CoDesign With Data

Graham Michael Dove
Centre for Creativity in Professional Practice
City University London

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Abstract

Design is a process of changing current situations into preferred ones, through conversations with design materials, and an understanding of the present practice of the designed artefact's future users. Domain-relevant data, such as those generated by personal and autonomous computing systems, are an increasingly important design material presenting new ways to explore current practice. Examples of these data include that being generated by people using smartphones, health and fitness monitors, smart energy meters and social media; or that from official statistics made publicly available via Open Data initiatives.

This thesis details research developing CoDesign With Data, a novel approach to collaborative early-stage design workshops in which working with domain-relevant data is the key distinguishing feature. During a CoDesign With Data workshop participants are given the tools and techniques to help them seek insight from data, gain an understanding of the context these data might come from, and to inspire creative design ideas. These tools and techniques build on an understanding of research into information visualization and applied creativity. The activities in which they are used build on the experiences reported from other approaches to creativity in collaborative requirements gathering and design workshops.

The aim of this research is to support design innovation that results in new products or services appropriate to the contexts in which they will be used. To investigate the primary research question, and evaluate the tools and techniques being developed, two design experiments and three case studies were undertaken. In each study, examples of tools, in the form of workshop materials and information visualization interfaces, and techniques, in the form of workshop activities, are presented, and simple takeaways for design practice are offered. Finally, the knowledge and understanding gained during this research is presented as a series of guidelines and recommendations, and a description of the current state-of-the-art CoDesign With Data workshop.

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Acknowledgements

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Publications

Dove, G., & Jones, S. (2014, June). Using data to stimulate creative thinking in the design of new products and services. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (pp. 443-452). ACM. http://openaccess.city.ac.uk/3761/

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1 Introduction

Designing new products or services is a process by which "*courses of action aimed at changing current situations into preferred ones*" (Simon, 1996, p.111) are devised through a "*reflective conversation with the materials of a design situation*" (Schön, 1992) and where to "*design with future use activity in mind means to start out from the present practice of the future users*" (Bødker et al., 1988). This thesis details research developing a novel approach to early-stage design workshops, the CoDesign With Data approach. This approach uses domain-relevant data that describe aspects of the present practice of future users, for example the data from smart energy meters or responses to official questionnaires, as a material to inspire creative design ideas.

This chapter begins by describing the background to this thesis, outlining its inspirations and presenting the motivations for undertaking the research it details. Here I discuss the wider cultural context of technological, political and societal developments that forecast the growing importance of domain-relevant data to many design projects. This will outline why the detailed research is both interesting and important to fellow researchers of design and human-computer interaction. Following this, I present the questions that were investigated during this research, and state the academic contribution that it makes. Finally the thesis structure is laid out and the contents of the remaining chapters outlined.

1.1 Background and Motivation

What are domain-relevant data? And why should they be of interest? The short answer is that they can be a variety data that describe or represent some aspect of the wider context or domain of a design situation. This is explored in more detail below. They are also an increasingly available resource following the growth in ubiquitous computing systems (Weiser, 1991; Abowd, 2012) and the rise of the open data movement[1]. Finally, they are a resource that is likely to become more important as people generate increasingly large and detailed records describing their everyday activities.

It is now commonplace to carry a smartphone or tablet device that keeps one constantly connected to location services, search engines and social media (Nielsen, 2014; Lomas, 2012). Personal health, wellbeing and fitness monitors, such as those made by Fitbit[2] and Jawbone[3], which can capture and record activity and biometric data, are also growing in popularity and have the potential to change people's relationships with the medical profession. Similarly, smart energy meters and smart electricity plugs that capture fine-grained information about the way people use energy are becoming familiar[4]. As are smart thermostats that learn about people's habits from the detailed data they collect, such as Nest[5] and Hive[6]. The records generated and stored by each of these technologies represent an example of domain-relevant data, and the trails they leave behind can tell stories that we might use to understand the

[1] www.theodi.org
[2] www.fitbit.com
[3] www.jawbone.com
[4] e.g. www.plugwise.com/smart-home
[5] www.nest.com
[6] www.hivehome.com

ways that existing products and services are being used in current practice. In addition, where products that generate these data do not exist already, it is now relatively straightforward to devise custom low cost data gathering solutions, which utilise cheap sensors to meet specific research requirements (Burke et al., 2006).

These types of data are rapidly becoming a key component in the way major societal issues are addressed (Ofcom, 2013). For example, one of the primary motivations behind the UK Department of Energy and Climate Change's plan to rollout smart energy meters to upwards of twenty four million UK homes and businesses by 2020 (Department of Energy and Climate Change, 2012) is that they expect the consumption data these smart meters generate to kick start the development of new services that encourage customers to shift energy consumption away from peak demand times. This in turn will reduce the need for those standby power stations that are most polluting, and thereby help the UK meet sustainability and green energy targets (Ofgem, 2011).

Another reason to be interested in domain-relevant data is the increasing public availability of official statistics, which is due in part to the impact of the open data movement. Examples of such open data include census and demographic information, government spending and service provision, housing market statistics and real-time transport information, all of which are accessible via the UK government's data website[7]. Each of these is an example of domain-relevant data that might help us better understand the changes taking place at the wider level of community or society. Data from all

[7] data.gov.uk

of these different sources have the potential to inspire important new insights that inform design research and ultimately lead to better design solutions.

But how should we interrogate these data in order to extract value from them? Many current approaches to extracting value from data are based on the algorithmic use of statistical and machine learning techniques (Witten & Frank, 2005), a good example of this approach being Amazon's recommendation system (Linden et al., 2003). However, these approaches, which are often associated with so-called 'Big Data', can have a number of potential problems relating to the context the data are drawn from or the individual stories they can represent (Boyd & Crawford, 2012). The CoDesign With Data approach that I have developed through the research detailed in this thesis offers an alternative based on human creativity rather than machine learning. This approach is not meant to compete with Big Data algorithms. Indeed, it might be used to complement the kind of understanding that can be derived automatically.

During a CoDesign With Data workshop participants take part in a series of activities that help them seek insight from domain-relevant data and share their individual knowledge and experience in order to gain a better understanding of the context these data may have come from, and to provide inspiration for creative design ideas. In the studies reported in chapters 4, 5 and 7 the domain-relevant data used are the kind of quantitative data generated by smart energy meters. Additionally in Chapter 7 the energy domain is also represented by the kind of data available in social media, in this case Flickr[8] photographs. In Chapter 8 the domain-relevant data are responses to a large-scale questionnaire study and data representing contamination in university waste bins. Chapter 6 explores the different types of data available within the domain of a European research project investigating reflective practice at work.

1.2 Research Question and Contribution

The research detailed in this thesis aims to respond to the opportunities offered by the growing availability of domain-relevant data. In so doing I have developed a novel approach to early-stage design workshops, the CoDesign With Data approach. This approach uses tools that represent data interactively and techniques that prompt creativity to help participants gain and share an improved understanding of the contexts these data might be drawn from, and in turn inspire creative design ideas. This is done with the ultimate aim of delivering better products and services.

1.2.1 Research Question

Section 1.1 identified the new opportunity these domain-relevant data offer. This might be summed up as the chance to present a view of potential future users' current practice at a scale or resolution that is not generally practical with most human-centred or user-centred design methods. For example, domain-relevant data might offer the opportunity to study the activities of larger numbers of people, over longer periods of time than methods such as Contextual Design (Beyer & Holtzblatt, 1999), albeit at a relatively course granularity.

[8] www.flickr.com

The objective of the research detailed in this thesis is to investigate how this opportunity can be exploited, and the research question that guided this enquiry was:

How can seeking insight into domain-relevant data help participants in early-stage co-design workshops gain a richer understanding of the context under investigation, and provide inspiration for creative design ideas?

This research question assumes two key relationships, which are discussed below. First, the relationship between data and context; how exploring domain-relevant data and the context of the activities being undertaken when they are generated can provide insight into what might be considered design problems. Second, the nature of inspiration, and how insights into domain-relevant data can provide inspiration for possible design solutions.

1.2.1.1 Data and Context

Section 1.1 introduced domain-relevant data, gave examples of what they might be, and explained that algorithmic or Big Data approaches to understanding these data can been criticised for failing to appreciate the context surrounding the practices and activities they are drawn from (Boyd & Crawford, 2012). Such an appreciation and understanding of the context surrounding future users' current practice is a key principle of user-centred design, as we see for example in the Contextual Design approach (Beyer & Holtzblatt, 1997).

My research question reflects this tension between domain-relevant data offering potential insights into the practice and activities of a large number of possible future users over a long period of time, and the user-centred requirement to understand the specific context in which these activities and practices take place in close detail. It asks how we might help co-designers gain a richer understanding of the context from which these data are drawn, through sharing their knowledge, including implicit knowledge, of particular instances, activities or practices that these data might represent. This can be understood as an investigation into the ways that domain-relevant data might provide the raw material from which insights into the problem space of a design situation can be found.

1.2.1.2 Inspiration

In addition to inquiring how domain-relevant data might support an improved understanding of the problem space of a design situation, my research question also asks whether exploring domain-relevant data might inspire ideas for possible design solutions. This is important because activities in which external inspiration is intentionally sought are included in many design processes, for example those used at IDEO (Kelly & Littman, 2001, pp.142-46), and have been shown to be an effective source of creative design ideas (Halskov, 2010; Eckert et al., 2000).

My research question asks how co-designers' insight seeking can be supported so that any insights they might find inspire creative design ideas. Within this I include enquiry into different ways in which domain-relevant data might be represented, and also different ways in which workshop activities might be structured so that creative exploration of domain-relevant data can inspire participants to look at the data in ways that lead them to discover new, unexpected and inspirational insights.

Having a single research question addressing both the problem and the solution spaces of a design situation reflects the complexity of the relationships between seeking insight, understanding the domain context, and generating creative design ideas. These may not be clearly separate stages that progress in a simple linear fashion but may be more iteratively intertwined. Indeed, this is likely to be the case, given the way in which design problems and design solutions can be said to co-evolve (Dorst & Cross, 2001).

1.2.2 Academic Contribution

The main contribution to academic knowledge in the field of Human-Computer Interaction made in this thesis is the CoDesign With Data approach that I developed during this research. This is a novel approach to collaborative early-stage design in which working with domain-relevant data is the key distinguishing feature. During a CoDesign With Data workshop participants take part in a series of activities using the tools and techniques I have developed to help them: *seek insight into domain-relevant data*; *share their individual knowledge to gain an improved understanding of the possible contexts these data might come from*; and *use the insights gained as inspiration for creative design ideas*. During this research I developed and published a number of tools and techniques, which I combined in novel workshop methods. I also developed and published a new method of evaluating creativity support using Reflection Postcards. The CoDesign With Data *approach* describes how a set of *tools*, in the form of example information visualization interfaces and other workshop materials, and *techniques*, in the form of example workshop activities, can be combined into *methods* for undertaking early-stage collaborative design workshops.

1.3 Structure of this Thesis

Chapter 1 introduces the research detailed in this thesis, places it in a social and technological context, and outlines my research questions and academic contribution.

Chapter 2 provides an academic background to the research, in which important literature are reviewed and related work described. In doing so, it places the work described here in an academic context of design research.

Chapter 3 introduces the research and evaluation methods used during the individual studies undertaken for this thesis, and provides a roadmap for how these studies relate as the research progressed.

Chapter 4 describes my first design experiment investigating how to represent domain-relevant data to workshop participants. In this study ambiguity in the visual encoding with which data are represented is considered. I found that ideas generated in workshops using an interface where ambiguity was intentionally increased were found to be significantly less appropriate to the domain under consideration. This work was presented in a paper at the ACM Designing Interactive Systems conference, Vancouver, June 2014 that is included in Appendix A.

Chapter 5 describes a case study in which the findings from the first design experiment are put into practice in a service design workshop held with customers and staff of E.ON Energy. I found that activities using visualized domain-relevant data and generative design techniques were engaging for participants, helped them gain a better understanding of the design context, and inspired creative ideas. This work was presented in a paper at the

ServDes.2014 Service Design and Innovation Conference in Lancaster, April 2014 that is included in Appendix A. The novel Reflection Postcard method of evaluation was developed for this study and presented at the CHI 2013 Workshop: Evaluation Methods for Creativity Support Environments, a short paper is included in Appendix A.

Chapter 6 describes a case study in which I continue to investigate the generative design approach used in Chapter 5 in a workshop held with representatives of MIRROR, a European research consortium. I found this to be an effective way of gaining an improved understanding of the data available to a design situation, and of inspiring and recording creative design ideas.

Chapter 7 describes my second design experiment investigating how to represent domain-relevant data to workshop participants. In this study two interfaces designed to prompt different styles of creative thinking are compared. I demonstrate distinct differences in the way these two interfaces were used, and show that certain aspects of participants' creative processes were supported more effectively in workshops where quantitative data were visualized in a way designed to prompt an analytical style of creative cognition.

Chapter 8 describes a final case study in which the lessons learnt in previous studies are brought together, and the emerging CoDesign With Data approach is studied, during a service design workshop held with representative students and staff from City University London's Environmental Champions. I found positive evidence of effective support and inspiration for participants' creative design processes, both through directly prompting ideas and also by providing a common ground on which participants can share their differing knowledge and experience.

Chapter 9 provides a discussion of, and reflections on, the research carried out for this thesis. My research questions and contribution are revisited, and the recommendations for practitioners presented in full. I also revisit the research methods I used and discuss their suitability and effectiveness. Finally, I outline some key limitations, and suggest areas for future research.

Each of the chapters 4 to 8 reports a specific study, addressing sub-questions of my primary research question:

Chapter 4	**RQ4** *What would be the effects of increasing the ambiguity in the visual encoding used to represent smart energy data on workshop participants' ability to gain insight, and on the creativity of the product and service ideas those participants subsequently generate?*
Chapter 5	**RQ5.1** *Would using iPad interfaces to explore visualized domain-relevant data be engaging to workshop participants, and support collaboration in a real world setting?*
	RQ5.2 *Would participants successfully gain an understanding of the data and therefore insight into the design context from their activities using the information visualization interface?*
	RQ5.3 *Would the combination of insight seeking using information visualization interfaces and generative design activities help participants share their existing knowledge and explore different possible interpretations of an ambiguous design context?*
Chapter 6	**RQ6.1** *Would workshop activities in which generative design is combined with applied creativity techniques help co-designers share their individual perspectives*

	on the data available to a design situation?
	RQ6.2 *Would these activities improve individual co-designer's understanding of those data, where they come from and how they might be used?*
	RQ6.3 *Would these activities inspire co-designers' creative ideas as they look for possible new uses for these data during exploratory design?*
Chapter 7	RQ7.1 *How would participants' idea generation activities differ? When given:*
	A: *A digital design artefact designed to prompt creative cognition in an analytical way by visualizing smart energy data in a traditional style.*
	B: *A digital design artefact designed to prompt creative cognition in an intuitive way by presenting photographs from social media in a direct visualization style.*
Chapter 8	RQ8.1 *Would the CoDesign With Data tools and techniques support participants' insight seeking and help them gain a better understanding of the design context? During workshops in which they:*
	A: *Identify and formulate a specific Problem Statement*
	B: *Generate candidate solutions and select a Design Idea*
	RQ8.2 *Would the CoDesign With Data tools and techniques support and inspire participants' creative design processes? During workshops in which they:*
	A: *Identify and formulate a specific Problem Statement*
	B: *Generate candidate solutions and select a Design Idea*

Table 1: Listing of individual studies' research questions

1.4 Appendices

Volume II of this thesis contains the following appendices:

Appendix A: *Papers published during the period of this research*.

Appendix B: *Design outputs resulting from the case studies reported in chapters 5, 6 and 8*

Appendix C: *Design materials used in the workshops detailed in this thesis.*

2 Research Background

This thesis details my development of a novel approach to early-stage design workshops, the CoDesign With Data approach. The research it describes is situated within the field of human-computer interaction, which, Fallman has argued, is increasingly becoming a "*design-oriented field*" (Fallman, 2003). This work can therefore usefully be described as *design research*. I will briefly discuss how this term can be understood, and clarify how it is used in this thesis.

2.1 Design Research

In discussing the nature of research and it's standing with regards to academic degrees in the field of design, Archer (1995) makes the distinction between "*research about practice; research for the purposes of practice; and research through practice*" (underlined emphasis in the original). According to Archer, research about practice includes studies of the materials, processes, methodologies and outputs of design. Research for the purpose of practice underpins practitioner activity and refers to the work done to gain the understanding that informs product or service development. Research through the medium of practitioner activity involves exploring and testing a proposition by constructing or enacting some intervention in the real world, and in which the investigator is likely to be a significant actor. This is otherwise known as Action Research.

When I talk about *design research* with regards to the studies detailed in this thesis, I am usually referring to research ***about*** practice. Here, new methods for early-stage design workshops, featuring novel combinations of tools and techniques, are described, and their use explored and explained. The case studies described in chapters 5, 6 and 8 were undertaken as part of real world design processes in which I was an active participant. Here I was selecting and enacting interventions with the aim of testing propositions and therefore *design research* might also be thought of in terms of research ***through*** practice. Also, the outputs from these case studies informed ongoing design activity and therefore the *design research* was at times research ***for the purpose of*** practice.

This indicates that there are situations where the term *design research* may have multiple interpretations, and retain a certain degree of ambiguity. However, I believe that the context of each instance of use should be clear enough for the meaning at that time to be apparent. An alternative is to understand *design research* along similar lines to Ezio Manzini who has described it as being "*an activity that aims to produce knowledge useful to those who design:* ***design knowledge*** *that designers and non-designers (individuals, communities, institutions, companies) can use in their processes of designing and co-designing*" (Manzini, 2009) (emphasis in the original).

2.2 The Landscape of Design Research

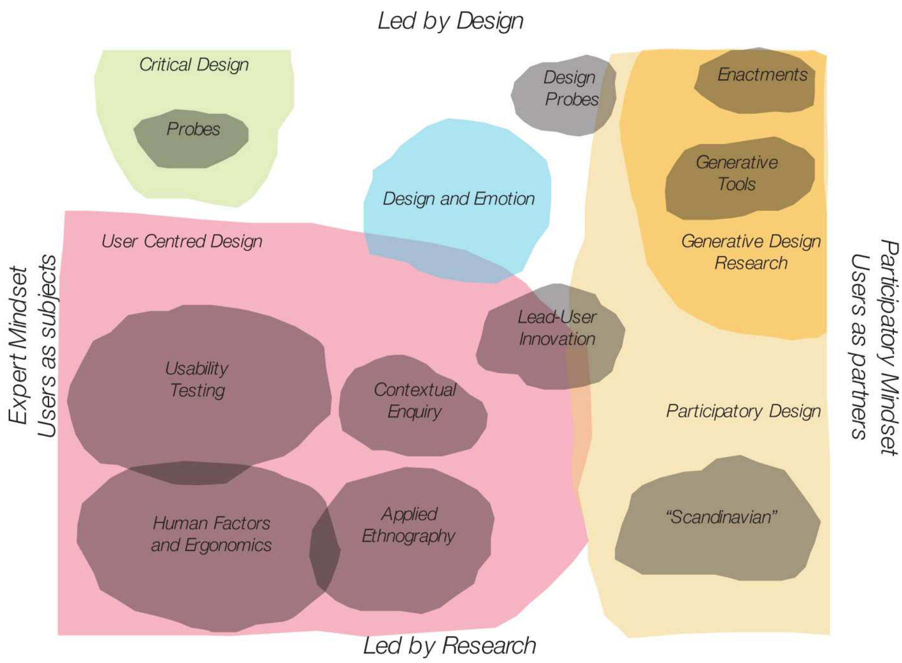

Figure 1: Reproduction of Sanders & Stappers' Map Describing the Emerging Landscape of Design Research Approaches and Methods (Sanders & Stappers, 2012, p.21)

This thesis describes the development of CoDesign With Data, a design approach that adopts an explicitly human-centred mindset. In this section, my approach will be placed in the wider context of contemporary human-centred design and design research. This is in order to place some important philosophical markers and signpost key decisions described in later chapters.

The landscape of human-centred research for product design, service design, and human-computer interaction design has developed significantly since the 1970s when User Centred Design (Norman & Draper, 1986) and Participatory Design (Bødker et al., 1988) practices emerged. This developing design space, in which practitioners and researchers are closely concerned with the future users of their design outputs, has been usefully described by Sanders and Stappers (2012, p.21) through a two dimensional map in which the vertical axis describes different design approaches and runs from *'led by research'* through to *'led by design'* and the horizontal axis describes a varying mindset from *'users as subjects'* to *'users as partners'*. Figure 1 shows a reproduction of this map.

The vertical axis strongly reflects the background that the different approaches have emerged from. Towards the *'led by research'* end of the vertical axis lie approaches such as Applied Ethnography and traditional Human Factors research that have been strongly influenced by disciplines such as cognitive psychology, sociology, engineering and anthropology. In contrast the *'led by design'* end of the vertical axis is populated by approaches to design research that are based in exploration through design artefacts, such as Critical Design and Generative Design Research. These are approaches that have emerged from practices developed in schools of art, design and architecture.

Positioning along the horizontal axis reflects a given approach's mindset with regards to the role of the future user in the design process. Towards the *'users as subjects'* end of the spectrum lie Critical Design approaches and methods such as Usability Evaluation that reflect the position of design researcher as expert who designs for people. Towards the *'users as partners'* end lie those methods and approaches such as Scandinavian Participatory Design and Generative Co-creation where the role of design researcher is closer to that of a facilitator who designs with people.

In Figure 2, the map's original content has been updated with the addition of the CoDesign With Data approach that was developed through the research detailed in this thesis. The aim of the CoDesign With Data approach is to design with people by inspiring their creativity and facilitating their exploratory insight seeking, using data that represent aspects of current practice and behaviour. This places it close to the *'users as partners'* end of the horizontal mindset axis. Along the *'led by research'* to *'led by design'* axis it sits closer to the centre, as it has been influenced and informed both by methods with a flavour of the social sciences, which explore current user behaviour by gathering data about current practice, and also by methods that use generative techniques to explore the experiences and desires of the future users of new products or services.

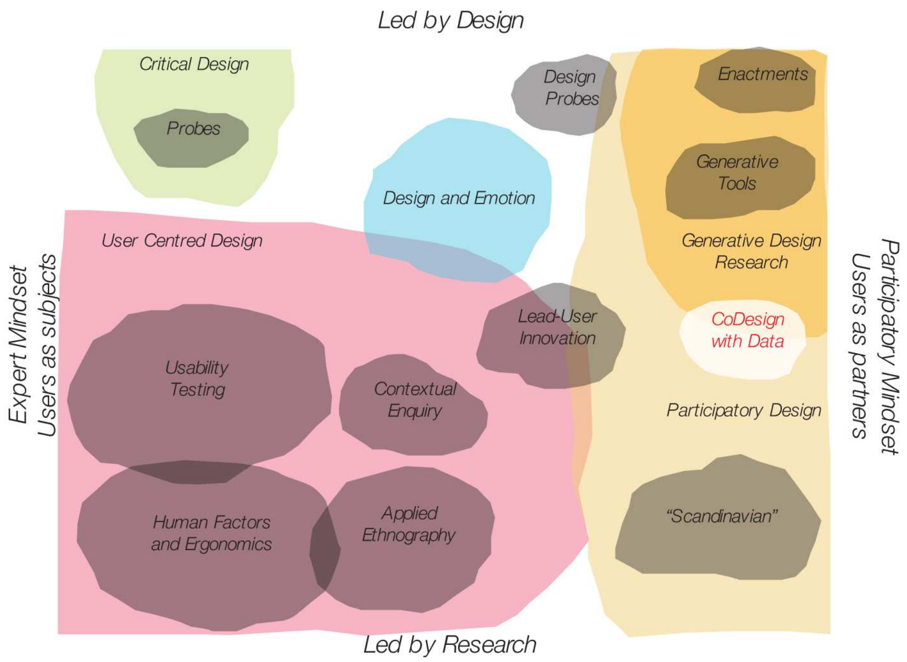

Figure 2: Sanders and Stappers' emerging landscape of design map. Updated to show where the CoDesign With Data approach sits (Sanders & Stappers, 2012, p.p.21)

2.3 Tools, Techniques, Methods and Approach

The aim of the research presented in this thesis is to develop an approach to early-stage co-design workshops in which domain-relevant data that represent aspects of current practice provide inspiration for creative design ideation. By exploring these data creatively with stakeholder representatives, we can share an understanding of the context they are drawn from, and use the insights gained and ideas generated to design innovative products and services appropriate to their future users. The primary challenge faced is to find ways of presenting these domain-relevant data in a way that is appropriate for the participating stakeholder representatives, our co-designers. These co-designers are unlikely to be experienced data analysts and therefore data should be presented in a way that makes them accessible. Also, I want to inspire co-designers' creativity and use this to explore a broad context for these data, which should therefore be presented in a way that is engaging, inspiring and that prompts creative ideas.

To describe how the CoDesign With Data approach responds to such challenges, the distinction between ***tools***, ***techniques***, ***methods*** and ***approach*** made by Sanders, Brandt and Binder (2010) in their framework for describing the application of participatory design practices has been adopted. This distinction helps to generalise the results found in this research by allowing other design researchers to adopt individual elements and combine them with tools and techniques described elsewhere or to extend them and develop methods and approaches of their own.

Description at the level of ***tools*** tells us about the material component of a particular intervention or what that intervention looks like. In the research detailed here, the tools used are the design artefacts used. These are the interactive interfaces in which the domain-relevant data are visualized, together with the worksheets and other materials used to inspire, prompt, capture and record design ideas, during particular workshops.

Description at the level of ***technique*** tells us how these tools are used in a particular situation. In the research detailed here, this is a description of the specific activities undertaken during particular workshops.

Description at the level of ***method*** tells us how the combination of tools and techniques are put together to address defined goals. In the research detailed here, this is the format of particular workshops.

Description at the level of ***approach*** tells us about the mindset within which the research is conducted and can provide a guide to the type of ***methods*** that are likely to be adopted. As Figure 2 shows, in the CoDesign With Data approach this is a collaborative, participatory mindset that seeks to works with stakeholder representatives, and that combines elements of design led and research led techniques.

During the development of the CoDesign With Data approach I have trialled several *methods*, each involving different combinations of *tools* and *techniques* inspired by previous research. In section 2.4, three different approaches to stimulating and inspiring creativity in early-stage design and requirements gathering workshops will be discussed, and the tools and techniques they employ described.

This related work shows how others have responded to the challenge of designing better products and services by employing the creativity of stakeholder representatives. This will be followed in section 2.5 by a discussion of key research in the fields that have influenced important elements in the development of the example *tools*, *techniques* and *methods* that I have used in the CoDesign With Data approach, and that are described in the research detailed in the remainder of this thesis.

2.4 Related Approaches

Design is an inherently creative process in which consciously seeking inspiration can play an important role. This is evidenced in the innovation strategies practiced at design companies such as IDEO where sources of inspiration such as The Tech Box, a centrally located filing cabinet filled with a changing array of things such as smart materials, interesting toys, miniature batteries and electroluminescent displays, are seen as pivotal (Kelly & Littman, 2001, pp.142-46; McGrane, 1999) Bødker, Nielsen and Petersen (2000) describe how systematic collaboration between designers and stakeholder representatives leads to creative design results that are based on but transcend current user practice, and Greenbaum & Madsen (1993) describe how workshops can be used to give stakeholders an important voice in design projects. It makes sense, therefore, that activities in which there are deliberate attempts at prompting creativity and inspiring ideation should also be an important feature of collaborative or participatory design workshops.

In the following sections I will discuss three examples where these types of activities have been used to: *uncover novel requirements*

(Maiden et al., 2004), *explore future experience* (Sanders & Stappers, 2008), and *create new concepts for design* (Halskov & Dalsgård, 2006). There are a number of other tools and techniques used in collaborative design, participatory design, co-design, and co-creation practice and research e.g. (Brandt, 2006; Bødker et al., 2000); however, the three approaches discussed have been comprehensively reported and are explicit in the methods they use to inspire or stimulate participants' creativity. Each of these examples takes a distinctly different approach to collaborative design workshops. They were selected for closer discussion because the approaches they adopt are effective in addressing specific aspects of the design workshop space that are important to my research.

The *Creativity Workshop* discussed first was selected because it takes place in the very earliest, requirements gathering phase of a design project. It is distinctive because it represents pre-design work being undertaken for large-scale and complex socio-technical systems. The project undertaken with E.ON, which included the studies described in chapters 4 and 5, was aimed at a similar scale. The activities that take place during this workshop are strongly rooted in psychological theories of creativity and the applied creativity techniques based on these. This might be described as a scientific approach to inspiring participants' creativity, based on participants searching for ideas. These factors are explored in the studies reported in chapters 4, 5, 7 and 8.

The *Generative Design Research* discussed next also takes place at the very front end of design projects. However, the techniques used here, whilst also based on psychological theories, are more strongly rooted in the expressive elements of creativity i.e. making things. This approach is co-creational, i.e. closely collaborative, with the design researcher's role being to facilitate participants' expressive creativity. *Generative Design Research* explicitly aims to explore the experiential aspects of the requirements that future users might have from the product or service being designed. Generative tools and techniques are investigated in the studies reported in chapters 5 and 6, where they were used to help participants' gain an understanding of the context data come and to express future design opportunities.

The *Inspiration Card Workshop* discussed third is important because it takes place at a later stage in the design process where design concepts are being generated. The described workshop is also shorter and more closely focused on designing interactive systems than the *Creativity Workshop*. The *Inspiration Card Workshop* shows how selected images can be used as a material to represent features of the domain of a design situation, and how these can be combined creatively to generate useful design concepts. Domain-relevant images and photographs are used to help participants explore and understand the context data might come from, and to prompt different kinds of creative thinking during the studies reported in chapters 5 and 7.

2.4.1 Creativity in Requirements Gathering Workshop

In recent years there has been a move towards understanding requirements engineering as a process of creative problem solving e.g. (Maiden et al., 2004; Maiden et al., 2007; Jones et al., 2008; Maiden et al., 2010). As part of this process, a format for the *Creativity Workshop* has been developed in which a range of stakeholder representatives undertake a series of different activities that generate ideas and identify requirements for large-scale socio-technical projects, such as air traffic control systems. These requirements have been shown to be both novel and appropriate for their context, and may otherwise have remained unexpressed.

The structure of this workshop, and the activities undertaken during it, are based on the application of psychological models of creative processes, such as those put forward by Poincaré (1913), Boden (2004), and Csikszentmihalyi (1997), and applied creativity models, such as the Creative Problem Solving (CPS) method (Isaksen et al., 2011). This workshop typically takes place over two days to allow for a period of incubation (Poincaré, 1913), in which ideas subconsciously germinate. It is made up of iterations of divergent idea generation activities followed by activities in which convergence and agreement are sought. These activities aim to stimulate three types of creativity: exploratory, combinational and transformational (Boden, 2004, pp.3-6). Another important part of the philosophy behind these workshops is the desire to create a playful and supportive atmosphere, where tensions or conflicts from everyday work are removed, barriers broken down, and which encourages creative flow (Csikszentmihalyi, 1997).

