consultancy: ‘The problem with Market Research is delay.’ The biggest design consultancies like IDEO and Pankhurst Design & Development (PDD) are in a stronger position to dictate to clients the type of design process which should be undertaken because they have multidisciplinary teams making them able to deal with large and complex projects in their entirety. In the short term this process costs the client more money and time but in the long term they see the benefit from a product which is able to capture a greater market share. Smaller consultancies are faced with a stark choice: accept the terms the client offers, that is, short time-to-market and low cost, or see the work go elsewhere. In short, their work is cost-based and other considerations must often be given less priority. Consider the example below:

Company D is a medium-sized company who specialize in industrial design. An employee of Company D who had worked on the design of an information appliance was asked; “How did you design it?”

Answer: ‘I produced templates in Photoshop for design critique and then we developed those into fully working interfaces on screen in Director or Flash and when the basic structure was approved we employed a technology company to develop a test rig, it was programmed and Company D built a full working prototype.’

Question: ‘Did users test these? Or a designer (like yourself)?’

Answer: ‘Well it starts off just internal testing but eventually the client takes it away and goes around the globe presenting it to investors and panels for review, so we have phases and they come back and we get feedback and work from there – depends on cost, schedule, and whether you have time for all of that’.

Question: ‘OK, tell me, when is the actual “user” involved for testing the interface, at the end? E.g. You guys create what you can from your experiences, and then is there an actual “end user” testing, to test the interface, or do you rely on the designers’ knowledge?’

Answer: ‘It’s up to the client how they want to manage that. To be honest, the Company D interface was poorly conceived and I tried to warn them, but time doesn’t allow it, it just gets done and you go with it. It was more design led than usability. A senior worked on the ID, and I worked on the screen interface when really we should have worked TOGETHER and I keep asking him about the locations of buttons and things, because the interface should reflect that but there was no time, he just gets on with it, and I just have go do it, with or without knowledge of what he is doing!’
In addition to the factors mentioned above, designers in smaller companies are frequently presented with an electronics ‘package’ complete with control inputs (often with the interfaces fully designed) and then simply told to ‘box’ them. PDR’s design department, for example, received a total of 20 design jobs related to information appliances between December 2003 and February 2007. Of these, two were developed only to concept level and one involved the development of CAD data to output rapid prototypes. Of the remaining 17, ten involved ‘boxing’ an existing electronic package. Because most small- to medium-sized consultancies do not have teams of designers and engineers working together, the designer becomes disempowered because he or she has no way to properly test ideas in three dimensions. All of the methods mentioned in the introduction, including the current IE System (Gill, S., 2003) require levels of time commitment that are frequently too high for many small- and medium-sized consultancies.

**The company is too big**

Surprisingly, multinationals designing information appliances can suffer from many of the same problems as SMEs. Their very size means that they can only be effectively managed if they are split into smaller components. Sachs (1995) noted that the way these components are organized is often influenced by an organizational view which defines structure by sets of defined tasks and operations. She argues that organizing companies by activity is a better strategy: ‘An activity orientation draws on insights about work practice from several disciplines, including anthropology, history, and psychology, and in so doing provides a holistic approach to the analysis of work.’ One of the consequences for task structured companies (which include Company A and Company B) is that many of these smaller components are the size of SMEs and, being structured by task (for example, software interface) rather than by activity (such as appliance design) do not have very diversified facilities or skill sets.

Iansiti and West (1999) note an additional problem for companies who wish to efficiently employ new technologies and must therefore integrate their Research and Development (R&D) activities into their design departments: ‘if a company selects technologies that don’t work well together, it can end up with a product that is hard to manufacture, is late getting to market, and does not fulfill its envisioned purpose’.

The problem in this case is often not limited resource but limited organizational remit. As the various components of the design are processed (user interface, electronics, programming, graphical layout, product design and so on), it is almost inevitable that important aspects are left out because they become apparent ‘too late’ in the development cycle to influence product architecture, in other words, when too many factors are already defined or determined. This problem is exacerbated by communication problems between the
various task-oriented departments. Multinationals may have design departments, R&D, market research units and so on, but because of the size of their operations these tend to be placed in separate units, sometimes in different countries or even continents. Each of these units is frequently reliant on the work of another, so a unit working on usability cannot start to integrate product design within their own remit since this work is carried out elsewhere. Fernandez (2004) describes working out the entire camera interaction software for the Palm Zire without having any knowledge of the product form. In certain cases much of the work that takes place in one department is also confidential from another and so the job of effectively coordinating the various skill sets in the company as a whole is very problematic. The result is that, like in an SME, each unit in a multinational frequently finds that it is unable to work in a fashion best suited to producing effective information appliances. As with the SME, the design department may be told to ‘box’ electronics designed by the engineering lab and the usability experts told to work with the layout that product design have selected for them. Some of the problems related with this type of company structure are related in Buchanan and Huczynski (1997).

**Challenge 6: Company politics**
Companies are frequently described as being ‘design led’ (Apple) or ‘technology led’ (IBM) and this is a direct reflection of their ethos. The differences are summarized by Hagedoorn et al (2001): ‘The IBM approach to personal computing as found in the PC, introduced in 1981 . . . was designed by technologists for use by technologists. Users with some technical ability could open the computer, add and remove components, and otherwise modify the system, but such activities required an understanding of the technical principles.’ ‘In contrast’, they continue: ‘The “philosophy” behind the introduction of the Macintosh computer to the mass market in 1984 represented a change within the existing technological paradigm. First, the Macintosh approach introduced the concept of “user-friendliness” with the graphical user interface (GUI) using icons on a desktop to represent programs and files. Second, the overall architecture of the Macintosh was conceived as a single integrated unit, . . . Third, and most important, the Macintosh was developed as an integrated system which made the technical aspects of the computer opaque to the user.’ By and large, both companies have the same ethos today.

When companies change ethos however, new management structures alter the ‘balance of power’ and the product design process can be altered according to which discipline is dominant. Dr Z was previously a manager charged with overseeing usability issues of new products at Company B (mentioned above, a well-known multinational company who produce mobile phones). Interviewed on behalf of PDR, he said: ‘Company B was traditionally engineering
led. In that climate the industrial design department did as the engineers told them and were not consulted on many aspects of the design. Following a change in strategic direction the industrial design department gained dominance and failed to consult adequately with engineering, causing an equal amount of difficulty in producing a good product.’

**Overcoming the Six Challenges**

The six issues outlined above amount to a small proportion of the problems faced by design teams. Nevertheless, it is quite possible to overcome them and successful design approaches certainly exist, the Steelcase Roombooker for example (O’Hara et al, 2003). The case study below also illustrates a methodology and team structure that seeks to overcome the barriers to the creation of successful information appliances.

Company X specialize in designing information appliances. Their size, mix of expertise and approach address each of the six issues outlined in this paper, as illustrated by an information appliance designed by them, the *Navitile*.

**Case Study: The Navitile**

The Navitile is a good example of Company X’s methods. In approaching the problem of route-finding within large buildings they used ethnographic research techniques to look at conventional methods before proposing a solution. Sharpe and Stenton (2002) note: ‘Humans tend to build up very rich physical environments that help reduce the load on our cognitive functions. A classic example is wayfinding. The rich variety of mechanisms we use to guide us around the environment offer and reduce choices in ways that we can deal with as we move around.’

There are two common methods of helping users navigate a building: maps and signs. Company X considered that maps provide a ‘big picture’ view with huge amounts of information that users are required to sift. Signage on the other hand, while requiring less sifting, only works on a localized level, expressing the choices of route faced by a traveller at any given junction.

The Navitile system (see Figure 4) consists of a series of networked Radio Frequency Identification (RFID)-enabled floor tiles. On their surface is a series arrows arrayed on the eight main points of the compass. It is designed for large public buildings such as hospitals where people not familiar with the building are frequently asked to navigate their way through it.

The concept is very simple. At reception the visitor is given an object such as a name badge, a brochure or card, for example, that has an RFID tag attached to it on which is encoded the visitor’s destination. Navitiles are placed on every corridor junction in the building so that every time he or she reaches a junction they simply stand on the tile. The tile senses the weight of the person on it then...
reads the RFID tag and points the visitor in the right direction by illuminating the appropriate arrow.

So, why is it an example of good practice?

- The system seeks to perform only one task. This means that fewer compromises have had to be made. If it was designed to perform two tasks, it might perform both less well.
- Visitors can take detours and still find their way to their destination. So if they have arrived early and decide to go get a coffee before their appointment they can still find their way, even from a different point in the building.
- Unlike a map, it only gives you specific information about a single destination. So although the system covers all locations, it only shows a user the information they require.
- It breaks with convention (using maps or diagrams to navigate), an issue well understood by designers. Breaking convention is often achieved by using a series of techniques (mind mapping, group discussion, direct observation) to suppress prejudices and preconceptions. The problem achieving it tends to make itself felt when other factors such as social context, company politics or company size/structure come into play (see Challenges 3, 5 and 6) preventing the full design process coming to bear on a design problem. Company X has been careful to create conditions whereby they are free to operate outwith those constraints. Key to this approach is the use of ethnographic research techniques.
- Creative stimulation study techniques were employed to look for latent consumer need by looking at the ways in which products or artefacts are converted or subverted for uses other than those for which they are designed (see Figure 5). The process involves viewing users in their social context, observing conscious
and unconscious interactions with products, people and the environment.

Again, this method of gathering information is not new, it is an established design technique, widely taught in universities and used at the highest levels by the likes of IDEO and PDD. Unfortunately, however, for the reasons mentioned above and others, the technique is frequently not applied to information appliances. Because they have both technological and usability expertise ‘in house’, Company X is able to construct working prototypes and test products in their ‘natural’ environment, thus it is able to benefit from unexpected ‘windfalls’ such as the one in Figure 4.

**Conclusions**

The context of a designer’s day-to-day work can have a dramatic impact on their effectiveness. This paper has argued that there are six major challenges that most affect designers of information appliances:

- Unwitting cultural bias;
- Inappropriate breaking of conventions (caused by lack of support in training, time or tools to carry out the job);
Six Challenges Facing User-oriented Industrial Design

• Designing without reference to social context because of time, cost and/or IPR issues;
• Ingrained thinking, (creativity suppressed by commercial and time pressure realities and compounded by a lack of fast, easy to use tools for the iterative design development of information appliances);
• Issues with company size/structure (either too small to drive the design agenda or too large so that expertise exists across different departments, countries or even continents);
• Company politics (one part of a team has dominance over another with negative results).

As Figure 6 illustrates, each of the six issues has potential consequences to the success of a product.

**Dealing with the six challenges**
While the Company X case study above demonstrates that all of these challenges are surmountable, the fact remains that there are significant barriers to overcoming them in anything less than ideal design set ups:

<table>
<thead>
<tr>
<th>Cultural Bias</th>
<th>Inappropriate design decisions</th>
<th>Non-iterative design process</th>
<th>Lack of innovative solutions</th>
<th>Product fails in everyday use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking of Conventions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failing to Consider Social Context</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingrained Thinking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Company Politics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Company Size/Structure (big)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Company Size/Structure (small)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6**
The six challenges: potential consequences.

**KEY**
- Low risk
- Risk
- Certainty
Cultural bias
PDR’s research found that companies like Company A understand the problem of cultural bias and have put experts in place to deal with it. The real issue is that they are not yet making full and proper use of that expertise by devolving decision-making powers to those on the ground.

Breaking of conventions
Iterative product development is not a new concept and proper rig testing and user involvement have been picking up issues such as the inappropriate breaking of conventions, for many years. Given the time and opportunity any designer ought to know how to develop a product this way. The issue for a designer developing an information appliance is that they frequently do not have the training, skills or appropriate range of tools necessary for the effective development of that type of product. This issue is particularly critical at the fast and fluid low to medium fidelity development stage of a project when most of the key decisions are made.

Social context
Companies need to understand the commercial value of products that are appropriately designed for their social context and realize that time and cost can be recouped from a design that gives a market what it wants, be it explicitly or implicitly. Where IPR issues are particularly sensitive, techniques already exist to give designers detailed information about the user and offer ways to simulate context of use, these need to be implemented more widely than they already are but that implementation is dependent on recognition of their value at all levels.

Ingrained thinking
Ingrained thinking can also be tackled by persuading companies to release their designers’ skills for innovation at a fundamental level using some of the standard techniques mentioned above. Unfortunately, this will again be hampered by the lack of training, skills or a complete range of tools (to supplement the likes of Experience and Paper Prototyping) specifically to empower designers to develop ideas for information appliances in a fast and fluid fashion early in the design process.

Company size/structure
Companies approaching design consultancies need to understand that they frequently undermine their own interests by restricting briefs and failing to allow designers to use their training to approach a project from a fresh perspective. Large consultancies such as PDD and IDEO have, in part, become large precisely because they have been able to persuade clients of sense in this approach. It must be recognized, however, that small consultancies often simply do not
have the resources to undertake information appliance development work in this manner because, at present, a lot of very specialist knowledge is required to prototype them and it takes a long time, thus we return to the issue of providing designers with appropriate tools. As discussed above, large companies have all the expertise required but it tends to be compartmentalized so that employees in one department find it difficult to effectively access the skills available in another for political, geographical and confidentiality reasons. These issues are complex simply because the scale of operations in a large multinational means that teams have to be very large. It is clearly in accord with the best commercial interests of a company of whatever size to operate a sensible, well-structured approach to information appliance development. To that end, and in the context of information appliances it would make sense to implement Sach’s concepts of company structure based upon activity rather than tasks. Failing that, improved communication between departments might make a significant difference. Protocols for the treatment of IPR sensitive data would keep the risk to sensitive data at a minimum, and the use of secure links for the electronic transfer of CAD and other design data wedded to the appropriate implementation of products such as the Virtual Desk (Ashdown and Robinson, 2005) that allow for collaborative work practices regardless of geographical remoteness would further ease the communication and organizational issues.

Company politics
Company politics causing one part of what should be a team of equals to have dominance over another is a perennial issue not restricted to information appliances. The growing consumer pressure to produce usable products is likely to aid the resolution of this issue but again, giving designers the tools to make low, medium and high fidelity prototypes would make a significant difference, returning rig development to its rightful place in the development process and removing the skills bottleneck that frequently exists, especially when dominance issues come into play.

Possible solutions
The issues summarized in the above section (dealing with the six challenges) can be grouped into two areas: Company Management and Design Tools.

Company management
Cultural bias, company size/structure and company politics might all be combated by the implementation of team structures that:

- ‘allow the views of those best placed to judge specialist issues, the power to make decisions related to that specialism;
- recognize the commercial value of innovative design that breaks boundaries and invest accordingly;
Design tools

Inappropriate breaking of conventions, design for social context and ingrained thinking can all be tackled by new techniques and tools that facilitate a return to basics, ensuring that an iterative design process is implemented for information appliances as much as for any other. Such tools need to be fast and flexible, allowing the rapid exploration and testing of design concepts at a very early stage. They will have to be a good fit with designer’s existing working habits and capable of working with ethnographic methods such as Experience Prototyping and Paper Prototyping. Like Experience Prototyping and Paper Prototyping they will also need to be capable of different fidelity levels, and no complex electronics or programming should be required. One last issue not addressed so far: universities need to engage more with this subject. Design undergraduates need to be taught new techniques as they evolve, so that each new generation of designers brings to the market up-to-date skills that improve the profession’s grasp of the issue.

Notes

1. The authors define Persuasive Technology as ‘any interactive product designed to change attitudes or behaviours by making desired outcomes easier to achieve’.
2. To contextualize this remark, he was expressing the opinion that ideally, a designer should make it their business to become an expert in their given field, to the extent that most parameters of the design are understood. In this scenario, user testing ought to validate the design although it may raise minor modification issues.
3. 2005 confidential report commissioned by PDR, carried out by Lightminds and funded via the Knowledge Exploitation Fund exploring industry practice on the design development of Information Appliances.

References


Biography
Steve Gill is a product designer with 14 years experience in industry and academia. He is a Principal Lecturer at the University of Wales Institute Cardiff 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 approximately 50 products to market and has published 20 academic journal and conference papers. He has a range of research interests related to product design and development including the rapid design development of information appliances and the role of physicality in the design process. He works closely with academic partners such as Lancaster University and those in blue chip industry such as Sony Ericsson (whose Smartphone division have altered their interface design strategy to implement his research work through a working partnership). He is currently engaged in a major project investigating the nature of physical interaction and its effects on design with the help of a Research Council grant.