2.4.1.1 Tools

Typically, the tools used in a Creativity Workshop might include post-it notes and marker pens for collecting and organising ideas, flip charts and boards for gathering outputs, and tools for describing requirements e.g. use-case cards. In addition to these, large sheets of paper and other materials for creating rich storyboards might be used in combinational creativity activities. Other tools, for example balloons that might be used to make animals, play an important role in the scene setting and staging of a Creativity Workshop.

2.4.1.2 Techniques

Typically, a Creativity Workshop will include a series of different activities based on a number of techniques. For exploratory creativity the aim is to search the space of partial or complete possibilities. Effective techniques for exploratory creativity include analogical reasoning and brainstorming with creativity triggers. Analogical reasoning is a process of mapping or transferring information from a source domain to the target domain, the target domain being the domain of the problem currently being considered (Maiden et al., 2004). Key here is the idea that each domain should be a different instantiation of a shared abstraction, that they should share knowledge structures, but that they should have syntactical differences. Brainstorming with Creativity Triggers is a process in which ideas are generated in response to specific triggers, such as '*Service*', '*Participation*' or '*Connections*'. These activities are typically used during divergent phases of the workshop (Jones et al., 2008).

Transformational creativity is the result of changing or breaking the rules that are implied by or constrain the partial or complete possibilities that define the search space in which exploratory creativity takes place. To achieve this, techniques such as constraint removal, in which domain assumptions are challenged and ideas previously considered impossible are suggested, have proved effective. These activities also typically take place during divergent phases of the workshop (Maiden et al., 2010).

In activities based on combinational creativity techniques, elements from multiple sources, for example randomly introduced objects or pairs of existing requirements, are combined to create new ideas. Typically, these combinational ideas might be expressed in a rich storyboard. These activities would typically take place during convergent phases of the workshop (Maiden et al., 2007). In addition to the techniques that inform the workshops' main activities, other techniques that encourage playfulness, breakdown inhibitions and let off steam, and support a positive atmosphere, are important to the success of Creativity Workshops (Maiden et al., 2004).

2.4.1.3 Takeaways

The use of applied creativity techniques, which are based on a solid theoretical basis, to structure workshop activities and support participants' creative processes, is a key lesson that can be taken from the body of work describing the Creativity Workshop in requirements engineering.

2.4.2 Generative Design Research

Generative approaches, in which the co-creation of artefacts is used to uncover insights into people's lives and materialise knowledge for design requirements e.g. (Sanders, 2000; Sanders, 2005; Sanders & Stappers, 2008; Sanders & Westerlund, 2011; Sanders & Stappers, 2012) have increasingly been recognised as an effective approach to design research. Key to this approach is the practice of design researchers creating generative toolkits. These toolkits are made up of intentionally ambiguous stimuli and given to co-designers who use them to make expressive artefacts. These artefacts can describe future objects and become the focus of discussions that encompass future experience.

The Generative Design Research approach is based on theories of everyday creativity (Bohm, 2004), an appreciation that all people have the capacity to be creative in their everyday activities. This is similar to Boden's concept of p-creativity, or creativity in the psychology of an individual (Boden, 2004, p.2). Another key idea underpinning this approach is that design is increasingly concerned with experience, and that experience is best understood as the subjective moment at which dreams and memories meet (Sanders, 2001). According to Sanders, exploring what people make is an important technique in designing for experience, because it extends further into the past memories and the future dreams of participants than either watching what they do, which covers the current situation, or listening to what they say, which typically extends only to the recent past and near future (Sanders, 2001). This exploration of what people make tells design researchers about ideas and feelings that cannot be shared easily in purely verbal terms, helps to bring out tacit knowledge and highlight unknown wishes or desires not met by existing products or evident in current practice.

2.4.2.1 Tools

The tools of generative design research are typically organised and presented as toolkits, a toolkit being "*a collection of tools that are* *used in combination to serve a specific purpose*" (Sanders et al., 2010). According to (Sanders & Stappers, 2014), these "*[t]oolkits are made of 2D or 3D components such as pictures, words, phrases, blocks, shapes, buttons, pipe cleaners, wires, etc.*" In addition, they are specific to the project or domain under investigation, and are used by co-designers "*to make artefacts about or for the future*" (Sanders & Stappers, 2014). Toolkits are used both by individuals and small groups, in processes that are typically guided and facilitated. The tools in these toolkits may be intentionally ambiguous, so that different people can interpret them in different ways, opening room for creativity.

2.4.2.2 Techniques

Specific examples of the techniques used in generative design research are closely tied to the particular toolkits prepared for individual design projects. However, collectively these techniques can be described as facilitated making, where both factors, the making and the facilitation, are considered important. The making will generally result in the creation of an artefact, which might take the form of a collage or model, and through which competing ideas can be considered and ambiguities resolved. The facilitation provides guidance, instruction and scaffolding for participants, encouraging their creativity and structuring activities to help them recall and interpret memories, explain feelings, and express imagined future experiences.

2.4.2.3 Takeaways

Generative design research demonstrates the importance of encouraging participants' creativity with making activities. It also reminds us that the design qualities of the tools we provide our co-designers are an important feature of these tools. Finally, this research shows us that making use of ambiguity can be a key technique for exploring experience, and activating different memories and feelings in people.

2.4.3 Inspiration Card Workshop

The Inspiration Card Workshop (Halskov & Dalsgård, 2006; Halskov & Dalsgård, 2007; Halskov, 2010) takes a shorter form than the Creativity Workshop described above. It has been used to develop design concepts in participatory interaction design projects. This workshop may last somewhere in the region of two hours, and is undertaken with the objective of combining the findings of initial domain studies with sources of technological inspiration, to create new design concepts.

The activities undertaken in an Inspiration Card Workshop are based on Schön's theoretical understanding of design as a reflective conversation with materials (Schön, 1992), and Ehn's identification of the balance between tradition and transcendence in design innovation (Ehn, 1988, p. 28). These workshops also build on previous work in which small cards are used to represent ideas, aspects of the design context and other design materials by, amongst others (Brandt & Messeter, 2004; Tudor et al., 1993).

2.4.3.1 Tools

The key tool used in the Inspiration Card Workshops is a set of Inspiration Cards. These Inspiration Cards are small, 2" by 3", cardboard cards that represent either information about the domain of the current design project, Domain Cards, or applications of novel and inspirational technologies, Technology Cards. Along with the Inspiration Cards, large worksheets are used to create collages describing novel design concepts, called Concept Posters. In addition to these custom materials, standard workshop stationary, such as marker pens, is also used.

2.4.3.2 Techniques

The structure of an Inspiration Card Workshop is simple, consisting of three stages: *shared understanding*; *combination and co-creation*; and *concept presentation*.

During the shared understanding stage, each of the selected Inspiration Cards is presented in turn. During the combination and co-creation activity, which makes up the majority of the workshop, participants collaboratively combine Inspiration Cards on the large worksheets, and add textual descriptions or sketches, to make Concept Posters. Halskov (2010) has described four main techniques at play when interacting with the Inspiration Cards. The most fundamental is Selection, in which a certain aspect or feature is picked; this may be followed by Adaptation in which these features undergo a modification so they better fit the current situation; Translation is the process of taking a source of inspiration from one place or situation and transplanting it to another; and Combination, which for Halskov is the most necessary for innovation, involves combining previously unrelated elements. This is similar to Boden's combinational creativity (Boden, 2004, p.3), which has also been applied in the Creativity Workshops discussed above.

In the final section of the Inspiration Card Workshop, a reflection technique is used in which participants discuss or present each of the design concepts that have been generated. This reflection is to share a common understanding rather than to evaluate ideas. In this way knowledge from the field under investigation and experience from previous situations can be shared and explored as a way of encouraging innovative ideas.

2.4.3.3 Takeaways

The Inspiration Card Workshop shows us how inspiration can be found in images and other representations of the design situation's domain context, and how exploration of that context can be a creative activity. They also show us that participatory creativity activities can be successfully undertaken in time-restricted formats.

2.5 Related Tools and Techniques

In this section, the research background to the data exploration tools and applied creativity techniques used in the CoDesign With Data approach will be discussed. Section 2.5.1 provides a background to the information visualization research that has informed the way domain-relevant data are presented to workshop participants. Section 2.5.3 discusses techniques that deliberately structure and facilitate the creative process with the aim of stimulating ideation and inspiring innovation. Using combinations of these tools and techniques enables me to make domain-relevant data accessible, engaging and inspirational to participants, and is one of the factors that differentiate CoDesign With Data from other approaches to collaborative workshops during early-stage design.

2.5.1 Information Visualization: Tools for Exploring Data

A key challenge for CoDesign With Data workshops is to present domain-relevant data in a way that is accessible to participants and which engages and inspires them. These participants are representative stakeholders and it is unlikely that they will be skilled or experienced data analysts. The field of information visualization research provides important guidance for using interactive interfaces to represent data in a way that supports insight seeking in diverse audiences.

Information visualization has classically been defined as "*the use of computer-supported, interactive, visual representations of abstract data to amplify cognition*", its purpose being "*insight not pictures*" (Card et al., 1999, p.7). To achieve this, information visualization makes use of the human visual system's powers of pattern recognition and discrimination, mapping selected data to visual variables such as colour, shape or size in order to support perceptual processing and therefore enable users to explore large amounts of what may be complex data. A detailed explanation for this process can be found in Ware, who argues, "*perception and cognition are closely interrelated, which is why the words understanding and seeing are synonymous*" (Ware, 2012, p.xvi). Information visualization has entered popular culture and been used to present data in ways engaging to public audiences in examples like Hans Rosling's Gapminder [9] presentations of international development data and Aaron Koblin's Flight Patterns [10], which displays the flight paths of US air traffic.

[9] www.gapminder.com
[10] www.aaronkoblin.com

Tufte provides seminal guidance on visually representing quantitative information, showing ways to effectively present numbers through abstract graphical images, and providing advice on how to communicate with clarity, precision and efficiency, and avoid ambiguity or distortions of what the data have to say (Tufte, 1983). Similarly, Bertin argues "*[t]he entire problem is one of augmenting this natural intelligence in the best possible way, of finding the artificial memory that best supports our natural means of perception*" (Bertin, 2011, p.xiv). By this he means finding the visual variables that will most effectively convey information and lead to insight and understanding. Few provides guidance for how these ideas of graphical clarity and effective use of visual variables can be applied to the visual analysis of data using interactive software (Few, 2009). His focus in this guidance is an understanding of how best to represent quantitative data for the purposes of analytical exploration. This is important because we aim to present information in ways that are understandable to participants.

Shneiderman identified information visualization as one of the key tools to support twenty-first century creativity, when describing the GENEX model of creative processes (Shneiderman, 1999; Shneiderman, 2000). According to Shneiderman, it is particularly the opportunities information visualization provides for comparing alternatives thoroughly and rapidly, to help users gain insight and generate ideas or hypotheses that are important in supporting creative activities. This is important because my aim is to use the insights gained from data to inspire participants' creativity, and to provide a platform on which they might share their experiences and knowledge to better understand the context these data come from.

Elmqvist et al. discuss interaction in information visualization using Csikszentmihalyi's term *flow* as a key signifier for what they term '*fluid interactions*' (Elmqvist et al., 2011). Flow describes the state of total immersion in an activity, particularly creative activities (Csikszentmihalyi, 1997). Elmqvist et al. use *fluid interactions* to breakdown and describe the aspects of interaction style used in those visualizations highlighted as best in class. These best in class exemplars then form the basis for a useful set of design guidelines. (Elmqvist et al., 2011).

One of the systems highlighted as demonstrating fluid interactions is the Name Voyager application (Wattenberg & Kriss, 2006). This is an online application for exploring the historical popularity of American baby names. Through tools such as Name Voyager, Wattenberg and Kriss have shown how information visualization can encourage people to undertake data exploration as a social activity. They describe how the Name Voyager application was often used by groups of two or more users to find subtle patterns and gain or share knowledge. Wattenberg and Kriss argue that it is factors such as smooth animation and large prominent interaction elements that facilitate this social activity (Wattenberg & Kriss, 2006). These are important lessons for this research, where information visualization will be employed to inspire the creativity of non-expert users working in collaborative activities.

As the field of information visualization research matures, the range of activities visualization is employed to support has expanded, and new styles of visualisation design have emerged. Pousman, Stasko and Mataes (2007) describe a class of *casual information visualization* characterised as being non-work related, with a user base not necessarily expert in data analysis, and where utilitarian design goals can be traded in for a wider interpretation of what is deemed useful. The visualization styles they describe are used to support peripheral or ambient information seeking, social data analysis, and as data art. Viégas and Wattenberg (2007) use *artistic visualization*' as a classifier to describe visualization techniques that express a particular, contextualized viewpoint. Kosara (2007) uses '*artistic visualization*' to describe examples that evoke deep emotional or intellectual responses.

Manovich (2011) makes a distinction between traditional information visualization and '*direct visualization*'. According to Manovich, information visualization uses graphical primitives, such us point, line, and simple geometry, "*to stand in for objects and the relations between them*"; and spatial variables, such as size, position, and shape, "*to represent key differences in the data and reveal patterns and relations*". Manovich then identifies *direct visualization* as a new form "*creating new visual representations from the actual media objects (images, video) or their parts*" (Manovich, 2011). An example of this can be seen in TimeLine[11]. Manovich has also noted elsewhere that any mapping between data and representation is potentially arbitrary, and has argued, therefore, that information visualization techniques might be employed to display the ambiguity inherent in experience (Manovich, 2002). These different ways of

[11] manovich.net/index.php/exhibitions/timeline

representing data are of particular importance to the design experiments described in Chapter 4 and Chapter 7.

As we can see from this brief discussion of the literature, information visualization research provides a wealth of resources to help select appropriate representations with which to present domain-relevant data to workshop participants. However, there remain some key gaps in this research. Most notably, Shneiderman first identified information visualization as being a key technology for supporting creative processes at the turn of the twenty-first century (Shneiderman, 1999). However, there has been little or no research that has focused on explaining why this might be so, or on how this support can be provided since then.

Evidence for this gap in the research is provided by a search of the IEEE Explore, ACM Digital Library, Academic Search Complete, Science Direct and JSTOR databases, together with the City University London library online database. This search, using the search terms 'creativity AND information visualization' and 'creativity AND data visualization' and searching title, abstract and author keyword fields, returned just one entry (apart from that related to Shneiderman's original work), which described in detail how information visualization was explicitly used as a creativity support tool. Webb and Kerne seek to support information-based ideation for users of digital libraries or information collections (Webb & Kerne, 2011). They highlight the implicit structuring of information used in their visualization technique, as being in opposition to the formalization and explicit structuring typically required by information visualization. Whilst there are lessons to be learnt from this work, it is not an approach directly relevant to the research detailed in this thesis.

This research gap also tells us that, although there are key lessons to be learnt from research in this field, I cannot simply import the practices of information visualization designers into my work without seeking some empirical evidence for their efficacy in the setting I aim to employ them. This is a key motivation for undertaking the design experiments described in Chapter 4 and Chapter 7.

2.5.2 How Visualization Tools are Used in this Research

2.5.2.1 Insight Seeking

Insight is the key reason for visualizing information (Card et al., 1999, p.7). It is also a key stage in many models of creative processes (Lubart, 2001). Exploring ways to help co-designers find insight in domain-relevant data is one of my research objectives. However the processes by which information visualization users seek and gain insight are not well understood (North, 2006; Yi et al., 2008). North suggests that to study such insight seeking, it is better for researchers to observe the insights users gain on their own, through the use of think-aloud or similar protocols, rather than instructing them on exactly what insights to look for (North, 2006). However, within the constraints of time limited workshop activities, there may also be a requirement to provide some structure or guidance for participants. With this in mind, I experimented with techniques that encourages participants to freely explore the visualized data but that also use simple, open questions to provide loose guidance and prompt participants to record the things that they find interesting or important. Examples of this *Insight Seeking* technique can be found in the workshops reported in chapters 4, 5 and 8.

2.5.2.2 Using iPads for Visualization Interfaces in Workshops

The form factor of the device used to present interactive information visualization interfaces to participants is another important factor in a co-design workshop setting. Henderson and Yeow (2012) studied the use of iPads in primary education and found that children would pick the device up and use it intuitively. They found strong evidence that the iPads were engaging for, and supported the collaboration of, groups of children undertaking project work. The form factor, mobility and relatively large multi-touch screen, they suggest, are well suited to facilitating shared use. This suggests that an iPad would also support workshop participants in collaborative data exploration whilst they simultaneously undertake other tasks associated with idea generation, such as sketching, note taking, writing on post-its and generative activities. Another option that might have been an alternative, tabletop computers, was ruled for practical reasons of portability. Whilst other devices may also be suitable, iPads have proved effective in all the studies in which I have used them, giving me no practical reason to experiment with alternatives as part of this research.

2.5.3 Applied Creativity: Techniques for Ideation

The application of techniques, methods or activities that aim to deliberately stimulate creativity, innovation and ideation has been a subject of interest at least as far back as the publication of Alex Osborn's seminal Applied Imagination (Osborn, 1952) in 1952. This was the book in which the term and technique of brainstorming, probably the most widely known method of deliberate creativity, was first introduced. Since then, many different techniques have been published and popularised e.g. (De Bono, 2010; Foster, 1996), and Osborn's original ideas expanded and developed into the Creative Problem Solving (CPS) framework (Isaksen et al., 2011). A key aspect of the CPS approach, also found in similar methods e.g. Synectics (Gordon, 1961), is the role of facilitation as a form of creative leadership. This, according to VanPatter (2012), is a major factor in distinguishing such applied creativity techniques from Design Thinking, e.g. (Brown, 2008), because it separates process knowledge, about how to stimulate and organise creative ideas, from content knowledge, about the subject of design. For an overview of the development of CPS, and a listing of some of the empirical research that has gone into its verification, see (Isaksen & Treffinger, 2004). Elsewhere, Biskjaer et al. (2010) provide an overview of methods for inspiring creativity in interaction design.

The techniques these approaches to applied creativity use have been categorized on a number of occasions, most of which have resulted in two distinct groups of techniques. These two groupings have variously been labelled *logical* and *intuitive* (Shah et al., 2000), *linear* and *intuitive* (Miller, 1987, pp.64-81), and *analytical* and *intuitive* (Couger et al., 1993). In each case the discriminating features of the two groups are closely similar, and in this thesis I have adopted the terminology *analytical* and *intuitive* when discussing these two categories.

2.5.3.1 Analytical Techniques for Idea Generation

Applied creativity techniques that promote an *analytical* style of creative thinking or problem solving provide a structure within which candidate solutions can be sought. They take advantage of different ways to organize known information and can be described as being sequential, systematic, logically ordered and involving an organized decomposition and analysis of the problem at hand. When a candidate solution is discovered using an *analytical* style of creative thinking, it may seem like the obvious or inevitable result of the process undertaken. Examples of *analytical* style creativity techniques include: Force Field Analysis, Progressive Abstraction, 5WsH, and Inversion. In this research I have used the 5WsH analytical creativity technique, see section 2.5.4.1.

2.5.3.2 Intuitive Techniques for Idea Generation

Applied creativity techniques that prompt an *intuitive* style of thinking are described as being holistic, taking a single step, and often rely on a single image or symbol to stimulate unconscious thought processes. Candidate solutions that are discovered using an *intuitive* style of creative thinking may appear to come from nowhere and be surprising to the person who generates them. They may be considered unpredictable, and yet they can also lead to novel ideas. Examples of *intuitive* style creativity techniques include: Wishful Thinking, Metaphor, Imagery, and Brainstorming. In this research I have used the intuitive creativity technique Brainstorming with Post-its, see section 2.5.4.2. The generative design research techniques I have used can also be said to prompt a similarly intuitive style of creative cognition, see section 2.4.2.

2.5.4 Using Creativity Techniques in this Research

Whilst the activities in each of the workshops reported in this thesis were designed specifically for the purposes of that particular workshop, a number of these applied creativity techniques are repeated, or are influential, across different workshops. 5WsH was selected because it is a simple and powerful technique for structuring co-designers' ideas, which can be used in many situations. Brainstorming was selected because it is probably the most familiar creativity technique, is a powerful way of generating ideas quickly and offers variations that make it useful in different situations. Combinational creativity was selected because it makes explicit the key factor explaining creative processes, i.e. combining existing ideas and concepts into new ones. Each of these techniques is described in detail below.

2.5.4.1 5WsH

As we saw in section 2.5.3.1 a subset of applied creativity techniques has been categorised as *analytical*. Amongst these is 5WsH in which the six basic *who, what*, *why*, *where*, *when* and *how* questions, often associated with detective work or journalism, are used in a systematic and cyclical way to widen an individual or group's perspective on the situation at hand. In the CPS approach 5WsH is associated with an exploration of the available data during the '*Understanding the Challenge*' phase (Isaksen et al., 2011, p.p.66). In other instances it is used as a structured framework to identify problems and opportunities, and to provide a comprehensive approach to describing resolutions (Couger et al., 1993).

In the workshops described in chapters 6, 7 and 8, I used custom hexagonal worksheets as a way of further structuring participants' outputs when using this technique. These hexagons are divided into six triangular segments, each of which contains one of the '*who, what*, *why*, *where*, *when* and *how*' questions. These are used because the hexagonal shape suggests equal weighting for each question, and because they require turning and manipulation such that the questions might be answered in any order chosen by the participants. In addition, hexagons can also be tessellated to make connections between the edges, linking different ideas, entities, or data. The 5WsH technique is used in the workshops reported in chapters 6, 7 and 8.

2.5.4.2 Brainstorming

Brainstorming, first described by Osborn, is arguably the most widely known and widely used applied creativity technique (Osborn, 1952, p.52). It is an important and effective part of the Creative Problem Solving (CPS) framework (Isaksen et al., 2011, pp.39-41). In Brainstorming, a problem is stated and then ideas off the top of the head are suggested in any order. One of the key ground rules is that evaluation and judgement are suspended until all ideas have been collected.

A variation on brainstorming is Brainstorming with Post-its, in which participants write down their ideas individually and then share and build on them. This results in a reduction in the effect of dominating individuals, ensures all participants have an opportunity to share their ideas, and can lead to idea rotation, with different participants expanding and improving the ideas of others (Couger et al., 1993).

Brainstorming with Post-Its has been widely used in the requirements gathering Creativity Workshops discussed in section 2.4.1 (Maiden et al., 2010). Another variation on this technique is Brainstorming with Creativity Triggers (Jones et al., 2008). In this technique, specific words or *triggers* are used to prompt and focus idea generation in particular areas. Creativity Triggers have been used as an effective guide to brainstorming in requirements gathering workshops. Brainstorming with Post-its is used in the workshops described in chapters 4, 5, 7 and 8. A variation on Brainstorming with Creativity Triggers, which used Behaviour Change Triggers, is used in the workshop described in Chapter 8.

2.5.4.3 Combinational Creativity

Creativity has often been described in terms of a process that involves combining existing concepts (Boden, 2004, p.3), or blending matrices of thought (Koestler, 1964, p.95) into novel ideas. In CPS (Isaksen et al., 2011, p.39), *Seeking Combinations* is a technique for building on previously generated ideas by using them as the basis for suggesting new ones, and connecting one option to another. Combinational creativity techniques that explicitly ask participants to take ideas from two different sources, such as unconnected functions or features, and combine them, or to apply a familiar service to new information or new delivery mechanisms, have been used effectively in requirements gathering workshops (Maiden et al., 2004). Activities in which aspects of combinational creativity techniques are used feature in each of the workshops reported in this thesis. The most explicit examples of this are in the workshops reported in chapters 4, 6 and 7.

2.6 Summary of the Research Background

In this chapter we have seen how organising and describing the contributions made by the research undertaken for this thesis in terms of tools, techniques, methods and approach can help to generalise its findings. This is because each of the different elements can then be taken by other design researchers and refined, combined, and applied in new contexts. We have also seen how positioning the CoDesign With Data approach within human-centred design research, as an approach that aims to design with stakeholders, and as one that has been inspired by design-led and research-led methods, helps to clarify its philosophical grounding. I have described some key related work, providing details of three different approaches to stimulating or inspiring participant creativity in design workshops. Each of these approaches has provided important lessons, regarding different tools and techniques and how they can be applied, to take into my own workshop design. Finally, I have discussed in detail, research in information visualization that strongly informs the tools I develop for creatively exploring domain-relevant data with workshop participants; and also applied creativity techniques that inform and inspire the activities where these tools are used. Chapter 4 through to Chapter 8 report individual studies. Where appropriate, each of these chapters reviews additional literature of specific importance to that study. A listing of the tools and techniques used in each of these studies is provided below.

Chapter 4	Tools: *iPad Information Visualization Interface, Workshop Stationary.* Techniques: *Brainstorming with Post-its, Combinational Creativity, Insight Seeking.*
Chapter 5	Tools: *Generative Design Toolkit, iPad Information Visualization Interface.* Techniques: *Brainstorming with Post-its, Generative Design, Insight Seeking.*
Chapter 6	Tools: *Generative Design Toolkits* Techniques: *5WsH, Combinational Creativity, Generative Design.*
Chapter 7	Tools: *iPad Information Visualization Interface, iPad Flickr Photograph Interface, Printed Reports, Supplementary Information Sheets, Worksheets, Workshop Stationary.* Techniques: *5WsH, Brainstorming with Post-its, Combinational Creativity*
Chapter 8	Tools: *iPad Information Visualization Interfaces, Worksheets, Workshop Stationary* Techniques: *5WsH, Brainstorming with Behaviour Change Triggers, Brainstorming with Post-its, Insight Seeking.*

Table 2: Listing of the tools and techniques used in individual studies

3 Methods

3.1 Research Methods

In order for enquiry to qualify as research suitable for academic recognition, it should meet the criteria of being "*systematic enquiry whose goal is communicable knowledge*" (Archer, 1995). This requires that: "*it is pursued according to some plan*"; "*it seeks to find answers to questions*"; "*the objects of the enquiry are posed by the task description*"; "*the findings of the enquiry must go beyond providing mere information*"; and "*the findings must be intelligible to, and located within some framework of understanding for, an appropriate audience*" (Archer, 1995). To help assess whether enquiries meet these criteria, particularly where they involve an element of enquiry through practitioner activity, such as the case studies reported in chapters 5, 6 and 8 of this thesis, Archer suggests we ask seven questions:

1. *Was the activity directed towards the acquisition of knowledge?*
2. *Was it systematically conducted?*
3. *Were the data explicit?*
4. *Was the record of the conduct of the activity "transparent", in the sense that a later investigator could uncover the same information, replicate the procedures adopted, rehearse the argument conducted and come to the same (or sufficiently similar) conclusions?*
5. *Were the data employed, and the outcome arrived at validated in appropriate ways?*
6. *Were the findings knowledge rather than information?*

7. *Was the knowledge transmissible to others?*

Furthermore, to be considered useful design research, studies should also aim for a degree of generalizability because this "*enables the designer to move from an endless succession of unique cases to broad explanatory principles that can help solve many kinds of problems*" (Friedman, 2003). I will return to these questions in section 9.4, where I will reflect on the methods adopted in this research to provide evidence that it should be considered suitable for academic recognition.

Generating the new design knowledge that makes the academic contribution stated in section 1.2.2, and answers the research question set in section 1.2.1 has largely been a pragmatic and practical undertaking. Therefore, within this thesis I do not take a dogmatic position with regards to the philosophy of design research, but rather take what I feel to be the best and most useful advice on a case-by-case basis. This pragmatic approach combines simple design experiments, reported in chapters 4 and 7, and situation specific case studies, reported in chapters 5, 6 and 8.

The aim of a design experiment is to explore the practice and performance of design teams in an empirical study where variables of interest are as far as possible controlled, while other factors remain as representative of real world design contexts as possible. Cash et al. (2012) argue that such experiments can be very useful in showing possible trends and giving valuable insights into particular design contexts.

The purpose of a design case study is to investigate the effects of the intervention being studied in a particular real world context. Here the researcher may be an active participant, devising, planning and implementing the intervention, such research is termed Action Research. Whilst the findings of such research may well be situation-specific and non-objective, the value of Action Research to design studies is widely acknowledged e.g. (Archer, 1995).

Such an approach is not novel. Design researchers have used experimental studies for over forty years and such empirical study forms a valuable part of design research providing insight in support of theory generation (Cash et al., 2012). Likewise, studying the effects of interventions made in a particular context is also valuable as it can "*produce insights which might otherwise never be obtained*" (Archer, 1995) and which can lead to hypotheses for testing in a more generalised setting.

3.2 Evaluation Methods

To evaluate the research detailed in this thesis, I have attempted to follow Cross (1999) in investigating three main factors: *the people designing*, including empirical studies of designer's behaviour; *the design processes they undertake*, including the development and application of techniques to help the designer; and *the design products that result*. I have adopted a pragmatic, mixed methods approach to evaluation and data collection in which I have combined the responses from questionnaires with the qualitative reflections of participating co-designers, evaluated the creativity of design outputs, and analysed video data. Triangulating different evaluation metrics is an approach that has been used successful in evaluating creative experiences (Carroll & Latulipe, 2012).

Each of the studies reported in this thesis includes methods for asking the *people designing* to provide data evaluating the *design processes they undertake*. This data is provided through their written reflections and their completed questionnaires. I have labelled this evaluation: ***Supporting the People Designing***. Each of the studies reported also includes an evaluative measure of the *design products that result* from the workshops. I have labelled this evaluation: ***Assessing the Design Product***. The two design experiments reported in chapters 4 and 7 also use analysis of video recordings to report on detailed aspects of how the *people designing* perform the *design processes they undertake*. In these design experiments I have labelled this evaluation: ***Understanding the Design Process***. Descriptions of the key evaluation methods I have used are listed below.

3.2.1 Creativity Support Index

3.2.1.1 Data Collection

The Creativity Support Index (CSI) (Carroll et al., 2009) is a standardised survey metric, similar to the NASA TLX questionnaire (Hart & Staveland, 1988), and is used for evaluating the effectiveness with which a given tool provides support for it’s user's creative processes. It is a questionnaire made up of two parts. In the first part, participants answer twelve questions, which assess six different dimensions associated with creativity. These six dimensions have been derived from the literature on creativity and creativity support tools. They are: *Collaboration*, *Enjoyment*, *Exploration*, *Expressiveness*, *Immersion*, and *Results Worth Effort*. There are two questions for each dimension, each addressing it from a slightly different perspective. In the second part of the CSI, participants are asked to answer a total of fifteen questions that are designed to assess the relative importance of each of the six creativity support dimensions to the activity the participant has been undertaking. The participants in the studies reported in chapters 7 and 8 were each given printed copies of the CSI questionnaire to complete individually.

3.2.1.2 Data Analysis

To calculate an individual participant's CSI evaluation score, I first take the rating they gave for each of the six creativity support dimensions. Following this, the rating they gave for the importance of each of the creativity support dimensions to the activity they have just undertaken is calculated. The product of these two values is then standardised to give a score out of one hundred. This provides a metric based not only on the effectiveness of the tool with relation to the different dimensions of creativity support, but one that also reflects the relative importance of each off these dimensions to the creative task being undertaken; an indication of the extent to which each participant felt that the tool they had been using supported their own creative processes. The analysis of CSI evaluation scores for the studies reported in chapters 7 and 8 are included in Appendix D of this theses.

3.2.2 Evaluating Generative Design Outputs

3.2.2.1 Data Collection

The outputs generated in activities 1 and 5 of the E.ON workshop reported in Chapter 5, and in each of the activities in the MIRROR workshop reported in Chapter 6, resulted from the type of *making* activities used in the Generative Design Research detailed in section 2.4.2. They might best be described as collage and are captured on the worksheets co-designers created. The video recordings of co-designers explaining their design ideas and talking through the things they have made provide supporting data here.

3.2.2.2 Data Analysis

Generative Design Research is typically *research for the purpose of design practice* (Archer, 1995), and its qualitative outputs are typically analysed rather than evaluated or assessed for creativity. In order to evaluate these outputs, I built on guidance provided for analysing their content (Sanders & Stappers, 2012, pp.197-206). I sought to assess whether participants were gaining insight and understanding from the CoDesign With Data activities that would lead to creative design ideas. To do this I looked at the degree of richness and detail in the representations co-designers created, as this would provide evidence of their gaining and/or sharing an improved understanding of the workshop's domain context.

In the study reported in Chapter 5 examples of this richness and detail might include: the way that insights found in the data were explained with combinations of photos; the number of these representations of data insight; the detail with which they are represented; whether the insights found were connected to form a consistent story; and how the stories created by different groups differed from each other (thereby reflecting the individuality of the participants creating them). In the study reported in Chapter 6 examples of this richness and detail might include: the detail with which data are represented, e.g. the type of data, how they are generated and where they are used; the number of implicit connections between existing applications that had been made explicit; and the number of new opportunities identified. The processes and measures involved in these evaluations are discussed in detail in their respective chapters. Examples of the outputs generated in these activities are included in Appendix D of this thesis.

3.2.3 Rating the Creativity of Design Outputs

3.2.3.1 Data Collection

A number of other workshop outputs were also assessed for creativity. In the study reported in Chapter 4, the ideas generated during each instance of Activity 3 in all the workshops were collated, counted and rated. In the study reported in Chapter 6, the new connection ideas from Activity 2 and the new use ideas from Activity 3 were collated and counted. In the study reported in Chapter 7, individual ideas on post-it notes, generated during Activity 3, were collated and counted, and the design concepts generated during Activity 4, represented on hexagonal 5WsH worksheets, were rated. In the study reported in Chapter 8 the Problem Statement generated at the end of day 1 of the workshop, and the Selected Design Idea described at the end of day 2 of the workshop, and captured on a 5WsH worksheet, were assessed. A full listing of the ideas generated in Activity 3 of the study reported in Chapter 4 and in Activity 3 of the study reported in Chapter 7, together with a transcript of each of the design concepts generated in Activity 4 of the study reported in Chapter 7 are included in Appendix D of this thesis. The Problem Statement and Selected Design Idea from the study reported in Chapter 8 are included in Appendix B of this thesis.

3.2.3.2 Data Analysis

The first step in the analysis and rating of design ideas is to collate all the ideas from a single study together. Each idea, either from an individual post-it note or other representation such as a 5WsH worksheet, is transcribed into a separate spreadsheet entry. Video recordings of co-designers' explanations of their design ideas are also transcribed. Following this I then took two different approaches to assessing the creativity of these design outputs. First, where there were multiple ideas generated during a workshop activity, I calculated the total number of ideas generated for each instance of that activity. This gives a measure of fluency, which has been identified as being an important attribute of creative thinking (Guilford, 1966). It was an approach used to assess the outputs of Activity 3 in Chapter 4, activities 2 and 3 in Chapter 6, and also Activity 3 in Chapter 7.

The second approach is for the creativity of individual ideas to be assessed through a rating. In these assessments of the creativity of design ideas, two components are generally considered. These components are *novelty*, and some notion of utility, such as *usefulness* or *appropriateness*. This is because novelty and appropriateness (or usefulness) are considered to be the two key dimensions to many definitions of creativity, for example (Sternberg & Lubart, 1999). Such an approach to evaluation is outlined in Dean et al (2006) and has been previously used in Jones et al (2008). This measurement can typically be done through the subjective ratings of domain experts (Hocevar, 1981). In the study reported in Chapter 4, three independent domain experts assessed each idea generated during Activity 3 for *novelty* and *appropriateness*. These experts were two postdoctoral engineers and an experienced domestic energy advisor.

In addition to measuring aspects of novelty and utility separately, Amabile has argued that assessors are able to consistently rate creative output as a single measure, using their own consensual definition of creativity (Amabile, 1983). Following this, each output from Activity 4 in the study reported in Chapter 7 was assessed by participants, each of whom rated the ideas of all groups apart from their own, for all three factors: *creativity*, *novelty* and *usefulness*. Similarly, each of the two outputs from the study reported in Chapter 8 was assessed by three independent domain experts; including a manager responsible for recycling and waste, a student union official running a waste and recycling initiative, and an associate editor of the UK's leading materials and recycling magazine. These evaluations are discussed in more detail in their respective chapters. The collated assessments for each of the studies reported are included in Appendix D of this thesis.

3.2.4 Reflection Postcards

The Reflection Postcard method of evaluating creativity support during workshop activities is a novel method I developed during this research. It was presented at the ACM CHI 2013 workshop '*Evaluation methods for creativity support environments'* (Kerne et al., 2013). A short paper is included in Appendix A of this thesis.

3.2.4.1 Data Collection

During a co-design workshop we often want to create and maintain an atmosphere that is relaxed, supportive, engaging and playful. However, we might also want to gather evaluation data whilst participants' experiences using the tools or techniques under investigation are fresh, i.e. during the workshop itself. This can lead to a conflict of interests. Stopping generative or ideation activities to ask participants to complete questionnaires highlights academic concerns, which may lead them to feel they are being tested. This may cause anxiety, which has been shown to impact negatively on creative processes during idea generation activities, for examples of this see (Baas et al., 2008).

The Reflection Postcard method is a way of capturing evaluation data that can become part of the workshop's creative activities. Participants are given individual postcards containing reflection prompts derived from the study's research questions, which are used to assess selected aspects of the workshop's activities. Each postcard captures evaluation data similar to that gained from an open questionnaire question, but uses a more playful form factor that I believe is more appropriate to the workshop context. This is a form factor familiar to many people and that is also evocative of sharing experiences. The prompts should be relatively short and directed towards answering a particular area of concern. The postcards should feel personal, encourage reflection and allow space for creative responses.

A typical example of the prompt used in a Reflection Postcard is:

"Please reflect on your involvement in the previous two activities. Write a few sentences thinking in particular about how

engaged you were, how absorbed or distracted, and how easily you feel you worked with other members of your team. Try to think about the extent to which the technology helped or hindered you in this regard"

This was used to address issues of engagement and collaboration during the case study reported in Chapter 5. Another example prompt is:

"Please reflect on your involvement in today's workshop. Write a few sentences thinking in particular about whether your understanding of the subject matter has increased and if so which were the particular elements of the workshop that helped you gain this improved understanding."

This was used to assess changes participants' domain understanding in the case study reported in Chapter 8. The prompts on each of the Reflection Postcards given to participants during this research can be found in the chapters reporting the studies in which they are used. They are also included as part of Appendix C.

3.2.4.2 Data Analysis

The first step in analysing Reflection Postcards is to transcribe and collate each participant's response. Typically a single postcard will be used to address two related areas of concern. Therefore, the next step is to check that the participants' response has addressed each of these concerns. Following this, each response is placed into one of five categories: *totally positive*, *partially positive*, *neutral*, *partially negative* or *totally negative*. The purpose of these categories is to gain a simple overview of the tone of participants' responses that reflects the exploratory nature of this research.

Finally, individual quotes are taken from the responses to provide a detailed illustration of participants' views. The categorisation process is explained below, using examples taken from the study reported in Chapter 5

To be considered *totally positive* the participant's response should address each of the areas concerned with only positive comments. This example shows a totally positive response to the issues of collaboration and engagement:

"I felt that we worked well as a team and found it interesting to decide on the type of family and their possible activities. The iPad was useful in deciding the uses the family made of possible equipment they had."

To be considered *partially positive* the participant's response might use qualifying words like *quite,* as we see in this example, again looking at collaboration and engagement:

"*Generally felt quite interested in the tasks as they were quite fun, I worked quite well with my team and the tech made it a lot easier to look through the data*."

Another way in which a response might be considered *partially positive* is if there is a mixture of positive and negative comments, but where the overall response is still positive, as we see in this example where engagement was considered *totally positive* but collaboration *partially positive*:

"*I felt engaged all the time; found it easy to concentrate and time passed quickly. Worked easily with other team members. Technology helped but with only one iPad it was difficult to analyse all the data in the time allowed.*"

Responses classed as neutral were generally those where a particular concern was not addressed.

To be considered partially negative, a response might include qualifying language, as seen in this example that was considered *partially negative* for both gaining an overview and spotting patterns and relationships:

"*A bit difficult to get the info from the iPad. So some of the patterns were not too easy to appreciate*."

Another way a response might be considered partially negative is if it included a description of a problem or a negative experience that was mitigated in some way, as seen in this example that was considered *partially negative* for generating ideas and exploring alternatives but *neutral* with regards to incorporating existing knowledge:

"*Not too easy to explore the ideas suggested by the iPad, but I did get used to it!!*"

To be considered totally negative, a response might report a problem or a negative experience without any additional mitigating details, as seen in this example that was considered *totally negative* for both gaining an overview of the data and also spotting patterns and relationships:

"*It was difficult to form an overview as there seemed little consistency in the data. If I knew the household this would be ok. Very hard without some more information.*"

Each use of Reflection Postcards is discussed further in the relevant chapters. A full listing of all the analysed postcard responses can be found in Appendix D of this thesis.

3.2.5 Video Analysis

3.2.5.1 Data Collection

In order to help me gain a better understanding of participants' creative processes, each of the design experiments reported in chapters 4 and 7 were video recorded. In each workshop undertaken for these studies a single video camera was placed at a distance that would not interfere with participants' activities but would capture an overview of their actions, together with their associated conversations.

3.2.5.2 Data Analysis

To better understand the specific activities under investigation, key segments of these video recordings were selected for close analysis. These key segments were selected using a critical incident approach in which "*important facts concerning behaviour in defined situations*" are extracted using a technique in which "*only simple types of judgement are required of the observer*" (Flanagan, 1954).

In the study reported in Chapter 4, it is participants' insight seeking and sensemaking activities that are under investigation. In this chapter, a thematic analysis (Braun & Clarke, 2006) based on theories of sensemaking (Pirolli & Card, 2005; Russell et al., 1993) was used to explain participants' behaviour. In the study reported in Chapter 7, it is the way in which participants' ideas emerge during divergent ideation sessions in which they are given one of two digital design artefacts as a source of inspiration that is investigated, using a microanalysis technique of critical incidents (Flanagan, 1954) that describe this behaviour. These examples of video analysis are discussed in detail in their respective chapters. Examples of the transcribed video data taken from these studies are included in Appendix D of this thesis.

3.2.6 Additional Evaluation Methods

In addition to the methods described above, other evaluation methods used during this research include: questionnaires to assess the importance of the tools and techniques under investigation, and the influence of these tools and techniques on participants' design ideas; analysis of the provenance of design ideas; and thematic analysis (Braun & Clarke, 2006) of design outputs to assess sensemaking. Further details of these evaluation methods are included in the relevant chapters. Examples of the questionnaires can be found in Appendix C and of the analysed data in Appendix D of this thesis.

3.3 Roadmap to the Individual Studies

Chapter 4 through to Chapter 8 report individual studies in which the particular workshop details describe the *method* adopted, the activities undertaken represent the *techniques* chosen, and the information visualization interfaces and materials used make up the *tools*. Each of these chapters also includes a reflection upon the activities undertaken, the materials used, the evaluation methods adopted, and the lessons learnt. This is to provide space to discuss the overall development of the CoDesign With Data approach, whilst using the discussion section of these chapters to discuss the findings of the individual studies. It follows Schön's understanding of "[d]*esign as a reflective conversation with the situation*" (Schön, 1995, p.76), where the design situation is the development of the CoDesign With Data approach itself. Each of these chapters also describes the particular research and evaluation methods adopted for that study. Finally, each of these chapters also finishes with a brief takeaway outlining the lessons from the study that can be offered to design practice. A list of the evaluation methods used in each study is provided below:

Chapter 4	*Questionnaires; Rating the creativity of design outputs; Thematic analysis of design outputs; Tracing the provenance of ideas; Video analysis.*
Chapter 5	*Evaluating generative design outputs; Reflection Postcards.*
Chapter 6	*Evaluating generative design outputs; Reflection Postcards.*
Chapter 7	*Creativity Support Index; Questionnaires; Rating the creativity of design outputs; Video analysis.*
Chapter 8	*Creativity Support Index; Questionnaires; Rating the creativity of design outputs; Reflection Postcards; Tracing the provenance of design ideas.*

Table 3: Listing of evaluation methods used in this thesis

Figure 3 presents a graphical representation of the *roadmap* to the individual studies reported in chapters 4 to 8. It shows the development of the *tools*, *techniques* and *evaluation methods* used in this research, highlighting where they were first used and how their use progressed.

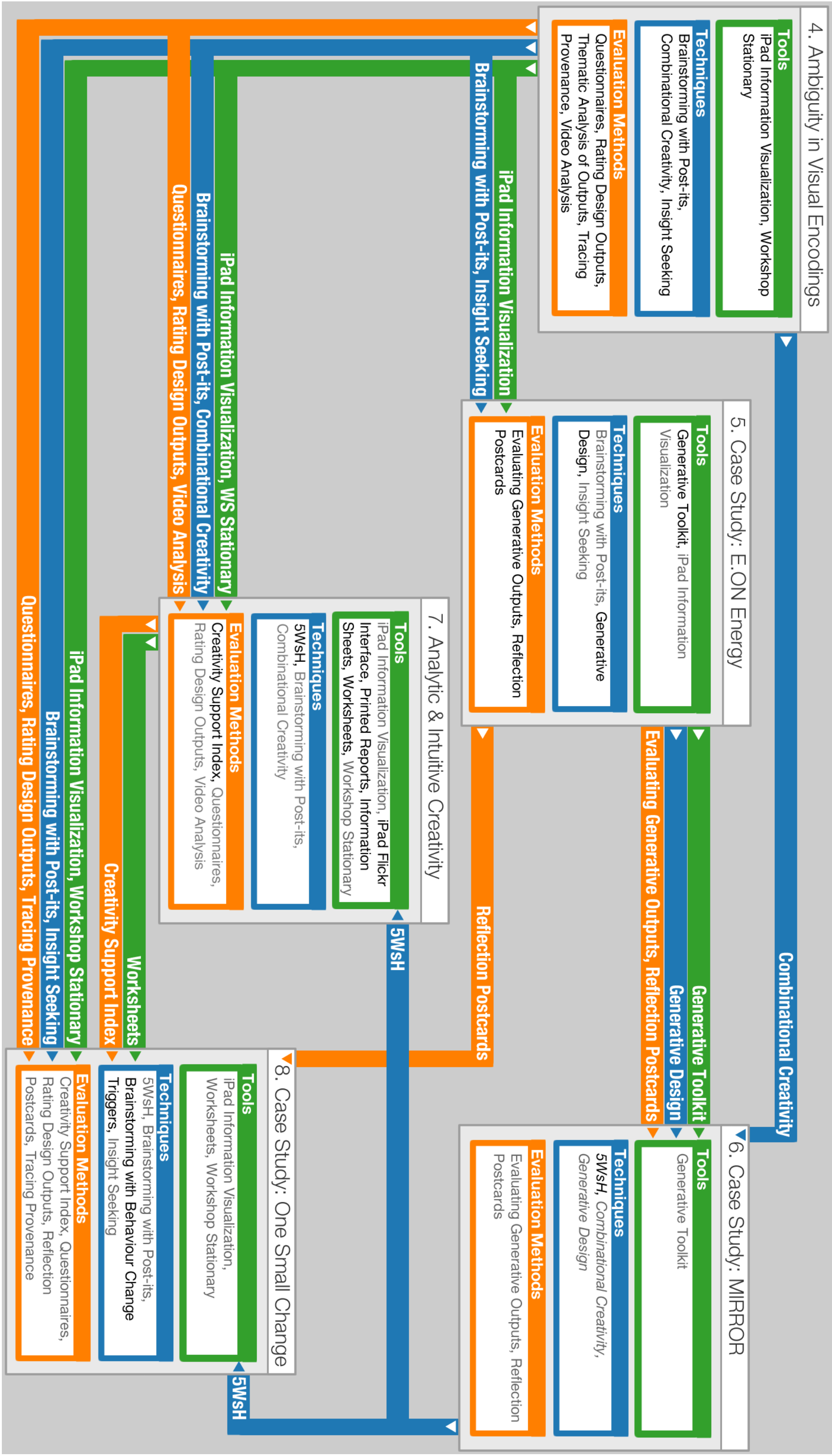

Figure 3: Roadmap to the tools, techniques and evaluation methods used in each individual study undertaken for this research

4 Ambiguity in Visual Encodings

This design experiment begins to investigate how best to present domain-relevant data to workshop participants. It studies the effects of increasing the ambiguity in the visual encoding with which smart energy data are represented on participants' ability to gain insight from these data, and on the creativity of their subsequent design ideas. Increasing the ambiguity in the visual encoding is found to have a negative impact on participants' sensemaking and therefore their ability to gain insight. This in turn led to design ideas that were considered significantly less appropriate to the domain of domestic energy. A paper detailing this design experiment was presented at the ACM Designing Interactive Systems Conference DIS 2014, in Vancouver June 2014 (Dove & Jones, 2014(b)), and is included in Appendix A of this thesis. The study was conducted as part of the "*Visualising the smart home: creative engagement with customer data*" (E.ON International Research Initiative, 2012) project, funded by the E.ON International Research Initiative.

4.1 Introduction

Design problems often exist in a complex and messy context, without stopping points, and with a high degree of associated ambiguity. Such ambiguity is a reflection of the difficulties of what have become known as *wicked problems* (Rittel & Webber, 1973; Buchanan, 1992). Yet the same ambiguity also provides an opportunity or a resource that can be embraced, both during the design process (Sanders, 2001), and in the designed artefact (Gaver et al., 2003).

In section 2.4.2 we saw how ambiguous stimuli are used in generative design research, where they are employed in toolkits to inspire workshop participants' exploration of experience and desire (Sanders, 2000; Sanders, 2001; Sanders, 2005). In another example, Gaver and Dunne (1999) use ambiguity as a key feature of the artefacts created for cultural probe packages given to older residents of a large Dutch housing development to elicit creative responses to design research questions. Similarly, Cruz and Gaudron (2010) exploit ambiguity with Open-ended objects, employed as a preparatory tool in design workshops. In addition, there are also many practitioner-oriented and commercial approaches to applied creativity, especially those used in design, which urge followers to be comfortable with ambiguity in their own creative thinking, and to experiment playfully with the many possibilities it can present e.g. (Brady, 2012; IDEO, 2013).

Several lines of research in the psychological study of creativity also suggest that working successfully with ambiguous stimuli is likely to be associated with creative outcomes. This relationship, between a tolerance of ambiguity and creativity, was highlighted in Guilford's foundational research (Guilford, 1957). Vernon considered it to be a necessary condition for creative personalities, because it permits individuals to be satisfied with partial or sub-optimal solutions to complex problems (Vernon, 1970). Sternberg & Lubart suggest that a tolerance of ambiguity enables people to remain open and continue working through complex situations longer, thereby increasing the probability that they will discover a novel solution (Sternberg & Lubart, 1995), and Zenasni, Besançon and Lubart have demonstrated the relationship empirically (Zenasni et al., 2008).

In section 2.5.1, we saw how information visualization techniques can offer a number of different ways to represent data. The data graphics described by influential authors such as Few (2006; 2009) and Tufte (1983), in which the clear and unambiguous presentation of quantitative data for analytical exploration is valued, are widely familiar through their association with business analytics. However, we also saw a number of alternative categories of information visualization design style including: *casual information visualization* (Pousman et al., 2007), *artistic visualization* (Kosara, 2007; Viégas & Wattenberg, 2007), and *direct visualization* (Manovich, 2011). Each of these shows that information visualization techniques are not restricted to the unambiguous representation of quantitative data. Moreover, Manovich also argues that any mapping between data and representation is potentially arbitrary, and that information visualization techniques might therefore explicitly display the ambiguity inherent in experience (Manovich, 2002).

4.2 Research Question

In developing the CoDesign With Data approach I am asking how domain-relevant data might be used to help co-designers find insight, and inspire creative design ideas. Therefore, investigating appropriate ways to represent these data for workshop participants is a fundamental research interest for me. For the reasons outlined above, the degree of ambiguity in the visual encoding, i.e. the mapping between data elements and graphical elements, is an important variant in the information visualization design space for me to explore. In this design experiment I wanted to know what the effects of increasing the ambiguity in the visual encoding would have on the creativity of participants' design ideas. To help understand this, I also want to know the impact on participants' ability to gain insight into the underlying data.

My initial exploration of this area was guided by the following research question:

RQ4 *What would be the effects of increasing the ambiguity in the visual encoding used to represent smart energy data on workshop participants' ability to gain insight, and on the creativity of the product and service ideas those participants subsequently generate?*

An opportunity to investigate this question came through my involvement in the "*Visualising the smart home: creative engagement with customer data*" (E.ON International Research Initiative, 2012) project. Here, we were working with E.ON Energy to creatively use the data generated by smart energy meters to inspire design ideas that would benefit consumers and help to reduce peak energy demands. Before holding a workshop with E.ON customers and staff, see Chapter 5 of this thesis, I wanted to better understand how the smart energy data should be represented. To achieve this, and answer my research question, I carried out a design experiment in which ambiguity in the visual encoding was the variable under consideration. The reasons for undertaking design experiments are discussed in section 3.1.

4.3 Workshop Details

Tools used: *iPad Information Visualization Interface, Workshop Stationary.*

Techniques used: *Brainstorming with Post-its, Combinational Creativity, Insight Seeking.*

4.3.1 Background

This design experiment consisted of four workshops with three participants each. The objective in every workshop was the same, to *'generate ideas for new products or services that could utilise the energy data generated by a smart home to benefit its occupants in a future scenario where variable electricity pricing has been introduced'*. In each workshop participants undertook two rounds of similar idea generation activities. In each of these rounds a different information visualization interface was used to provide a source of information and inspiration. Both of these interfaces represented the same domain-relevant data, but each used a different degree of ambiguity in its visual encoding. There were therefore two conditions under investigation in the design experiment:

C1: *Idea generation with inspiration and insight gained from energy data visualized with a less ambiguous visual encoding (IV1).*

C2: *Idea generation with inspiration and insight gained from energy data visualized such that ambiguity in the visual encoding is intentionally increased (IV2).*

4.3.2 Participants

Twelve participants were recruited from City University London's School of Informatics and School of Engineering and Mathematical

Sciences. Seven participants were female and five male. Ten were in the age range 25-34 and two were in the age range 45-54. Participants of different ages, gender and experience were evenly distributed across each workshop.

4.3.3 Workshop Materials

Workshop participants were provided with the following materials to undertake activities:

- *An* ***iPad Information Visualization Interface****, described in section 4.3.4.*
- *A selection of standard* ***Workshop Stationary****, including coloured marker pens and post-it notes to record their ideas, flip chart sheets and boards to capture and organise their ideas.*

Each workshop took place around a large table with plenty of space to move around and participants were provided with refreshments. The workshops were all videoed using a single camera. The facilitator used the same script in every workshop to ensure instructions were given consistently. Examples of each of the materials used can be found in Appendix C of this thesis.

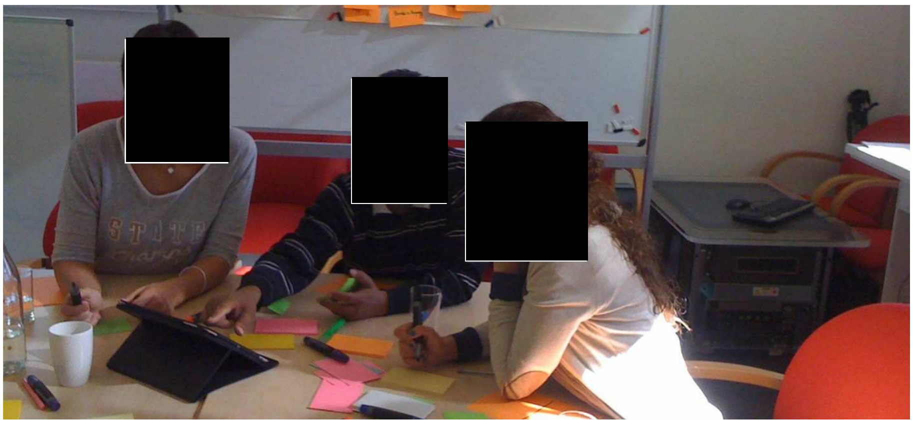

Figure 4: Participants exploring one of the information visualization interfaces during a workshop activity

4.3.4 Visualization Interface Design

This study used two custom designed interfaces. Interface IV1 was designed with a less ambiguous visual encoding, and interface IV2 was designed with ambiguity in the visual encoding intentionally increased. Both were developed using the D3 JavaScript library (Bostock et al., 2011), and presented to participants using iPads (see Figure 4), for reasons discussed in section 2.5.2.2.

4.3.4.1 Data

The same data were visualized in both interfaces. These data were randomly selected from a set of anonymised electricity consumption data generated by the smart plugs and smart meters deployed in a test-bed of one hundred and thirty households that make up a long-term technology trial in Milton Keynes, UK. These represent consumption records for selected appliances named by the household (e.g. refrigerator or T.V.), and for total electricity consumption, all generated at three-minute intervals.

4.3.4.2 IV1: Less Ambiguous Visual Encoding

4.3.4.2.1 Visual Design

Interface IV1, Figure 5 and Figure 6, is designed with a less ambiguous visual encoding. It is based on a dashboard style of interface that utilizes features including a bar chart to show consumption within price bands; a linear timeline and bubble chart to show consumption through 24 hours; and area charts to show percentage of consumption in price bands. Each of these elements is commonplace within information visualization design. IV1 follows guidelines for designing quantitative data clearly and unambiguously to enable analytical exploration, found in Few (2006; 2009) and Tufte (1983). In particular, Tufte advises that it is important to include "*Clear detailed and thorough labelling to defeat graphical distortion and ambiguity. Write out explanations of the data on the graphic itself. Label important events in the data.*" (Tufte, 1983, p.56) Few describes well-designed dashboard interfaces as delivering information that is: "*[d]isplayed using concise and often small media that communicate the data and its message in the clearest and most direct way possible*" (Few, 2006, p.98). In this interface, the days, appliances and units of measure (cost and kilowatt hours) are clearly labelled, and easily identifiable scales are used to help fix the values of data items in users' minds.