Address for Correspondence
Steve Gill, National Centre for Product Design & Development Research (PDR), University of Wales Institute (UWIC), Western Avenue, Cardiff CF5 2YB, UK.
Tel: +44 (0) 29 2041 6732
Email: sjgill@uwic.ac.uk

Acknowledgements
The author would like to thank the members of the Programme for Advanced Interactive Prototype Research (PAIPR) for their informal input to this paper and for their professionalism and support.
Paper 4: Developing Information Appliance Design Tools for Designers

By Steve Gill

Published in *Ubiquitous Computing*, (7.3-4), *Springer*, London, 2003, ISSN 1617-4909 (print) 1617-4917 (online)

Subject: Presents the *IE System* including the *IE 1 Unit* and the *PowerPoint/VBA* method of programming presented as building blocks of code in a VLE.

Reason for inclusion: It describes the *IE System* which has been core to the author’s research activities
Developing Information Appliance Design Tools for Designers

Steve Gill, University of Wales Institute Cardiff

Introduction

Industrial Design, like other design disciplines, is an evolving profession whose roles and boundaries constantly change, particularly in regard to the embrace of the Information age.

In its early days, Industrial Design dealt largely with defining the aesthetics of mass-produced products (it still deals with these) but we increasingly deal with the entire design process from concept to manufacture. I.T.’s all-pervading dominance has led to a boom in the number of products with a high level of complex human-machine interaction. Anyone living in this day and age who deals frequently with this type of product will know that many of them are badly designed.

Part of the reason for this is that the current design process means that the design of the human-computer interface frequently falls between disciplines. Most frequently those disciplines are Industrial Design and Electronic Design (See Figure 1)

A problem of disciplines

The invention of digital products with multi-functionality has meant the designer having to understand complex psychological issues relating to users’ attitude to products and the ways they interact with them. Traditional methods of prototyping don’t answer and as yet there are no new ones that allow industrial designers (as opposed to closely integrated industrial designer/engineer teams) to develop product prototypes with user-interface emulations. This explains the all-too-common phenomenon of the oft. quoted video recorder that no one can programme.
Margolin (1998) noted the changes of the role of product design:

... In recent years, the boundaries around these (design) problem areas have begun to collapse due to the influence of new technology, new management strategies, new social forces, and new intellectual currents. As a result, the old divisions of design practice now appear increasingly inadequate and ineffectual. This situation has caused a major upheaval within community of design educators as well as an intense rethinking of the designer’s role by users of design services. (Margolin 1998, p16)

*Figure 1: A typical design process for digital interface appliance*

*Figure 1* shows one typical design process for a digital interface appliance. (The other most common, and just as unsatisfactory, involving the Industrial Designer “cladding” an existing interface design) The clear division of labour means that there is no chance to evaluate the interaction between the user and an accurate representation of the product until the design process is very advanced, in fact almost at the point of no return.
Branham (2000) suggested the need for new interactive design methods, techniques and tools to externalise thoughts and ideas, forcing the designer to be more explicit.

So that’s the challenge: To find methods by which Industrial Designers can explore Information Ergonomics, encompassing the dynamic and interactive aspects of interactive product hardware and software.

**Creating an emulation technique**

The Product Design team at the University of Wales Institute, Cardiff (UWIC) have spent some time looking for ways in which to tackle the problems outlined above.

Although many interface issues can and are tested using multimedia products, these are not designed for the task. Industrial Design is a 3D discipline leading, ultimately, to the mass-production of objects with which a user physically interacts. The lack of dedicated software for prototyping computer-embedded products has led to the use of multimedia authoring tools like *Toolbook* (Hustedde, 1996), *Director* (Gross, 1999), *Hypercard* (Goodman, 1998) and (most commonly), *Flash*.

All of those packages deal well with monitor-bound interactive surfaces, but the size, shape, weight, balance of the product are all very important to the user’s experience of it. The traditional Industrial Design process relies heavily on the frequent output of three-dimensional form. According to Myerson (2001), *IDEO* always produce tangible model at each stage of the design process. Design courses teach a similar approach, and most designers would agree that this is the best way to design products. *So why change this thinking for products with complex interactive elements of which the shape, number/type of controls and digital interface are all important elements?*

What we need is a new design methodology that successfully integrates interactive elements with traditional methods. The ideal will be to integrate these at the
earliest possible stage of the product’s design so that the traditional elements of
design and the new, complex interactive design issues are dealt with equally. *Figure*
2 illustrates a potential methodology.

![Diagram: A streamlined design process for digital interface appliances]

*Figure 2: A streamlined design process for digital interface appliances*

The method employed at UWIC to develop an approach as illustrated above will
surprise many. Complex multimedia software was abandoned in favour of *another*
product not designed to deal with this type of problem; *Microsoft PowerPoint*.

*PowerPoint* has several key strengths relevant to our purposes:

1. It is very easy to learn
2. It is able to deal effectively with a number of media types; JPEGs, MPEGs,
   Wavs, GIFs, Animated GIFs etc. This means that sophisticated graphics,
sounds and movies can be easily imported and handled
3. It uses a slide metaphor which ties in very neatly with State Transition chart
   methods of designing user-interfaces
4. It can be customised almost endlessly through an embedded programming
   language (Visual Basic for Applications)
The design process

The prototyping methods below are described in more detail in Nam and Gill (2000 & 2001).

Design of the graphical user interface begins by using the “Post-it method” of state transition chart. Designers sketch each state of the product on a Post-it note. The transition between each state and the control that effects it are also sketched on. By moving Post-its and changing the way state changes are effected, a swift and effective method of denoting and designing state transitions is formed.

Figure 3: The Post-it method showing the ON/OFF state transition of an MP3 player

One of the key advantages of the UWIC approach is that this flexible method of designing state transitions fits snugly with PowerPoint’s slideshow metaphor. All that now needs to be done to try out the newly designed interface is to produce a graphic, place it in PowerPoint then create as many PowerPoint “slides” as there are Post-its. Next, number the Post-its with “slide” numbers ensuring that the corresponding “slide” shows the state sketched on the Post-it. Finally link the “slides” together by using hyperlink shapes for control inputs.
When *PowerPoint* is run it can be treated like a regular multimedia interface prototype, while problems discovered at that stage can be solved by making adjustments to the *Post-it* state transition chart and subsequently the *PowerPoint* show.

**Dynamic hardware-software-hybrid prototyping**

As noted above however, many design practitioners have stressed the importance of a tangible prototype and it’s a view with which we concur. So: having developed this approach our next goal was to look at methods of building software-driven hardware prototypes.

Once the design has reached a stage where the designer is satisfied that major and obvious glitches have been eliminated, *PowerPoint’s* embedded programming language, VBA, is brought into play.

In developing this approach to prototyping, we quickly recognised that successful implementation would rely on programming learning being kept to a bare minimum. In order to achieve this, a web-based Virtual Learning Environment (VLE) developed by UWIC’s Product Design Programme team was utilised. Strips of code were loaded onto the VLE with clear instructions on how to use them. In order to achieve a given effect, the designer simply has to download the code from the VLE and adjust small elements within it to achieve a desired effect. This method has been used with Level 2 Product Design students at UWIC and has proved extremely successful.

The VBA coding allows the *PowerPoint* presentation to achieve more complex operations but its key benefit is that it allows transitions to be made using keyboard inputs. By using a product put together at UWIC that interrupts the connection between the PC and the keyboard, it is possible to trigger events on the screen by activating micro switches that emulate keyboard inputs. By embedding these
switches in a soft or facsimile model an extremely realistic interactive model is achieved. See Figure 4, below:

![Diagram of prototyping method]

**Figure 4: The prototyping method**

**Conclusions**

A successful product prototyping method has been achieved that allows designers to explore, in an intuitive and *integrated* fashion, complex user-interaction issues at the early, fluid stage of the design process. By creating a method that allows sophisticated emulation of this increasingly numerous and important product type *before* the full electronic prototyping stage, it is possible to achieve a stronger, more logical link between the equally vital roles of the industrial designer and the electronic engineer.

**References**


Paper 5: The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance

By Steve Gill, Paul Johnston, James Dale, Gareth Loudon, Bethan Hewett and Gareth Barham


Subject: Uses the case study of the Audi 24 hour Product Project to compare and contrast the work of the UWIC/Alloy team with that of the Nottingham Trent/PDD team. An analysis is made of the ways each team used their time and conclusions drawn about the IE System’s usefulness and deployment.

Reason for inclusion: This was a trial of theories about how information appliances should be designed and developed. By analysing how it performed against a more traditional method conclusions were drawn regarding future system development paths
THE TRADITIONAL DESIGN PROCESS VERSUS A NEW DESIGN METHODOLOGY: A COMPARATIVE CASE STUDY OF A RAPIDLY DESIGNED INFORMATION APPLIANCE

Steve Gill¹, Paul Johnson², James Dale² Gareth Loudon¹ Bethan Hewett¹  Gareth Barham¹

¹National Centre for Product Design Research (PDR)  ² Nottingham Trent University

ABSTRACT
This paper reports on the results of an exercise held at the National Centre for Product Design Research (PDR) which is based at the University of Wales Institute, Cardiff (UWIC) in partnership with Nottingham Trent University, and two UK Top Ten design consultancies, Alloy Product Design and PDD. The event was sponsored by the Audi Design Foundation and set out to cover the ground from briefing document to the full design and prototyping of an Information Appliance within 24 hours.

The exercise was undertaken by two teams, one based in London at PDD’s headquarters and comprising staff from PDD and Nottingham Trent, and another comprising staff from UWIC and Alloy Product Design, based in Cardiff. The latter team had access to an interface development methodology described in the paper while the former did not.

This paper will initially concentrate on the activities of the interface design team based in Cardiff, their design strategies and, in particular, their use of the prototyping methodologies developed at UWIC.

The paper reports on the structure of the “day”, negotiations between the various teams, the consequent concessions and the integration of GUI and hardware aspects of the interface design process.

It then examines the results of the Nottingham Trent/PDD team’s efforts and compares the approaches and the results.

In conclusion it examines the UWIC interface development methodology process’s strengths and weaknesses, particularly through comparison with the more traditional design approach undertaken by the other team.

Keywords: Interaction, Design, Information Appliance
Word count: 275

1. INTRODUCTION
The concept of designing and prototyping a product in twenty-four hours belongs to Roger Griffiths, a member of the product design programme at UWIC. The concept and management are described in Griffiths (2004).

The exercise was undertaken with Nottingham Trent University, Alloy Total Product Design, PDD and PDR. When agreement had been reached regarding the goals of the exercise, an approach was made to the Audi Design Foundation for funding.

The aim of the exercise was threefold:

1. An educational exercise for product design students to test the creative process, time management and organisational limits of the design process

2. A test of the fast and flexible interface design and prototyping methodologies developed at UWIC in response to the challenge laid down by Margolin (1998), Branham (2000) and others

3. A comparison of the approaches of two design teams working on an identical brief within a very short time frame

2. THE PROCESS EMPLOYED AT CARDIFF
The project team was divided into four groups covering Product Design, Interface Design, Computer Aided Design (CAD) work and prototyping/modelmaking.

The twenty-four hours are detailed below. Interface Design and prototyping matters are given precedence because one of the major aims of the exercise was to test UWIC’s design and prototyping methodology which seeks to accommodate the types of design thinking advocated by Sharpe and Stenton
Audi briefed the team to design a “blue sky” communications device for use by design-aware 18 - 25 year olds interested in extreme outdoor pursuits.

2.1 – Mind Mapping
The first priority for the team following the briefing was to rapidly arrive at a series of concepts. Creative Problem Solving technique (CPS), (Van Gundy, 1988)) and De Bono’s Six Hats idea evaluation sessions (De Bono (1990)) were run simultaneously to answer this requirement. The teams discussed the way in which any resulting product might work, the social and technological preferences of the target user and how any product would service these. Materials and technology research & interviews with target user group were undertaken by a third sub-team and the results were fed to the two mind mapping groups. Intriguingly the conclusions of both groups were dramatically similar. There were three main conclusions:

1. A “safety product” would not appeal to our intended user.
2. The product should have a competitive element.
3. The product should have a social element.

2.2 – Review of creative processes and research data
The two concept generation teams were merged to discuss their conclusions, and more detailed discussions took place informed by reports from the research team regarding new materials plus the information gleaned from the target user group. A large part of the discussion revolved around the functions of the product and the wishes and habits of the user. Some details of control inputs were discussed at this stage but the overall look of the product was not.

2.3 – Concept design phase

Figure 1 The Cardiff team’s chosen concept

The chosen concept sketch is shown in Figure 1. It includes features agreed by the concept development team including a single-use “panic button” and a wrap-around Light Emitting Polymer (LEP) touch screen that can be removed from the product and attached to the user’s body.

2.4 – Interface Design
The user interface team consisted of four designers. At 11:00 it separated itself from the other teams and set about conceiving an interface that would deliver to the user the functionality conceived by the design team as a whole. Early on in their discussions it was agreed that the major control input device should be in the form of a rotary dial, because a glance at the position of the dial would make it easy to see the current interface state. This had important implications for the product’s design but the interface team felt strongly the importance of this type of control input. A representative from the interface team negotiated changes in the design with the product design team. Further communications were required, to decide on the number of functions and their sequence on the dial. The designs of symbols also required negotiation and discussion between the two teams.

When the basic functions of the product were decided and the negotiations between product and interface design teams satisfactorily completed, the interface design team began detailed design work. The first step in this process was the production of a state transition chart which effectively became the design specification of the interface prototype. Landay and Myers (2001) report on a similar integration of state transition diagrams in the design development of websites.

The system is described in more detail in Gill (2003) but briefly it involves sketching each state of the product on a Post-It note, then numbering each one (see Figure 2).
The use of Post-It notes allows the designer to change the diagram quickly and easily so that the design is able to evolve as new ideas are inputted to the process.

2.5 – GUI Prototyping

When the state transition diagram is complete each numbered Post-It is reproduced as a PowerPoint slide. Within each of these states there is frequently other work to be completed in the PowerPoint prototype that would not have been possible on the state transition diagram, for instance speech to text, text to speech, animations or sound (see Figure 3). All states of the GUI are prototyped individually before work commences linking them and detailing the GUI “skeleton”.

Using PowerPoint’s embedded language, Visual Basic for Applications (VBA), hyperlinks are made linking each of the “states” of the interface together. The control inputs triggering each of these changes in state are effected by a QWERTY keyboard press. The end result of this element of the prototyping work is a PC-based simulation of the GUI where transitions between states are effected by keyboard presses.

2.6 – CAD data

With the external surfaces of the product fully detailed the interactive prototype designers and makers could start work. Their job was to create a model which would link up to the GUI prototype allowing potential users to gain a good feel for how the completed product would be in actual use. Sharp (1998) demonstrated that virtual prototyping of touch-screen GUIs could be effective this way. The product in Sharp’s study however was a microwave oven with a flat vertical surface. Users interacted with it in the way they would a touch-screen, so a 3D product was not in effect tested. Pering (2002) describes a bespoke method called “the Buck System” used at Handspring where an existing product was used to trigger a PC programme. As she points out, however, flexibility remained a serious problem with this method. The UWIC method described below is designed to circumvent both these problems.

2.7 – Interactive and facsimile models

Once the CAD work for the interactive prototype was completed the files were sent to a CNC machine which began to manufacture the shapes from solid blocks of model board.

In order for the interactive prototype to connect to the PC-based GUI prototype, switches had to be embedded in it. In this case these are simple micro switches attached to a ribbon cable and tested before they are mounted within the model. When wired to a product called an IE Unit (Gill 2003) they allow the PC to receive keyboard inputs via the model (see Figure 3). Thus when a user activates a switch in the model, the PC behaves as if it has received a keyboard input so the GUI prototype responds accordingly.
2.8 — Presentation to user group

The Cardiff team’s answer to the brief was Mohawk, a device for extreme sports enthusiasts of the “PlayStation Generation”. The device would allow users to record their performance in a "real world" activity (in this case mountain biking), publish it to the internet, keep track of their “tribal” and world rankings, and challenge and meet others from their “tribe”. Users could even race “virtually” because the device would have the ability to “ghost” an image of a competitor's experience on top of their own. Similar approaches to the use of social enabling technology can be found in Vogiazou et al. (2004), Frohlich (2004) and Reid (2003).

3. THE PROCESS EMPLOYED IN LONDON

The methodology and outputs of the two teams varied significantly. Many of PDD’s commercial techniques such as “culture hunt”, user profile generation, creative brainstorming, brand intelligence, commerciality investigation and focus group reviews were utilised. These were employed to reduce the risks of the product development process and identify product opportunities, understand the needs of consumers and create a brand identity. They are briefly described below.

3.1 Market research via Culture Hunt (thirty minutes)

This activity was carried out by talking to members of the general public to identify what the target market wanted from a communications device.

Profile Generation exercise

Various tools were used to examine the product’s user. As a PDD employee stated: “Don’t forget we are designing something for a future target market. We are not ourselves the market, and we can’t ask those who are now in their pre-teens the relevant questions.”

In order to create a profile, a lot of information about the target market was required, e.g. their tastes in music and fashion and their aspirations and interests. Each Product Profile generation team had different age ranges to consider and paperwork with basic headings was distributed to each group to facilitate discussion.
In PDD's estimation the exercise failed to garner enough useful data principally because it did not gather the views of a wide enough cross-section of the target market. Furthermore, what was identified were aspirations rather than needs. They stated: “This represents a very small part of the population. The only learning we can take from this exercise is that we do not know our target market.”

3.3 Facilitated Concept Brainstorming Six Hats & Needs Review

One of the advantages of the Six Hats method (De Bono (1990)) is that it democratises the design process and prevents dominant personalities from controlling it. Accordingly, the contributions of all members of the team are granted equal status. The process briefly involves participants being asked to think about a given subject from six different viewpoints (thus the reference to six “hats”).

The primary aim of the process is to “undo” the way in which the brain is conditioned to think and thereby generate unusual ideas. Each idea generated is recorded on a Post-It note. The members of the group review the Post-It notes and share their ideas before separating to develop these further on an individual basis.

![Figure 5 Six Hats & Needs Review and Concept sketch](image)

Members of the team then voted on each others’ ideas and rated them by allocating a number of stars. The highest scoring ideas were selected and the authors asked to explain their ideas more fully, resulting in six concepts. Each person on the team was then given two votes and by 12:00 noon the choice had narrowed to three concepts.

3.4 Concept “work up”

Three hours were allocated for three teams to produce a full product design specification, in visual form, of each of the potential ideas. Deliverables included rough 2D visuals and a specification of materials, finish and functionality. In essence these were used as feasibility studies of external form, internal components, interface, interaction and key features.

3.5 Teams present and agree final product

The final stage of the concept selection process involved the three teams making presentations for debate and discussion to each other, the PDD technicians, and administrative and marketing staff. The final design was selected by this group as a whole.

3.6 Product detailing

Once a concept had been selected, the design process employed was similar in several ways to that followed in Cardiff. One notable exception to this was the interface design which was tackled with very different methods. Following the selection of the final concept the main design team was split into a series of sub-teams, each of which was set the task of detailing various aspects of the product’s design. Interface design issues were dealt with during this phase with each sub-team producing interface concepts as part of the detailing process. These were presented in the form of storyboards which, as well as illustrating the concept’s interface proposals, also contextualised its use. Storyboards were presented to the team as a whole and critiques were held which served to “debug” the concepts.

Form and scale were evaluated through the production of foam models and were subjected to design review by a focus group. Once the form and detailing had been agreed upon, the work of producing the finished product was handed to the CAD team for modelling. CAD data was sent for CNC machining. Once this was complete model makers produced a facsimile model of the design that was presented at the project’s conclusion. There were some additional processes employed in London however, including packaging design, brand intelligence, storyboarding, commerciality checks and photography. Some of these are described in more detail below.
3.6.1 Brand Intelligence Workshop

The Brand Intelligence Workshop exercise was designed to ensure that the concept's branding created the right associations in the minds of potential users. The exercise was in two phases. The first involved placing 400 cards with images of known brands on them and asking members of the team to choose three cards which possessed the attributes they wished to have associated with the concept (e.g. "excitement" "quality" etc.). Each member laid their choices before the rest of the team and further "filtering" took place. The second exercise involved the team's leader choosing four words appropriate to the concept and writing them on a quadrant (see Figure 6). Team members were asked to place selected brand cards in the quadrant that they felt best suited their attributes. Of particular interest were brands that crossed multiple boundaries.

Figure 6 Brand Intelligence sorting grid & storyboarding of the chosen concept

The results of both exercises were then analysed in order to produce an appropriate brand for the chosen concept.

3.6.2 Storyboarding

As well as their role in the interface design development, storyboards were also used to explain and contextualise the way in which the concept worked at the final presentation (see Figure 6).

3.7 Touchstone

The London team's answer to the brief was called Touchstone (see Figure 7). The concept enables people to record a memory or experience onto a server located at points of geographical interest to be accessed by like-minded travellers in the future. Went (2004) describes the concept: The final product, Touchstone, was conceived as a digital version of a cairn. Instead of stones to mark and memorialise, Touchstone builds layers of digital experience. Personal memory and data pass between a static digital message-board and a personal handheld unit, allowing images and messages to be left on the Touchstone for others to see and hear. The durable alloy casing, dual display, GPS and short-range radio make Touchstone as useful in town as in the country. The product also includes a keypad interface integrated into an intelligent textile strap, augmented reality graphics, induction recharging, integral imaging and sound recording capability.

Figure 7 The Touchstone facsimile model

4.0 COMPARISONS OF METHODOLOGY AND RESULTS

The two teams approached the same problem in different ways. There were a number of similarities, both used Six Hats, both divided their teams into sub teams to tackle specialist areas of operation and both used regular review meetings to manage and control this process. The main area of difference is that the team in Cardiff were driven from the beginning to deliver a working prototype. The team in London were
not and this had important ramifications on the design process and outcome. Figure 8 illustrates the two approaches.

**Figure 8 The Cardiff and London Team’s Design Processes**

The London-based team spent a much higher proportion of its time conceptualising and researching. This meant that the product development process was fuller and that considerations such as the end-user, tactility, weight and balance were given greater attention than was the case in Cardiff. Other areas that received more consideration were commercial concerns such as packaging, branding and product specification.

The team in Cardiff committed to a specific concept and design aesthetic a full 21 hours before the deadline, meaning that this aspect was allocated only 12% of the total project time. The London team did not commit until 12 hours before the deadline meaning that they allocated a full 50% of their project time to conceptualisation, research and branding. In contrast the London team spent approximately 2 hours (8%) using 17% of the total team for that time on the interface design while the Cardiff Team spent a full 20 hours (83% of total time) with a full 34% of the project team committed to this aspect. Figure 9 shows total team effort on interface design and prototyping by each of the two teams.

**Figure 9 Proportion of team effort on interface design**
The necessity of producing a working prototype forced the Cardiff team to commit to key decisions at an earlier stage so that CAD data could be shared and used on two quite separate operations. From the time the data was “divided”, changes to the design could only be made by negotiation between teams, effectively ending any design review opportunities as each team became committed to a particular course of action.

![Diagram of Cardiff & London Team's workflow to scale against Time](image)

**Figure 10** The Cardiff & London Team’s workflow to scale against Time

The “trade off” is that the Mohawk’s interface design is better understood than that of the Touchstone, and this means that the interface and product design were in better equilibrium. However, one never gains without loss, and in terms of a complete, market-targeted package the Touchstone is the more complete of the two.

It is important to note that despite the significantly different approaches of the two teams, they arrived at some very similar conclusions. Like the team in Cardiff, the London team concluded that it was important for the product to be a social device that enhanced communication between groups with similar interests. Both teams in fact used similar terminology for this cultural aspect, Tribe.

### 5.0 CONCLUSIONS

The rapid interactive design and prototyping methodology developed at UWIC has been proven to be capable of being implemented within a very short timescale. The Cardiff team showed it was possible to conceive a product, develop its interface and create a three-dimensional prototype with a fully operational GUI inside twenty-four hours. The process influenced the product design process significantly and, while it enhanced some areas, it also forced decisions and resources to be committed earlier than was the case with the London team who considered more closely a number of subtle design matters including tactility, weight, packaging and branding. They were also able to devote more time to researching user needs and wants to ensure fitness for purpose at a conceptual level.

It would be fair to conclude that while the Mohawk demonstrated a better balance between product and interface, it lacked some of the simplicity and subtlety of Touchstone, arising from a more in-depth analysis of user and design issues.

It could further be extrapolated that the London Team deployed their resources more appropriately than the team in Cardiff. Given the timescale and desired outcome, it was more appropriate to concentrate on the thorough understanding of market placement and the development of the concept to a higher degree of “polish” than to move ahead to interface design issues before these were fully resolved.

In the end analysis, the interface design methodology was proven, but, perhaps, inappropriately applied.
REFERENCES


Paper 6: Designing a Design Tool – Working with Industry to Create an Information Appliance Design Methodology

By Steve Gill, Gareth Loudon and Darren Walker

Published in the Journal of Design Research, *Inderscience*, (7.2) 2008/2009. ISSN 1748-3050 (print), 1569-1551 (online)

Subject: The problems facing designers trying to implement useful and efficient methods for the design and development of information appliances. The work draws on ethnographic studies of companies commissioned by PAIPR as well as on literature

Reason for inclusion: Points the way for future research by summarising the lessons learned from implementation of the *IE System* in an industry setting
Designing a design tool: working with industry to create an information appliance design methodology

Steve Gill* and Gareth Loudon
National Centre for Product Design & Development Research, UWIC, Western Avenue, Cardiff, CF5 2YB, UK
Email: sigill@uwic.ac.uk Email: gloudon@uwic.ac.uk
*Corresponding author

Darren Walker
Cardiff School of Health Sciences, UWIC, Western Avenue, Cardiff, CF5 2YB, UK
Email: dwalker@uwic.ac.uk

Abstract: This paper details collaboration between the Programme for Advanced Interactive Prototype Research (PAIPR) based at the National Centre for Product Design and Development Research (PDR) and three key collaborators: Sony Ericsson, Samsung and Alloy Total Product Design (a UK top-five design consultancy). These partners have been involved in trialling a design method centred on a deliberately ‘low-tech’ hardware product called an IE Unit developed to tackle the problems that designers face when designing information appliances without having the skills to produce working three-dimensional prototypes. The paper uses the IE System’s deployment as a vehicle to draw out lessons that will be of use to a range of research groups tackling similar and overlapping issues.

Keywords: computer embedded; design; design development; design methodology; design prototyping; design tool; information appliance; interaction; journal design research; product design; products; prototyping; rigs.

Reference to this paper should be made as follows: Gill, S., Loudon, G. and Walker, D. (2008) 'Designing a design tool: working with industry to create an information appliance design methodology', J. Design Research, Vol. 7, No. 2, pp.97–119.

Biographical notes: Steve Gill is a product designer with 14 years experience in industry and academia. He is a Principal Lecturer at the University of Wales Institute Cardiff 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. He 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 role of Cradle to Cradle theories in product design & development. He works closely with academic partners such as the University of Lancaster and those in blue chip industry such as Sony-Ericsson. He is currently engaged in a major project investigating the nature of physical interaction and its effects on design.

Copyright © 2008 Inderscience Enterprises Ltd.
1 Introduction

There has been much written about the convergence of the computing, communications and media industries and the advent of information appliances. Many new information appliances, such as 2.5G and 3G mobile phones, Blackberry devices, car navigation systems and new wireless music players have started appearing in recent times as a result of the convergence of the three industries. Several authors have distinguished information appliances from personal computers by defining information appliances as being designed to perform a specific function where, in contrast, personal computers are designed to support multi-tasking (Norman, 1999; Sharpe and Stenton, 2002). Other common features of information appliances are the ability to share information with other devices, and the use of embedded computers inside a physical product together with an integrated screen, usually referred to as a Graphical User Interface (GUI).

The development of information appliances has created new challenges for design teams. Designers wish to deal with issues of user interaction quality and mental modelling as described by Sharpe and Stenton (2002) and English (2000). Unfortunately the traditional product development process fails to cover key elements of the design of information appliances. Technologies such as Organic Light Emitting Polymers (OLEPs) which allow the creation of low power, ultra-thin, flexible screens are already in production and on reaching maturity are likely to make colour screens relatively inexpensive to the extent that they are likely to cause a further increase in the number of cheap products with multi-state functionality available to the consumer. Who will ensure that those products are useable? Prototyping information appliance concepts requires an advanced level of electronics knowledge that most designers do not possess, and the process is unsympathetic to the designer’s traditional experimental culture at what might
be called the ‘fast and fluid’ stage of the conceptual process. Electronic engineers, conversely, have the necessary prototyping skills, but not the training or user awareness. The clear division of labour between the two professions means there is frequently no chance to evaluate the interaction between the user and an accurate representation of the product and interface until the design process is very advanced, almost, in fact, at ‘the point of no return’ (Figure 1).  

Branham (2000) suggested the need for new interactive design methods, techniques and tools to externalise thoughts and ideas, forcing the designer to be more explicit, and that is what the authors and others have been trying to achieve.

Figure 1  A common design process for information appliances
2 Previous work

Companies have tried to overcome the interaction design challenges mentioned above by taking a user-centred approach to the development of new information appliances. Norman (1999) describes the approach as human-centred product development where the development starts with users and their needs rather than with technology. Beyer and Holtzblatt (1998) describe their customer-centric approach as contextual design. Sacher and Loudon (2002) emphasise culture-based design where the development starts by uncovering the shared values, beliefs and protocols of a cultural group to help drive appropriate rules and designs for applications and products.

All these approaches emphasise the importance of observing potential customers in their normal setting to discover their needs. They also emphasise the importance of rapid iterative design and user testing (what Schrage, 1999, describes as serious play). Therefore, other key skills required for user-centred product development, in addition to design, marketing and engineering, are from anthropology and experimental psychology. Problems still remain, however, due to the multi-disciplinary nature of user-centred product development (see Sacher, 2002). For example, interaction designers need to rapidly create and test new concepts including both industrial designs and software interfaces, but do not want to wait for fully operational prototypes to be available because of high costs, very long development times, or worse still, few or no iterations of the design.

Designers have tried to tackle this problem by simulating prototypes early in the design process. Doing so, they have, by and large, been forced to rely on monitor-bound interfaces developed on tools such as Toolbook (Hustedde, 1996), Director (Ludi, 2000), Hypercard (Goodman, 1998) and most commonly, Flash. Industrial design is a three-dimensional discipline however. The traditional process relies heavily on the frequent output of 3D form. Buchenau and Suri (2000) and Myerson (2001) documented the way in which IDEO produce tangible models at each stage of the design process. Design courses teach a similar approach, and most designers would agree that this is the best way to create good products. So why alter this thinking for products with complex interactive elements of which the shape, number/type of controls and digital interface are all important elements? A number of companies (notably IDEO and PDD) have developed expertise in the development of information appliances and have multi-disciplinary teams ‘in-house’ who are able to deal with complex prototyping issues. Research commissioned by the authors however found that many designers do not have access to the same facilities or expertise. A number of attempts have been made to tackle this issue, among them are:

- The Buck Method (Pering, 2002) which involves using an existing product wired to a PC.
- Experience Prototyping (Buchenau and Suri, 2000), an ethnographic approach involving the use of low tech. props, role play and improvisation.
- Wizard of Oz simulations (Maulsby et al., 1993) involving unseen human operators simulating sophisticated machine responses.
- Augmented Reality (Nam and Woohan, 2003) using a combination of real and virtual simulations.
The Calder Toolkit (Lee et al., 2004) involving prototyping via ad hoc networks.

Phidgets (Greenberg and Fitchett, 2001) and Arduino (Burleson et al., 2007) both providing electronic ‘building blocks’.

Paper Prototyping (Snyder, 2003) a well tested and entirely low tech approach involving a facilitator observing user interactions and simulating machine responses by, for example, placing drawings of screens on a model of the appliance held by the user.

Switcheroos (Avrahami and Hudson, 2002), an RFID based system allowing for short range wireless interaction between a prototype and a PC.

iStuff (Ballagas et al., 2003) are a series of artefacts designed for use within a specially constructed augmented environment.

DTools (Hartmann et al., 2006) is a toolkit with bespoke hardware and software. It is the first attempt to produce an integrated solution to the hardware/software prototyping problem. The toolkit has been designed with some input from designers and it has been trailed by design students but not tested on commercial design projects.

Exemplar (Hartmann et al., 2007) is a system that allows for sensor triggered prototyping by non technical users through a method involving ‘programming by demonstration’.

VoodooIO (Villar and Gellerson, 2007) is a development of the Pin & Play system, an ad hoc networking toolkit allowing a variety of control inputs to be quickly and flexibly connected through a specially designed substrate.

Silk (Landay and Meyers, 1995) and its successor, Denim (Lin et al., 2002) are a method of developing ‘quick and dirty’ prototypes for 2D web-based applications – they allow rapid webpage design via roughly sketched state transition diagrams linked through the exploitation of gesture recognition.

All of these approaches represent real progress for the field and some can be used in conjunction with others (generally speaking, the ‘low tech’ and ‘high tech’ methods can be used together rather than choosing one or the other). However those methods that use electronics tend to focus on solving technical problems whereas the intended users (designers) are, by and large non-technical.