4.3.4.2.2 Interaction

IV1 is an interactive information visualization interface. The data in IV1 are filtered via buttons: along the bottom, representing the appliance types; along the top, representing days of the week; and on the right hand side of the interface, representing the units of measure. Figure 5 shows IV1 in its default state displaying the data for *total electricity* consumption, on *Monday*, and measured in *kilowatt-hours*. The filtering is AND filtering, Figure 6 shows how the updated data reflect selection of the *washing machine* from the appliances list, *Thursday* from the days, and *cost*, as a unit of measure. These selections update each element of the visual interface to reflect the corresponding data values. Interface IV1 is available to use online[12]

[12] www.grahamdove.com/eon/infovis1.html

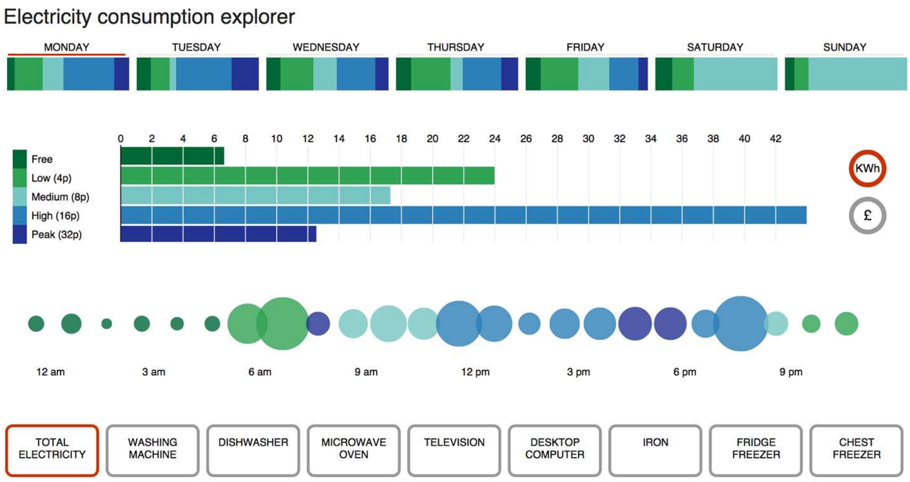

Figure 5: Screenshot of IV1 the information visualization interface designed with a less ambiguous visual encoding

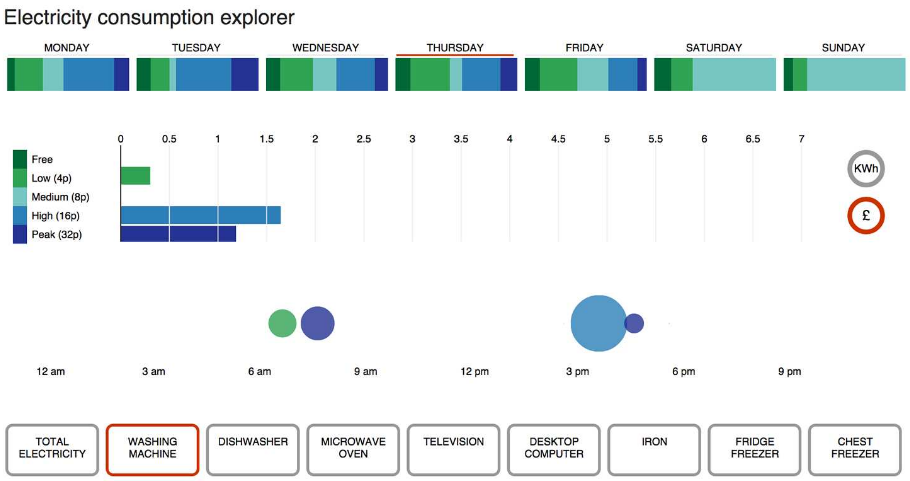

Figure 6: Screenshot of IV1, filtered to show the cost of washing machine energy consumption on Thursday

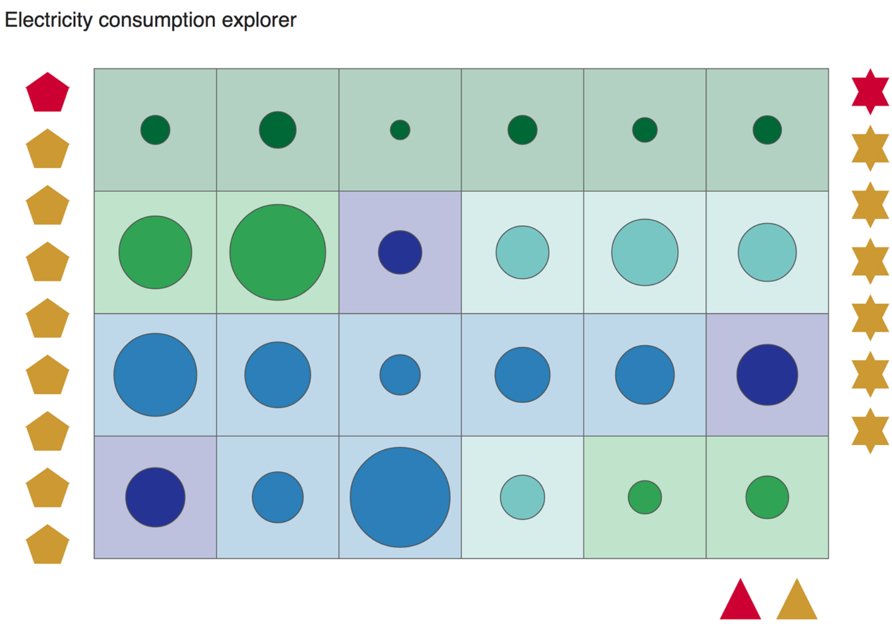

Figure 7: Screenshot of IV2 the information visualization interface designed with a more ambiguous visual encoding

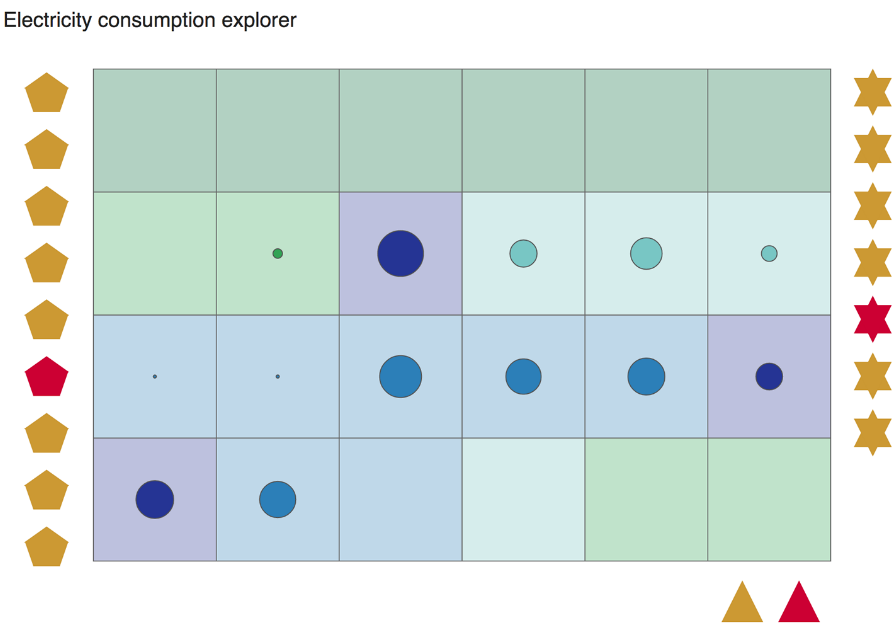

Figure 8: Screenshot of IV2, filtered to show the cost of washing machine energy consumption on Thursday

4.3.4.3 IV2: More Ambiguous Visual Encoding

4.3.4.3.1 Visual Design

IV2, Figure 7 and Figure 8, is designed with ambiguity in the visual encoding intentionally increased. With this design, the aim is to represent the data at a level of abstraction that offers multiple possible interpretations. In IV2 the familiar linear timeline was replaced with a grid-based representation of the 24 hours in a day. However, the use of a bubble chart representation to show energy consumption was retained. This hinted at consumption within a given period of time but also remained open to alternative interpretations.

IV2 avoids using textual or numerical labels that would define visual items, and instead uses abstract symbols to represent the interactive features that control how the data are filtered. Here, the pentagons represent different appliances, the stars days and the triangles are used to switch between units of measure (cost and kilowatt hours). Abstract symbols are used because they retain the ability to suggest similarity groupings without using textual labelling or explanation. This follows an understanding of visual variables (Bertin, 2011, p.42) and Gestalt principles of visual perception (Wertheimer, 1938).

4.3.4.3.2 Interaction

IV2 is an interactive information visualization interface. The data are filtered via the abstract graphical symbols found to the left hand side of the interface, where there are a total of nine representing the appliance types, and along the right hand side, where there are a total of seven representing the days of the week, and also towards the bottom of the interface, where there are two that represent the units of measure. For example, Figure 7 shows the interface in its default state displaying the data for *total electricity* consumption, on *Monday*, and measured in *kilowatt-hours*. As in IV1, the filtering is AND filtering. For example, Figure 8 shows how the data are updated to reflect the selection of the *washing machine* from the pentagons on the left, *Thursday* from the stars, towards the right, and *cost*, as a unit of measure via the triangles at the bottom. These selections will update each element of the visual interface to reflect the corresponding data values. Interface IV2 is available to use online[13].

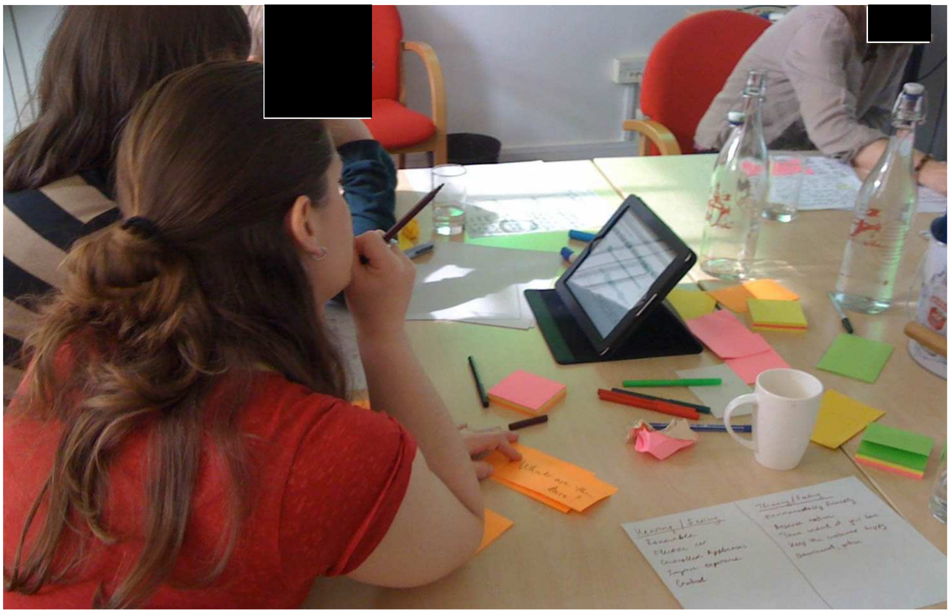

Figure 9: Participants using the less ambiguous information visualization interface during Activity 2

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[13] www.grahamdove.com/eon/infovis2.html

4.3.5 Workshop Activities

4.3.5.1 Activity 1: People or Things that Exert Control

In previous work undertaken for the project this study was a part of (E.ON International Research Initiative, 2012), *control* had been identified as an important concept when trying to engage consumers with smart home energy technologies. In the workshop's first activity participants were presented with a number of definitions of and synonyms for control, and then asked to brainstorm as many ideas for different people or things that exert control, together with the people or things that they exert control over. This was achieved in a simple *brainstorming with post-its* activity, using the technique introduced in section 2.5.4.2. These ideas would be used to provide input to combinational creativity later in the workshop. Participants were given two examples, as illustration of what was required:

A conductor controls an orchestra

Traffic lights control the flow of vehicles

This activity lasted approximately 25 minutes.

4.3.5.2 Activity 2: Seeking Insight in Domain-Relevant Data

In Activity 2, participants were instructed to explore the information visualization interface they had been given and record any insights or observations they thought important or found interesting on individual post-it notes as they went along. They were also instructed to try and think-aloud and discuss this process. This follows my understanding of techniques for prompting and studying participants' insight seeking, which are detailed in section 2.5.2.1. To provide some scaffolding and guidance during this activity, participants were asked to consider the following five questions:

'*What do you see?*'

'*What do you think it is for?*'

'*What are you thinking whilst you explore?*'

'*What do you notice in the visualization?*'

'*What story does it tell?*'

This activity typically lasted approximately 25 minutes.

4.3.5.3 Activity 3: Generating Product and Service Ideas

In this activity participants were instructed to select one of the outputs from Activity 1 and one of the outputs from Activity 2, and combine them to inspire an idea for a new product or service that would utilise smart home energy data to benefit the occupants of that home. The background to this type of combinational creativity technique is described in section 2.5.4.3. Participants were instructed to repeat this process as often as they could, re-using ideas from Activity 1 and Activity 2 as often as they liked and in any combination they chose. Each idea was recorded on a separate post-it note. After about twenty minutes participants briefly explained their ideas to camera. These were later transcribed and given to the independent domain experts who would evaluate them for novelty and appropriateness.

4.3.5.4 Repeat Activity 2 and Activity 3

After a short break and refreshments, participants were asked to repeat Activity 2 using the second information visualization interface, and then to repeat Activity 3, combining the outputs of Activity 1 with those generated in the second instantiation of Activity 2.

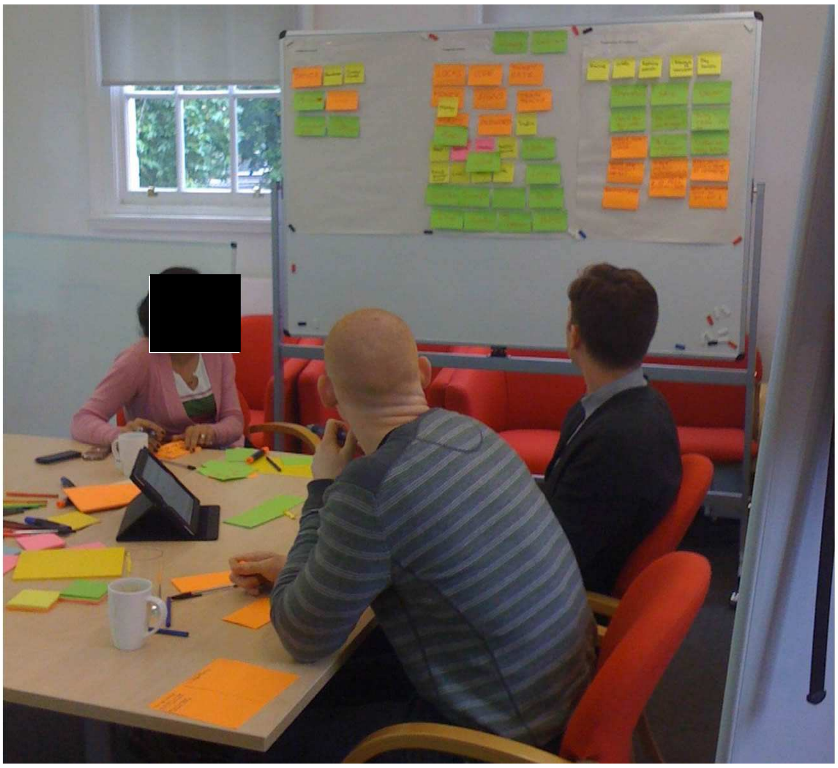

Figure 10: Participants generating new product or service ideas using a combinational creativity technique during Activity 3

An example workshop structure was therefore as follows:

1: *Activity 1*

2: *Activity 2: using IV1 (less ambiguous)*

3: *Activity 3: combining outputs from Activity 1 with insights gained from IV1*

Break and refreshments

4: *Activity 2: using IV2 (more ambiguous)*

5: *Activity 3: combining outputs from Activity 1 with insights gained from IV2*

The order in which the information visualizations were used was counterbalanced, so that in two of the four workshops participants explored the more ambiguous interface IV2 first and interface IV1 second.

4.4 Evaluation Methods

My aim with this design experiment was to investigate the effects of increasing the ambiguity in the visual encoding used to represent smart energy data on the workshop participants' design ideas. To help understand this, I also wanted to know the impact of increased ambiguity on participants' ability to gain insight into the underlying data. Based on my understanding of the literature discussed in section 4.1 I thought that an increase in ambiguity might reduce the appropriateness of the ideas generated, as a result of difficulties in participants' insight seeking. However, I thought it also possible that an increase in ambiguity might lead to increased novelty because of the greater space available for imaginative leaps.

To help answer the research question outlined in section 4.2, I gathered evaluation data in five ways. First, after each round of workshop activities, participants were given a questionnaire to complete. Second, all the product or service ideas generated in each round of Activity 3 were collated and transcribed; these were then given to domain experts to rate for novelty and appropriateness. Third, the post-it notes on which participants wrote their observations in each round of Activity 2 were collated and sorted to help evaluate their insight seeking. Fourth, video data of participants using the information visualizations interfaces in each round of Activity 2 were analysed. This was again to help understand their insight seeking. Finally, I traced the provenance of the elements that were combined to generate the most appropriate idea that emerged. Each of these is discussed in more detail during the following sections.

The evaluation methods used in this study, and the data collected will be discussed in terms of *Supporting the People Designing*, *Assessing the Design Product*, and *Understanding the Design Process*. This structure follows Cross (1999), and is explained in more detail in section 3.2.

4.4.1 Supporting the People Designing

The questionnaire given to participants after each round of Activity 3 consisted of seven questions. Four of these, Q1 to Q4, were derived from the Creativity Support Index (Carroll et al., 2009), a standardised survey metric for measuring the support that tools provide for creative processes, which is discussed in more detail in section 3.2.1. These were:

Q1: *I was very engaged and absorbed using the visualization. I enjoyed it and would do it again.*

Q2: *I was prompted to generate ideas that were new and varied.*

Q3: *I was able to work together with others easily.*

Q4: *I felt able to explore many different options, ideas or outcomes.*

The final three questions were concerned with the extent to which the tools and techniques used in Activity 2 supported participants' insight seeking whilst they explored the smart energy data. These questions were derived from research describing how users gain insight from information visualization undertaken by Yi et al (2008) and North (2006). They were:

Q5: *I could easily identify relationships and patterns in the data that contributed to new ideas.*

Q6: *It was easy for me to gain an overview of the data using the visualization.*

Q7: *I was able to combine my existing knowledge with insights from exploring the visualization to generate ideas that I had not previously considered.*

Responses to all questions were collected using a Likert scale rating from 1 *strongly agree* to 5 *strongly disagree*. To analyse the questionnaire data, I first collated the individual responses. Following this, I first used Levene's test of equality of variance, followed this with the relevant Student's or Welch's t-test, and finally used Cohen's d measure of effect size for those results that were significant.

4.4.2 Assessing the Design Product

To evaluate the creativity of design ideas that were generated in each round of Activity 3, I looked at three factors. First I looked at the total number of ideas generated under each condition, to give a measure of fluency, an important attribute of creative thinking (Guilford, 1966). Having looked at the fluency with which participants generated ideas during Activity 3, the next step was to look at the appropriateness of these ideas. To do this, the ideas from each round of Activity 3 had been transcribed, collated and their order randomized, they were then presented to three separate domain experts. The experts included two postdoctoral engineering researchers, working on the wider project, and a member of the research team with over three years experience in advising and helping domestic energy consumers. These domain experts were also asked to rate each idea from 0 to 5 for *appropriateness*, based on their view of the idea's usefulness within the domain of domestic smart home energy services and it's fit to the workshops' objective, *'generate ideas for new products or services that could utilise the energy data generated by a smart home to benefit its occupants in a future scenario where variable electricity pricing has been introduced'*. The other key facet of creativity under investigation in this evaluation is novelty. To assess this, the same domain experts were also asked to rate each of the transcribed ideas generated during the different rounds of Activity 3, from 0 to 5 for *novelty*. This they based on their understanding of how new the idea was to the domain of domestic smart home energy services. The background to this approach to evaluating the creativity of workshop outputs is described in more detail in section 3.2.3.

To statistically compare the fluency of participants' idea generation, and the appropriateness and novelty of those ideas generated, I adopted the same approach as with the questionnaire data. Again, I first used Levene's test of equality of variance, and followed this with the relevant Student's or Welch's t-test, before finally applying Cohen's d measure of effect size for those results that were significant.

In addition to assessing the design products that were generated in each round of Activity 3, I also looked at the outputs from each round of Activity 2. This was to help me understand and evaluate participants insight seeking using each of the information visualization interfaces. Yi et al (2008) have suggested using models of sensemaking such as those proposed by Pirolli and Card (2005) and Russell et al (1993), to help understand the process through which users gain insight from information visualization. These models describe how people:

1: *Iteratively search the available information in order to create useful mental representations.*

2: *Instantiate and manipulate these representations to create possible schemas that describe the subject currently of interest.*

3: *Investigate these schemas to develop new insight on the subject.*

4: *Use these insights to generate new knowledge products.*

To help understand participants' insight seeking during Activity 2, my focus was on the first three stages of these models. If successful, this would result in participants' gaining, and recording on a post-it, new insights. On this basis, four distinct categories of post-it note data were identified:

Data Insight (DI): *An insight gained into the underlying data. In sensemaking this would be the point where investigating a schema produced new insight.*

Data Hypothesis or Question (DQ): *A hypothesis or question about what the data being visualized represent. In sensemaking this is where schema are being instantiated, manipulated and investigated.*

Observation About Use (OU): *A suggestion for a context in which the visualization would be useful or an observation about its purpose. In sensemaking this is the initial search for useful mental representations.*

Observation About the Interface (OI): *A statement, comment, question or criticism of some part of the visualization's interface or interactions. In sensemaking this is the initial search for useful mental representations.*

Once again, to analyse differences in the number of post-its that fell into each category following the sorting process, I first used

Levene's test of equality of variance. I followed this with the relevant Student's or Welch's t-test, and finally used Cohen's d measure of effect size for those results that were significant.

The final stage of my analysis of the design products was to look at the idea that had been given the highest average score for appropriateness, and to trace the elements that had been combined to generate this idea. This was done with the aim of identifying whether the idea was the result of a successful episode of sensemaking, and if so, using which information visualization interface.

4.4.3 Understanding the Design Process

The aspect of the design process of most interest in this evaluation was the insight seeking during Activity 2. To facilitate this evaluation I analysed the video recordings from each workshop. In this analysis the conversation and activity surrounding periods where participants were interacting with the information visualization during each round of Activity 2 were transcribed. Following this, a thematic analysis technique (Braun & Clarke, 2006) was used to assess the effectiveness of these episodes of attempted sensemaking behaviour. This thematic analysis used a coding scheme that was based on the four categories of post-it I had derived from models of sensemaking (Pirolli & Card, 2005; Russell et al., 1993), and which is described above.

4.5 Results

4.5.1 Supporting the People Designing

Question	IV1 (less ambiguous)	IV2
Q1 (* p<0.05)	M=1.5, SD=0.67	M=2.25, SD=1.28
Q2	M=1.91, SD=0.66	M=2.16, SD=0.71
Q3	M=1.66, SD: 0.77	M=1.91, SD=0.99
Q4	M=1.83, SD=0.83	M=2.08, SD=0.9

Table 4: Mean and standard deviation for the responses to questions relating to creativity support given by participants after each round of Activity 3

Question	IV1 (less ambiguous)	IV2
Q5 (* p<0.05)	M=2, SD=0.73	M=3, SD=1.41
Q6 (** p<0.005)	M=2.08, SD=0.79	M=3.75, SD=1.48
Q7 (* p<0.05)	M=1.66, SD: 0.65	M=2.66, SD=1.37

Table 5: Mean and standard deviation for the responses to questions relating to insight seeking given by participants after each round of Activity 3

Analysis of the data from the questionnaire given to participants after each round of Activity 3 indicates that increasing the ambiguity in the visual encoding used to represent energy data for workshop participants in interface IV2 led to reduced engagement and had a negative impact on their ability to gain insight. When we look at the analysis in detail, we see that responses to Question 1 – '*I was very engaged and absorbed using the visualization. I enjoyed it and would do it again'* – show a significant negative impact on engagement at $p < 0.05$ (effect size = 0.73). Responses to Question 5 – '*I could easily identify relationships and patterns in the data that contributed to new ideas*' – also show a significant negative impact at $p < 0.05$ (effect size = 0.886). Responses to Question 6 – '*It was easy for me to gain an overview of the data using the visualization*' – show a significant negative impact at $p < 0.005$ (effect size = 1.4).

Finally, responses to Question 7 – '*I was able to combine my existing knowledge with insights from exploring the visualization to generate ideas that I had not previously considered*' – also show a significant negative impact at $p < 0.05$ (effect size = 0.932).

There was no significant difference in responses to Question 2 - *'I was prompted to generate ideas that were new and varied'* - ($p = 0.193$). There was also no significant difference in responses to Question 3 - *'I was able to work together with others easily'* - ($p = 0.25$). Finally there was also no significant difference in responses to Question 4 – *'I felt able to explore many different options, ideas or outcomes'* - ($p = 0.244$). Table 4 shows the mean and standard deviation for the scores given in response to those questions relating to support for creative processes when using IV1 or IV2, the interface designed with a more ambiguous visual encoding. Table 5 shows the mean and standard deviation for the questions relating to insight seeking when using each interface.

4.5.2 Assessing the Design Product

Table 6 shows the number of ideas generated in each workshop, under each condition. In it we can see that participants were able to generate design ideas in both conditions, but that there was no significant difference between conditions ($p = 0.697$). Table 7 shows the mean and standard deviation for the assessed appropriateness of these ideas. Here there was a significant difference at $p < 0.05$ (effect size = 0.347), with ideas generated following insight seeking using the interface designed with increased ambiguity in its visual encoding (IV2) being judged significantly less appropriate. Table 8 shows the mean and standard deviation for the assessed novelty of the ideas generated under each condition. There was no significant difference found for this measure between conditions (p = 0.525).

Workshop	IV1 (less ambiguous)	IV2
WS1	16	14
WS2	23	24
WS3	14	12
WS4	14	11
Combined	67	61

Table 6: The total number of ideas generated in Activity 3 of each workshop, under each condition. There was no statistical difference observed P=0.697.

Workshop	IV1 (less ambiguous)	IV2
WS1	M=3.48, SD= 0.94	M=2.98, SD=1.10
WS2	M=2.20, SD=1.15	M=2.53, SD=1.02
WS3	M=3.52, SD: 0.84	M=1.92, SD=1.44
WS4	M=2.31, SD=1.42	M=1.76, SD=1.35
Combined	M=2.81, SD=1.26	M=2.37, SD=1.24

Table 7: The average appropriateness rating for ideas generated during Activity 3 in each workshop. Using IV2 (the interface with a more ambiguous visual encoding) resulted in ideas considered significantly less appropriate *P<0.05 and effect size = 0.347

Workshop	IV1 (less ambiguous)	IV2
WS1	M=2.98, SD=0.70	M=3.00, SD=1.17
WS2	M=2.68, SD=1.10	M=3.24, SD=0.90
WS3	M=2.71, SD=0.43	M=1.83, SD=0.75
WS4	M=2.19, SD=1.17	M=1.79, SD=1.20
Combined	M=2.66, SD=0.94	M=2.64, SD=1.18

Table 8: The average novelty rating for ideas generated during Activity 3 in each workshop, and under each condition P=0.525

Observation Type	IV1	IV2
Data Insight (* p<0.05)	21	6
Data Question or Hypothesis	6	9
Observation About Use	7	3
Observation About the Interface	32	58

Table 9: The total number of categorised post-it notes generated by participants during instances of Activity 2

In Table 9 we see analysis of the different categories of post-it note created under each condition in Activity 2. This provides evidence to help explain the differences in participants' insight seeking and idea generation when using the different information visualization interfaces. Here we see that increasing the ambiguity in the visual encoding used in interface IV2 had a significant negative impact at $p < 0.05$ (effect size = 1.884) on the number of observations that were subsequently categorized as *Data Insight*. The differences seen between the numbers of post-it notes in each of the other categories was not found to be significant. These were: post-its categorised as *Data Hypothesis or Question* ($p = 0.723$); post-its categorised as *Observation About Use* ($p = 0.426$); and post-its categorised as *Observation About the Interface* ($p = 0.113$).

Finally for this section I investigated how the idea that received the highest average score for appropriateness, 4.66 out of a possible 5, developed. We look at the idea with the highest average score for appropriateness because this is the aspect of creativity for which there was a statistically significant difference between conditions. I found that the idea emerged during a round of activities in which the less ambiguous IV1 interface was being used. The idea that scored most highly for appropriateness was a suggestion to install a microcontroller into fridges so that their energy consumption could be regulated away from peak hours, and it was recorded in workshop WS4 with the post-it headline ***"Microcontroller to Fridge Energy Consumption".*** Looking at the outputs generated during Activity 1 in this workshop, I found that listed amongst the things or people that exert control was a ***microcontroller***. Then, looking at the post-it notes generated during the round of Activity 2 using IV1 (the less ambiguous interface) in this workshop, we find that there is the *Data Insight* ***"Fridge Is Almost Stable Consumption For Every Day"***. This *Data Insight* reflects the conversations participants had around fridge consumption, some of which is shown in Table 11. From this, and from the explanation of the idea given to camera, it seems plausible to suggest that the *Data Insight* gained exploring the data visualized in interface IV1 during Activity 2 contributed to the idea generated during the combinational creativity in Activity 3.

4.5.3 Understanding the Design Process

Analysis of the video data recorded during each occurrence of Activity 2 suggests that participants discuss instances of *Data Insight* (DI) more frequently whilst using IV1, the information visualization interface that was designed with a less ambiguous visual encoding. This indicates a greater number of successful episodes of sensemaking. Conversely, we see that when using IV2, the visualization in which ambiguity in the visual encoding was intentionally increased, participants spent the largest proportion of their conversation on *Observation About the Interface* (OI). Here it seems that participants' sensemaking was focused on searching for useful mental representations of the available information and they were less successful in creating and manipulating the schema that might lead to their gaining insight. Conversation is about the things that are immediately visible, the interface elements, rather than consideration of the data they may represent.

Table 10 shows a fragment of conversation between participants P1, P2 and P3 from workshop WS4, which demonstrates the difficulties they encountered using the more ambiguous IV2 to explore the energy data, and suggests why they were less successful gaining insight into the underlying data. Whilst this fragment is not meant to reflect the full extent of conversations during this activity, it does represent a good example of the way that participants were focused on the immediately visible interface elements and did not successfully complete episodes of sensemaking and gain new insight. Discussion is centred around a series of *Observation About the Interface* (OI) comments with a single instance of *Miscellaneous Comment* (MC), a category I introduced to denote comments that continue the conversation without applying directly to participants' insight seeking or sensemaking processes. In this instance the sensemaking process does not reach a conclusion as participants struggle to turn the visual elements of the interface into a useful mental representation of the underlying data.

P3:	What happens when you try that? You were going up that one? You were just going up like this…	OI
P3:	So how many?	OI
P1:	It's not really clear	MC
P3:	It's 5 across here, 4 up and down	OI
P2:	These or these?	OI
P1:	Shall I see what this one?	OI
P3:	That is… What does it do?	OI
P1:	More circles and less circles…	OI
P3:	What is changing when you touch those 2 triangles?	OI
P1:	So the colour is the same… colours… yes. Just the amount… the circles	OI
P3:	Do more than 1 change?	OI
P1:	More circles… It's hard.	MC
P3:	So there's a green up in here and a green down here…	OI

Table 10: Segment of analysed transcript showing sensemaking in WS4 using IV2 (the more ambiguous interface)

P2:	And this is washing machine. What does it look like? And there is nothing...	DQ
P3:	Oh but that's on a Monday	DQ
P1:	If it's on Tuesday...	DQ
P1:	Yeah so people doing their...	MC
P3:	So who is doing their washing when?	DQ
P1:	On Thursday people are washing their...	DQ
P2:	And on Sunday.	DQ
P1:	Thursday and Sunday	DQ
P3:	Oh! You never do washing on a Sunday	MC
P2:	And dishwasher... on Saturday only in the morning ... on Friday.... Thursday no dishwashers… and on Wednesday…	DQ
P1:	It's at midnight.	DQ
P3:	Oh. Is this one persons consumption? Do you think? Because they didn't do anything on those days. What about fridge-freezer? That one's continually on... So does that one have something on every day? Yes.	DQ
P3:	So something like that that's constantly plugged in is running throughout.	DQ
P1:	Yes and if we see the fridge... the circles are almost the same	DQ
P3:	So this is one person's consumption for a week and that's what the circle stands for.	DI

Table 11: Segment of analysed transcript showing sensemaking in WS4 using IV1 (the less ambiguous interface)

In contrast with this, in Table 11 we see a fragment of a conversation that took place whilst the same participants were undertaking Activity 2 using IV1, the information visualization interface designed with a less ambiguous visual encoding. Here we can see how the conversation develops and how the process of sensemaking can reach a successful conclusion with participants sharing a new insight relating to the context of the energy use the data represent. In this conversation, we see a series of *Data Hypothesis or Question* (DQ) comments interspersed with *Miscellaneous Comments* (MC). This indicates that participants have successfully formed mental representations of the underlying data and created schema relating to the information they represent, and that through their exploration these schema are being investigated, re-framed and manipulated. At the end of this conversation fragment we see the group reach a conclusion that the data relates to a single household's energy consumption, this I classified as *Data Insight* (DI).

4.6 Discussion

My aim with this design experiment was to investigate the effects of increasing the ambiguity in the visual encoding used to represent smart energy data on workshop participants' ability to gain insight, and on the creativity of the product and service ideas those participants would subsequently generate. The choice of ambiguity as the variable to investigate was inspired by the many connections that have been made between ambiguity and creative performance, some of which are outlined in section 4.1. Another key objective of this investigation was to start laying down guidelines for designing the information visualization interfaces that are a key tool in the CoDesign With Data approach ahead of the service design workshop described in the case study presented in Chapter 5.