The authors aim to create an improved process for designers (see Figure 2) by working with them, attempting to understand the broader issues and solve them via a package of measures that may well include one or more of the methods described above. This paper attempts to describe some of the lessons learned in working with industry towards the solution of a complex and multi-faceted problem. What makes this work different from others therefore is the degree to which it is applied research work attempting to solve real-world design issues in a range of design environments by implementing each new iteration of the system in actual design projects. While using the development of their own group’s system as a backdrop to the case studies, the authors use these real world lessons to propose a series of aspects to be considered by all research groups working in this general area.
Figure 2  A streamlined design process for information appliances
3 The Audi 24 Hour product challenge design process

The aim of the authors’ group as with others mentioned above is to empower designers to tackle usability aspects of the design whilst continuing to utilise the expertise of electronic engineers where it is most relevant, i.e. electronic design and prototyping. The authors’ technique was tested during an exercise sponsored by the Audi Design Foundation to design, prototype, and produce an information appliance in 24 h as detailed in Johnson et al. (2007) and Gill et al. (2005a,b). The process itself is described in greater detail in Gill (2003) but the ‘Audi 24 Hour Product Challenge’ case study described briefly below is used to provide context and is as an illustration of some of the issues that need to be tackled by teams working in this area as well as methods that might be adopted by designers in deploying whichever methods they choose to use.

Audi briefed the team to design a ‘blue sky’ communications device for use by design-aware 18–25-year-olds interested in extreme outdoor pursuits.

The project team was a mixture of design professionals, product design lecturers and students. It was divided into four groups covering product design, interface design, Computer-aided design (CAD) work and prototyping/model making. One of the team’s goals was to test the authors’ design and prototyping methodology which seeks to accommodate the types of design thinking advocated by Sharpe and Stenton (2002), Houde and Hill (1997) and Buchenau and Suri (2000). (Its underlying philosophies are described in greater detail in Gill (2003)).

3.1 Mind mapping

The first priority for the team following the briefing was to rapidly arrive at a series of concepts. Evaluation sessions using the Creative Problem Solving technique (CPS), (Van Gundy, 1988) and De Bono’s Six Hats (De Bono, 1990) were run simultaneously to answer this requirement. The teams discussed the way in which any resulting product might work, the social and technological preferences of the target user, and how any product would service these. Materials and technology research interviews with the target user group were undertaken by a third sub-team and the results were fed to the two ‘mind mapping’ groups. Intriguingly the conclusions of both groups were dramatically similar. There were three main conclusions:

- a ‘safety product’ would not appeal to the intended user
- the product should have a competitive element
- the product should have a social element.

3.2 Review of creative processes and research data

The two concept generation teams were merged to discuss their conclusions, and more detailed discussions took place informed by reports from the research team regarding new materials plus the information gleaned from the target user group. A large part of the discussion revolved around the functions of the product and the wishes and habits of the user. Some details of control inputs were discussed at this stage but the overall look of the product was not.
3.3 Concept design phase

The chosen concept sketch is shown in Figure 3. It includes features agreed by the concept development team including a single-use ‘panic button’ and a flexible wrap-around Organic Light Emitting Polymer (OLEP) touch screen that can be removed from the product and attached to the user’s body.

**Figure 3** The chosen concept – initial concept on the left, finished design on the right (for colours see online version)

The concept was for a ‘playstation for the active’. The device presented was for use in activities such as mountain biking. Users would take the device with them when they were going to complete a difficult course, for example. The device would fix to the handlebars of the bike, and would video the descent. Using GPS, the device would track the rider’s location, speed etc. and users could then easily upload this information to the internet so other users could view the video, try the course and attempt to better the time taken. The wraparound screen would also be removable and could fix onto, for example, the user’s arm. If required, the ‘ghost’ image of a previous rider’s progress on the same course could be projected onto the screen allowing ‘virtual racing’. The dial on the top allowed users to review their performance, look at previous videos, see their location etc. The ‘panic button’ would provide a beacon for the emergency services sending information on the location of the user in case of serious injury. It was designed to be used only once before being returned to the manufacturor for re-setting to ensure that it was only used when absolutely crucial.
3.4 Interface design

The user interface team consisted of four designers. At 11:00h it separated itself from the other teams and set about conceiving an interface that would deliver to the user the functionality conceived by the design team as a whole. Early on in their discussions it was agreed that the major control input device should be in the form of a rotary dial, because a glance at the position of the dial would make it easy to see the current interface state. This had important implications for the product’s design but the interface team felt strongly the importance of this type of control input. A representative from the interface team negotiated changes in the design with the product design team. Further communications were required to decide on the number of functions and their sequence on the dial. The design of symbols also required negotiation and discussion between the two teams.

When the basic functions of the product were decided and the negotiations between product and interface design teams satisfactorily completed, the interface design team began detailed design work. The first step in this process was the production of a state transition chart which effectively became the design specification of the interface prototype.

Briefly, the system involves sketching each state of the product on a Post-It note, then numbering each one (see Figure 4).

Figure 4 Post-It state transition diagram of the interface (top) and a diagram showing how a typical Post-It state transition diagram is laid out.
The use of Post-It notes allows the designer to change the diagram quickly and easily so that the design is able to evolve as new ideas are inputted. This element of the design process is a good fit with both the Denim and DTools approach to prototyping.

3.5 Prototyping of the GUI

When the state transition diagram is complete each numbered Post-It is reproduced as a PowerPoint slide. Within each of these states there is frequently other work to be completed in the PowerPoint prototype that would not have been possible on the state transition diagram, for instance speech to text, text to speech, animations or sound (see Figure 5). All states of the user interface are prototyped individually before work commences linking them and detailing the GUI 'skeleton'.

Figure 5 Illustration on the left shows the IE Unit linking a prototype to a PC; illustration on the right shows the design including graphics, video and sound being controlled via a model created during the Audi 24 Hour Product Challenge

Using PowerPoint’s embedded programming language, Visual Basic for Applications (VBA), hyperlinks are made linking each of the 'states' of the interface together. The control inputs triggering each of these changes in state are affected by a QWERTY keyboard press. The end result of this element of the prototyping work is a PC-based simulation of the GUI where transitions between states are effected by keyboard presses.

3.6 CAD data

The two groups shared CAD data. Once the product design group had completed work on the external surfaces of the product a copy of the data was passed to the interactive prototype designers. The inside of the interactive prototype was then developed using that data. This tangible prototype would eventually be linked up to the PC-based GUI prototype allowing potential users to gain a good feel for how the completed product would be in actual use.

3.7 Interactive and facsimile models

Once the CAD work for the interactive prototype was completed the files were sent to a Stereo Lithography (SLA) machine which made models directly from the CADs of the designers.

In order for the interactive prototype to connect to the PC-based GUI prototype, switches had to be embedded in it. In this case these are simple micro switches attached
to a ribbon cable and tested before they are mounted within the model. When wired to a product called an IE Unit (Gill, 2003) they allow the PC to receive keyboard inputs via the model (see Figure 5). When a user activates a switch in the model, the PC behaves as if it has received a keyboard input so the GUI prototype responds accordingly.

One aspect of the system in its current form is that the display is not shown on the product but on a remote PC screen. Experience within the group had led to the conclusion that this was not as important as it might appear for the development of many types of product. Warburton (2001) had similar findings. Essentially, she recorded that users are quite able to interact on a tactile level with one product while looking at another. Sharpe (2002) demonstrates the principle again through the Quorum concept which allows a number of users to share digital imagery inputting in one area and receiving feedback from another. The authors’ research to date backs Warburton’s findings, and the speed and flexibility of any prototyping method must be balanced with the desire to create an exact facsimile of the finished product. Other industrial partners were very much against creating too close a replica of the eventual product because they had found that people are very much more reluctant to criticise a piece of work that gives the impression of being ‘finished’.

3.8 Lessons learned

The Audi 24 Hour Product Challenge proved it was possible to conceive a product, develop its interface and create a 3D prototype with a fully operational GUI inside 24 h (with approximately 12 of those hours being used for actual prototyping). The process implemented in this case influenced the product design process significantly and, while it enhanced some areas, it also forced decisions and resources to be committed earlier than might otherwise have been the case (see Gill et al., 2005a for more details).

It would be fair to conclude that while the product resulting from the process demonstrated a good balance between product and interface, it lacked some of the simplicity and subtlety of a design based on a more in-depth analysis of user and design issues. The interface design methodology was proven, but, perhaps, inappropriately applied. Were it even quicker than it already is, it might better facilitate this type of approach, a point that will be discussed further below. The general and transferable lessons learned were:

- Given a short timescale to achieve a creative outcome, it might be more appropriate to concentrate on a thorough understanding of market placement and the development of the concept to a higher degree of finish than to move ahead to interface design issues before these are fully resolved.

- Any system aimed at helping designers prototype as part of the creative process needs a wide range of control input options including rotary switches, dials, touch screen, sliders and so on. The authors’ system had strengths in this area in that it could use a wide range of simple off the shelf control inputs, its weakness in this regard lay principally in the fact that at the time it was difficult to use rotary switches with the system. Also, analogue inputs such as sliders could be simulated to a degree but not fully implemented. Some systems by other research groups and some commercial systems are capable of using both analogue input devices and rotary dials. In all cases however they are bespoke and ‘smart’ which gives the designer a very limited choice of input options. The lack of choice over devices and the scales thus imposed can have a severe restraining influence on creativity and on user testing accuracy (more below).
Wires can affect usability. In the case of the system used for the case study above, the wire got in the way of the user to a modest degree. In other cases the adverse effects of a wire might be more pronounced. It is clear that a wireless system is preferable, but where wires are necessary it is clearly important to keep them to a minimum. There are systems already available that are either entirely wireless or have some wireless options. Some of the issues these systems currently face are:

- problems of scale and complexity because power must be internal and components need to be ‘smart’
- problems of range because of the restrictions with passive RFID technology
- restriction to essentially two dimensional implementation because the system is based on a networking substrate.

These lessons, along with those learned in collaboration with industry were used to continue the evolution of the authors’ own system in a meaningful direction.

4 Collaboration

The group made the establishment of close industrial partnerships a priority. Samsung, Sony Ericsson and Alloy Total Product Design accepted the invitation to trial the development of information appliances in ‘real-world’ situations using the IE System. Partners were offered an IE Unit and its peripherals at cost, along with free training and full access to the expertise of the authors’ research group. In return collaborators agreed to share their experiences and any resulting knowledge, to allow the authors to publish case studies and to participate in the development and improvement of methods and techniques for designing and prototyping information appliances.

Each partner has approached the issue in a different way and it has been most instructive to view the results. A brief overview of the work undertaken by each collaborative partner is presented below.

4.1 Sony Ericsson

The authors’ approach to developing a prototyping solution had been with an industrial design consultancy model in mind. The smart phone team at Sony Ericsson operate in a different fashion, dealing with user interface issues while product design takes place at different sites. Since the IE Unit had been designed as an industrial designer’s tool, the assumption had been made that those using it would have access to 3D modelling facilities. This was not the case for Sony Ericsson because although the company has of course got facilities of this kind it was not in the nature of their set up at the site where the smart phone user interface team reside. There were two other important issues:

- While having the graphic user interface appear on a PC screen was a workable solution, the user interface designers at Sony Ericsson would have preferred a screen in the prototype itself. There are two particular reasons for this: firstly small screens, such as those on phones, require careful interface design to make good use of limited space and resolution. Testing those designs as accurately as possible is important. The second major reason is that devices such as smart phones can involve more intense use with more control inputs over longer periods of time than many information appliances. This means that the screen being placed separately has potential to make user testing less accurate.
The **IE Unit** can only cope with 13 active inputs for any given state of the appliance. Sony Ericsson needed a lot more simultaneous inputs, so they were originally quoted a price for the design and construction of a generic phone model to connect to a specially converted **IE Unit** with the necessary control inputs for user testing. Luckily however, Sony Ericsson arrived at a better solution for their needs (see Figure 6).

**Figure 6**  *Sony Ericsson T610 driving software on a laptop PC*

The **Sony Ericsson** T610 has a mode that allows it to be linked to a PC for certain procedures. Software technicians there created a programme that converted a T610’s outputs from each of its controls to **ASCII** character codes. In effect, they created something similar to Pering’s ‘Buck System’ (2002). The difference in this case is that re-mapping of the controls is not a problem as Pering complains of with the ‘Buck’. Because the hardware delivers **ASCII** codes, the designer simply alters what the code triggers in the software to effect a change. This system is a better fit for **Sony Ericsson**’s needs than the modified **IE Unit** coupled to a specially designed mock up because it costs less and delivers as good results. Although designing the entire software/hardware package together might be preferable, this is the best fit for this specific set up. As Pering noted, one reason hardware and software were not developed in tandem at **Handspring** was that hardware development was so much slower and more expensive than software development. This is the very problem the system sets out to tackle but the wider picture in respect to large companies must be kept in view.

The **Sony Ericsson** team used the modified T610 to trial a component of a user interface for a new smart phone concept. User testing within the office on a touch-screen had proved so successful that serious consideration was given to cancelling these trials. The team eventually decided that they should take place because the way users interact with a touch-screen and the way they interact with a **product** could be very different. The modified T610 highlighted a number of problems that had been missed using the on-screen set up and **Sony Ericsson** were in a position to make changes to the design before any expensive or irreversible decisions had been made. This confirmation that the interaction between a user with a product and a user with a touch screen differs, would appear to contradict Sharp (1998) who concludes that users find no difference between the two types of activities. In Sharp’s case however, the product studied was a microwave oven. Interaction with a microwave takes place on a flat, rectangular, vertical surface with
membrane buttons that give little feedback, like a touch screen. In this case however, the
user’s interactive experience differs significantly from the one-fingered touch screen
interaction, which could explain the findings. In other words, while Sharp’s users
interacted with the ‘virtual’ microwave much as they might the real one, a mobile phone
user might send texts using a thumb while the rest of their fingers are wrapped around the
product. Alternatively they might hold it in two hands and use two thumbs. What they are
almost certain NOT to do is balance it vertically and operate it with their index finger, and
even if they did, the buttons of a mobile phone give a far higher degree of feedback than
those of a standard microwave. Repo et al. (2005) however make a more pertinent claim.
The authors of this paper used virtual prototyping techniques to design an RFID function
for a Nokia mobile phone. No user testing was mentioned however, empirical or
otherwise, and the results of the authors’ own experiments (see below) shed some doubt
on the appropriateness of virtual prototyping for handheld information appliances.

4.1.1 Lessons learned
The team learned from their Sony Ericsson experiences that the system appears to give
different results to touch screen simulations. The expectation was that this is a positive
attribute and that the system was showing weaknesses in screen-based simulations, but it
was clear that empirical tests would have to be conducted in order to be sure. Tests were
carried out with the assistance of 79 participants ranging in age from 18 to 30 years. Three
manifestations of an information appliance (a phone called an Equinox) were used; a
production Equinox, a model of an Equinox wired to a PC through an IE Unit and a touch
screen mock up of an Equinox. Participants were divided into three independent groups
(one for each manifestation of the interface, referred to as Equinox, IE Unit and Software)
and given a series of six tasks. Two researchers monitored each user trial and each task
was timed graded and video-recorded.

4.1.2 Results
Performance of participants was converted to interval data by a system devised by Molich
and Dumas (2006) which assigns the following numerical values to their outcome per task
(0 = success, 1 = minor problem, 2 = serious problem, 3 = catastrophe). Outlying task
times (three standard deviations from the mean) were replaced with the next highest or
lowest task times to prevent loss of data points (Figure 7).

Figure 7  Graph on left shows mean time taken to complete six phone tasks as a function of
device type; graph on right shows success outcome (rating) for each of the six phone
tasks as a function of device type
The more variance from the results of the IE Unit prototype versus the actual product (whether the IE Unit results are more successful or less), the less effective a tool it would be. The data made it clear that the Equinox and the IE Unit performed in a more similar fashion than the software alone. In Norman’s (1988) theorising, the system image created by the IE Unit is a better fit of the user’s mental model of a phone device than a purely software simulation.

The general and transferable lessons learned were:

- Any system that is designed to allow the rapid design and development of information appliances should be developed with a good understanding of the diversity of circumstances, facilities and requirements of a range of potential users. Not all of those who design and prototype information appliances are industrial designers.

- Any system intended for use in the design and development of sophisticated information appliances (like mobile phones) would need to be able to handle a minimum of 25 control inputs on a single prototype. A system able to use 50+ inputs would be preferable.

- The requirements of teams who are not in control of hardware designs are likely to be different from those of industrial designers. Such set ups are more suited to a system that allows them implement prototype software solutions quickly with a hardware interface that may be generic but which has the right number and type of controls located correctly on the appliance (see Fernandez, 2004).

- The results of the trials above (to be published in more detail shortly) show the importance of physicality in user testing. This means that issues such as componentry scale may become critical. If the size and shape of a handheld product is wrong because the prototype has been governed unduly by the method of prototyping, then the lessons learned from the prototype run the risk of being misleading, just as those of the touch screen were proved to be. Most prototyping solutions currently rely on oversized bespoke components.

- For mobile phones, the inclusion of the screen within the prototype is preferred. This may also be the case for other types of product. Scale becomes an issue in this case, not only for reasons of physicality, but also resolution, because the size of the screen and the way information is presented is of key importance. This is a major challenge for any toolkit. Taken in conjunction with the scale issue above, it means that they will have to provide for a range of ‘plug and play’ screens. These will have either to communicate with an external PC or involve making the prototype ‘smart’ by accommodating a very small and powerful computer. Another method might involve placing a power source within the prototype and a means of communicating wirelessly with a remote PC. In any case it is perhaps one of the more difficult problems facing teams who wish to develop rapid and flexible methods of designing and prototyping information appliances.

4.2 Samsung Design Europe

The team the authors collaborated with at Samsung were working in a very different fashion to the one at Sony Ericsson. Although Samsung is a large multinational company,
the European design office (SDE) is modestly sized and houses industrial and interaction designers together. Among their facilities is a small ‘soft’ modelling workshop (facsimile models are sub-contracted). In many ways SDE operates like a design consultancy. Although it only deals with Samsung products, the range is diverse and includes mobile phones, hi-fi’s, ovens, printers and air-conditioning units. SDE was established by Samsung in order to advise the company on European tastes and trends. One consequence of this is an exercise SDE refer to as ‘feature stripping’. The Far Eastern market is very technologically aware and consumers are content to spend time learning the features of a product. One of the consequences of this is that companies from that area tend to place a great deal of functionality in their products. The increasing backlash against this type of approach in Europe and America is witnessed by the volume of work that seeks to create usable technology principally through the creation of interfaces simple enough for children to use, as exemplified by Dix (2003) and Vogiazou et al. (2004). Part of the job of the team at SDE is to reflect this trend in Europe by removing functionality seen as unnecessary in Western eyes.

Given their interests, SDE were well-placed to exploit the IE Unit and it was delivered along with some basic electronic components and a tutorial CD. The hardware prototyping side of the system was demonstrated but not the PowerPoint/VBA method because SDE preferred to use Macromedia Flash and had strong expertise in this area.

SDE consolidated their understanding of the hardware prototyping methodology by setting themselves a preparatory task, designing an electronic game using the IE Unit to drive Flash through a soft model (see Figure 8). This worked most successfully and encouraged them to use the system for commercial work at the next opportunity.

Figure 8  Samsung PC game using an IE Unit/Flash combination

The first appropriate vehicle was an oven design. The design relied heavily on rotary switches and whilst the IE Unit is able to deal with any type of digital switch in theory, in fact, because of the way in which the unit is wired, the switches to which it is connected
must have pairs of contacts rather than using one contact for each pole coupled to a ‘common ground’. Most rotary switches use the ‘common ground’ method. Rotary switches with up to four pairs of contacts were sourced, but unfortunately SDE wanted a switch capable of anything up to 15 positions which necessitated designing a switch. This issue was ultimately addressed by the IE2 Unit (see Figures 9 and 10).

Figure 9  Diagram on left shows standard rotary switch layout with common ground (as used in the IE2), diagram on right shows the specialised rotary switch layout required by the IE1’s wiring

Figure 10  Diagram on left shows the IE1’s pin layout (marked in the ASCII output from each pairing) as pairs of pins; diagram on the right shows IE2’s pin layout utilising the common ground method (for colours see online version)

A further issue was a requirement from SDE to design methods of including small interface screens within appliance mock-ups. While possible, driving very small screens in a very flexible fashion via a PC is in fact technically challenging because of the specialised nature of their driver software. In the end they elected not to attempt the incorporation of the screen.

Following research, SDE designed an information architecture and a physical user interface system that they believed demonstrated marked improvements on those currently available. Because the new concept was so removed from what had gone before, it was necessary to test the concepts quickly and realistically enough to explain them to the design team and management. An interface (constructed in Flash) and a circuit board with appropriate inputs were constructed in a single day and were ready to test the next day.

The project team were able to grasp the concept easily. Samsung stated: ‘Its main benefits on the projects was its speed, and its ability to instantly prove/or dismiss a concept, allowing for shortened turnaround time and better ideas’.

The general and transferable lessons learned were:

- Prototyping systems are likely to be used in ways that their developers did not consider (see Section 4.1.2). In this case the envisaged use was for the design and development of handheld products but a good flexible toolkit ought to be effective for larger computer embedded products such as ovens and printers.
Generally speaking it would be easier to embed the screen in a larger computer embedded product because there is more space within which to accommodate boards, power supplies etc. The other technical issues with including a screen mentioned above remain (size; definition, and the flexibility of the toolkit to drive a wide variety of screens). This is an important area in which no current prototyping methodology is strong.

- The issue of a range of control inputs came up again (see Section 3.8): A really flexible prototyping system will be able to make use of a broad and varied range of (preferably standard, "off the shelf") control input methods thereby giving design teams the flexibility to operate freely in a creative manner.

4.3 Alloy total product design

Alloy is a Top 10 UK design consultancy. They cover a large range of products but are specialists in designing communications devices. This made them another ideal partner.

There was a great deal of discussion regarding how best to deploy the IE System within Alloy. In the end, it was decided that a Knowledge Transfer Partnership (KTP) scheme was the best way to modify and develop the system to Alloy’s specific requirements and work methods. Alloy first wished to benchmark the system in order to assess its capabilities. The first task was to mimic the interface of an existing phone. This would assess firstly whether the system was capable of dealing with the complexity of a modern telecommunications interface design and secondly to what extent it gave a true feeling of the finished interface to a potential user.

The product chosen was the BT Equinox phone (the same product later used in the empirical tests above. The interface was mocked up using a set of the finished product’s mouldings with its buttons wired to the IE Unit and a representation of the screen’s output on a PC monitor (Figure 11).

Figure 11 On the left a mock-up of the Equinox linked to a PC through an IE1 Unit; on the right the BT Equinox phone

Flash was used to prototype the GUI in preference to PowerPoint. There were a number of reasons for this, including the preferences of the KTP Associate and the design profession as a whole but principally because of its superior animation capabilities and faster key input response.
The set-up worked effectively and proved to Alloy’s satisfaction that the system was capable of producing an effective ‘mock up’ of a real information appliance interface. The only problems of note were that:

- the number of functions was again restricted because of the IE Unit’s input limitations
- the cable, which exited through the back of the phone, got in the user’s way.\(^4\)

Having proven that the interactive experience was good enough, the associate next worked with the product design team on a ‘live’ project, prototyping selected interface aspects of a design for one of Alloy’s major clients. The resulting prototype (see Figure 12) was demonstrated to the client without charge to assess its potential value and a positive response was received.

**Figure 12** ‘Soft’ model designed for use with an IE Unit to demonstrate an interface to a client

![Image of phone demonstrating interface](image_url)

The effectiveness of both the system’s technical capability and commercial potential had been proven and so the next task was to devise the most effective way to integrate it into Alloy’s systems.

The KTP Associate was tasked with demonstrating the system and the results of the initial trials to the designers and managers of Alloy. Interestingly, Alloy were not merely unconcerned by the lack of an integrated screen within the prototype, they were actively against its inclusion. There were two reasons; firstly, having tried the prototype, the design managers were not convinced that the extra time and technical difficulties required to include a screen represented a good return. Secondly, the company were concerned that clients would be convinced that the design process was near completion on being shown a prototype that worked in a manner too closely matching the finished product. This would be misleading and could cause the company problems.

The response to the system’s capabilities was broadly positive, with both designers and managers convinced of its value. However:
Design consultancy is a highly competitive industry that is both cost and time sensitive. The system presented to Alloy at this point was capable of producing a prototype in about 12 h. There were times when this would be useful (primarily for client demonstration purposes), but to allow real integration of prototyping into the design process, rough prototypes would need to be produced in between 1 and 2 h.

There were three new skills required: basic electronics, Flash, and customisation of Flash via its embedded programming language. Within an environment where time was at a premium and the workload on each individual designer was high, this tended to ensure that the skills for developing prototyping became the purview of the KTP Associate rather than becoming knowledge learned by a range of individual designers and deployed as appropriate.

4.3.1 Lessons learned

The general and transferable lessons learned were:

- Even though PowerPoint’s slideshow metaphor is a better fit for state transition diagrams than Flash’s timeline metaphor and even though any VBA coding needed for PowerPoint was provided, designers at Alloy as well as those at Samsung prefer to use Flash. The fact that significant sections of the design community already use and like Flash appears to be a major factor. Given this, the flexibility of a system to be deployed with a number of different software platforms (by, for example, triggering via ASCII characters) is likely to be important. One approach might be to work on plug-ins for software such as Flash rather than designing bespoke solutions. A general point to note is that designers tend to favour tools that give them a lot of flexibility (e.g. Flash) over those that are merely conveniently set up to cover common scenarios (e.g. PowerPoint). ‘Pick and Mix’ solutions that allow limited amounts of customisation may not find favour with the design community.

- If Alloy is typical, then in order to work within a small- to medium-sized design consultancy model, any system for prototyping information appliances should be capable of doing so at low fidelity in between 1 and 2 h.

- Incorporating a screen into an information appliance prototype is not always important and may actually be detrimental.

- A good system has to be a good fit for designer methods and culture. Systems that require time to learn or that rely on programming and/or electronics are less likely to succeed in a design environment.

- As mentioned in Section 3.8 a system that is either wireless or which at least minimises wires would be an advantage.

5 Overall conclusions

- A successful system must provide a good fit for the way designers work. To achieve this, toolkits need to enable low fidelity prototyping in between 1 and 2 h. At this level they should require no electronics knowledge, no knowledge of programming and should be very easy to learn. Consideration might be given to developing plug-ins for existing software such as Flash to exploit the fact that it is already widely used in design practice.
• A large range (25–50) of varied types of inputs, including touch screen, would be useful attributes to any toolkit. Control inputs should allow analogue type controls (dials, sliders etc.) as well as digital inputs (e.g. push buttons and rotary switches). Ideally, systems should be capable of utilising off the shelf components.

• A wireless solution would be ideal in all the scenarios the authors have so far encountered. However the problems teams might face achieving totally wireless systems include: the component footprint, the complexity of the prototype (due to the requirement for internal power and the need for ‘smart’ components) or problems of range (because of the restrictions of e.g. passive RFID technology).

• Any successful toolkit will likely be used by a range of disciplines and in a range of situations. Not all of those who design and prototype information appliances are industrial designers and not all computer embedded products are information appliances.

• Scale may be more important than was previously realised because of the effects of physicality on interaction. It follows that a successful toolkit should be capable of prototyping information appliances at a 1:1 scale.

• There are some applications where the inclusion of the screen is required and some where it is not. More research is required to ascertain the exact circumstances where inclusion of a screen is critical because to include one greatly increases the complexity of providing an appropriate solution.

• More design courses need to train students to prototype information appliances as part of their standard curriculum.

References


Designing a design tool: working with industry


Notes

1 However some might argue that this is the result of technical limitations rather than being a design requirement.

2 Since then the authors’ group have developed solutions for using screens as small as 2.5’ by exploiting analogue TV screens driven by a PCTV card.

3 The KTP scheme was set up by the UK Department of Trade and Industry and is designed primarily to allow the transfer of knowledge from universities to Small to Medium Enterprises (SMEs) and can be of between 1 and 3 years duration. An associate is employed by the university but based for the most part within the SME. The university provide support and advice to the associate and the company.

4 Both of these issues were solved prior to the tests described in Section 4.1.1 by using a more advanced IE Unit, the IE2, which was capable of nearly twice the number of inputs through a much smaller cable.
Paper 7: Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time balance

By Steve Gill, Darren Walker Gareth Loudon, Alex Woolley, Jo Hare, Alan Dix, and Devina Ramduny-Ellis

Published in the *International Journal of Arts and Technology* special issue on *Tangible and Embedded Interaction*, 2009. ISSN 1754 - 8853 (print), 1754 - 8861 (online)

Subject: Conclusions about the value of low fidelity tangible prototypes versus the traditional methods of developing information appliance early prototypes on a touch screen.
Reason for inclusion: Presents empirical data that proves the value of the *IE System*. 
Rapid development of tangible interactive appliances: achieving the fidelity/time balance

Steve Gill*, Gareth Loudon, Alex Woolley and Jo Hare
National Centre for Product Design & Development Research, UWIC, Western Avenue, Cardiff CF5 2YB, UK
E-mail: sgill@uwic.ac.uk
E-mail: gloudon@uwic.ac.uk
E-mail: a.woolley@gmail.com
E-mail: juhare-pdr@uwic.ac.uk
*Corresponding author

Darren Walker
Cardiff School of Health Sciences, UWIC, Western Avenue, Cardiff CF5 2YB, UK
E-mail: dwalker@uwic.ac.uk

Alan Dix and Devina Ramduny-Ellis
Computing Department, InfoLab21, South Drive, Lancaster University, Lancaster LA1 4WA, UK
E-mail: dixa@comp.lancs.ac.uk
E-mail: Devina@comp.lancs.ac.uk

Abstract: For some years, the global research community has been developing techniques to rapidly design and develop information appliances. Despite significant advances, many industrial and user interface designers still rely on 2D, software only interactive prototypes, particularly early in the design process when many key decisions are made. A core assumption of many of those tackling this issue is that designers need to be able to make ‘quick and dirty’ 3D prototypes to evaluate their concepts properly. Some attempts have been made to examine how quick or how dirty the prototyping process can be for software only applications, but to date no one has carried out a similar exercise for 3D information appliance prototypes. This article presents the results of three experiments, presenting empirical data that determines whether tangible prototypes are better than software prototypes and how ‘quick and dirty’ designers should be prototyping.

Keywords: fidelity; interactive appliances; interface design; physicality; rapid development; tangible appliances; tangible prototype; time.
Reference to this paper should be made as follows: Gill, S., Loudon, G., Woolley, A., Hare, J., Walker, D., Dix, A. and Ramduny-Ellis, D. (xxxx) ‘Rapid development of tangible interactive appliances: achieving the fidelity/time balance’, Int. J. Arts and Technology, Vol. x, No. x, pp.xx–xx.

Biographical notes: Steve Gill is a Principal Lecturer at the University of Wales Institute Cardiff and Director of the Programme for Advanced Interactive Prototype Research (PAIPR). He has published 20 academic journals and conference papers and has a range of research interests related to product design. These include rapid design development of information appliances and the role of physicality in the design process. He works closely with academic partners, particularly Lancaster University and Sony-Ericsson. Currently, he is engaged with partners at Lancaster in a major Arts and Humanities Research Council funded project investigating the effects of physicality on design.

Gareth Loudon is a Senior Lecturer in Product Design and a Director of the Innovation Forum Ltd. He has over 18 years of experience in academic and industrial research and has taken several research ideas all the way through to commercial products for large companies such as Apple Computer and Ericsson. He has several patents to his name and over 35 publications. He graduated with a First-Class Honours degree in Electrical and Electronic Engineering in 1988 and a PhD from the Leicester University in 1991 and is a Fellow of the Institution of Engineering and Technology.

Alex Woolley is a PhD student in his final year of study. He graduated with a First-Class Honours degree in Product Design in 2005 winning a research degree bursary later that same year. His PhD work has been concerned with the development of techniques for the rapid design and development of information appliance prototypes for testing within the context of use.

Jo Hare is a Product Designer and Research Assistant working on DEPtH project in collaboration with Lancaster University and funded through the AHRC’s Designing for the Twenty-First Century call. Previous to joining DEPtH, he worked as a product designer for a company producing medical equipments.

Darren Walker is a Senior Lecturer in Psychology at the University of Wales, Institute, Cardiff. He completed his PhD in Cognitive Psychology from the University of Reading, looking at the role of reminders. He has a range of research interests, including the role of music and emotion in cognition, the application of psychological theories to the design of cognitive artefacts and issues surrounding ageing and cognitive performance. Interspersed with academia, Darren has held industrial posts in the Aviation sector. He collaborates with colleagues at the Universities of Exeter, Leeds and Trinity College, Dublin. His work has been disseminated in journals along with national and international conferences.