When we look at this study's findings, they indicate that the tools and techniques used to explore domain-relevant data in a CoDesign With Data workshop can inspire participants to generate ideas for new products and services that are highly appropriate to the domain for which they are intended. These results also indicate that intentionally increasing the ambiguity in the visual encoding used in the interface with which participants explore these domain-relevant data has a negative impact on creative performance. In particular, this is shown with respect to the appropriateness of the ideas generated. There was no evidence to support the suggestion that increased ambiguity might result in ideas that are more novel. There was also no evidence found in this study that increasing the ambiguity in the visual encoding used to represent data had increased the fluency of participants' idea generation. The body of work discussed earlier, which suggests a strong connection between ambiguity and creativity, indicates that this is an area for future study.

The evidence from the questionnaire data, the thematic analysis of post-it note outputs from the insight seeking in each round Activity 2, and the detailed video analysis of participants' conversations during the same activity, all demonstrate the relative difficulties in participants' sensemaking when using the interface with increased ambiguity. These difficulties had a subsequent impact on participants' ability to gain insight into the context of energy consumption from the data visualized in the interface, and I suspect this is the chief contributing factor to the significant differences in the appropriateness of the creative outputs generated in the two conditions. It should be noted that in this within subjects design experiment, in which the same data were visualized in both conditions and the colour schemes in both interfaces were largely similar, there appeared to be no evidence of a learning effect (Greenwald, 1976). There was nothing in the data collected that suggested those groups using the less ambiguous IV1 in the first round of activities had benefitted from their successful insight seeking when subsequently using IV2 in the second round of activities. This too is an area for further investigation.

In this study each group of participants was given a single iPad on which to collaboratively explore the visualized information. The evidence from the video recordings of each workshop suggests this use of an iPad was a success. As Figure 4 also indicates, the single iPad supports co-designers' collaborative creative activities during workshop activities providing additional evidence in support of previous findings (Henderson & Yeow, 2012), which are discussed in section 2.5.2.2. There was no evidence in this study of factors that are known to impact on group creativity, such as production blocking where one participant may dominate group work, evaluation apprehension where participants may be reluctant to share ideas, or free riding where participants may take a back seat and not contribute. However, because these factors have been noted in other studies, for examples see (Warr & O'Neill, 2005), they should remain a consideration in future studies.

Whilst there was also no evidence found in this study of any positive benefit for participants' creativity when ambiguity in the visual encoding of data was increased, a positive relationship between ambiguity and creativity has been acknowledged previously, for example (Gaver et al., 2003; Sanders, 2001). As an alternative to giving ambiguous representations of domain-relevant data to co-designers, we might consider designing workshop activities that are more able to exploit the ambiguity in the design context the data are derived from and in the different interpretations that participants' personal experiences and knowledge suggest. For example, we might consider introducing tools and techniques based on the *Generative Design Research* discussed in section 2.4.2, or employing images such as those contained on the *Domain Cards* used in the *Inspiration Card Workshop* discussed in section 2.4.3. Another way of approaching this might be through the use of brainstorming prompts, such as the Creativity Triggers used in the requirements gather workshops discussed in section 2.4.1, which are open to a range of possible interpretations.

The findings from this design experiment provide a useful start to understanding the role that domain-relevant data might play in inspiring stakeholder creativity during early-stage design workshops. Whilst the constraints of visualizing the same data with sufficient differences on a single parameter to facilitate two distinct conditions for experimental comparison mean that the interpretation of ambiguity is arguably a simplistic one, the findings still indicate that we should be wary of intentionally increasing the ambiguity employed in the visual encoding used to represent these data to co-designers. In addition, the designs chosen for this study were based on an understanding of previous research, existing guidelines and practice, and also benefitted from the advice of visualization experts in City University London's giCentre. Therefore, accepting the exploratory nature of this research, I am confident in the lessons suggested in this study's findings.

4.7 Reflections

4.7.1 Research and Evaluation Methods

4.7.1.1 Benefits and Limitations of Study Design

This study was a small-scale, within subjects, experimental comparison of two conditions. It enabled me to observe the effects of using two different information visualization interfaces on the same groups of participants, undertaking the same activities. One benefit of this approach is that it reduces the impact of human variables, such as individual differences in problem solving style (Selby et al., 2004), which can play an important role in creative activities. This increases confidence in the reliability of the study's findings. However, the relatively small number of participants limits their generalizability. A full checklist of threats to the validity (Cook & Campbell, 1979, pp.37-95) of this study's findings is included in Appendix D, Section 9.6.

The importance of the role of the facilitator during a design workshop was made evident when participants were using the more ambiguous interface IV2. Under experimental conditions, when participants struggled to make sense of the interface the facilitator was unable to step in and provide assistance, as these difficulties were amongst factors being investigated. In addition, there were occasions when the facilitator's interventions, e.g. to provide scheduled time checks, impacted negatively on participants' creative flow. This is a potential limitation of such design-experiments.

4.7.1.2 Limitations of Data Collection and Analysis

The thematic analysis undertaken for this study was based on models of sensemaking (Pirolli & Card, 2005; Russell et al., 1993) previously identified as a suitable way of understanding information visualization users' insight seeking (Yi et al., 2008). Whilst these sensemaking models appear to have provided an effective framework for undertaking such an analysis, future studies would benefit from independent coding by additional researchers to mitigate threats to the validity of findings.

Counting ideas and having domain experts rate them for novelty and appropriateness are both recognised methods of measuring the creativity of ideas participants' record during divergent idea generation tasks (Dean et al., 2006). However, there were difficulties in precisely transmitting participants' intentions through transcripts of the descriptions made during the workshop activities. This can result in unreliable ratings. Previous research has also noted problems with the reliability of this method to produce replicable results (Christiaans, 2002).

The questionnaire data provided insights into participants' perceptions of the support and inspiration provided for their creative design activities. However, using the full version of the Creativity Support Index (Carroll et al., 2009), backed up with a similarly validated measure of insight support, would have offered a more robust way of assessing this.

4.7.2 Takeaways

T4.1 *Designing interfaces that visualize domain-relevant data with an intentionally ambiguous visual encoding appears to have a negative impact on co-designers' sensemaking, and reduces the appropriateness of their subsequent design ideas.*

T4.2 *Interactive interfaces in which domain-relevant data are visualized appear to provide an engaging tool for co-designers.*

T4.3 *Presenting visualized data to co-designers on a tablet device such as an iPad appears to provide a form factor that supports their collaborative design activities.*

5 Case Study: E.ON Energy

This case study puts into practice the findings from the design experiment reported in the previous chapter. It investigates the effectiveness of presenting visualized data to co-designers on an iPad in a real world setting. Generative design tools are introduced so that I can investigate how effectively they help improve co-designers' understanding of the possible contexts that domain-relevant data might come from. A paper detailing this case study was presented at the Fourth Service Design and Service Innovation Conference: ServDes.2014, in Lancaster April 2014 (Dove & Jones, 2014(a)). It is included in Appendix A of this thesis. The novel Reflection Postcard method of evaluation was developed for this study and presented at the CHI 2013 Workshop: Evaluation Methods for Creativity Support Environments, a short paper is also included in Appendix A. The case study was conducted as part of the *"Visualising the smart home: creative engagement with customer data"* (E.ON International Research Initiative, 2012) project, funded by the E.ON International Research Initiative. Details of the design idea that resulted from this workshop are included in Appendix B, and are available online[14].

5.1 Introduction

In recent years design practice has moved closer to the future users of the product or service being designed (Sanders & Stappers, 2008).

[14] www.grahamdove.com/energyaudit

In design processes where stakeholder participation is a key element, designing the design process and organising participation become cornerstones (Brandt, 2006). I had two primary research objectives for the workshop reported in this case study. The first was to apply the lessons learnt in the design experiment reported in Chapter 4 in a real world design situation. This was to find out whether the information visualization tools would be an effective part of co-design activities when working with members of the public. The second was to see whether seeking insight from information visualization interfaces could be combined with 'making' activities, similar to those used in the Generative Design Research approach outlined in section 2.4.2, to provide a source of inspiration. As discussed in section 4.6, this might be an alternative way to make use of the positive aspects of ambiguity in design situations.

In the toolkit I put together to support co-designers' generative activities, I opted to use images and photographs taken from online sources as a way of representing selected aspects of the design context. A similar use of images to represent the domain of a design problem can be found in (Sanders & Stappers, 2012, p.71), and in the Inspiration Card Workshop discussed in section 2.4.3. To facilitate the co-designers' exploration of the many different possibilities implied by the ambiguous nature of any design context, I gave them a wide variety of images in each category. These are discussed further in section 5.3.3.

5.2 Research Questions

In this case study my aim was to investigate whether presenting visualized information to co-designers on an iPad would be effective in a real world setting, working with members of the public. Would it be engaging, support their insight seeking, and inspire their creative design ideas? If this were the case it would provide supporting evidence for the findings of the design experiment reported in Chapter 4. The design of the information visualization interface used would also put into practice the lessons I had learnt during that study. In addition, I wanted to investigate workshop activities that would combine insight seeking using the information visualization interface with generative design toolkits. My aim was to help co-designers explore and understand the domain context, share their individual knowledge, and to inspire their design ideas. This study was guided by three research questions:

RQ5.1 *Would using iPad interfaces to explore visualized domain-relevant data be engaging to workshop participants, and support collaboration in a real world setting?*

RQ5.2 *Would participants successfully gain an understanding of the data and therefore insight into the design context from their activities using the information visualization interface?*

RQ5.3 *Would the combination of insight seeking using information visualization interfaces and generative design activities help participants share their existing knowledge and explore different possible interpretations of an ambiguous design context?*

An opportunity to investigate these questions came through my involvement in the "*Visualising the smart home: creative engagement with customer data*" project. Here, we were working with E.ON Energy to find creative ways of using the data generated by smart energy meters as inspiration for the design of consumer services that help to reduce peak energy demands. This case study describes the early-stage service design workshop that was arranged as part of this project.

5.3 Workshop Details

Tools used: *Generative Design Toolkit, iPad Information Visualization Interface*

Techniques used: *Brainstorming with Post-its, Generative Design, Insight Seeking*

5.3.1 Background

This case study describes a collaborative, early-stage design workshop held over one full day in Milton Keynes, UK with customers and staff of E.ON Energy. The objective of this workshop was to generate ideas for new consumer services that would utilise data generated by smart energy products, such as smart plugs and smart meters, to reduce peaks in energy consumption. This should be achieved in the context of an energy market in which variable pricing is used and align with objectives of the wider project that were introduced in section 5.2.

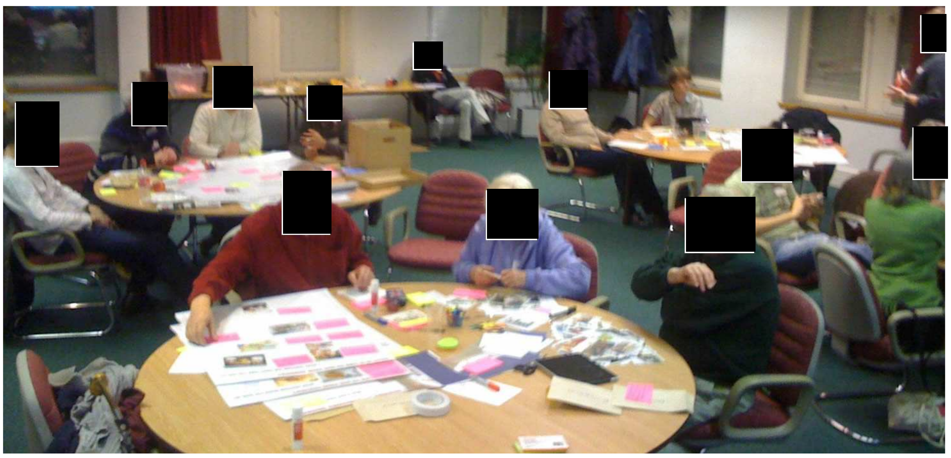

Figure 11: Co-designers create new service ideas during workshop activities

5.3.2 Participants

The workshop took place with a total of thirteen co-designers, ten male and three female. Eleven of the co-designers were E.ON customers who were recruited from amongst the households taking part in a long-term trial of smart energy technologies, which E.ON have been conducting in Milton Keynes. The remaining two co-designers were members of E.ON staff, one technical and the other from marketing. Both members of E.ON staff were employed within their smart meter programme. All co-designers were familiar with energy monitoring and the data that smart meters generate. They all had prior experience with simple visualizations of energy data through the monitors used in the technology trial. The customers who took part in the workshop were already engaged in and informed about energy related issues. This is evidenced by their voluntary participation in E.ON's technology trial.

5.3.3 Workshop Materials

Each group of co-designers were given the following materials to help them during their design activities:

A ***Generative Design Toolkit****, described below*

An ***iPad Information Visualization Interface****, described in section 5.3.4*

The workshop took place in a large room. Group work took place around large tables with plenty of space. Co-designers were provided with refreshments and a video camera was used to record co-designers' explanations of their design ideas after Activity 1 and Activity 5. The generative design toolkit given to each group of co-designers to support their design activities was made up of the following items:

- *A1 sized worksheets for creating the collages that would represent co-designers' design ideas in Activity 1 and Activity 5*
- *A1 sized worksheets for capturing and organising co-designers' ideas, recorded on post-its during Activity 4*
- *A collection of around three hundred individually printed photographs that were collected from various websites and organised into five categories: people, buildings, transport, food and technology. Each category included a variety of representative examples so that co-designers could interpret and combine them in the way they thought best.*
- *Typical workshop stationery, such as coloured marker and felt-tip pens, post-it notes, coloured paper shapes, glue, tape and scissors.*

Examples of each of the materials used in this workshop can be found in Appendix C of this thesis.

5.3.4 Visualization Interface Design

The information visualization interface used in this workshop was designed specifically for this purpose. It reflects the lessons learnt during the study reported in Chapter 4. In that study it was found that increasing the ambiguity used in the visual encoding of data elements, resulted in ideas that were considered significantly less appropriate to the domain of domestic energy. The interface was developed using the D3 JavaScript library (Bostock et al., 2011), and presented to each group of participants via the web browser on a single iPad for the reasons discussed in section 4.3.3. This interface is available to use online[15].

5.3.4.1 Data

The energy data visualized for this workshop were generated from a model of typical energy consumption developed for the "*Visualising the smart home: creative engagement with customer data*" project (Gruber & Prodanovic, 2012). These are different data than were visualized in the interfaces described in section 4.3.4 for two main reasons. First, the previous interfaces visualised the anonymised smart meter data being generated in the E.ON technology trial. Therefore, in this study, there was a realistic prospect of unwittingly presenting a co-designer with a representation of his or her own consumption data. Because these trial data are anonymised, there was no way to match data to households and ask for prior consent. Second, in order to explore the ambiguity of the design context, I did not want the data to represent a real household. This was particularly important for Activity 1, which is described in section 5.3.5.1. The data generated using the model represent seven days' energy use for one possible household. Their selection was based on consumption patterns rather than demographic factors. This was so that there would be no single correct description of the people who might make up such a household, again this was important for Activity 1. Five different price bands, reflecting consumption at different times of the day, were created in order to introduce participants to the idea of variable tariffs. Such variable price tariffs are considered one possible route towards reducing peak energy demand.

[15] www.grahamdove.com/eon

5.3.4.2 Visual Design

In addition to responding to the lessons learnt during the study described in Chapter 4, the design of the visualization interface was also informed and guided by our work with visualization experts at City University London's giCentre, co-investigators on the wider E.ON smart energy project, and with whom we were creating designs for new visualizations to be used by E.ON's energy analysts (Goodwin et al., 2013). Further guidance came from considering Tufte's (1983) and Few's (2009) influential design guidelines, and Wattenberg and Kriss' (2006) description of designing for social data analysis through the use of expressive spectator interfaces. These are discussed in detail in section 2.5.1

The information visualization interface shows energy consumption for nine classes of appliance type: *lighting*, *heating*, *hot water*, *cold appliances*, *cooking*, *washing and cleaning*, *audio visual*, *computing*, and *beauty and grooming*. These are listed in the buttons towards the bottom of the interface. It uses a linear timeline and bubble graph to show consumption over time. A green to blue colour scheme is used to represent each of the variable pricing bands. To the left hand side of the interface, the buttons listing the days of the week each use an area chart to depict the percentage of energy used during periods when different prices are in effect.

The two buttons in the bottom left-hand corner distinguish between units of measure, either cost or consumption in kilowatt-hours. The selected appliance type and unit of measure are indicated with a red highlight. These features are all informed by the lessons learnt using the interface described in section 4.3.4.2. In Figure 12 we see the interface filtered to show lighting consumption in kilowatt-hours.

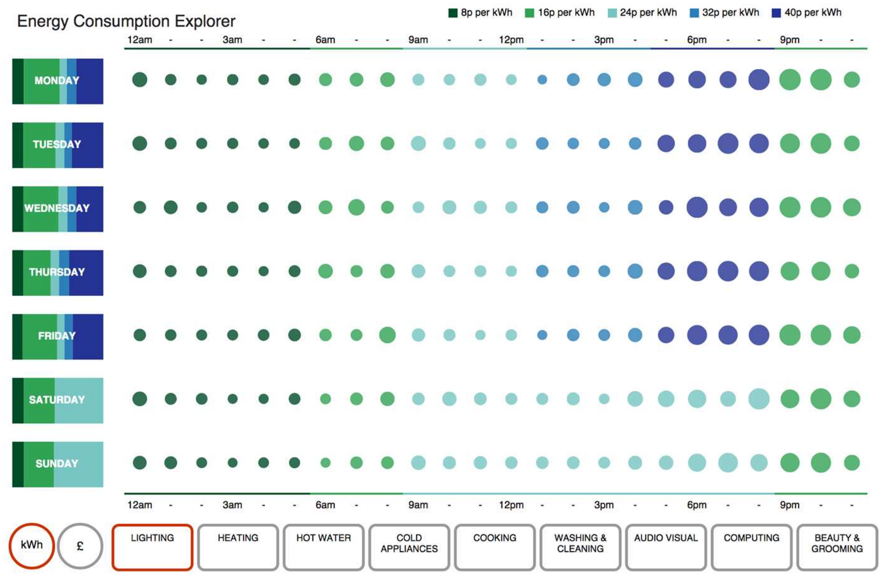

Figure 12: Screenshot of the information visualization interface filtered to show lighting consumption in kilowatt-hours

Figure 13: Screenshot of the information visualization interface filtered to show consumption of the audio visual class of appliances in kilowatt-hours

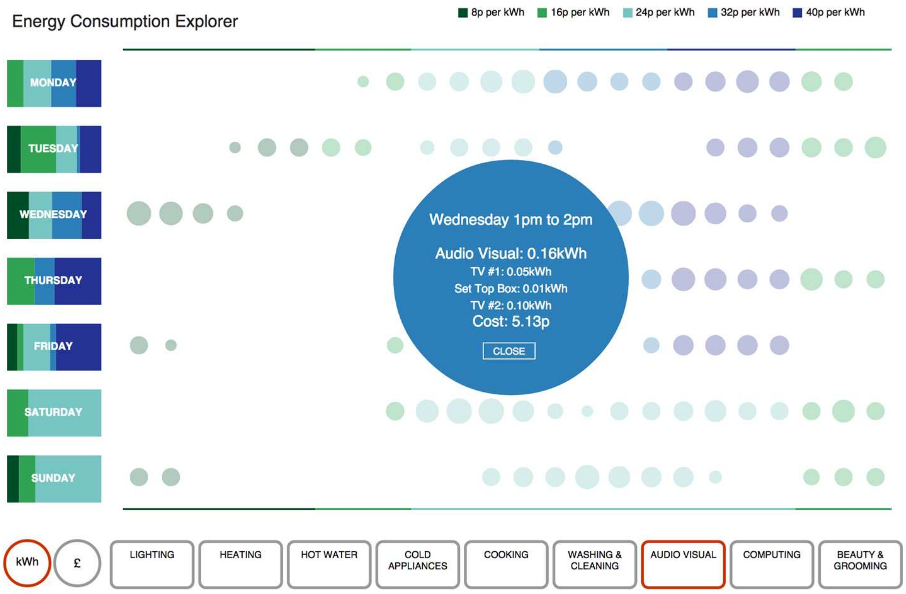

Figure 14: Screen shot of the information visualization interface showing details for the audio visual class of appliances during the 1pm to 2pm time slot on Wednesday

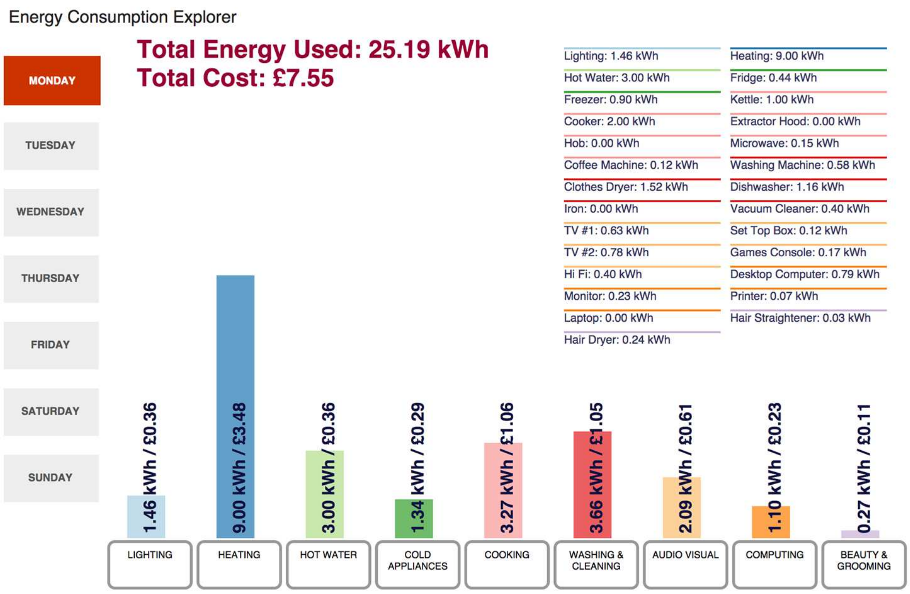

Figure 15: Screenshot of the information visualization showing energy consumption for Monday

Figure 13 shows the interface with the data filtered to show consumption for *audio visual* appliances. In Figure 14 consumption for the *1pm to 2pm* time slot on *Wednesday* is shown in the large bubble in the centre of the screen. This bubble is coloured to reflect the price-band in effect at that time. This feature provides more fine grained detail than had been available in the interfaces used in the previous design experiment.

Figure 15 shows the details for *Monday*. Here, a bar graph is used to show consumption for the different classes of appliance, each of which contains specific instances of appliance. For example, the *cooking* class contains instances of *cooker*, *hob*, *kettle*, *microwave*, *coffee machine*, and *extractor hood*. The details for these individual appliances are shown towards the top right-hand corner, as can be seen in Figure 15. Again, this view was introduced into the interface design to provide more fine grained detail than had been present in the interface described in section 4.3.4.2. It also reflects the larger number of appliances present in the data generated by the model than was present in the data being generated by the trial participants. The colour schemes used in the interface are derived from examples in (Harrower & Brewer, 2003).

5.3.4.3 Interaction

Figure 12 shows the interface filtered to show the data for *lighting* consumption in *kilowatt-hours*. Having selected the *audio visual* button towards the bottom of the screen, Figure 13 shows the data filtered to represent those appliances in the *audio visual* class. In addition to these buttons, the interface also adopts a direct manipulation of the data approach to interaction. This means that the visual elements representing these data are also the interaction elements that control how the data are filtered. For example, when the bubble representing consumption between *1pm* and *2pm* on

Wednesday is selected, as in Figure 14, the details for that time slot are displayed. This follows Shneiderman's (1996) mantra of "*Overview first, zoom and filter, then details on demand*". In a similar way, selecting the button for Monday towards the left-hand side of the interface displays the full details for that day, as in Figure 15.

5.3.5 Workshop Activities

The workshop lasted a total of approximately 6 hours, including a break for refreshments. It was made up of five activities. Four of these were design activities. Activity 3 was used to gather evaluation data. In this activity co-designers worked individually. In Activity 4 all co-designers worked in a single large group. All other activities were undertaken in small groups of three or four co-designers. Co-designers self-selected these groups, with the only criterion being that each group should have at least one member experienced and confident using an iPad, as this was how they would interact with the visualized energy data.

5.3.5.1 Introduction

Prior to the start of the workshop's activities the day's objectives were outlined and co-designers were reminded of the benefits of a positive and supportive atmosphere to their collaborative idea generation. Each group of co-designers was also given their iPad with the information visualization interface. A brief introduction to its visual encoding, data and interactive features was given, and a short period of time was allowed for co-designers to familiarise themselves with its use. Each co-designer was also given a document describing the information visualization interface. This is included with the workshop materials in Appendix C of this thesis.

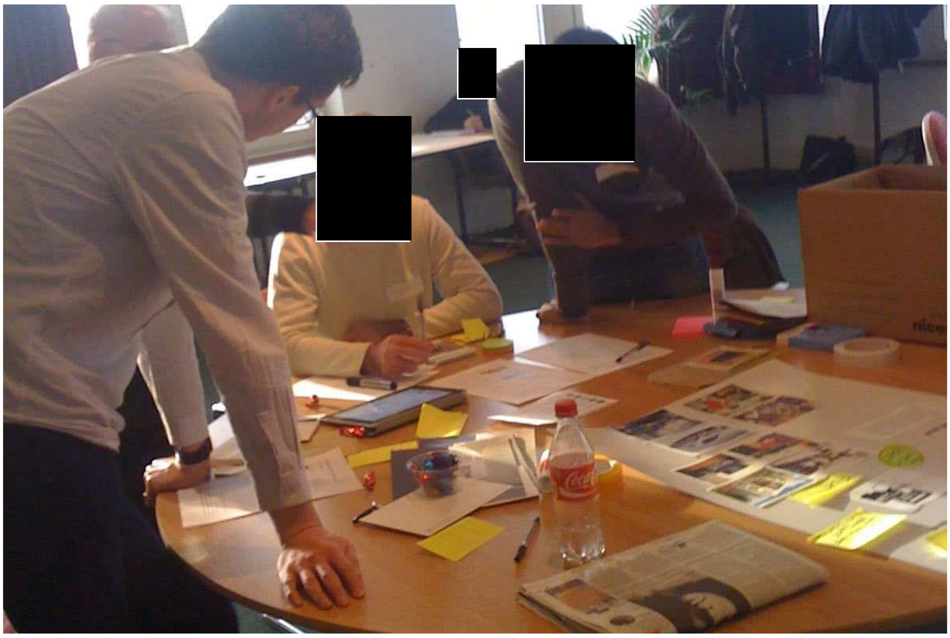

Figure 16: Co-designers using the iPad information visualization to generate ideas

5.3.5.2 Activity 1: Who Lives Here?

In Activity 1 the co-designers were instructed to use the iPad interface to explore the visualized energy consumption data and imagine what type of household might be represented. They were asked to look for possible patterns of consumption that might indicate the makeup of the household, what their lifestyle might be like, and what their attitudes to energy and technology could be. The purpose of this activity was to encourage co-designers to think about possible energy consumption behaviour based on the patterns they might find in the data. The insights they gained as a result would then form the basis of their exploration of the context in which that behaviour might take place, and therefore their description of the household generating the consumption data. My intention was that participants should also share their knowledge and experience of energy related issues in order to investigate different possible explanations and approach the subject from different perspectives. This is an important step towards co-designers gaining a richer understanding of the design context, which would help to inspire creative ideas. In addition, because there was no correct answer to the '*Who Lives Here?*' question I felt there would be space left for co-designers to say something about what they thought to be important, whilst at the same time reducing any reticence they might feel talking about data that represented their own consumption in a group setting.

Each group used the generative design toolkit to create an A1 sized collage that described the imaginary household who best reflected the insights they found in the data. The worksheet contained areas to show the household's *members*, the *type of property* they live in, the *type of energy consumer* they are, how they might feel about *technology*, what their *mealtimes* might look like and the ways they *travel*. These representative households were subsequently used as personas that the group would consider when developing their smart energy service ideas. After approximately 45 minutes working on their collage, each group in turn presented their household to the whole workshop. This was recorded on video. During this explanation, they described the insights they had found and how these contributed to the household they had created. This activity lasted a total of approximately 60 minutes.

5.3.5.3 Activity 2: Win a State of the Art Smart Home

In Activity 2 co-designers were again instructed to investigate the energy consumption data that was visualized in the iPad interface. This time they were asked to put themselves in the position of the household they had described in Activity 1 and look for ways they could be smarter in their energy use. This could mean reducing the total amount of energy consumed, or changing consumption behaviour to reduce their potential energy bill. The purpose of this was first to capture ideas about which behaviours were using significant amounts of energy at peak times, and second to investigate which instances of energy consumption it would be acceptable to change. Activity 2 took the form of a competition, in which the prize was to have their home retrofitted with the state-of-the-art in energy saving smart home technologies. Each group completed an entry form on behalf of the household they described in Activity 1. On it they listed their top five ideas for smarter energy use together with their answer to a tiebreaker question, which asked them to briefly describe a piece of smart home technology that would improve their household's lives and lead to smarter use of energy. This activity lasted approximately 40 minutes.

In the refreshment break that followed Activity 3, each co-designer was given a sticker and asked to vote for which of the competition entries they thought had responded most effectively and most creatively to the questions asked.

5.3.5.4 Activity 3: Reflection Postcards

This activity was used to gather evaluation data. It was the first time that the Reflection Postcard technique described in section 3.2.4 was used. Each co-designer was asked to work individually to reflect on their experiences using the information visualization interface during the previous two activities. To guide their reflections, and gather their responses, co-designers were asked to complete three postcards, each of which had a short prompt printed on it. These prompts are discussed in detail in section 5.4.1. This activity lasted approximately 30 minutes and ended with participants '*posting*' their Reflection Postcards into a small red post box.

5.3.5.5 Activity 4: Smart Home Data

For this activity all the co-designers came together to work as a single large group. It was made up of three rounds of brainstorming with post-its in which the opportunities offered by and possible implications of the energy consumption data that might be generated by a smart home were explored, and ideas for possible new services generated. In this activity the co-designers were asked to imagine that they had won the smart home technology competition they entered in Activity 2. It was now five years in the future and they have been living with the technology as part of their lives for some time. The aim with this activity was for co-designers to think a little more widely about the types of data that might be generated in a smart home, the new services this might enable, and the possible implications associated with these data and services.