Alan Dix is a Professor at Lancaster University. A mathematician by training, mathematics is remains 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. He has worked in several universities, agricultural engineering research, local government and hi-tech start-ups. Interests include: formalization and design, physicality and digitality, the economics of information, structure and creativity and the modelling of dreams. Recently, he and his colleague developed technology for autonomous pixels that can be configured in turn on any surface/space into a 2D or 3D display.
Devina Ramduny-Ellis is a Researcher in the Lancaster University. She gained her PhD in 2003 for her work on developing architectural frameworks for enhancing temporal interface behaviour for distributed collaborative users. Her research interests range from devising methods for work analysis and interaction properties, modelling techniques and interface design, to computing infrastructure and employing empirical field studies involving ethnographic techniques to inform novel designs and prototypes. She has over 25 publications and she is currently managing and working on the AHRC/EPSRC-funded Designing for Physicality project. She has been active in a community in physicality through the Physicality 2006 and 2007 International Workshops.

1 Introduction

There has been much written about the convergence of the computing, communications and media industries, particularly with reference to the advent of a particular form of tangible interactive device, the information appliance. Several authors have distinguished information appliances from personal computers by defining information appliances as being designed primarily to perform a specific function, whereas, in contrast, personal computers are designed to support multi-tasking (Norman, 1999; Sharpe and Stenton, 2002). Many new information appliances, such as 2.5G and 3G mobile phones, Blackberry devices, car navigation systems and new wireless music players have started appearing in recent times as a result of the convergence of the three industries.

For some years now, both academic and industry research communities have been working towards developing techniques to design and develop information appliances rapidly and efficiently, aiming to meet what Branham (2000) described as ‘the need for new interactive design methods, techniques and tools to externalise thoughts and ideas, forcing the designer to be more explicit’. Several attempts have been made to tackle this issue, among them Wizard of Oz simulations (Maulsby, Greenberg and Mander, 1993), Experience Prototyping (Buchenu and Suri, 2000), Phidgets (Greenberg and Fitchett, 2001), Buck Method (Perring, 2002), Switcheroos (Avrahami and Hudson, 2002), Augmented Reality (Nam and Woohan, 2003), iStuff (Ballagas et al., 2003), Paper Prototyping (Snyder, 2003), Calder Toolkit (Lee et al., 2004), DTools (Hartman et al., 2006), Exemplar (Hartman et al., 2007) and VoodooIO (Villar and Gellerson, 2007).

One of the core recognitions that tie these works together is that designers need to be able to make quick and ‘dirty’ prototypes [what Schrage (1999) described as serious play in order to evaluate the tangible interactions of their designs early in the design process. Landay and Meyers (1995) identified the value of quick and ‘dirty’ prototyping for two-dimensional web-based applications, their answer being Silk (later developed into Denim, Lin, Thomsen and Landay, 2002), a programme that allows rapid web page design via roughly sketched state transition diagrams linked through the exploitation of gesture recognition.

McCrudy et al. (2006) made an attempt to examine how quick or how ‘dirty’ the prototyping process can be for software only applications (using what they called mixed fidelity prototypes), but to date no one has carried out a similar exercise for tangible information appliance prototypes. Does prototyping a handheld information appliance have to involve tangible three-dimensional prototyping as in the cases mentioned before? Lim et al. (2006) conducted a qualitative study in this area but their investigation was
focussed more on prototyping methods than fidelity levels. The tools described in earlier work such as Toolbook (Hustedde, 1996), Director (Gross and Tucker, 1999) or Hypercard (Goodman, 1998) are all monitor-based, two-dimensional systems and the derivatives of these approaches continue to be the most common methods practiced in the industry. To what degree is the work developing methods for three-dimensional prototypes at an early stage of product development really relevant? In other words, to what fidelity levels should industrial designers be aiming to prototype?

This paper presents empirical findings that suggest some answers. It will confine itself to examining performance, leaving more qualitative matters for future studies. Two distinct facets of physical interaction are discussed, tangible interaction and physicality. For the purposes of this paper, we define tangible interaction as the interaction between a physical interface and digital information, in this case through interaction with a physical interface and digital information, in this case through interaction with an information appliance. Physicality, on the other hand, is a broader term that encompasses our entire interaction with the physical world. In the case of this paper, we principally discuss physicality’s influence through touch, feel, weight, scale, etc. on our interactions with the tangible interfaces of information appliances.

2 Our approach

One of the tools that the authors use is a system that allows designers to develop rapid interactive prototypes. It works by facilitating the connection of a model embedded with switches to a PC-based GUI prototype via a product called an IE Unit (Gill, 2003). The system allows the PC to receive keyboard inputs (see Figure 1) so that when a user activates a switch in the model, the PC responds to a perceived keyboard input and a keyboard-triggered GUI is activated.

One aspect of the system in its current form is that the display is not usually shown on the product but on a remote PC screen. The system is capable of facilitating models that include screens, and several prototypes have been created that include these embedded displays. However, experience within the group had led to the conclusion that for the development of many types of products, this was not as important as it might appear. If this is the case, it is important as including a real screen brings with it very significant time penalties compared with an emulated screen on a PC. Sharpe and Stenton’s (2002) findings were encouraging in this regard. His Quorum concept allowed a number of users to share digital imagery inputting in one area and receiving feedback from another.

The authors wished to find a method whereby two important questions might be answered in a quantifiable fashion:

1. Is a three-dimensional, handheld prototype more similar to the final output than the now traditional monitor-based systems most commonly used by industry?

2. How quick or how ‘dirty’ can the prototyping process be to gain valuable feedback early in the design process, i.e. what level of fidelity is required to obtain an acceptable degree of accuracy?

The vehicle chosen for testing was the BT Equinox cordless phone. The authors had worked on an IE Unit-based prototype as part of a benchmarking exercise for a design consultancy. Part of the task of prototyping had involved mimicking the Equinox’s GUI interface using Macromedia Flash. The aim of the exercise was both to assess whether
the system was capable of dealing with the complexity of a modern telecommunications interface design and to quantify to what extent it gave a true feeling of the finished interface to a potential user.

The prototype was mocked up using a set of the finished product’s mouldings with its buttons wired to the *IE Unit* and a representation of the screen’s output on a PC monitor via the *Flash* Graphic User Interface (see Figure 2).

In the context of the design consultancy the set-up worked effectively in that it demonstrated to the managers’ satisfaction that the system was capable of producing an effective ‘mock up’ of a real information appliance interface by effectively mimicking the interactions of the real product. The team decided to develop the simulation further in order to carry out some empirical testing. With this in mind, some modifications were made to the mock up to enhance its functionality and a purely screen-based version of the prototype was made by modifying the way in which the *Flash* file was triggered.

**Figure 1**  Illustration shows the *IE Unit* linking a prototype to a PC

**Figure 2**  On the left, a mock-up of the *Equinox* linked to a PC through an *IE Unit* whereas on the right is the *BT Equinox* phone
2.1 High-fidelity empirical testing

The team designed a programme of tests for comparing the performance of a real Equinox phone, the IE Unit and the Software prototypes. A method of conducting the tests was designed by the authors based on a methodology developed by Molich (2006). Tasks were chosen to include common functions (ranging from simple to complex), unusual functions (such as the Equinox’s SMS button) and functions that involved more than straightforward transitions between the product’s states.

The programme was trialled on six participants to test its effectiveness. As a result, some modifications were made to the software, hardware and methods of testing and recording data; e.g. auditory feedback was added to the software simulation to confirm that a control input had been received. The team realised that this was an important aspect of the design that had to be included for a balanced trial to take place.

Experiment 1. Seventy-nine undergraduate students and staff from the University of Wales, Institute Cardiff (UWIC) took part, ranging in age from 18 to 30 years (average age 23, 44 females and 35 males). No computer science students were included as participants, but all had at least one year of experience using mobile phones with an average experience of seven years. They sent an average of six text messages a day, suggesting good familiarity with ‘typical’ phone interfaces.

Procedure. The participants were divided into three independent groups (one for each manifestation of the interface, i.e. Equinox, IE Unit and Software) and were given a series of tasks. Each participant was given an instruction sheet to read and they were allowed to ask questions if they were unsure of the procedure. They were then given one minute to familiarise themselves with the interface and technology before the tasks commenced. This was done for all participants for consistency, but was particularly important for participants using the touch screen computer (for the Software prototype) as this technology was unfamiliar to many. Six tasks were set for the participants. These were:

1. turn the phone on,
2. call a number,
3. add an entry to the phone’s contact list,
4. send an SMS to a contact,
5. change the phone’s background picture,
6. turn the phone off.

The six tasks were chosen because they are common mobile phone tasks. The order of the tasks was set such that the first two tasks were relatively simple so that users gained confidence using the prototype. The following three tasks were relatively complex, followed by a relatively simple task to complete. Two researchers monitored each user trial and each task was timed and graded.

The trials were also video-recorded (see Figure 3). The comments were noted as were actions or errors of specific interest.

Results. Performance of participants was converted to interval data by assigning the following numerical values to their outcome per task (0 = success, 1 = minor, 2 = serious, 3 = catastrophe). Outlying task times (three SD from the mean) were replaced with the next highest or lowest task times to prevent loss of data points. Two values were replaced
for On task, one value was replaced for the Call task, one value for the SMS task and four values were replaced for the Off task. Replacements happened across all groups. Analysis of performance outcome and performance time used a 3 (device type) × 6 (phone task) mixed analysis of variance (ANOVA). The alpha level was set at 0.05 for significant (or reliable) differences, but given the exploratory nature of these studies an alpha level of 0.10 was accepted as conferring marginal significance. Thus unless otherwise stated the alpha level for non-significant (or non-reliable) differences was 0.10. Confidence intervals of 95% follow reporting of means in the text.

Performance time. Figure 4 shows that the mean completion times for the software simulation were longer for all tasks, but for the other devices time difference trends were dependent on what task was undertaken. The ANOVA\(^1\) supported this revealing a main effect of task type, \(F (5, 380) = 193.08, p < 0.001\); device, \(F (2, 76) = 25.01, p < 0.001\) and an interaction between task type and device, \(F (10, 380) = 2.21, p = 0.04\). Post-hoc tests (Tukey’s highest significant difference, HSD) revealed that there were highly reliable differences (\(p < 0.001\)) between the IE Unit and Software \([M = 35.08s (30.78, 39.38)\) vs. \(M = 55.54s (50.08, 61.0)\)] and between the Equinox phone \([M = 32.35s (28.25, 36.45)\) and Software. However, no reliable difference was found between the Equinox phone and IE Unit. To unpack the interaction, simple main effect analyses were undertaken looking at the difference between devices for each type of task. These showed that for every task there was a significant difference between devices (smallest \(F = 4.18, \text{largest } p = 0.019\)). Subsequent simple comparisons (Tukey’s HSD corrected) showed that with the exception of Add to phonebook task there were reliable pair-wise differences (\(p < 0.05\)) between IE Unit and Software, Equinox and Software but no reliable pair-wise differences between IE Unit and Equinox for any of the tasks. In the case of the Add task, Equinox was reliably different from Software (\(p < 0.05\)) but IE Unit was marginally different from software (\(p = 0.06\)). As per the other tasks, Equinox and IE Unit did not differ reliably. Thus, the interaction suggests that while IE Unit and Equinox are more alike than the Software solution (in terms of time taken) on each task, the magnitude of this effect is mediated by the type of task undertaken.

Figure 3  IE Unit user trial
Figure 4  Mean time taken to complete each of the six phone tasks as a function of the device type; bars are standard error (see online version for colours)

Performance rating. Figure 5 shows that Equinox and IE Unit were more similar for most tasks than the Software, but that over all three devices task-specific differences did exist. The ANOVA supported this revealing a main effect of task type, $F(5, 380) = 62.43$, $p < 0.001$; device, $F(2, 76) = 12.34$, $p < 0.001$ and an interaction between task type and device, $F(10, 380) = 7.47$, $p < 0.001$. Post-hoc tests revealed that there was a highly reliable difference ($p < 0.01$) between IE Unit and Software [$M = 0.95$ (0.81, 1.10) vs. $M = 1.39$ (1.20, 1.58)] and between the Equinox [$M = 0.81$ (0.67, 0.95), $p < 0.001$] and Software. However, no reliable difference was found between Equinox phone and IE Unit. Simple main effect analyses showed that there were significant differences between devices for the On, SMS and Off tasks (smallest $F = 4.40$, largest $p = 0.02$), and marginally significant differences between the devices for the Call and Picture tasks (smallest $F = 2.89$, largest $p = 0.06$) but no significant difference existed between the devices for the Add task. Subsequent simple comparisons revealed that for the Off and On tasks there was a reliable ($p < 0.05$) difference both between IE Unit and Software and between Equinox and Software. For the Call task, there were marginally reliable differences between Equinox and software ($p = 0.07$) and between IE Unit and Software ($p = 0.08$). For the SMS task, there were reliable differences ($p < 0.05$) between Equinox and Software and Equinox and IE Unit. For the Picture task, there was a marginally reliable ($p = 0.06$) difference between Equinox and IE Unit. None of the other task by device comparisons showed reliable differences. Thus, the interaction shows that while IE Unit and Equinox exhibit similar success patterns on some tasks there are others where they can be quite dissimilar. It is important to note however that in the two areas where significant differences occurred, the IE Unit was similar to Software. In other words, the tangible model is never significantly worse than a software only simulation, but in some tasks offers far closer results to the real device.
These analyses show that, on both the time taken to complete a task and on how successfully it is performed, the *IE Unit* tangible prototype was more like the real *Equinox* phone than the *Software* simulation. Nevertheless, there were also significant interactions between the different phone tasks and the performance measures, particularly those measuring ‘success’ in completing the tasks.

The exceptions are the *Call* and *Picture* tasks. Although we do not have hard data, we can speculate as to why these may have been different.

The tasks fall into three main types.

1. The *On* and *Off* tasks that require finding a physical button on the phone, but do not require viewing of the screen, except maybe to confirm it has turned on/off.

2. The *Call* task that is mainly concerned with typing a number, then possibly checking the number on the screen before locating the ‘call’ button. Like (1), this is predominantly an ‘eyes down’ task looking at the device, except that the keys to press are more obvious.

3. The *Add*, *SMS* and *Picture* tasks all require divided attention between the device (eyes down) and the screen (eyes up).

The problems with (1) are discussed next based on participant comments. The *Call* task (type 2) involves either hitting buttons, or pressing clearly identifiable buttons on screen, both of which are straightforward actions and specifically do not involve any attention switching. Both *SMS* and *Picture* tasks are of type (3) where the user has to switch attention between device and screen during interaction.

There is a strand of research looking at the way personal devices such as phones or PDAs can be used to interact with larger displays (Sas and Dix, 2008). In one of these studies, Gostner et al. (2008) found that users indeed appear to perform acceptably with the divided attention and yet still comment on the problems it causes them. The higher rate of outcome problems with these tasks when the *IE Unit* is used may be due to this...
attention switching. This is not evident in the Add tasks, but it is reasonable that errors or difficulty due to attention switching are related to fine details of the task.

Discussion. The data makes it clear that the Equinox and the IE Unit performed in a more similar fashion than the software alone. This is significant because the IE Unit is intended as a design tool to prototype and test tangible user interfaces. The more variance from the results of the IE Unit prototype vs. the actual product (whether the IE Unit results are more successful or less), the less effective a tool will be. As has been demonstrated, the IE Unit produced a consistently more realistic simulation than software alone, which opposes the claims made by Sharp (1998). In Norman’s (1988) theorising, the system image created by the IE Unit is a better fit of the user’s mental model of a phone device than a purely software simulation. This result is all the more significant for two major factors.

1. A phone is a ubiquitous information appliance (Weiser, 1994) and all participants had experience with similar devices.
2. The chosen appliance had a push button interface with all its controls mounted on the top surface. This combination allows the software prototype to compete on favourable terms with the other methods. It is of course conjecture at present, but had the selected appliance featured sliders, dials, triggers, etc. or had the controls been mounted in a more three-dimensional fashion around the product, then the software simulation may have matched the performance of the real product even less.

As mentioned, it is likely that many learnt phone tasks place more demands on implicit than explicit memory systems (cf. Graf and Schacter, 1985). When solving novel tasks, people will draw upon previous experience or schemas (Anderson, 2005). We might hypothesise then that participant’s phone schemas contained much information in a motoric (and implicit) representational format. Thus when completing the phone tasks used in the current studies, the IE Unit afforded better use of past experience, as the need for physical interaction effectively served as a memory trigger for this schematic knowledge.

Nevertheless, designers do need to exercise some caution. Good as the tangible prototype’s performance was overall, it did simulate some tasks better than others. Thus, further work now needs to be carried out to ascertain how very rapidly conceived and prototyped three-dimensional appliances designed using the latest techniques perform against those prototyped using traditional methods. The participants were encouraged to comment on their experiences. Some of these comments have been included next to illustrate certain assertions.

Software simulation. There were two highly visible issues with the Software method. The first was with the Power On and Power Off tasks. Participants repeatedly struggled to detect the location of the switch. A very common error was to press the power symbol as opposed to the switch that was situated to the left of the symbol (see Figure 6): ‘The only problem I had was switching it on … the power button is much clearer on the real phone’.