The first round of brainstorming collected ideas for different types of data that their smart home could generate. Here co-designers were asked to consider the services provided by the smart home, how it might manage appliances, and the data it would need to capture in order to function effectively. The second round of brainstorming asked participants to think about how they felt about these data being collected. They were asked to consider the different things, both good and bad, that could be done with these data, and to share the emotions they felt and thoughts they had about these. In the third round of brainstorming participants were asked to think of ideas for products or services that might utilize these smart home data to make their lives better. They were asked to consider the emotions that had been triggered and support positive feelings or turn negative responses round so that the product or service would mitigate this to provide a positive outcome. This activity lasted approximately 50 minutes

5.3.5.6 Activity 5: Generating Service Designs

In the day's final activity, each group of co-designers selected one or more of the ideas generated during the day, which they developed these more fully into an idea for a new service for customers that would be based on smart home energy data. This service should reflect the needs identified for the representative household that the group had created in Activity 1. Each group's generative design toolkit included three A1 worksheets on which to describe their service at each of three key stages. On the first worksheet they were asked to describe what it would be like when the household sign up for the new service, addressing factors such as their household's motivations. On the second worksheet they described how it would feel the first time that the service was used by their household. On the third worksheet they described what it would be like once the service was an established part of their household's life. These worksheets were completed in a similar fashion to those used in Activity 1. After approximately 60 minutes working on their service designs, this activity concluded with each group describing their idea to the workshop as whole and to camera. They also explained how the proposed new service reflected insights they had found in the data during the morning's activities. This activity lasted approximately 90 minutes.

5.4 Evaluation Methods

My aim in this case study was to test in practice the lessons regarding information visualization design I had learnt during the design experiment reported in Chapter 4. Would co-designers find exploring visualized smart energy data engaging? Would the interface support their insight seeking? And would the data inspire their creative design ideas? Would an iPad be a suitable form factor to use during workshop activities? I also wanted to investigate workshop activities that would combine insight seeking using an information visualization interface with generative design techniques. Would this help them share a richer understanding of the domain context and inspire their design ideas?

The evaluation methods and data collected for this case study will be discussed in terms of two factors highlighted as important to design research. These are: the *people designing* and the *design product* (Cross, 1999). The reasons for adopting this structure are explained fully in section 3.2. I used two evaluation methods to help answer the research questions detailed in section 5.2. To better understand how the tools and techniques used were *Supporting the People Designing* I used Reflection Postcards. When *Assessing the Design Product*, I evaluated each group's final service design idea, together with the outputs from Activity 1 and Activity 2. These were the activities in which co-designers worked most closely with the domain-relevant data.

5.4.1 Supporting the People Designing

To assess how co-designers felt their insight seeking was being supported and their creative processes were being inspired during workshop activities I used the Reflection Postcard method. This method is presented in detail in section 3.2.4. It was developed for this case study, and this was the first time that it was used. For this evaluation I gave each of the co-designers three postcards. Each postcard had a different reflection prompt printed on it for the co-designer to respond to. These prompts were derived from the questions I used in the evaluation of the previous design experiment, reported in section 4.4. The postcards were given to co-designers to complete during the workshop, immediately following the activities in which they worked most closely with the visualized domain-relevant data. This meant that Activity 3 was dedicated to gathering this evaluation data.

The first of the Reflective Postcard prompts addressed the issues of co-designers' engagement and collaboration. The prompt was derived from statements 1 and 3 in the earlier questionnaire. It read:

"Please reflect on your involvement in the previous two activities. Write a few sentences thinking in particular about how engaged you were, how absorbed or distracted, and how easily you feel you worked with other members of your team. Try to think about the extent to which the technology helped or hindered you in this regard"

The second of the Reflective Postcard prompts addressed codesigners' ability to gain an overview and to identify relationships and patterns within the energy consumption data. This prompt was derived from statements 5 and 6 in the earlier questionnaire. It read:

"Please reflect on your understanding of the information contained in the data visualization. Write a few sentences, thinking in particular about how easily you managed to gain an overview of what was represented. Also think about how quickly you grasped what the information meant, did you spot clear patterns and relationships or did you find it confusing? Did it prompt you to think of ideas you had not previously considered?"

The third of the Reflective Postcard prompts addressed co-designers' idea generation, their exploration of alternative ideas, and the degree to which co-designers' previous knowledge and experience could be incorporated with the insights gained exploring the visualized data. This prompt is derived from statements 2, 4 and 7 in the questionnaire:

"Please reflect on how you used the data visualization to first create your household and then to devise competition answers. Write a few sentences, thinking in particular about how easily you were able to explore possible options and come up with different ideas. Did you use your prior knowledge as well as the information shown? And how easy you found it to relate that prior knowledge to the data?"

Analysis of the transcribed Reflection Postcards involves first assessing whether each of the concerns mentioned in the prompt has been responded to, and then assigning the reflections on each concern to one of five categories: *totally positive*; *partially positive*; *neutral*; *partially negative*; and *totally negative*. In each case individual responses are used to illustrate findings.

5.4.2 Assessing the Design Product

To assess the *design product* I looked at the outputs from each of Activity 1, Activity 2 and Activity 5. For the collages created during Activity 1 and Activity 5 I followed the evaluation method outlined in section 3.2.2. Here I was looking for evidence that insight gained from the data and understanding gained from shared knowledge was being used to describe a possible context for those data, and inspire creative design ideas that would respond appropriately to that context. The video recordings of co-designers explaining their design ideas and the insights that had gone into them to the whole workshop supported this analysis.

When analysing the outputs from Activity 1, I was looking for evidence that co-designers had based the households they described on insights gained from patterns in the visualized data. I was looking for evidence that patterns describing particular energy consumption behaviour had been identified and interpreted according to the co-designers own knowledge and experience, and that explanations for the different individual behaviours could be combined to create an internally consistent description of a household. I was also looking for evidence that co-designers had explored different possible alternatives. This might be shown if the households they described were distinct, and the factors that had led to them were different. Evidence of inspiration for co-designers creativity would be found in imaginative details in the stories behind these households.

My analysis of the service design outputs created during Activity 5 followed a similar process to that for the outputs from Activity 1. I was looking for evidence that each group of co-designers had developed ideas appropriate for the representative household that they had created during Activity 1. If this was the case, these ideas should also represent the insights found in the patterns of visualized data and the shared understanding of the possible design-context. Again I was looking for evidence of inspiration, and here I was also looking for any evidence of novelty in the form of unfamiliar services or new implementations of familiar services. Richness and detail in the collages created for both Activity 1 and Activity 5 would be evidenced by co-designers selection and use of the photographs they were given. Further evidence would be provided by sketches, text and use of other materials such as coloured paper shapes.

Analysis of the competition entries that were completed for Activity 2 looked for evidence that the ideas co-designers suggested ideas for smarter energy use were based upon evidence they had found exploring the visualized data. These ideas should reflect the insights that had led to the descriptions, in Activity 1, of the households represented by the consumption data. In addition, more than one group suggesting the same ideas would also provide evidence of insights gained from the visualized data.

5.5 Results

5.5.1 Supporting the People Designing

Figure 17 shows an overview of the Reflection Postcard analysis. We see the number of responses directly addressing each concern, and the number of these that are in each category from *totally positive* to *totally negative*. It is immediately apparent that a large majority of co-designers' reflections on the workshop activities were either totally positive or partially positive.

Figure 17: Overview of participants' responses to the Reflection Postcard prompts

Analysis of co-designers' responses to the prompt on the first of the postcards shows that all thirteen responded to the *engagement* aspect and twelve to *collaboration*. In both cases the responses were all either totally or partially positive. This indicates that the co-designers found exploring the visualized data as part of Activity 1 and Activity 2 engaging and that the tools and techniques supported their collaboration. This is demonstrated in individual quotes from codesigners' responses. First a *totally positive* response, followed by two partially positive examples.

"I felt that we worked well as a team and found it interesting to decide on the type of family and their possible activities. The iPad was useful in deciding the uses the family made of possible equipment they had": co-designer #11

"The activities were interesting and engaging. I think we worked well within the team and the technology was a help but would have liked longer to analyse trends": co-designer #13

"I felt engaged and absorbed with the tasks and comfortable working with the other members. Some of the information in task 1 was a little overwhelming. The technology was very useful": co-designer #1

There were eleven responses to the prompt on the second Reflection Postcard that directly addressed co-designers' ability to *identify patterns and relationships*. Five of these were totally positive, four were partially positive, and there was a single partially negative and a single totally negative response. There were also eleven responses about the ability to gain an *overview* of the data. This time there were four totally positive and five partially positive responses. The same two co-designers were again partially negative and totally negative in their responses. This indicates they may have struggled to make sense of the data represented in the information visualization interface. Overall it seems that the co-designers' insight seeking was supported during the activities in which the information visualization interface played a leading role. It appears that co-designers could gain an overview, and also discover patterns and relationships. Again, this can be illustrated with individual responses. First there are two *totally positive* examples, these are followed by a *partially positive* example.

"Yes it clearly helped you to understand patterns. Usage, timelines and others quickly": co-designer #5

"Yes we were able to interpret the information. Yes there were patterns which could be followed and in turn used to our advantage": co-designer #3

"There were patterns in the data for some activities but for a couple of them it was a bit inconsistent. However I managed to find some patterns to work out the type of family and their energy use": co-designer #4

Negative responses are also informative. The *totally negative* response, which came from one of the E.ON customers, said:

"It was difficult to form a good overview as there seemed little consistency in the data. If I knew the household this would be OK. Very hard without some more information": co-designer #9

Analysis of the responses to the third of the Reflection Postcard prompts shows that ten co-designers responded to the element of *idea generation*. Of these, three responses were totally positive, four were partially positive and three were partially negative. Eleven co-designers responded with regards to their ability to *explore options*. Of these, four were totally positive, four were partially positive, one of the responses was neutral, and two were partially negative. There were also eleven responses to the element of the prompt referring to codesigners' ability to *use their existing knowledge* in conjunction with the insights gained from the visualized data. Eight of these responses were totally positive and three were partially positive. Individual quotes are informative. First there are two *totally positive* examples followed by a *partially positive* example.

"The iPad data visualisation was very useful as it made it surprisingly easy to look at each piece of data and also caused

the data to be better laid out. I could also use it with my own knowledge which I had to do for the first task.": co-designer #12

"Easy to imagine the type of people in the house. My existing knowledge fitted well with the issues raised by the data": co-designer #8

"The iPad was easy to use and helped with data visualization, although the day views were good a week overview would have helped. It was easy to incorporate this data with existing knowledge": co-designer #1

The negative comments regarding idea generation and exploring alternatives are also informative. First a *partially negative* example followed by one that was *totally negative*.

"Having only one iPad made it harder to explore ideas in time available. Knowledge from Thinking Energy project helped with analysis of information": co-designer #2

"Did use prior knowledge, as did other team members. Needed to focus back on house and empathise what they were like. iPad and data didn't really contribute to ideas": co-designer #7

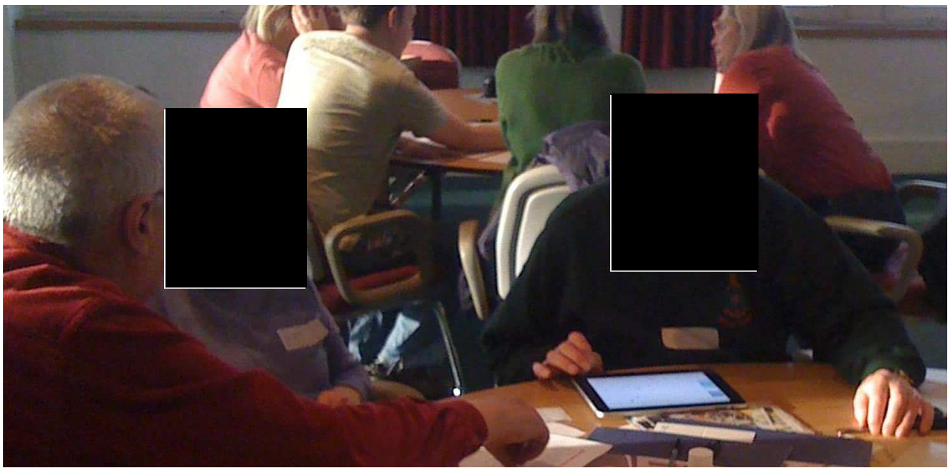

Figure 18: Co-designers working collaboratively to describe their household in Activity 1

Figure 19: Examples of outputs produced in Activity 1: Who Lives Here?

5.5.2 Assessing the Design Product

Analysis of the outputs from Activity 1 suggests that each group found insights in the visualized data and was able to explore different possibilities. It also suggests that during the generative design activities they combined these insights with their prior knowledge and experience to share a richer understanding of an ambiguous situation and describe possible design contexts. These factors are reflected in the different practices and lifestyles the groups gave their households, which were described in the video recordings of co-designers explaining these collages and the households they represent. The imaginative detail they included in their collages and the stories they told suggests that the activities also provided inspiration for their creative design ideas. Figure 19 shows how the different photographs were combined and also how these were augmented with text. Examples of how each group described the household they thought best represented the energy consumption data are helpful in demonstrating this.

The first group saw a pattern in which the household used entertainment equipment late at night and another pattern showing relatively frequent washing machine use. They thought the data best represented a family with children. The second group also saw these patterns, but thought that additional patterns showing irregular cooking and repeated use of a hairdryer indicated that the household might be single, urban and female. The third group also spotted the irregular cooking patterns but thought that this indicated an outdoor lifestyle, which suggested that the household were '*concerned greens*'. Finally, the fourth group spotted that more cooking was being done on Monday and thought this meant the household might batch cook meals and reheat them later in the week. They also noted a pattern in the heating that suggested a household member worked from home or worked part-time.

Each shows that a pattern was first identified in the visualized data, for example the apparently infrequent cooking. This was then explained in a way that reflected the knowledge, experience and concerns of those co-designers, and also the insights gained from other patterns identified in the data, for example when the cooking data was combined with data about using the hairdryer. These insights and the shared understanding then seem to provide inspiration for creative descriptions explaining the contexts in which the energy consumption data might have been generated.

Looking at the collages describing new service design ideas that were created in Activity 5, for example Figure 20, there is again evidence of the way that insights found in the visualized energy consumption data, which were represented in the households created in Activity 1, are reflected in the service deign ideas. Two of the groups each developed separate ideas for a detailed energy audit. Both of these ideas described energy and money saving services that would be built on top of the fine-grained information and detailed historical consumption reports that can be generated from smart home energy data. Both of these were the result of patterns of energy consumption, particularly in lighting and heating, that the groups thought reflected inefficient use. This also reflected the group members' interest in reducing their own energy consumption and saving money.

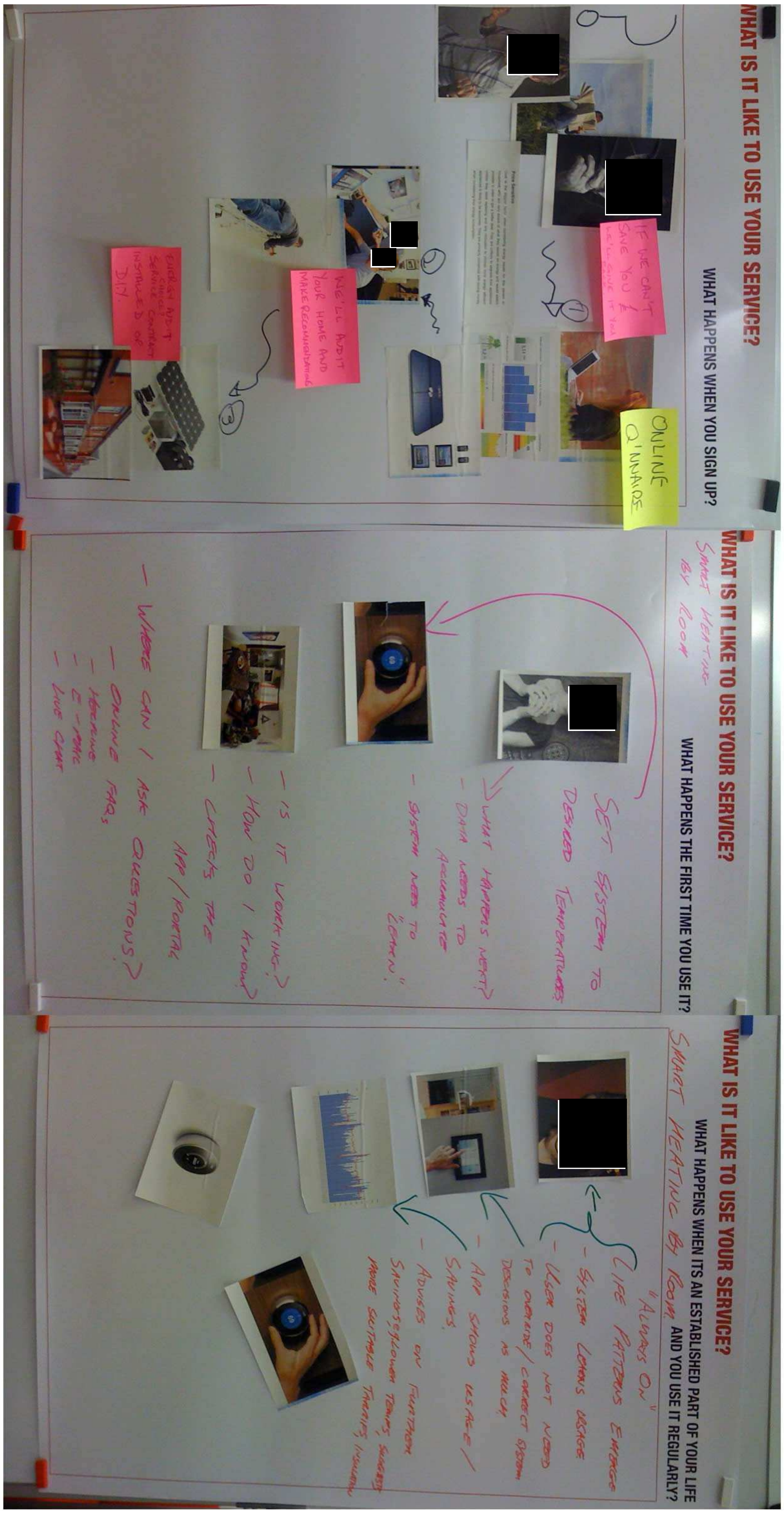

Figure 20: Example of the outputs produced during Activity 5 Generating Service Designs

The third group developed a service that would automatically manage heating and lighting based on what it can learn about the household's behaviour from the data generated by the smart energy products over time. This service similarly reflected the patterns of heating and lighting consumption highlighted by the two groups who suggested the energy audit services. These patterns of heating and lighting consumption were also highlighted in the competition responses that were completed for Activity 2, and which are discussed below. The final group developed an automated shopping service based on a smart fridge. This reflected the cooking patterns they had seen and which they thought meant the household lived a busy, outdoor lifestyle.

To assess the creativity of these outputs I was looking for evidence of two key factors. First, that the ideas developed were appropriate for the household that group of co-designers had identified as being represented in the data, and which reflected patterns of energy consumption behaviour they had uncovered. Second, I was looking for novelty, in the form of ideas for new services or new implementations of existing services, but which were different from those already familiar. This follows an understanding of creativity as being something that can show both novelty and a measure of utility e.g. (Sternberg & Lubart, 1999), and provided a connection to the way design outputs were evaluated in section 4.4.2.

In each of the service ideas described there was evidence of appropriateness. All were a development of the insights and ideas gained from the visualized data during the first two activities, and a coherent story of how the service ideas respond to the needs of the household members can be told. In addition, all of these ideas have elements of novelty in the way they were to be implemented. They can be considered to show what we might term incremental creativity as they build on the already familiar. The energy audits build on ideas already current in the longer term E.ON technology trial that the workshop participants were recruited from. The smart fridge is an idea, which in different forms has been around for the last decade, occasionally gaining a high public profile (Kuniavsky, 2008). The service that would automatically adjust heating and lighting has some similarities to products like the Nest thermostat[16].

Finally, analysis of the competition entries completed during Activity 2 also shows evidence of co-designers' insight seeking being effectively supported. This is because they were clearly able to spot patterns and relationships between the data. Similarities between the different groups' responses show how these were consistently found. The following three ideas were listed somewhere amongst their five suggestions by all the groups:

Use washer and drier overnight during cheaper tariffs

More intelligent and efficient use of heating and hot water

Turn lights off when out of the room

5.6 Discussion

This case study suggests that the activities in which co-designers used an iPad to investigate visualized smart energy data were engaging in a real world setting. It also suggests that the visualized data represented in the iPad interface provided effective support for co-designers insight seeking, through their finding clear patterns and relationships, and that using the iPad to present the

[16] www.nest.com

visualization enabled collaboration and fitted in well with other design activities. The combination of generative design techniques and visualized domain-relevant data appears to have been effective. Co-designers used their knowledge and experience to develop possible explanations for things that the data left ambiguous, such as different reasons for why the household's cooking might appear erratic. There is also some evidence that the insights from the data and the shared understanding of the design context inspired creative ideas. Similarly to the design experiment reported in Chapter 4, this seems more evident in the appropriateness of the ideas than in their novelty. However, such incremental levels of creativity are often the result of human-centred design methods (Norman, 2010).

Co-designers' responses gathered using the Reflection Postcards were not entirely positive, and there was evidence that working with the information visualization interface was difficult for two of the co-designers. To some degree this was mitigated by their involvement with the generative activities, which helped them share the insights gained by other group members, and contribute their own experience and understanding of the design context. This should be investigated further, and may indicate that co-designers would benefit from closer facilitation and more personal support. However, overall the evaluation data discussed here seem to provide additional evidence in support of the positive findings from the design experiment reported in Chapter 4.

In Activity1 and Activity 5, the visualized data, the photographs, and the worksheets play a role that is perhaps analogous to that of the Inspiration Cards and Concept Posters described in Inspiration

Card Workshop described in section 2.4.3. That is, they act as a catalyst for collaboration and ideation, and provide an external source of inspiration for emerging ideas. They also provide a framework for the kind of combinational creativity discussed in section 2.5.4.3. The worksheets provide a physical space for participants to collect representations of things they are familiar with, which can be associated with new insights gained from data exploration, to build a richer understanding of the design context.

This workshop, like the one reported in Chapter 4, demonstrated that working with domain-relevant data could inspire appropriate ideas that demonstrate an incremental type of creativity. Norman and Verganti (2014) discuss the difference between *incremental innovation*, which leads to doing something better, and the more rare *radical innovation*, which leads to doing something different. They argue that it is changes in the meaning ascribed to a product or service, perhaps following or alongside the introduction of new technology, which leads to these radical innovations. An important challenge for future work will be to try and move beyond the ability to generate appropriate ideas, and inspire participants' creativity in more radical directions.

5.7 Reflections

5.7.1 Research and Evaluation Methods

5.7.1.1 Benefits and Limitations of Study Design

This case study described a workshop where the aim was to engage members of the public and generate creative design ideas. A key research aim was to investigate how the findings from the design experiment detailed in Chapter 4 would translate to a real-world setting. Here, we see evidence in support of the previous findings. In particular we find that using an iPad to present visualized energy data to each group of co-designers was effective with the representative E.ON customers, much as it had with the previous study's participants, see section 4.6. Future workshops may investigate using multiple iPads. However, it seems likely that the penetration of smartphones and tablet devices is such that a degree of familiarity with and working knowledge of these devices can now be expected amongst large numbers the general UK public. It should also be remembered that this was a single workshop, held with a self-selecting group of participants who are engaged with the technology and issues surrounding smarter energy consumption. Because of this, the reliability of these findings in other contexts is limited, and further study should be undertaken in other domains and with other populations.

5.7.1.2 Limitations of Data Collection and Analysis

A key challenge in creative design workshops is generating an atmosphere that is relaxed, supportive, engaging and playful. Collecting evaluation data can interfere with this aim, because stopping creative activities to complete questionnaires may result in participants feeling that they themselves are being assessed, which can be a cause of anxiety and impact negatively on their creativity. The Reflection Postcards were successful in overcoming this issue, and they provide data similar to that available from open-ended questionnaire questions. Responses are also gathered at a timely point, when the experiences are fresh in participants' minds. However, they do not provide the depth of response that might be achieved with other more traditional qualitative approaches. Further questioning, asking for more detailed responses, either in follow up interviews or later questionnaires would be one method of augmenting this data.

Another way to support the data captured from Reflection Postcards would be to provide each group of participants with a facilitator who could observe and report on their activities in more detail. This might be further augmented by video recording each group. However, the use of video cameras might be counter productive, and have a negative, inhibiting effect on participants' creative activities.

5.7.2 Takeaways

T5.1 *Workshop activities that combine generative design techniques with seeking insight in visualized domain-relevant data appear to inspire useful design insights.*

T5.2 *Interactive iPad interfaces in which domain-relevant data are visualized appear to provide an engaging tool for co-designers who are members of the public, in a real world setting.*

T5.3 *Presenting visualized data on a tablet device such as an iPad appears to provide a form factor that is suitable for co-designers collaborative design activities during generative design.*

T5.4 *Generative design toolkits, which include items such as photographs, appear to be an effective way of helping co-designers interpret the ambiguous contexts that domain-relevant data are drawn from.*

6 Case Study: MIRROR

In this case study I continue to investigate the generative design approach used in Chapter 5. I also use the 5WsH creativity technique and custom hexagonal worksheets for the first time. These were then used in all of the studies that follow this one.

6.1 Introduction

Design problems are often complex and open, and in such cases it is typically only the value desired from the design outcome that is known upfront. One of the key challenges with such problems is to create both an artefact (product, service or system) and also an understanding of its intended use, the means by which this artefact contributes to the desired value (Dorst, 2011). In such a situation it is common for the design problem and the design solution to co-evolve as the designer's understanding increases and the creative design process progresses (Dorst & Cross, 2001). However, whilst such design problems are undetermined, they are not entirely free, and there remain a number of hard constraints to be identified through information gathering and analysis during early-stage design work (Dorst, 2003). When data are amongst a project's key design materials, the nature of those data available is likely to be one of these hard constraints. It is therefore important to understand their type and features, where they come from and how they might be used, and also to identify possible connections between them at an early stage.

As part of a longitudinal investigation into a human-centred approach to designing geovisualization applications, Lloyd and Dykes (2011) undertook collaborative stakeholder workshops. Their aim was to share an understanding of the domain data and of the possibilities offered by visualization during early-stage design and requirements gathering activities. This was to better understand needs, and to build knowledge and trust between collaborators. In design work undertaken with E.ON energy analysts, as part of the "*Visualising the smart home: creative engagement with customer data*" project discussed in chapters 4 and 5, this approach to human-centred information visualization design was extended to incorporate applied creativity techniques (Goodwin et al., 2013). In other instances, designers of information visualization interfaces and data graphics might typically undertake these exploratory processes using computational tools, such as the R programing environment, to work directly with data. Such a process is described in (Yau, 2011, pp.71-74). Here, I wanted to know if co-designers would be able to share their individual perspectives and gain an improved understanding of the available data, including how they are generated and where they might be used, through workshop activities that combined generative design with applied creativity techniques. I also wanted to know if these tools and techniques would support co-designers' creative processes as they investigate possible new connections and uses for these data.

6.2 Research Questions

In developing the CoDesign With Data approach I am seeking to understand how insight gained from domain-relevant data can improve co-designers' understanding of the domain context and inspire creative design ideas. As outlined above, a key aspect of this approach will be methods for understanding the nature and potential of those data available to a design situation. My initial exploration of this was guided by three research questions:

RQ6.1 *Would workshop activities in which generative design is combined with applied creativity techniques help co-designers share their individual perspectives on the data available to a design situation?*

RQ6.2 *Would these activities improve individual co-designer's understanding of those data, where they come from and how they might be used?*

RQ6.3 *Would these activities inspire co-designers' creative ideas as they look for possible new uses for these data during exploratory design?*

An opportunity to investigate these questions came through a workshop to explore ways of realising additional value from the data generated by different applications associated with MIRROR[17], a European FP7 research project. Here was an undetermined design problem, in which data were a key material, and that involved a number of different stakeholders, each with a partial understanding of, and a different perspective on, the available data. This case study describes the workshop that took place to explore this design opportunity. Details of the understanding captured and the design ideas generated during this workshop are available online[18].

[17] www.mirror-project.eu
[18] www.grahamdove.com/mirror

6.3 Workshop Details

Tools used: *Generative Design Toolkit*

Techniques used: *5WsH, Combinational Creativity, Generative Design*

6.3.1 Background

This case study describes a workshop held over one full day in Amsterdam, Holland. Co-designers were representatives from consortium members of MIRROR; a European FP7 research project investigating the creation of easily used applications to support employees' reflective learning at work. The aim for this workshop was for co-designers to gain a better understanding of the data generated by the applications being developed in some of the different work packages in MIRROR, and use this understanding to identify new ways of connecting these data to design novel services.

6.3.2 Participants

The workshop took place with a total of ten co-designers, six male and four female, representing six different work packages. Each of the co-designers had an in depth understanding of the data generated by the applications developed for their own work package, but more limited knowledge of that generated by other MIRROR applications.

6.3.3 Workshop Materials

Co-designers were given the following materials to help them with the workshop's activities:

A ***Generative Design Toolkit,*** described below

The workshop took place in a large room with plenty of space and tables that could be combined and arranged in a variety of ways to facilitate work in groups of different sizes. Co-designers were provided with refreshments and a video camera was used to record co-designers' explanations of their design ideas after each of the activities. The generative design toolkit that was put together for the activities undertaken in this workshop was made up of the following items:

A2 sized hexagonal 5WsH worksheets used in Activity 1

A3 sized hexagonal 5WsH worksheets used in Activity 2

A 2.1m x 1.8m blank sheet of paper used to layout the MIRROR data "map" for Activity 2 & Activity 3

Coloured embroidery thread to make data links explicit in Activity 2 and Activity 3

Materials for creating collages in Activity 1 and Activity 3 including coloured shapes, human figures, cut-outs of words relevant to MIRROR (e.g. Creative, Prompt, Reflection, Stories); the care home domain, which is one of the MIRROR test bed domains (e.g. Carer, Co-Worker, Family, Friend, Home, Manager, Notes, Resident); or data (e.g. Audio, Categorical, Complex, Date/Time, GPS Location, Image, Numeric, Simple, Text, Video)

Typical workshop stationary such as coloured pens, scissors, glue, tape and post-it notes

Examples of all the materials used in this workshop can be found in Appendix C of this thesis.

6.3.4 Workshop Activities

Following a brief introductory explanation of the day's proposed activities, the workshop was divided into three main sections. These were separated by a break for lunch and another for afternoon refreshments. Finally there was an individual reflection activity that was used for evaluation purposes, and is discussed in section 6.4.

6.3.4.1 Activity 1: Data Description

In this activity, participants worked in two smaller groups, each with five members. Its purpose was to start sharing individual co-designers understanding of the data generated in their MIRROR work package. In each group, the co-designers took turns to describe the application or applications being developed in their work package to the other members of that group. They were asked to outline how these applications would be used, the data they generate, and what that data is subsequently used for. To capture this knowledge, the remaining participants in the group were creating a visual representation of the data being described. To do this they used an A2 sized 5WsH hexagonal worksheet for each application, together with any of the other materials provided in their generative design toolkit. The co-designer who was describing the application and its data was instructed to use the questions printed on the 5WsH hexagonal worksheet as a guide for their description, and those creating the visual representation used these same 5WsH prompts as a basis for further questions of their own. The 5WsH technique was introduced in section 2.5.4.1.