The second conspicuous issue was that participants struggled to differentiate buttons from areas of the screen: ‘I kept on pressing the words on the screen but I suppose you wouldn’t if you had the actual phone’. ‘Because the screen icons looked like buttons I tried to press them’. ‘I keep wanting to press the symbols on the screen. It’s ‘cause I don’t have the phone in my hands’. One participant stated: ‘Technology gets in the way’.
These two problems were not observed in the tangible prototype because physical buttons have perceived affordances (Norman, 1988), i.e. they expose aspects of their potential behaviour through their physical appearance – screens, buttons and labels are all different. Furthermore, if one does mistakenly press a non-button it is immediately obvious as it does not depress. In contrast, an on-screen button and a labelling icon can look very similar, and the error of pressing the latter is only apparent in the semantic feedback of the phone not going on.

While in the experiment this was a problem in the fidelity of emulation, it is not uncommon to see flat membrane buttons on physical devices leading to similar problems. Indeed, one of the authors was once trapped in a train toilet until he realised that the label saying ‘press to unlock’ was not a label, but in fact the button!

It appears then that a participant’s mental model of phone interaction (derived from using a physical device) was not fully transferable to the touch screen software simulation. Thus, learning task-action mappings in one interaction domain does not necessarily transfer readily to another.

**IE Unit simulation.** On the whole, users commented on how closely the tangible IE Unit prototype simulated the real device: ‘Similar to the real product to use’. ‘Quite straightforward. Simulation fairly good, no problems’. One user commented that they: ‘Find simulation quite easy, had some problems with the raised buttons’. This was an important comment because while it is in one sense negative, in the ‘field’ the outcome would be positive, i.e. designers would have discovered a potential issue with the button design. The software method is not able to do this. As theorists such as Norman (1988) have highlighted, the feedback provided from buttons, dials, sliders, etc. is a crucial determinant in product usability.

There were two issues raised with the IE Unit method however. One user complained that it was: ‘More difficult using IE simulation – affected entry of text a little bit’.

A clearer issue was the fact that the interaction with the appliance and screen are separated. One participant summed this up: ‘More convenient if this was the real phone – had to look from the phone to the (PC) screen – this affected text messaging’. This aspect is significant. The authors’ research has found that some in industry view the screen being included as a strong necessity (particularly mobile phone designers) while others prefer the simplicity and flexibility of maintaining a discrete screen.
2.2 Low-fidelity empirical testing

So far, we have seen that at high fidelity levels, a handheld product linked to a computer simulation gives data that is of higher quality than the standard screen-based industry method of simulation. This is certainly useful but the benefits must be balanced against the extra work and therefore cost of creating a high-fidelity prototype connected to the simulation. Building a prototype at high fidelity might double the time and cost of creating the simulation and one must therefore ask whether the benefits of a more accurate representation of the end results are enough to outweigh the time and fiscal penalties.

The question now arose however as to how much effect the physical interaction was having on the user. In other words, could a lower-fidelity model and interface give useful results in the same or less time than an entirely screen-based prototype? The authors decided to run more empirical tests in order to test the hypothesis that physical interaction with a prototype was more important than the fidelity level of either the model or the interface.

Low-fidelity modelling. The team elected to continue using the Equinox for further tests so that direct comparisons could be made between the data gathered in the high- and low-fidelity testing phases. A new model was accordingly produced from ‘soft’ modelling materials. The main body of the phone was constructed in blue foam (a standard product designer’s soft modelling material) with the switches being topped with card cut-outs in the shape of the switches on the real phone. On top of these were glued the button graphics, and the screen was represented by a piece of coloured paper.

The modelling process took around one working day to complete including embedding the switches. A further working day was expended creating a new, low-fidelity GUI in Flash (see Figure 7). The new Flash GUI was created using sketch work produced on screen through the mouse. The GUI was driven via keystrokes in the same way as the higher-fidelity prototype described before.

Figure 7 Low-fidelity Equinox model connected to low-fidelity GUI (screen shot shown on right)
The low-fidelity prototype’s hardware was identical to that of the higher-fidelity model; indeed it worked as well as the high-fidelity GUI described in the first section though it was produced with reduced functionality, which decreased the mock up time of the interface. Nevertheless, the reduced hardware production time meant that for equivalent levels of functionality the low-fidelity GUI would still give a time-saving of around four days compared with the higher-fidelity GUI. The significance of these figures is that the low-fidelity Equinox prototype linked to the low-fidelity GUI was manufactured in 20% of the time it would take to create the high-fidelity touch screen interface with equivalent functionality. If, therefore, this method was found to produce results similar to the real product, then the viability of rapidly designed and the produced three-dimensional prototypes would have been proved. The team therefore set out to test the effectiveness of the low-fidelity setup using exactly the same testing methods as before but with a more limited set of tasks for speed.

Experiment 2. Sixteen undergraduate students and administrative staff from the UWIC took part ranging in age from 18 to 30 years. Experience of mobile phone interfaces was broadly similar to that in Experiment 1.5 The procedure was similar to Experiment 1 except that data was not collected for the SMS and Add tasks. Apart from this, all other conditions were identical allowing comparison between this new data on the new ‘low-fidelity’ interface and the data from Experiment 1. In the discussion that follows, the ‘low-fidelity’ interface is referred to as Sketch.

Performance time. Figure 8 shows that the mean completion times for all tasks except Call were slower with Software than the other prototypes. The ANOVA supported this revealing a main effect of task type, \( F(3, 273) = 123.77, p < 0.001 \); a main effect of device \( F(3, 91) = 19.06, p < 0.001 \); and an interaction between task type and device, \( F(9, 273) = 4.69, p < 0.001 \). Post-hoc tests revealed that Software was highly reliably slower \( (p < 0.001) \) than all the other devices \([M = 34.38s (29.79, 38.96) vs. M = 14.73s (11.29, 18.17), 15.34s (11.72, 18.95), 14.88s (10.0, 19.74) for Equinox, IE Unit, Software and Sketch, respectively]\) but that the other devices were not reliably different from each other. Simple main effect analyses showed that there was a significant difference between the devices for each of the four tasks (largest \( F = 32.53, largest \( p = 0.001 \)). Simple comparisons showed that for On and Off tasks Software was highly reliably slower \( (all \ p < 0.005) \) in response times than each of the other devices, although the other devices were not reliable from each other. For the Call task, Software was reliably slower \( (all \ p < 0.05) \) than Equinox, IE Unit and Sketch. For the Picture task, Software was reliably different \( (p < 0.05) \) than Equinox and marginally reliably different \( (p < 0.08) \) than both IE Unit and Sketch. For all of the devices and tasks, none of the other simple comparisons were reliably different.

Thus, in terms of the time taken to complete the tasks, it seems that in general, the software simulation was slower, while the physical prototypes were more similar to each other and the actual phone. However, this pattern was not of the same magnitude for all tasks, so this needs to be considered when interpreting the findings, i.e. physical prototypes (vs. software) appear to simulate most but not all tasks better.
**Performance rating.** Figure 9 suggests that overall performance of the low-fidelity prototype Sketch was more similar to the Equinox than the software simulation, but that this trend was more apparent for some tasks and less for others. The ANOVA supported this revealing a main effect of task type, $F(3, 273) = 34.29, p < 0.001$; device $F(3, 91) = 15.19, p < 0.001$ and an interaction between task type and device; $F(9, 273) = 7.60, p < 0.001$. Post-hoc tests showed that the Equinox [$M = 0.46 (0.30, 0.62)$], IE Unit [$M = 0.50 (0.33, 0.67)$] and Sketch [$M = 0.30 (0.07, 0.52)$] were all highly reliably different ($p < 0.001$) than Software ($M = 1.22 (1.01, 1.43)$) but none was reliably different from each other. Thus, on the four tasks chosen the low-fidelity Sketch prototype was more similar in success rating to the real product and the higher-fidelity ‘physical’ prototype than it was to the software simulation. Simple main effects analyses showed that there were highly significant differences between the devices for both the On and Off tasks (largest $F = 30.83$, largest $p = 0.001$) and a marginally significant difference ($p = 0.06$) between the devices for the Call task. However, the devices did not differ significantly from each other for the Picture task. Simple comparisons showed that for the On task, Sketch, IE Unit and Equinox were highly reliably different ($p < 0.001$) than Software and that Sketch was marginally different ($p < 0.06$) than Equinox, while for the Off task all devices were reliably different ($p < 0.05$) than Software but not reliably different from each other. For the Call task, Equinox and IE Unit were marginally reliably different from each other (all $p < 0.10$).

Thus, it seems that the behaviour of the low-fidelity Sketch prototype is most similar to that of the higher-fidelity IE Unit prototype and the Equinox device itself. In the case of success outcome for the Picture task, there is a less clear effect. However, if we look at those conditions where the software prototype differed substantially from the real Equinox device, specifically the On and Off tasks and even the performance data for the Picture tasks, it is evident that in these tasks Sketch is very similar.
Discussion. The software simulation continues to perform badly in comparison with the Sketch model. Generally speaking, Sketch continues to demonstrate the importance of physicality in gaining accurate results. Curiously it actually very marginally outperforms the higher-fidelity IE Unit prototype. In any case, the significance of these results lie in the fact that more accurate results were produced from a ‘quicker, dirtier’ tangible prototype produced with an 80% time saving over a high-fidelity screen-based interface.

Further fidelity reduction. After reviewing this data, the authors decided that it would be useful to investigate whether lowering the fidelity level further would maintain the tangible prototype’s performance edge over the virtual. A still lower fidelity tangible prototype was constructed. Like the other low-fidelity unit, the main body was constructed from blue foam. This time however, instead of modelling the front face, a full-size printout of a front view of the Equinox phone was glued over the tops of the buttons (see Figure 10). The paper allowed enough flex so that when the user pressed on a picture of a button, the real button under it was activated. There are three important factors that should be noted about this approach.

1. The user should, in theory have no more clues as to the functionality of this kind of tangible prototype than with the wholly screen-based prototype.

2. Notwithstanding that fact, when a control is activated the user does receive tactile feedback in a way that the screen-based prototype does not allow.

3. Other physical interactions are similar to the real phone and the other tangible prototypes.
Experiment 3. Sixteen undergraduate students and administrative staff, ranging in age from 18 to 30 years, from the UWIC took part. Experience of mobile phone interfaces was broadly similar to that in Experiment 2 and the procedure was identical, again allowing comparison with data from Experiments 1 and 2. The same low-fidelity GUI was used as in Experiment 2 with only the prototype itself changed as described before. This prototype is referred to as Flat Face in the following analysis and discussion.

Performance time. Figure 11 shows that the mean completion times for all tasks except Call (Flat Face was slowest here) were slower with Software than the other prototypes. The ANOVA supported this revealing a main effect of task type, $F (3, 318) = 148.86, p < 0.001$; a main effect of device $F (4, 106) = 15.58, p < 0.001$; and an interaction between task type and device, $F (12, 318) = 5.17, p < 0.001$. Post-hoc tests revealed that Software was highly reliably slower ($p < 0.001$) than all the other devices but that the other devices were not reliably different from each other. Simple main effects analyses showed that there was a significant difference between the devices for each of the four tasks (largest $F = 30.28$, largest $p = 0.002$). Simple comparisons showed that for On and Off tasks Software was highly reliably slower in response time than each of the other devices, although these other devices were not reliably different from each other. For the Call task Software was reliably slower than the Equinox, IE Unit and Sketch, but reliably faster than for the Flat Face. Flat Face was reliably slower (all $p < 0.02$) than every other device. For the Picture task, Software was reliably different ($p < 0.05$) than Equinox and Flat Face and marginally reliably different ($p < 0.09$) than IE Unit and Sketch. For all of the devices and tasks, none of the other simple comparisons were reliably different.

These results are very similar to those of Experiment 2. While the Flat Face prototype is, from the front, visually identical to the on-screen software interface, its behaviour is still very similar to the higher-fidelity prototypes. The notable difference is the slower time for the Call task. Given this is the most important function on the phone, this is not an unimportant difference! This reminds us that all results from prototypes need to be regarded with an element of caution. In addition, the Flat Face prototype is in some ways similar to touchscreen-based phones and consumer devices such as the iPhone, suggesting that care needs to be taken in designing such devices in order to ensure they are usable as well as desirable.
Performance rating. If we consider the outcome rating (Figure 12), we see a similar picture to the data for performance time. The ANOVA reveals a main effect of task type, $F(3, 318) = 31.82, p < 0.001$; device $F(4, 106) = 12.76, p < 0.001$ and an interaction between task type and device. Post-hoc tests showed that Equinox, IE Unit, Sketch and Flat Face were all highly reliably different ($p < 0.001$) than Software but neither was reliably different from each other. Again, simple effects analyses were used to unpack the interaction. These showed that there were highly significant differences between the devices for both the On and Off tasks (largest $F = 28.45$, largest $p = 0.001$) and a significant difference ($p < 0.05$) between the devices for the Call task. However, the devices did not differ significantly from each other for the Picture task. Simple comparisons showed that for the On task, both Sketch and Flat Face were highly reliably different ($p < 0.001$) than the Software simulation and that Sketch was marginally reliably different ($p < 0.06$) than Equinox, while for the Off task all devices were reliably different ($p < 0.05$) than Software but not reliably different from each other. For the Call task none of the simple comparisons were significant, suggesting that none of the devices were reliably different from each. This is despite the patterns that appear evident in Figure 12. However, when least significant difference (unadjusted)$^6$ simple comparisons were used, Flat Face and Software were again not reliably different from each other, though Flat Face was reliably worse than all the other devices (all $p < 0.05$) and Software was also reliably worse than all the other devices (all $p < 0.05$).

Figure 11  Mean time taken to complete each of the four phone tasks as a function of device type; bars are standard error (see online version for colours)
As with the task time measures, Flat Face has very similar behaviour to the real device and higher-fidelity prototypes, with the exception of the Call function, where, like the Software interface, we see more errors/problems. It was surprising that Flat Face did not have similar problems in tasks On and Off to those of the Software prototype. Recall that users tried to click the label on screen rather than the actual power button. However, in re-examining the Flat Face prototype, the reason for this became clear. Because the paper covering has certain stiffness, if the power icon is pressed the button next to it is in fact activated. This certainly emphasises that small differences in physical materials can make a significant difference in behaviour. This is important when choosing physical materials to use in prototyping, as is the case here, but also in selections for the product itself – in this case a form of membrane keypad has changed the effective ‘size’ of the buttons.

Discussion. The results of Experiment 3 were surprising in some instances. It was noted in Experiment 1 that the Power On and Power Off tasks were problematic on the purely screen-based prototype because users found it difficult to find the switch on the screen. In Experiment 3, the front of the tangible prototype was formed by a piece of paper on which was printed the exact image used in the screen-based prototype. So the visual clues available to the user were the same. The authors at first concluded that physicality must be playing a subtle role in the flat faced tangible prototype for this function. This may in fact be true, but as noted before, the user could in fact make an error with the Flat Face prototype that on Software would have resulted in failure. For the Call function, the Flat Face prototype performed similarly to the Software prototype and significantly worse than the Equinox, IE Unit and Sketch prototypes. The authors concluded that in this task where several numbers on the keypad needed to be pressed (rather than just the on/off button or navigation button in other tasks), the flat face of the prototype did not replicate the true physicality of the product sufficiently and the result was more of a user error resulting in slower performance times and worse performance ratings. It may also be that...
when a user chose a space between the actual buttons, the paper tension was causing adjacent controls to activate. User comments during the tests with fully 50% of the participants in the Flat Face trials reveal their frustration with the Flat Face prototype, making specific complaints about the quality of the prototype at the point where they had to activate a number of controls in a sequence (dialling a number).

3 Conclusions

The authors started this paper by raising the question of the speed of prototyping and prototype fidelity levels that industrial designers should be aiming for. The results of the experiments shown would suggest it is not the level of fidelity that is most important but rather considerations of tangibility and physicality. The extent to which tangible prototypes of handheld information appliances appear to outperform screen-based prototypes in the simulation of an actual product were perhaps its most unexpected features. The fact that the advantage continues even when the tangible prototypes are made five times as quickly and at much lower fidelity levels underscores the issue.