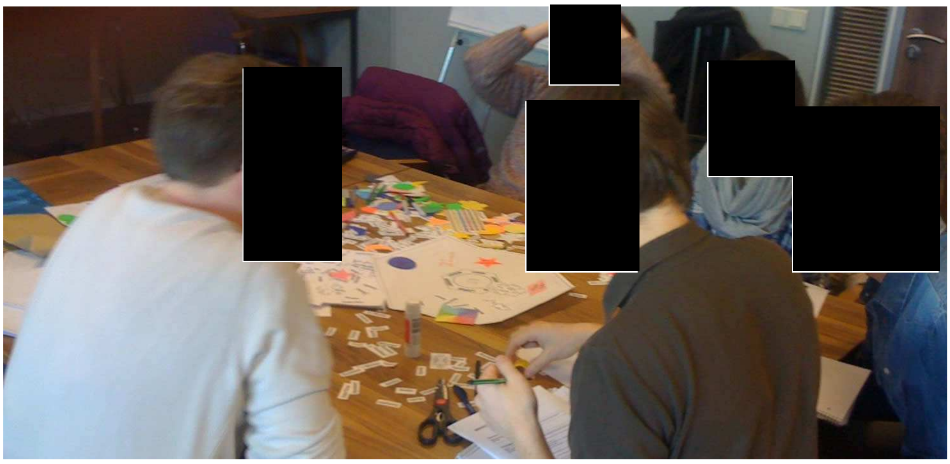

Figure 21: Participants creating descriptions of MIRROR applications and data in Activity 1: Data Description

The questions listed on the hexagonal worksheets were:

What is the data like?

Where is it generated? & Where is it used?

When is it generated? & When is it used?

Why is it being generated?

Who generates it? Who is it about? & Who uses it?

How is it generated? & How is it used?

The activity ended with the data description being explained to the workshop as a whole and to camera. This activity lasted approximately 2 hours.

6.3.4.2 Activity 2: Map the Present

In this activity co-designers worked in a single group. Its purpose was to build on the understanding of the available MIRROR data gained during Activity 1. To do this co-designers were instructed to place the hexagonal 5WsH worksheets they had created on the large (2.1m by 1.8m) blank sheet of paper. Data that seemed to be similar to each other, in their type or in the context they are generated or used, were placed close to each on the sheet. Any apparent connections that could be made between the data generated when different applications are used were marked out with coloured thread. In this way a large-scale visual representation of the relationships between the applications being built within the different work packages was made, and existing connections between the data these applications generate were made explicit. This activity was particularly aimed at highlighting similarities, connections and relationships in the data, and in the different contexts in which these data might be generated or used. In this way, co-designers created a *map* that would describe the MIRROR project's applications and data. This activity took approximately 1.5 hours, and ended with each connection being explained to camera.

Figure 22: Participants making a map of the MIRROR applications and data

6.3.4.3 Activity 3: Map the Future

In this activity co-designers worked in a single group. Its purpose was to use the understanding of the available MIRROR data gained during the previous two activities as inspiration for creative ideas. These ideas would describe new uses and novel combinations of the MIRROR data that might lead to innovative services being designed. Co-designers were instructed to look for three kinds of opportunity. They might: *identify data from one application that could be combined with data from another*; *take the data from one application and use it to extend the functionality of another application*; or to *take the data from one application and place it into the context in which another application is used*.

To help make these new connections explicit and generate ideas for new services, participants used the A3 sized 5WsH hexagonal worksheets, together with any of the other materials provided in their generative design toolkit. Each of these hexagonal new data connection idea sheets that the co-designers created was then placed on the MIRROR *data map* and any connections with existing applications were again made explicit with coloured thread. The questions listed on the 5WsH worksheets were:

What is the data?

Where is it going to be used?

When is it going to be used?

Why is it going to be useful?

How is it going to be used?

Who is going to use it?

This activity took approximately 1.5 hours, which included time for each idea to be explained to camera.

6.4 Evaluation Methods

My aim in this case study was to investigate whether co-designers would be able to share their individual perspectives and gain an improved understanding of the data available in a design situation through workshop activities that combined generative design with applied creativity. In addition I wanted to know if these tools and techniques would inspire co-designers' creative ideas as they investigate possible new connections and uses for these data. Similarly to that reported in section 5.4, the evaluation methods used here will be discussed in terms of the *people designing* and the *design product*. This choice is introduced in section 3.2. Again similarly to the evaluation reported in section 5.4, I used Reflection Postcards to better understand how the tools and techniques used were *Supporting the People Designing*, and used the methods introduced in section 3.2.2 when *Assessing the Design Product*.

6.4.1 Supporting the People Designing

To evaluate co-designers' perceptions of the support the tools and techniques used had provided for their insight seeking, and the inspiration provided for their creative ideas during the workshop activities, they were given three Reflection Postcards. The prompt on the first Reflection Postcard was used to evaluate whether the workshop's activities had helped to improve their understanding of the available data. It asked co-designers to consider whether they had an increased understanding of the data following the workshop, and whether this understanding was represented in the workshop outputs. The prompt read:

"Do you feel that the workshop has increased your understanding of the data being generated in the Mirror Project? Does the map we created represent this understanding?"

The prompt on the second Reflection Postcard was used to assess the inspiration provided for co-designers' creative ideas. The prompt asked participants to consider their creative contribution to the workshop's activities, and whether these contributions were represented in the workshop outputs. The prompt read:

"Do you feel that you were able to contribute new ideas and suggestions to the workshop? Were these reflected in the map we created?"

The prompt on the third Reflection Postcard was used to address the extent to which individual co-designer's were able to express their perspective on the emerging design situation, and how accurately these different views were represented in the workshop's output. The prompt read:

"Do you feel that you were able to express your perspective on the Mirror Project data? Was this satisfactorily represented when we created the map?"

Again in a similar way to that described in section 5.4.1, analysis of the responses involved: assessing whether the individual concerns had been responded to; and whether that response was a *totally positive*, *partially positive*, *neutral*, *partially negative* or *totally negative* reflection.

6.4.2 Assessing the Design Product

To assess the *design product* I looked at the output of each activity in turn. When analysing the outputs generated during Activity 1 I was looking for details such as: *the data type or types generated*; *how often data are generated*; *who the application's users are*; *where and when the application is used and data are generated*; *the work context in which the data are generated*; and *the work context in which the data are analysed or reflected upon*. This would suggest that the co-designer representing the work package developing the application in question had successfully shared their individual understanding of those data with the other members of the group, who had been able to represent that understanding with clarity and detail.

To analyse the outputs generated during Activity 2, I recorded the number of connections between existing MIRROR applications and their data, which the co-designers were previously unaware of, but that had now been made explicit. I then looked at these connections in more detail to check that they were consistent and valid and therefore provided evidence of an improved understanding of the data.

In my analysis of the outputs from Activity 3 I first recorded the number of new ideas for possible connections between MIRROR data or applications and possible new services. Following this, I looked at these ideas in more detail. Similarly to my analysis of the hexagons made in Activity 1, I was looking for details such as: *the data type or types being generated or shared*; *details about the users who the new service might benefit*; *where, when and in which work contexts the new service might be used*; and *how and in which contexts the new data connections might help reflective practice*. Examples of such richness and detail in the way co-designers' described and represented these ideas would suggest that they had gained an improved understanding of the data available, where these data came from and how they might be used. It would also suggest that the tools and techniques had inspired co-designers' creative ideas.

6.5 Results

6.5.1 Supporting the People Designing

Figure 23 provides an overview of the analysis of the Reflection Postcards. It shows the number of responses that directly addressed each of the concerns under investigation in the postcards, and the number of these that are in each category from *totally positive* to *totally negative*. We can immediately see from this overview that a large majority of co-designers' reflections on the workshop activities were either totally positive or partially positive, and that there wasn't a single totally negative response.

Figure 23: Overview of participants' responses to the reflection prompts

Analysis of the responses to the prompt on the first Reflection Postcard shows that all ten co-designers responded with regards to their increased understanding of the MIRROR data. Of these, eight responses were *totally positive* and that the two remaining were *partially positive*. A typical example of the *totally positive* responses comes from co-designer #2:

"*Yes, indeed. Although we have heard what different apps do in the past 2.5 years, I only now realised some new aspects of various apps that I didn't know*."

Of the *partially positive* respondents, one noted some new insight but considered their understanding before the workshop to already have been good, whilst the other acknowledged an increased understanding but noted that not all MIRROR work packages and application tools were represented.

There were nine responses regarding how this understanding was represented. Of these, one was *totally positive*, six were *partially positive*, and two were *partially negative*. A typical example of the partially positive responses comes from co-designer #8:

"*Yes! Though the map got a bit confusing at the end, which is basically awesome, because that means that we did (good) work :) Personally I suggest to write down the newly created knowledge of the map in an organised, structured textual way."*

Three of the co-designers who were *partially positive* had noted that they thought the map became either complicated, difficult to analyse, or hard to remember. A similar thing was also noted by one of the co-designers whose response was *partially negative*. This co-designer said they '*believe it is hard to understand the map afterwards, especially alone*'.

Analysis of co-designers' responses to the prompt on the second Reflection Postcard showed all ten responding with regards to their ability to contribute new ideas. Eight of the responses were *totally positive* with respect to this question, whilst the remaining two were partially positive. A typical example of the totally positive responses comes from co-designer #1:

"*Yes I was able to contribute a couple of ideas I had thought about in the past and set them into the right context*."

There were nine responses regarding how well this was reflected in the final output. Eight were totally positive, and one was partially negative. The partially negative response commented on the process becoming '*too much*' and that they had to concentrate on the contributions of other co-designers. A typical example of the *totally positive* responses comes from co-designer #3

"*and [Yes] to the map we made all together. I was a bit sad the session for generating new ideas didn't go on far longer*"

Analysis of responses to the prompt on the third Reflection Postcard showed all ten co-designers responded with regards to how well they could express their individual perspectives. Four responses were *totally positive*, three were *partially positive*, and one co-designer, who was unsure that they had a particular perspective on any of the data, was *neutral*. An example of the *totally positive* responses comes from co-designer #7:

"*Yes! It's interesting that there are that many different views on the project. Actually I wasn't aware of that fact. At least I did not know about all of them*"

The remaining two co-designers' responses were *partially negative*. An example of these comes from co-designer #2:

"*A more situation-driven approach could have worked better, i.e. what is the situation a carer encounters, then decide the data needed to assist them*"

There were seven responses regarding how well co-designers' perspectives had been represented in the data map. Four responses were *totally positive*, two were *partially positive*, and one was *neutral*. A good example of the *totally positive* responses comes from co-designer #1:

"*I think the perspective of all the participating partners broadened and we all gained new ideas of how close our attempts in app development are actually related.*"

6.5.2 Assessing the Design Product

Analysis of the hexagonal 5WsH worksheets created in Activity 1, supported by the video recordings of co-designers' explanations, shows many examples of detailed descriptions containing things like: *the data type or types*; *where, when and how often data are generated*; *where, when and by whom the applications are used*; and so on. For example, Figure 24 shows the representation of the *Carer* application and its data. It shows the application's purpose, how it is used, that it generates textual data relating to problem situations faced by carers in their interactions with care home residents, and audio data generated as carers explore possible plans of action. It also shows the relationships between the different actors in the work situation. All these details suggest that the co-designers in this group are likely to have gained an improved understanding of these data.

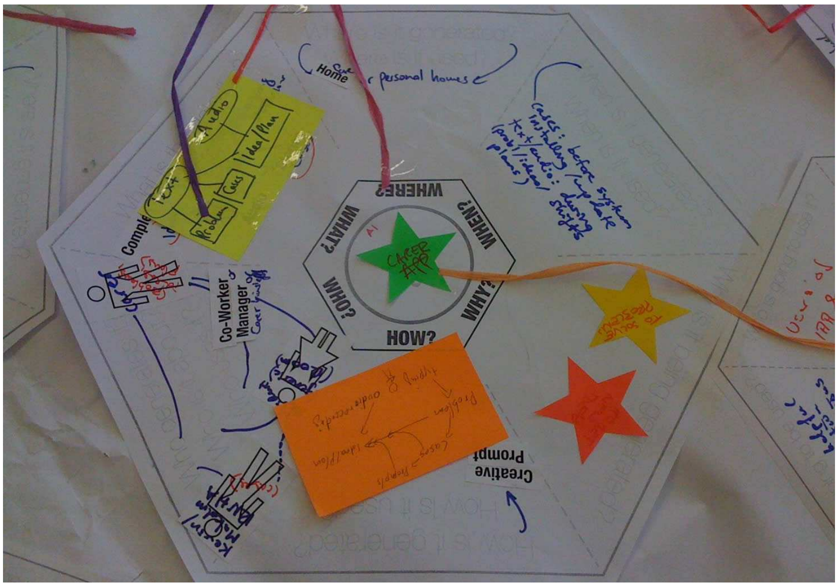

Figure 24: Completed 5WsH hexagonal worksheet describing MIRROR's Carer application

Figure 25 shows the representation of the *Sensor Data* application. This shows the data types automatically generated by proximity sensors recording interactions between care home staff and residents. It shows where and when the data are generated, who they represent and that they are automatically generated every ten seconds. It also shows that they are used in team meetings as a tool to support reflection on work practice, explaining why these data are generated, why they are important and how they will be used.

Similarly, in Figure 26 we see the description of the *WATCHiT / Timeline* applications that help emergency workers reflect on crisis events. Here we see that data such as date and time, location, status, work process, and environmental and biometric information are initiated by simple user gestures within the crisis situations, and used for later replay and reflection, helping emergency handling. Again in both of these cases, the detail suggests an improved understanding of the data.

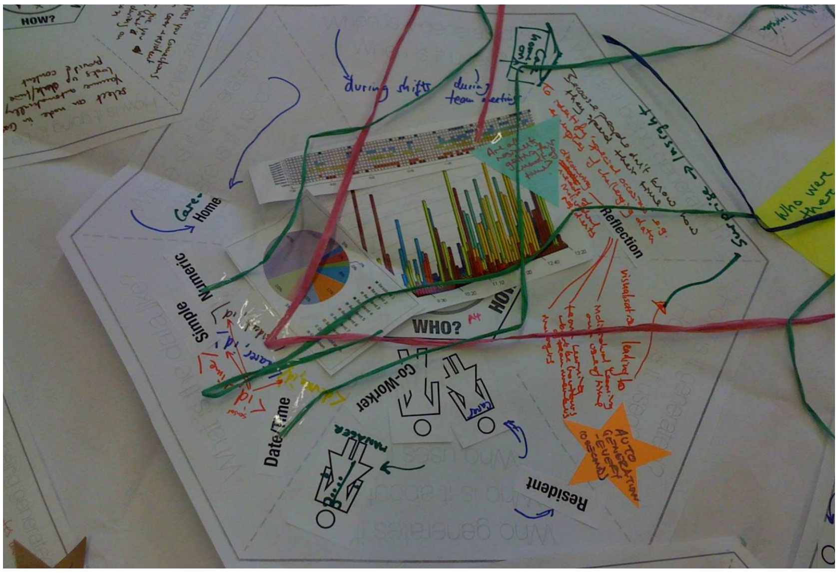

Figure 25: Completed 5WsH hexagonal worksheet showing MIRROR's Sensor Data application

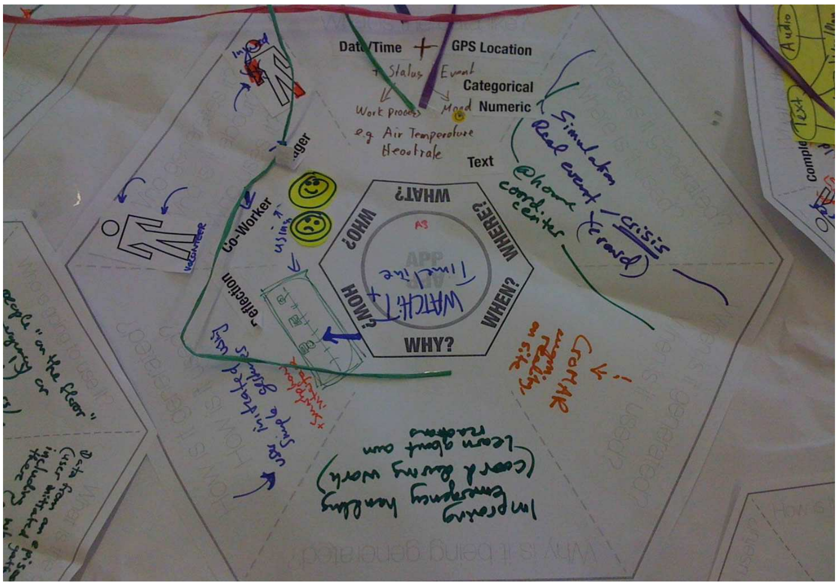

Figure 26: Completed 5WsH worksheet for MIRROR's WATCHiT / Timeline applications

Analysis of the *map* of MIRROR applications and data created during Activity 2 shows that seven connections between existing MIRROR applications and their data, which the co-designers were previously unaware of, had now been made explicit. These were typically between a pair of MIRROR applications and were represented with coloured thread connecting the relevant 5WsH hexagons in the *map*. Labels outlining the details of the data being shared were added with post-it notes wrapped around the thread. This can be seen in Figure 27. In three cases, the data from one application would augment the other. For example *Sensor Data* could be used to augment *WATCHiT/Timeline* by identifying who was present in a given situation. In two cases, the data from one application would be used as input to the other. For example, *Sensor Data* could be used as input for the *IAA/IMA* application. In another, the data and functionality of *Carer* and *IAA/IMA* were identified as similar. Finally, *KnowSelf*, *Sensor Data* and *WATCHiT/Timeline* were connected by complementary data measuring human tasks, using different measures in different work contexts. These demonstrate co-designers' improved understanding of the data and how they interact after the workshop.

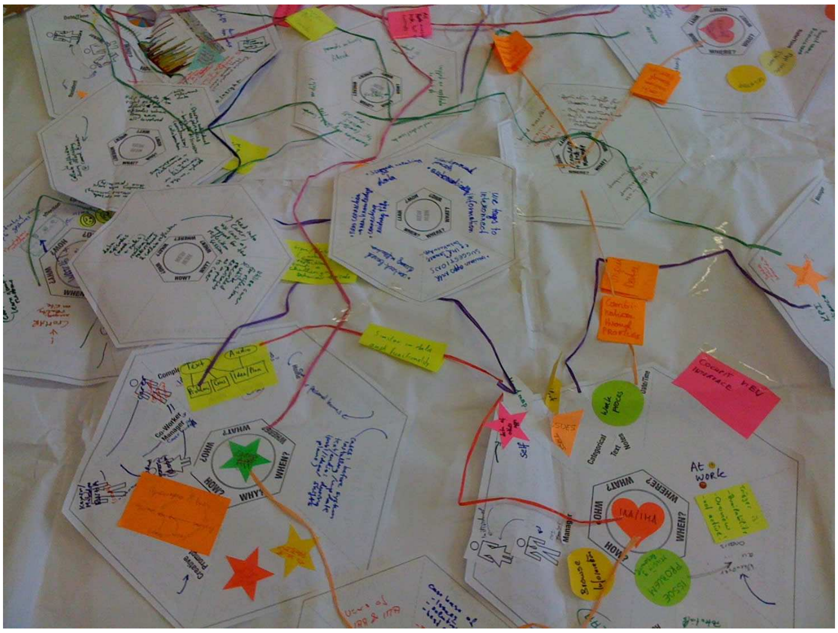

Figure 27: Map of MIRROR applications and data with coloured threads indicating connections and how they are made

Analysis of the outputs from Activity 3 identified a total of nine new ideas for possible uses of the data from MIRROR applications, described using the A3 sized 5WsH hexagonal worksheets. Looking at these, and the explanations of them given to camera, in more detail there are examples of: *the data types being generated and shared*; *the users who will benefit from the new service*; and *the work contexts the new service might be used in.*

For example, Figure 28 shows a new idea that connects three of the MIRROR applications: *WATCHiT/Timeline*, *CareReflect* and *KnowSelf*. Support would be provided for care workers by helping them to see what is important in an anomalous situation, reflect on and understand the situation and their response to it, and with suggestions for which of the other MIRROR applications might offer further help. This would be achieved using time stamped and tagged situation data to check and prompt activity.

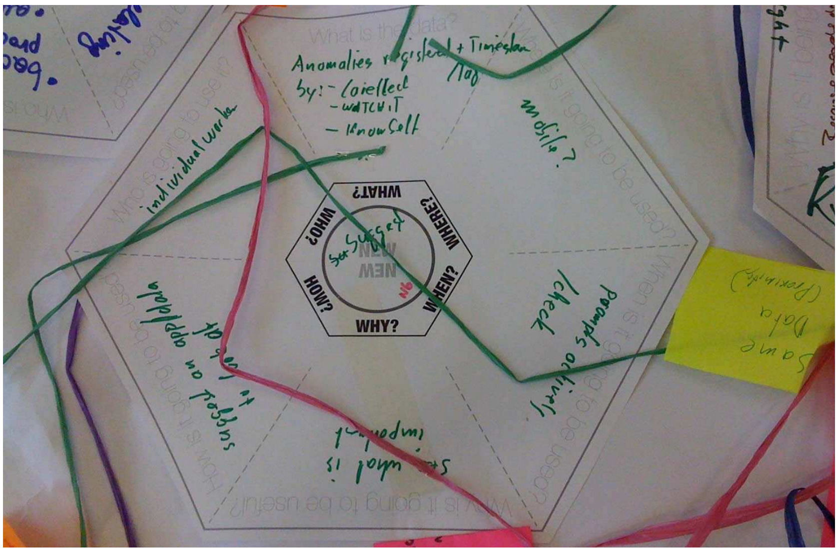

Figure 28: Hexagonal representation of a new idea connecting data from three MIRROR applications: WATCHiT, CareReflect and KnowSelf

Figure 29: Hexagonal worksheet describing a new idea to use proximity data from the Sensor Data application to augment the WATCHiT / Timeline application

Similarly, Figure 29 shows a new idea that would use proximity data generated by MIRROR's *Sensor Data* application and user initiated environmental, location and event data from the *WATCHiT/Timeline* applications, to support collaborative reflection during debriefing sessions. This would support emergency or care home workers and coordinating or management staff by helping to make sure that all necessary people are present to reflect on an incident in which they were involved. Each of these examples suggests that the tools and techniques used during the workshop had helped inspire co-designers' creative ideas.

6.6 Discussion

In this case study I wanted to know if activities inspired by a combination of generative design and applied creativity techniques would help co-designers gain an improved understanding of the data available in a design situation. I wanted to know if they would be able to share their individual perspectives on how the data are generated and where they might be used, and whether all this would help inspire creative ideas about new uses for these data. The detail and richness in the descriptions of MIRROR applications and their data made during Activity 1 suggests that the tools and techniques I used during this workshop were successful in helping co-designers share their individual perspectives, and that this contributed to an improved understanding of these data, where they come from and how they might be used. This improved understanding can also be seen in the number of connections between data that co-designers made explicit in Activity 2, and the number of new ideas they were able to generate in Activity 3.

Co-designers' responses to the prompts on the first and the third Reflection Postcards provide supporting evidence with regards to an improvement in their understanding and to how well individual perspectives were expressed. However, co-designers' reflective responses also highlight some areas for possible caution. Concerns were raised about the complexity of the *map* representation made during the workshop, and how effectively the knowledge it contained could be retained or re-used at a future date. The knowledge in this *map* was translated into an online resource[19], with the intention of providing a preparatory resource for a follow-up workshop, at which its effectiveness could be evaluated. Unfortunately time pressure meant that the focus of each of MIRROR's work packages returned to evaluating existing applications and this follow-up workshop was not possible.

The number and richness of new ideas generated during Activity 3 also suggests that the tools and techniques used during this

[19] www.grahamdove.com/mirror

workshop were effective in helping co-designers find inspiration in their improved understanding of the MIRROR data and their potential uses. Responses to the second Reflection Postcard prompt also suggest that co-designers felt able to contribute ideas, and that those ideas were reflected in the *map* they created. One of the co-designers again commented that the process of representing ideas had become "*too much*" and this, combined with the concerns about complexity shown earlier, suggests that co-designers may require different levels of support during these activities. Further study of effective facilitation techniques for these activities is an area for future work. Similarly, further study should be made into methods for effectively translating, organising, structuring and sharing the knowledge generated.

6.7 Reflections

6.7.1 Research and Evaluation Methods

6.7.1.1 Benefits and Limitations of Study Design

This case study described a workshop in which the aim was to help co-designers gain an improved understanding of the available data and use this to inspire creative design ideas. A key objective was to investigate whether activities combining generative design activities with applied creativity techniques would be effective in this regard. To do this, the 5WsH creativity technique, discussed in section 2.5.4.1 was used to help structure co-designers' thinking, and the hexagonal worksheets were used to help structure their outputs. This was successful, and I repeated this combination in the design experiment reported in Chapter 7 and the case study reported in

Chapter 8. The generative design activities appeared to help co-designers share their knowledge and represent new ideas. However, some co-designers expressed doubts about how well the knowledge generated could be transferred. This is a concern that will need to be considered in future studies. It should also be remembered that this case study was exploratory, and involved a single workshop with participants drawn from a very particular population. Because of this the generalizability of the findings is limited, and further study required.

6.7.1.2 Limitations of Data Collection and Analysis

This case study used Reflection Postcards as a key source of evaluation data. The strengths and limitations of this method are discussed in Chapter 5. However, in this workshop, given the background of the participants, I may also have been able to use questionnaires to gather more detailed evaluation data. The other source of evaluation data was the outputs generated during the workshop's activities.

Whilst the number of new ideas generated during the workshop's activities doesn't say anything definitively positive about the inspiration provided for co-designers' creative design ideas, a severe shortage of new ideas would have raised a warning flag about the activities' effectiveness. Assessing creativity through the qualitative aspects of the workshop's outputs is also challenging, relying on largely subjective judgements. The validity and reliability of this evaluation method would be improved if consistent ratings could be obtained from a number of independent domain experts. In an exploratory case study, this evaluation method provides early indicators, both positive and negative, of the intervention's possible impacts. Because of the evaluation difficulties highlighted above, I chose not to include generative design activities in either of my remaining studies, reported in chapters 7 and 8.

6.7.2 Takeaways

T6.1 *Workshop activities that combine applied creativity techniques, such as 5WsH, with generative design activities, such as mapmaking, appear to help co-designers gain an improved understanding of the data available to a design situation, which in turn can help inspire creative design ideas.*

T6.2 *Custom worksheets, such as the hexagonal worksheets used with the 5WsH, appear to help participants structure the ideas they generate using applied creativity techniques.*

7 Analytical & Intuitive Creativity

This chapter describes my second design experiment. Two interfaces designed to prompt different styles of creative thinking are compared. It builds on the lessons from the first design experiment in Chapter 4 and the use of photographs during the case study reported in Chapter 5

7.1 Introduction

Design can be described as an activity that takes place in the '*world of imagination*', and where exploratory interaction with artefacts such as sketches, models and diagrams is used to manipulate ideas and concepts (Rittel, 1987). The artefacts that facilitate this exploration are known as design artefacts (Bertelsen, 2000), and can take a number of different forms including pencil sketches and digital CAD drawings (Perry & Sanderson, 1998). Other examples include the interfaces and toolkits I have used in previous studies, the photographs and other generative design materials discussed by Sander and Stappers e.g. (2012, p.71) or the cards used in the Inspiration Card Workshop, see section 2.4.3.

A key aspect of developing the CoDesign With Data approach is building design artefacts to investigate different ways that domain-relevant data might be used to prompt workshop participants' insight seeking and inspire creative design ideas. In section 2.5.1, we saw that there are a number of possible ways to visually represent these data. These include the type of *information* *dashboards* used to analyse business data described by Few (2006), and the ambient, social or artistic visualization techniques that Pousman, Stasko and Mataes (2007) describe as *casual information visualization*. We also saw how different styles of visualization design have been categorised as *traditional information visualization* or *direct visualization* (Manovich, 2011), and as *analytical visualization* or *artistic visualization* (Kosara, 2007). In section 2.5.3 we saw how creative cognition can be prompted, inspired and supported using different styles of applied creativity technique, and how these techniques can be categorised as either *analytical* or *intuitive* (Couger et al., 1993).

Parallels can be drawn between *traditional* (Manovich, 2011) or *pragmatic* (Kosara, 2007) styles of visualization, used for analytical investigation of quantitative data, and *analytical* techniques for idea generation (Couger et al., 1993). Both prompt and support a structured, linear, stepwise interrogation and exploration of information as a route to gaining insight and generating new ideas. Both are also concerned with organizing and decomposing the available information as a tool for problem solving. Parallels can also be drawn between the *direct* (Manovich, 2011), *casual* (Pousman et al., 2007) and *artistic* (Kosara, 2007; Viégas & Wattenberg, 2007) styles of visualization, described in section 2.5.1, which are used to represent information, including media objects such as photographs, in an evocative, or ambient and peripheral way, and the *intuitive* techniques for idea generation. Both can be said to directly prompt more subjective insights, drawn from the unconscious in a way that might surprise the person involved.

In chapters 4 and 5 we saw how the type of quantitative data generated by smart energy meters can be represented in a dashboard style interface to reveal interesting insights into energy consumption practices, and how these can be used to prompt creative design ideas. Equally, it is also possible that insight regarding energy consumption practices might be gained through the study of social media data, such as photographs on Flickr[20] or Tweet[21] streams. Using these types of data as a way to understand social practice is discussed by Boyd and Crawford (2012) and Manovich (2012). My aim for this study was to investigate whether the parallels between the different categories of applied creativity technique and the different categories of information visualization design style could be exploited in digital design artefacts. If this is the case then participants might use these different sources of domain-relevant data in different ways, and to prompt different types of creative design idea.

7.2 Research Question

To explore this in more detail I investigated the ways in which participants' idea generation activities varied when given one of two alternative digital artefacts as a source of design inspiration. The first of these was an interface designed to prompt creative cognition in an *analytical* way by visualizing smart energy data in a *traditional* style. This was similar to the interfaces I had given to participants during the studies reported in chapters 4 and 5. The second of these was an interface designed to prompt creative cognition in an *intuitive* way by presenting Flickr photographs in a *direct*

[20] www.flickr.com
[21] www.twitter.com

visualization style. In addition to its role in prompting creative thought in an *intuitive* way, this interface was also an alternative way of introducing the more ambiguous domain-relevant information represented in the photographs used as part of the generative design toolkit I had given to participants in Chapter 5's study. In the study reported here I was guided by the following research question:

RQ7.1 *How would participants' idea generation activities differ?*

When given:

A: *A digital design artefact designed to prompt creative cognition in an analytical way by visualizing smart energy data in a traditional style.*

B: *A digital design artefact designed to prompt creative cognition in an intuitive way by presenting photographs from social media in a direct visualization style.*

To undertake this investigation I planned a small-scale design experiment (Cash et al., 2012). Design experiments are discussed in more detail in section 3.1. In this study, the design context was that of domestic energy consumption, and the variable of interest was the different digital design artefacts given to participants to inspire their idea generation. In addition to the two conditions represented by each of the design artefacts outlined above, this design experiment also had participants in a control condition, in which no additional source of inspiration was given, and in a condition where participants were given printed reports outlining changes in energy consumption. This last condition was intended to act in a similar way to that of a placebo condition (Cash et al., 2012) in that it would provide as an intervention a familiar artefact with which each of the interfaces under consideration could also be compared. In this condition, participants were given two printed reports generated by the UK Energy Saving Trust[22]. These reports are of the type often used to inform design projects and which might be made available to focus groups.