The findings’ significance therefore lie in the fact that there would appear to be merit in the adoption of tangible prototyping methods, particularly at low fidelity levels. However, if these low-fidelity tangible prototypes compromise on the physical attributes of the design, such as removing the tactile feedback of buttons (as was the case for the Flat Face prototype), this could affect user performance, significantly. The degree to which performance is affected alters dramatically according to task type (Table 1 summarises the main differences in behaviour). Physicality clearly plays an important role in users’ interaction with handheld products but the authors were surprised at the extent to which even very subtle tactile feedback such as the switches under the taut surface of a piece of paper appeared to make a very marked difference to the users’ ability to interact smoothly with the product. Clearly in some cases it leads to apparently positive results (good response times for Power On or Off) and sometimes poor performance (the number of users who complained that they were unable to work the prototype because it was not obvious enough where the buttons were). In any case, the authors are of the view that the Flat Face prototyping technique brought with it more compromises than the method used for Sketch.

Table 1  Summary of prototypes used in the experiments

<table>
<thead>
<tr>
<th>Material</th>
<th>Screen</th>
<th>Keypad</th>
<th>Behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equinox</td>
<td>Production mouldings</td>
<td>On device</td>
<td>Raised keys</td>
</tr>
<tr>
<td>IE Unit</td>
<td>Production mouldings</td>
<td>On PC</td>
<td>Raised keys</td>
</tr>
<tr>
<td>Sketch</td>
<td>Blue foam</td>
<td>On PC</td>
<td>Paper capped</td>
</tr>
<tr>
<td>Flat Face</td>
<td>Blue foam</td>
<td>On PC</td>
<td>Flat paper</td>
</tr>
<tr>
<td>Software</td>
<td>Virtual</td>
<td>On PC</td>
<td>Virtual</td>
</tr>
</tbody>
</table>
All of these factors create challenges for those researchers developing toolkits for the development of tangible information appliance prototypes. What is really needed by the design community is a toolkit allowing the flexibility and speed of Paper Prototyping (Snyder, 2003) or Wizard of Oz (Maulsby, Greenberg and Mander, 1993), the software integration of DTools (Hartmann et al., 2006), wireless capability and flexibility of input trigger placement of the Calder Toolkit (Lee et al., 2004) and the ability to use off the shelf components of the IE System (to exploit a wide range of appropriately scaled input mechanisms) as described in Gill (2003).

Hartmann et al. (2006) noted the importance of a small form factor and this work emphasises that aspect. In essence, if the physicality of tangible prototypes is important as this work suggests it might be, then it follows that scale is likely to be an equally important issue as key aspects of any interaction with a handheld device are heavily dependent on size and control input groupings. To date, most technology-based toolkits have only been capable of prototyping oversized representations of the appliances they represent. Further work is needed to determine whether the scale of a tangible prototype has a significant bearing on the accuracy of its simulation of a real information appliance.

The purpose of the experiments described in this paper was to understand the role of tangible prototypes and physical fidelity in the design process. However, as a side effect it has also studied what could be regarded as a range of separate interfaces to the same underlying functionality but with a range of different physical forms. Tangible interfaces and devices are often compared with a ‘normal’ interface with equivalent functionality, but the differences are typically large and cover many factors making it hard to trace precise causes. In contrast, we have a number of quite fine physical distinctions and can observe where these either have no effect, or where there was an effect, precisely which change caused it. Thus at various stages we have highlighted potential wider implications.

As an example of this, in Experiment 1 we saw that even problems with split attention tasks were highly dependent on the precise balance of the task. This has important implications for those experimenting with systems for using mobile phones to interact with public displays (Sas and Dix, 2008), or even designing television remote controls. Experimental tasks need to be carefully designed in order to cover, not only a range of eyes down and eyes up tasks, but also variants of each.

This study has dwelt primarily on quantitative methods, and for reasons of brevity and focus has not explored more qualitative aspects in depth. Future studies may benefit from a more qualitative approach. One of the aims of the AHRC/EPSRC-funded DEPtH project, of which most of the authors are members, is to explore these issues in detail, arriving at conclusions regarding the level of fidelity for which designers should be aiming in the prototype work. This exploration includes a variety of methods including qualitative ethnographic and content analysis techniques, and formal modelling of physical devices, as well as quantitative experiments.

Acknowledgements

This work has been supported by the AHRC/EPSRC-funded project DEPtH ‘Designing for Physicality’ (http://www.physicality.org/), part of the joint AHRC/EPSRC research ‘Designing for the 21st Century’ Initiative (http://www.design21.dundee.ac.uk/).
References


Notes

1 However, some might argue that this is the result of technical limitations rather than being a design requirement.

2 Reliable can be seen as a synonym for significant, but in common with many researchers, we tend to reserve this term for post-hoc comparisons following main or simple main effects.

3 For this and subsequent analyses, the main points of interest are:
   whether significant differences exist between the prototyping devices and
   whether these differences interact with the type of task undertaken.

4 Due to the ‘unique’ nature of each task, significant task differences by themselves are very much a secondary concern and hence not subjected to follow-up analysis.

4 It should be noted that this user failed in the first text entry task, although his time in the second was half the average for others using the IE Unit. It is therefore difficult to draw any strong conclusions.
Although slightly repetitive, complete ANOVA analyses are given despite the fact that many of the trends reported previously will obviously still remain, e.g. IE Unit vs. Software vs. Equinox comparisons. However, the addition of an additional prototype does increase the degrees of freedom and thus may have altered the pattern of previous findings.

Some researchers routinely use unadjusted simple comparisons following a significant simple main effect (as is the case with Call). However, as the other analyses in this paper have chosen to use a harsher criterion, the results must be treated more cautiously.
Appendix 2: Co-Author Statements
The Virtual Environment in Design Projects

Authors:
James Fathers (40%)

Steve Gill (60%)

Comments
SG provided the majority of the subject material and was the author of the first draft of the paper, JF produced the second draft which included significant additions and some extra reference material. The authors reviewed the paper together, jointly editing the final submission.
<table>
<thead>
<tr>
<th>Paper:</th>
<th>Designing a Learning Environment for Three Dimensional Thinkers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors:</td>
<td>Steve Gill and Tim Coward</td>
</tr>
<tr>
<td>Steve Gill (80%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Tim Coward (20%)</td>
<td>Tim Coward</td>
</tr>
</tbody>
</table>

**Comments**

My contribution amounted mostly to advice and critical feedback on shaping, structuring and some aspects of writing.

Tim Coward
<table>
<thead>
<tr>
<th>Paper:</th>
<th>The Traditional Design Process Versus a New Design Methodology: A Comparative Case Study of a Rapidly Designed Information Appliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors:</td>
<td>Steve Gill, Paul Johnston, James Dale, Gareth Loudon, Bethan Hewett and Gareth Barham</td>
</tr>
<tr>
<td>Steve Gill (77%)</td>
<td></td>
</tr>
<tr>
<td>Paul Johnston (7.5%)</td>
<td></td>
</tr>
<tr>
<td>James Dale (7.5%)</td>
<td></td>
</tr>
<tr>
<td>Gareth Loudon (3%)</td>
<td></td>
</tr>
<tr>
<td>Bethan Gordon (née Hewett 3%)</td>
<td></td>
</tr>
<tr>
<td>Gareth Barham (2%)</td>
<td></td>
</tr>
<tr>
<td>Comments</td>
<td>All were involved in the project.</td>
</tr>
<tr>
<td></td>
<td>Paper was conceived and written by SG.</td>
</tr>
<tr>
<td></td>
<td>UWIC Co-authors were there to help SG check facts etc.</td>
</tr>
<tr>
<td></td>
<td>Nottingham Trent co-authors supplied timeline notes and photographs.</td>
</tr>
<tr>
<td></td>
<td>SG worked up notes which Nottingham co-authors edited.</td>
</tr>
<tr>
<td></td>
<td>A number of telephone conversations took place between SG and Nottingham co-authors to ensure the facts were correct.</td>
</tr>
</tbody>
</table>
### Paper:

Designing a Design Tool – Working With Industry to Create an Information Appliance Design Methodology

### Authors:

<table>
<thead>
<tr>
<th>Author</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steve Gill</td>
<td>90%</td>
</tr>
<tr>
<td>Gareth Loudon</td>
<td>5%</td>
</tr>
<tr>
<td>Darren Walker</td>
<td>5%</td>
</tr>
</tbody>
</table>

### Comments

SG conceived the paper and did the majority of the writing. Following referees' comments a short section was added from another paper to which the other authors had contributed.
<table>
<thead>
<tr>
<th>Paper:</th>
<th>Rapid Development of Tangible Interactive Appliances: Achieving the Fidelity / Time balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authors:</td>
<td>Steve Gill, Darren Walker, Gareth Loudon, Alan Dix, Alex Woolley, Devina Ramduny-Ellis and Jo Hare</td>
</tr>
<tr>
<td>Steve Gill (50%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Darren Walker (18%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Gareth Loudon (22%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Alan Dix (5%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Alex Woolley (3%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Devina Ramduny-Ellis (1%)</td>
<td>![Signature]</td>
</tr>
<tr>
<td>Jo Hare (1%)</td>
<td>![Signature]</td>
</tr>
</tbody>
</table>

Comments
The paper was conceived by SG & GL. SG was the principal author. SG, GL and DW planned the user tests together. SG and GL carried out around 80% of the user tests with contributions from DW and AW. SG collated the data from all the user tests.

DW’s major contribution aside from helping plan user tests was analysis of the data via ANOVA etc. Other analysis and discussion was the work of SG with some key observations from GL and AD.

A.D. contributed to the discussion sections providing insights and connections to other works. He also made some structural suggestions. DR-E and JH’s contributions were principally editorial.
Appendix 3: Brief Author’s CV
Steve Gill – Brief Curriculum Vitae

Qualifications
- Member, Design Research Society
- Professional Member of Association of Computing Machinery
- BA (Honours). University of Northumbria at Newcastle, second class, upper division. Design for Industry 1993
- BTEC General Art & Design diploma 1989

Previous Experience
- Product Manager, 1995-1997 Retail & Commercial and Government Services Divisions Glasdon UK Ltd.
- Product Manager 1995 Government Services Division, Glasdon UK Ltd.
- Industrial Designer 1993-1995 Glasdon UK Ltd.

Current Position
- Director of Research, Cardiff School of Art & Design
- Principle Lecturer
- Coordinator of Programme for Advanced Interactive Prototype Research (PAIPR).
- Member of School Management & Planning Team 2000 – present
- Member of UWIC Academic Board
- PhD Director of Studies to three students, supervisor to two students
- Member of Research & Enterprise and Graduate Studies Committees 2005 - present
- Member of the UWIC Research and Enterprise and Research Degrees Committees
- Main Teaching Areas: Rapid Product Development, User-interaction, Product Design

Programme Management
- Programme Director MSc Advanced Product Design 2006 - 2007
- Programme Director MSc Rapid Product Development 2005 - 2006
- Programme Director, BA Product Design, strategic direction of BA courses within the Programme, budget control, chair Programme committee 1997 – 2005
- Course Director BSc (Honours) Product Design & Manufacture 1997 – 1998

Funding Record
- DEPTh: Designing for Physicality (AHRC/EPSRC Grant, £335K, 2006 – 2009)
- RAPID, (EPSRC WINES call + Large Grant Application short listings, £1m, 2006)
- Researching ways of improving the design of digital interface products (£3K, UWIC, 2004)
- Rapid Interface Development System for Designers (Knowledge Exploitation Fund, £10K, 2004)
- Enterprise funding for the development of IE4 Units arising from research work (UWIC, £20K, 2008)
- Cradle to Cradle Networking grant (Knowledge Exploitation Fund, £48K, 2007)
- (Total funding since 2004 = Approx £527K)

Reviewing and Editing
- Reviewer, CHI 2009
- Reviewer, EURAM 2009 conference
- Guest Editor of Physicality and Interaction Special Edition of Interacting with Computers Journal September 2008
• Reviewer for Interacting with Computers Journal 2008 – present
• Principal Organiser, Programme Committee Member and Reviewer for Workshop: "Physical Fidelity in Design: a Shared Exploration" July 2008
• Reviewer HCI 2008 Conference
• Programme Committee Member and Reviewer for 2nd Workshop on Physicality, University of Lancaster September 2007
• Programme Committee Member and Reviewer for Tangible and Embedded Interaction Conference 2007, Baton Rouge, Louisiana, USA
• Organiser 2nd SPED/PDR Symposium, UWIC July 2006
• Organiser Joint CSAD/PDR/UWN seminar on joint research strategy November 2006
• Reviewer Human Oriented Informatics & Telematics Conference, University of York May 2005
• Reviewer 2nd Appliance Design Conference, Hewlett Packard, Bristol May 2004

Panel and Working Group Membership
• Member of UWIC Intellectual Property Panel
• Subject Expert for quinquenial review of Product Design programme, University of Salford 2003
• Member of Preliminary Investigation Panel to consider the potential validation of HNC in Computing, Gorseinon College, March, 2004
• Internal member of validation committee for Environmental Risk Management within the School of Applied Science
• UWIC Moderator BA (Honours) Industrial Design Fundacion San Valero, Zaragoza 1997-2002
• Member of internal working group profiling the “UWIC Academic”
• University of Wales Moderator BA (Honours) Industrial Design, Fundacion San Valero, Zaragoza 2000 – Present
• University of Wales University Subject Panellist for validation of BA (Honours) Industrial Design, Fundacion San Valero, Zaragoza 1999
• University of Wales University Subject Panellist for validation of BSc (Hons) Industrial Design & Multimedia Engineering degree, CESINE, Santander, Spain

External Examinerships
• MSc Industrial Design, University of Salford 2004 – 2008
• BA (Hons) Integrated Product Design, Glasgow Caledonian University 2003 – 2007

Talks and Lectures
• Keynote Presentation to the 1st International Conference on Physicality, University of Lancaster, February 2006
• Keynote Presentation to workshop on Recent Technology of Prototyping and Usability Assessment of Information Appliances -from Practical Aspects to Future Trends, Hokkaido University, Sapporo, Japan, March 2006
• Invited Speaker, Bradford University, 2004
• Visiting Lecturer, University of Northumbria, 2004
• Visiting Lecturer, Leeds Metropolitan University, 2004
• Visiting Lecturer, University of Salford, 2004

Other Professional Activities
• Member of Design Research Society 2005 - present
• Member of Committee of Research Directors in Design (CoRDD)
• Member of the UWIC working party on Research’s relationship with L&T
• Academic Leader, Knowledge Transfer Partnership with Alloy Total Product Design
• Session Chair, 6th international conference on Computer-Aided Industrial Design & Conceptual Design, Delft University of Technology, May 29 - June 1, 2005
• Working with Samsung Europe, Sony Ericsson Kinneir Dufort Design and Alloy Total Product Design (top 5 UK design consultancy) to develop new methods of rapidly prototyping complex computer-embedded products with user interfaces June 2003 – present

Peer Reviewed Publications
• Dix, A., Sas, C., Ramduny-Ellis, D., Gill, S. and Hare, J.: Sociality, Physicality and Spatiality: touching private and public displays in the proceedings of Workshop on designing multi-touch interaction techniques for coupled public and private displays, part of AVI 2008 the International Working Conference on Advanced Visual Interfaces, Naples, Italy.
• Loudon, G., Gill, S. and Walker, D. How Different Prototyping Methods for Information Appliance Design Affect Usability Test Results Poster presentation at the Usability Professionals Association Conference, Broomfield, Colorado, June 12 – 16, 2006
• Woolley, A and Gill, S.: Information Ergonomics Lectures for Creative Prototyping, In the Proceedings of HCIEd.2006-1 inventivity: Teaching theory, design and innovation in HCI, Limerick, Ireland
• Wilgeroth, P Barham, G & Gill, S.; “HOW TO ACHIEVE THE IMPOSSIBLE: Team working and professional collaboration can design and produce an interactive prototype for an information appliance in 24-hours”. e&pde05. The 3rd Engineering and Product Design Education International Conference, Napier UK, 2005.
• Gill, S.: Designing Information Appliances for users to love: Have we got the answer? Poster, 2AD Conference 2004, Bristol, UK
• Nam, T.J. and Gill, S.: A rapid interface design and prototyping method for computer-embedded products; ICSID conference 2001, Seoul, Korea
• Presentation to 1st Learning & Teaching Conference, UWIC, June 2001 on The Virtual School: A Virtual Learning Support Environment
• Gill, S.: An Industrial Designer's approach to a Virtual Learning Environment; IDATER conference 2000, Loughborough, UK
• Nam, T.J. and Gill, S. An effective prototyping method for delivering interaction design in industrial design education; IDATER conference 2000, Loughborough, UK
• Gill, S. and Coward, T. Designing a Learning Environment for Three Dimensional Thinkers; International symposium on the dimensions of industrial design research conference 2000 Politecnico di Milano, Italy

Other Publications

• Gill, S.: Industrial Design and the User Interface; Article for New Design Magazine 2003 March/April edition
• Gill, S.: Industrial Choosing a Design Degree; Article for Designing Magazine 2003 October edition