7.3 Workshop Details

Tools used: *iPad Information Visualization Interface, iPad Flickr Photograph Interface, Printed Reports, Supplementary Information Sheets, Worksheets, Workshop Stationary*

Techniques used: *5WsH, Brainstorming with Post-its, Combinational Creativity*

7.3.1 Background

In this design experiment, eight groups of three participants each were taken through a workshop, typically lasting around two hours, in one of four conditions, with two workshops in each condition:

C1: *Idea generation with a digital design artefact designed to prompt creative cognition in an analytical way by visualizing smart energy data in a traditional style*

C2: *Idea generation with a digital design artefact designed to prompt creative cognition in an intuitive way by presenting photographs from social media in a direct visualization style.*

C3: *Idea generation with printed reports outlining changes in energy consumption practices.*

C4: *Idea generation with no additional source of inspiration.*

[22] www.energysavingtrust.org.uk

In each of these workshops, participants were given the same objective, derived from a public challenge set by NESTA (NESTA, 2013), and worded as follows:

'The aim of this challenge is to come up with ideas for new products, technologies, services or incentives that shift domestic electricity demand to off-peak times in order to reduce carbon emissions.'

To increase the ecological validity of the study (Brewer, 2000), the activities under investigation were carried out within a full workshop, taking participants through each stage of the creative design process. Each workshop followed exactly the same format.

7.3.2 Participants

A total of twenty-four participants aged between 22 and 45 were recruited, three in each of the eight workshops. There were fourteen male and ten female participants. These included members of the Environmental Champions Network at City University London, who are volunteer student and staff representatives with an interest in and knowledge of energy saving and environmental issues; postgraduate electrical engineering and environmental technology students; and postgraduate students studying interaction design, information visualization, and creativity science.

Participants from different backgrounds were distributed across the different workshops, with each workshop having a mix of participants who contributed knowledge from the energy domain, and of a design discipline or the study of creativity. The intention here was to provide each workshop with participants who had complementary skills and experience that would help them address different aspects of the design challenge.

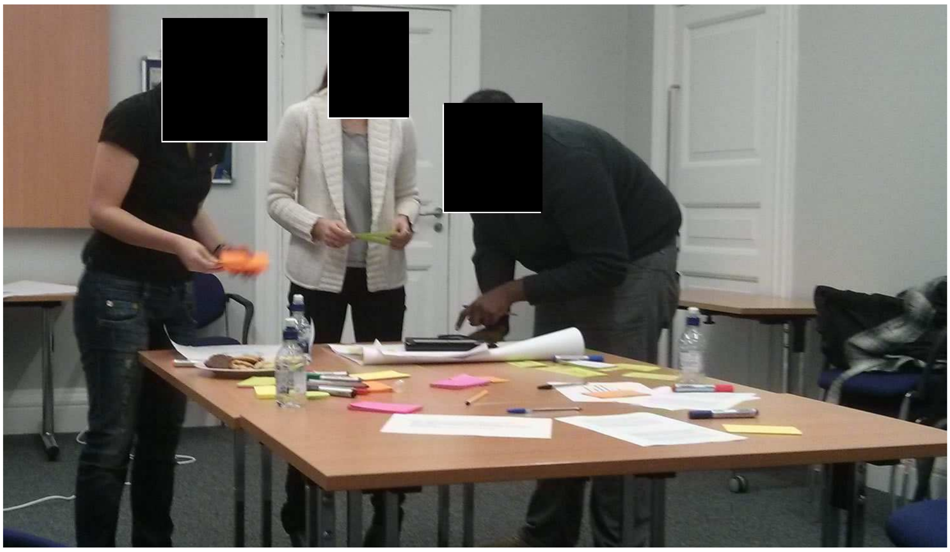

Figure 30: Participants using the iPad interface in which smart energy data are visualized to find inspiration for design ideas

7.3.3 Workshop Materials

Workshop participants were provided with the following materials to undertake activities:

An ***iPad Information Visualization Interface****, described in section 7.3.4.1 (Only used in the* ***C1*** *condition workshops).*

An ***iPad Flicker Photograph Interface****, described in section 7.3.4.2 (Only used in the* ***C2*** *condition workshops).*

Two ***Printed Reports****, described in section 7.3.3.1 (Only used in the* ***C3*** *condition workshops)*

Two ***Supplementary Information Sheets****, described in section 7.3.3.2.*

Two ***Worksheets****, described in section 7.3.3.3*

A selection of standard ***Workshop Stationary****, including coloured marker pens and post-it notes, to record their ideas.*

Each workshop took place around a large table with plenty of space to move around and participants were provided with refreshments.

The workshops were all videoed using a single camera. The facilitator used the same script in every workshop to ensure instructions were given consistently. Examples of each of the materials used in these workshops can be found in Appendix C of this thesis.

7.3.3.1 Reports

In the two workshops under the C3 condition participants were given a pair of printed reports produced by the UK Energy Savings Trust[23], which describe changes in energy consumption patterns. The UK Energy Savings Trust is a social enterprise that aims to offer impartial advice to communities and households on how to reduce carbon emissions, use water more sustainably and save money on energy bills. This was to fulfil a role similar to that of the placebo condition discussed by Cash et al. (Cash et al., 2012). These reports are of the type often used as background data to inform design projects.

The first of the two reports, '*Powering the Nation*' (Energy Savings Trust, 2012), shows an overview and summary of the data collected in the UK Household Electricity Use Study (DEFRA, 2012). This study also provided the data that was visualized for the interface used in condition C1, and discussed in section 7.3.4.1. The second, '*Rise of the Machines*' (Energy Savings Trust, 2011), provides a detailed analysis of changes in household appliance use since the 1970s, outlining differences in the number and types of appliances in typical households, and also the amount of energy these appliances typically use. Both reports feature a mixture of textual information

[23] www.energysavingtrust.org.uk

describing energy consumption in detail, data tables showing factors such as the penetration of household appliances and energy consumption rates, and graphs and infographics depicting these data. The report '*Rise of the Machines*' is 20 pages long and is available online (Energy Savings Trust, 2011). The report '*Powering the Nation*' is also available online (Energy Savings Trust, 2012), and is 15 pages long. Each report was printed in full colour on A4 paper and presented to participants bound in a plastic clear view folder.

7.3.3.2 Supplementary Information Sheets

Participants in all eight workshops were given the same two sheets containing supporting information. These two sheets were:

A ***Brief*** *document outlining the challenge being set; the problem of peak energy demand; example solution areas; and a graph showing electricity demand on the grid over one week.*

A ***Guide*** *document to suggest aspects of the design challenge participants might consider. This contained four questions: 'How might different people use electricity?' 'What might be taking place that causes peaks in demand?' 'What are the constraints that cause electricity to be used at different times?' and 'How might these constraints be overcome?'*

7.3.3.3 Worksheets

Each group of participants in all eight workshops was given the same two worksheets to help capture and organise their ideas. These two worksheets were:

An A1 printed worksheet to organise their ideas during the idea generation activity. This was designed with a pair of crossed axis representing two dimensions of a possible solution space. Top to *bottom the axis was 'Individual Households' to 'Communities'. Left to right the axis was 'Technology' to 'Behaviour Change'.*

An A2 sized 5WsH hexagonal worksheet to develop and describe their final solution idea at the end of the workshop. This contained six questions asking participants to consider the 'Who, What, Why, Where, When and How' that would describe their product or service when in use.

7.3.4 Visualization Interface Design

The digital design artefacts used in this study were both designed specifically for this purpose, and were developed using the D3 JavaScript library (Bostock et al., 2011). They were presented to each group of participants via the web browser of an iPad. Each of the groups in the relevant experimental condition was given a single iPad. Section 2.5.2.2 outlines the reasons for using iPads in a workshop setting.

7.3.4.1 Visualized Smart Energy Meter Data

With this interface the aim was to prompt participants' creative thinking in an *analytical* style (Couger et al., 1993). It uses a visualization style similar to that Manovich describes as *traditional* information visualization (Manovich, 2011), and that Kosara describes as *pragmatic* visualization (Kosara, 2007). This digital design artefact is available to use online[24].

[24] www.grahamdove.com/energyshift/infovis.html

7.3.4.1.1 Data

This interface visualizes the type of quantitative data generated by smart energy products, such as smart meters and smart plugs. The data were obtained from two sources. Energy consumption data were taken from the *UK Household Electricity Use Study* (DEFRA, 2012) commissioned by the Department for Environment Food and Rural Affairs (DEFRA). The study monitored domestic electrical appliances in a total of 251 owner-occupier households across England over the period of April 2010 to April 2011. Contained within this report is a catalogue of the range and quantity of electrically powered appliances, products and gadgets found in the typical home and a measure of the frequency and patterns of their use, indicating user habits. Information indicating peak demand times on the UK National Grid was derived from one year's historical demand data (National Grid, 2014).

7.3.4.1.2 Visual Design

This interface, see Figure 31, is based on what Few calls a '*faceted analytical display*' (Few, 2009, p.107), a style that is more commonly known as an information visualization dashboard. The interface is divided into three sections. Towards the top, it uses a combination of bubble chart and linear timeline techniques to show average hourly consumption of different classes of domestic appliance reflecting the users' currently selected filters. Below this a heatmap timeline displays half-hourly National Grid demand data in deciles, this reflects the currently selected season and day filters. Towards the bottom of the screen, the average yearly consumption for each of the appliances featured in the visualization is shown using a series of bar charts, one for each class of appliance. This reflects the currently selected demographic filter. The interface uses a divergent colour scheme for the demand data and a qualitative colour scheme for the domestic appliances, based on recommendations found in (Harrower & Brewer, 2003).

7.3.4.1.3 Interaction

Users interact with the visual interface of the design artefact to filter the data using a series of graphical icons, arranged around the top right hand corner of the screen. These represent household type: *single households*, *shared housing*, *families* and *older couples*; season: *summer* and *winter*; and day: *weekday* or *weekend*. The interface enables a simple AND filter. User interaction updates the visualization of hourly and yearly average consumption data, and also the national grid demand data.

In Figure 31 we see the data visualized with the filters selecting *weekday* consumption in *summer* for *families*, this is indicated with a dark outline given to the relevant buttons. Figure 32 pictures the interface updated to reflect the selection of single occupancy households energy consumption during winter weekends. Selecting any one of the bubbles representing a single hour along the timeline displays the details of the energy consumption of the relevant class of appliance during that hour. This is shown in Figure 33.

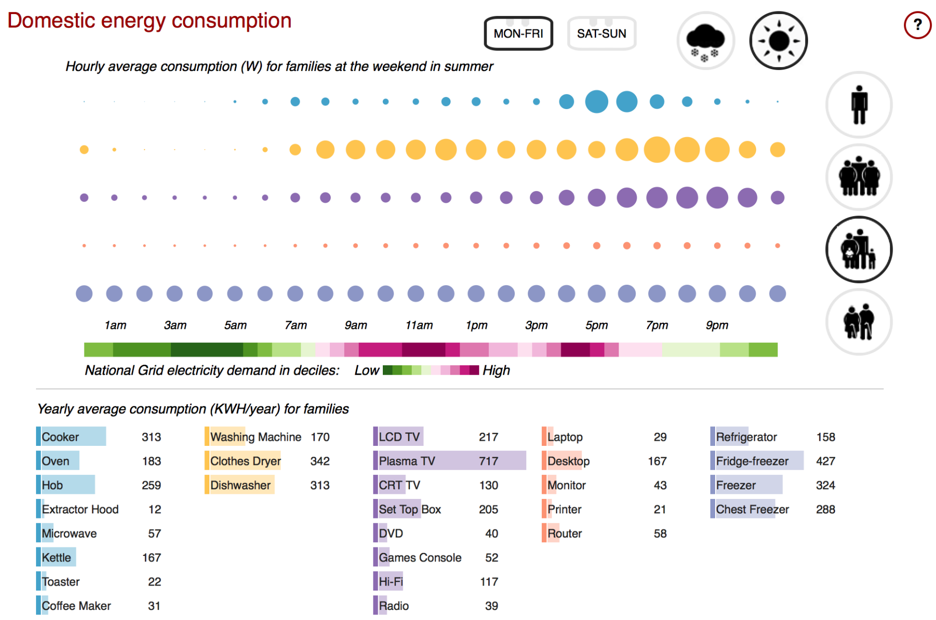

Figure 31: Screen shot of the interface visualizing smart energy data filtered to show the energy consumption of families during weekdays in the summer

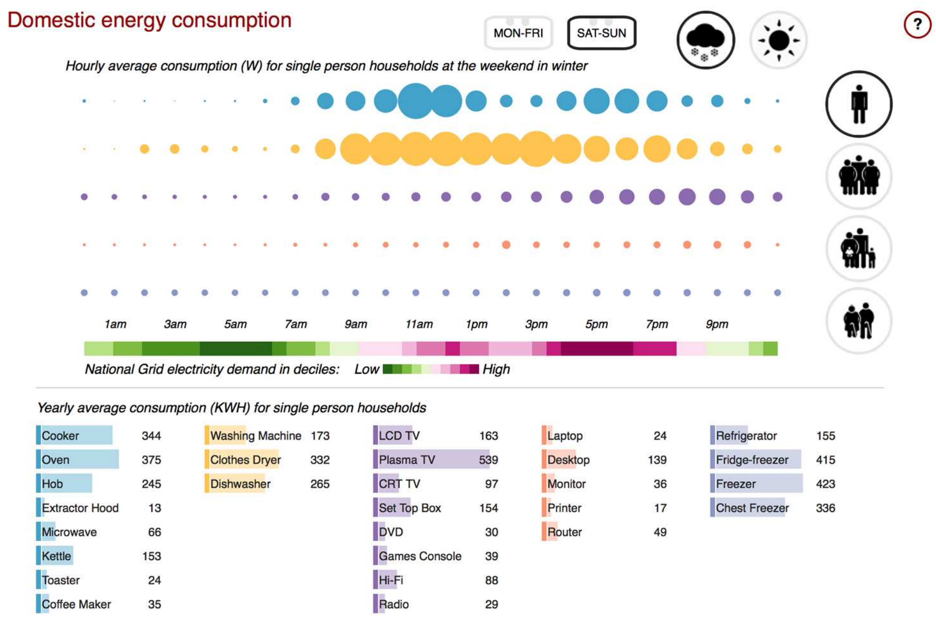

Figure 32: Screen shot of the interface visualizing smart energy data, filtered to show weekend consumption for single occupant households, on winter weekends

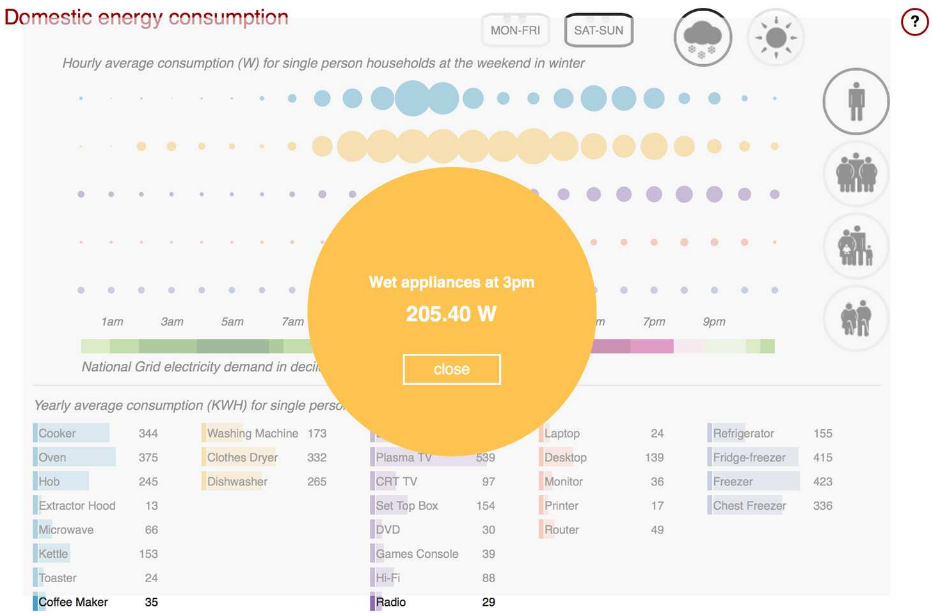

Figure 33: Screen shot of the interface visualizing smart energy data, showing the details for wet appliances at 3pm, filtered as in Figure 32

7.3.4.1.4 Creativity Support

With this interface my intention was to facilitate participants' exploration of quantitative data describing domestic energy consumption as a prompt to an *analytical* style of creative thinking. To support this participants were provided with user controlled interactions that allowed them to seek insight in a structured, linear manner, and organize the information in a way that allowed them to decompose the problem of peaks in energy demand into different possible causes. This follows Shneiderman's description of how information visualization techniques can support the cognitive processes that lead to hypothesis formation and testing, and therefore creative insight (Shneiderman, 1999; 2000).

7.3.4.2 Photographs Selected From Flickr

My intention with this interface was to inspire participants with a steady flow of photographs, each with a different connection to domestic energy consumption, to provide a novel perspective and prompt what Pousman, Stasko and Mataes term *reflective insights*. This, I believe, means it would fit into their classification of *casual information visualization* (Pousman et al., 2007). In this way, my aim was to prompt participants' creative thinking in an *intuitive* way (Couger et al., 1993). The interface is available to use online[25].

7.3.4.2.1 Data

In this interface, participants were presented with the kind of informal information available in the images that can be retrieved from social media sources such as Flickr[26]. The custom designed interface displays images selected via the Flickr search API[27], using the metadata description tags that were assigned when uploaded. Each call to the search API returns the data for 18 images taken at random from those that match the current criteria. In addition, the complete list of user assigned description tags, held in the metadata for these images, is also collected. The metadata description tags are stored locally and later selected randomly for display, as described in section 7.3.4.2.3.

7.3.4.2.2 Visual Design

The design of this interface was informed by techniques that visualize information for purposes other than data analysis. Pousman, Stasko and Mateas (2007) describe a class of *casual*

[25] www.grahamdove.com/energyshift/photos.html.
[26] www.flickr.com
[27] www.flickr.com/services/api/

information visualization, in which *utilitarian* design goals can be traded in for a wider interpretation of what is deemed *useful*. Further inspiration was taken from the type of visualization interface design that Manovich has described as *direct visualization*, in which "*new visual representations from the actual media objects (images, video) or their parts*" are created (Manovich, 2011).

The interface, Figure 34, is based on a photo browser style, and displays eighteen images in a six by three grid. The images displayed are those selected in the search process described in section 7.3.4.2.3. The initial request to the Flickr API when the representation is first loaded searches for images whose metadata description tags match the search term *Home appliances*. Every 750 milliseconds another API call is made and a single randomly selected image from the grid is replaced by a single image randomly selected from those returned in the new search. This means that users do not have direct control over the images that are being shown, and that they are presented with a diverse variety of photographs, without the option to narrowly focus their search. There is a smooth faded transition between these images. Two description tag strings, randomly selected from those in the local store, are also shown. Each of these is displayed separately in one of the two text boxes towards the centre of the interface. The tags displayed are updated every 1250 milliseconds.

7.3.4.2.3 Interaction

In this interface, interactivity is intentionally restricted. Images update automatically, which discourages users from focusing their attention too narrowly on images of a specific type or with specific content. Whilst users are not able to select and retain individual images, they can change the image search criteria by selecting from one of the preselected categories *Wash and clean*, see for example Figure 35, *Cook and cool*, *Home entertainment* or *Computers and gadgets*, each of which is shown at the top of the screen. Alternatively, users can input their own search terms using the large text entry box at the top right, see for example Figure 36. Changing the search term does not immediately update all the images in one go. Rather, individual images are updated more slowly over time, one at a time following each API call. This means that there is a slow transition from a visual interface that represents the old search criteria to one that represents the new, which creates an opportunity for new, perhaps unexpected, connections between more distantly related images or concepts to be formed. This follows theories of combinational creativity discussed in section 2.5.4.3.

7.3.4.2.4 Creativity Support

With this interface, my intention was to inspire participants' idea generation with imagery and expand the idea space they explored. The Flickr photographs are selected via description tags, which have connections to energy consumption that might be ambiguous, such as *Wash and clean*. Therefore the photographs displayed might be only be tangentially related to energy consumption. This was a deliberate attempt to widen participants' focus in order to increase the opportunities for unfamiliar connections to be made and combinations of possibly familiar concepts turned into creative ideas. Also, to reduce the likelihood that participants would focus their ideation on particular areas by retaining specific photographs, users could not directly control the images shown in the interface, which updates automatically. This was to prompt creative thought in an *intuitive* way (Couger et al., 1993).

Figure 34: Screen shot of the interface displaying Flickr photographs with the default filter search term ‘Home appliances’

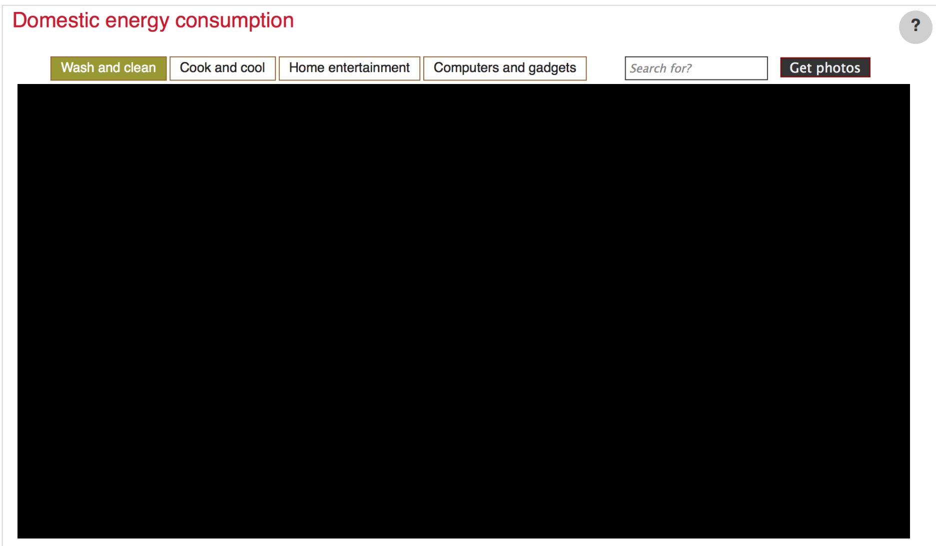

Figure 35: Screen shot of the interface displaying Flickr photographs filtered with the search term 'Wash and clean'

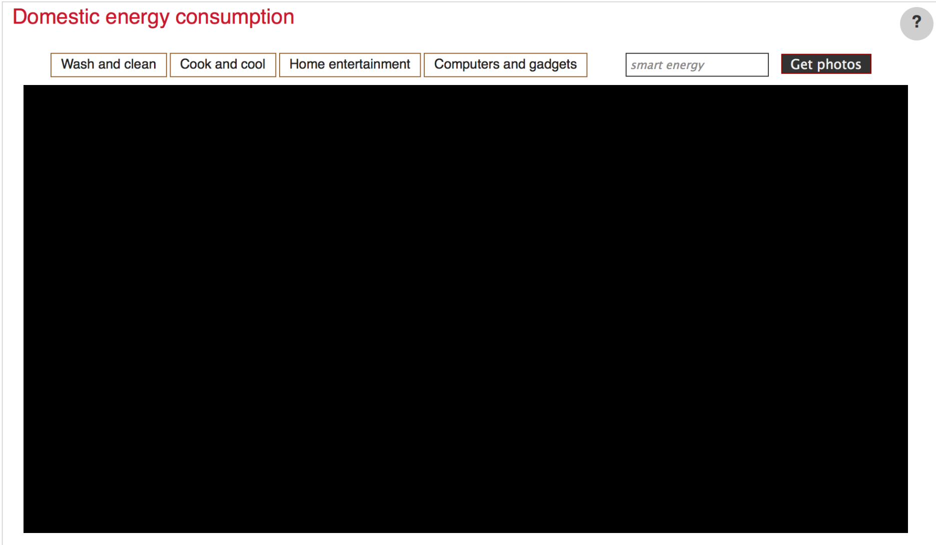

Figure 36: Screen shot of the interface displaying Flickr photographs filtered with the user entered search term 'smart energy'

7.3.5 Workshop Activities

Each workshop followed the same format and consisted of five different activities. Each workshop lasted a total of approximately two hours.

7.3.5.1 Activity1: Introducing the Challenge

In this activity, the workshop's design objective was outlined to participants. Participants were instructed to generate creative ideas for products, services or incentives to help shift domestic electricity consumption away from peak times. This might be achieved with domestic appliances that optimise their own energy consumption or through consumers choosing to change the way they use appliances. They were also instructed that ideas might target individual households or equally they could be aimed at whole communities. Each group was given the supporting materials described in section 7.3.3 and, where appropriate for the condition under investigation the iPad interface or printed reports. These remained available for participants to use as they wished throughout the workshop. This activity typically lasted 10 minutes

7.3.5.2 Activity 2: Discussing the Brief

In this activity participants were given a period of approximately ten minutes to read and discuss the design brief as preparation for idea generation. They were told that they should use any of the workshop materials, including the design artefact where appropriate, to help them with this. This activity typically lasted 15 minutes.

7.3.5.3 Activity 3: Generating Ideas

The third activity involved participants generating new ideas, and they were instructed to: "*try to come up with as many different ideas as you possibly can for products, services or incentives that will help us shift electricity consumption away from peak hours.*" Participants were asked to capture each idea they generated on a separate post-it note, were reminded of the standard brainstorming approach of receiving all new ideas with an open mind, and were again reminded that the supporting materials and, where appropriate the iPad interfaces and printed reports, were there to help them. This activity typically lasted around 40 minutes and was the primary evaluation focus for this study.

7.3.5.4 Activity 4: Developing a Solution

In this activity, participants were asked to select for further development the idea or combination of ideas that they thought represented the most creative response to the brief. Solutions were developed using the 5WsH hexagonal worksheets, which are described in section 7.3.3. This activity typically lasted 40 minutes.

7.3.5.5 Activity 5: Presenting the Solution

In the workshop's final activity each group was asked to describe their solution to camera. This activity typically lasted 10-15 minutes

7.4 Evaluation Methods

In this design experiment my aim was to compare how participants' idea generation activities might vary when given one of two alternative digital design artefacts as a source of design inspiration. The first of these was an interface designed to prompt creative cognition in an *analytical* way by visualizing smart energy data in a *traditional* style. The second was an interface designed to prompt creative cognition in an *intuitive* way by presenting Flickr photographs in a *direct visualization* style.

To answer my research question, see section 7.2, I collected three different kinds of data. First, participants were given a questionnaire to complete at the end of each workshop. This consisted of the questions required by the Creativity Support Index (CSI) (Carroll et al., 2009), plus two additional questions directly addressing the influence of the relevant design artefact on their idea generation. This questionnaire was not given to the groups in the control condition workshops, as under this condition there was no design artefact to evaluate. Second, each workshop was videoed with a single camera in order assess how the design artefacts were used during idea generation. Finally, the outputs of each workshop were assessed. As in the previous design experiment, reported in Chapter 4, the evaluation methods and data collected will be discussed in terms of *Supporting the People Designing*, *Assessing* *the Design Product*, and *Understanding the Design Process*. This choice of structure is explained fully in section 3.2.

7.4.1 Supporting the People Designing

To investigate the extent to which participants felt that the design artefacts supported their creative processes during their idea generation activities, I used the questions from the Creativity Support Index (CSI) (Carroll et al., 2009). The CSI is made up of two parts, and is a standardized survey metric for evaluating the effectiveness with which a given tool provides support for it's user's creative processes. This is discussed in detail in section 3.2.1. In the first part, participants answer twelve questions that assess six different dimensions associated with creativity. There are two questions for each factor, addressing it from a slightly different perspective. These were slightly reworded from the original questionnaire to refer appropriately to the relevant design artefact. For example the two questions addressing *Collaboration* that were given to participants who had used the interface that visualized smart energy data were:

"The iPad information visualization allowed other people to work with me easily"

"It was easy to share ideas with other people using the iPad information visualization"

For each question, the rating scale ranged from 1 *strongly disagree* to 9 *agree strongly*.

In the second part, participants are asked to answer a total of fifteen questions designed to assess the relative importance of each of the six dimensions to the activity the participant has been undertaking.

The final CSI score for each participant is calculated as a product of the ratings they provided for each of the creativity factors in the first part multiplied by the importance they attached to that factor in the second part. This enabled a comparison of the effectiveness of each of the different design artefacts given to participants to support their design ideation. To analyse this data, each participant's final CSI score was calculated and grouped according to which of the design artefacts they had used during their workshop. I then performed a one-way ANOVA, followed by a Tukey test, to evaluate for statistical significance between the scores for each condition.

In the second part of the CSI, participants are asked to answer a total of fifteen questions designed to assess the relative importance of each of six dimensions to the activity the participant has been undertaking. To assess which of the different dimensions of creativity support measured in the CSI were most important to participants I totalled the score given to each dimension by each participant after each workshop.

To directly investigate how important the different design artefacts were to participants' idea generation, two further statements were included in each post workshop questionnaire. As in the CSI, these addressed the same issue from two slightly different perspectives. Again the wording of these statements varied slightly to refer appropriately to the relevant design artefact. For example, the two statements given to those participants who had used the iPad interface visualizing smart energy data were:

"I had many ideas as a result of using the iPad information visualization"

"The iPad information visualization played an important role in the ideas I had".

These statements were rated on a scale of 1 *strongly disagree* to 9 *agree strongly*. The responses were analysed separately from the CSI data. To check for statistically significant differences between conditions, a one-way ANOVA test followed by a Tukey test for significance between scores for each condition was performed.

7.4.2 Assessing the Design Product

To assess the creativity of the workshops' outputs, the *design products*, I took two different approaches. First, I counted the number of ideas that were generated during Activity 3 in each workshop to gain a measure of creative fluency. Second, I asked each participant to evaluate all of the final solution ideas excluding the one developed during their own workshop. Participants were asked to rate each of the solutions between 0 and 5 for *creativity*: where 0 represented a solution with *no creativity* and 5 a solution that was *highly creative*. Because creativity of outputs is often understood in terms of *novelty* and *usefulness* e.g. (Sternberg & Lubart, 1999), participants were also asked to assess all of the solutions for *novelty*: where 0 was an idea that was *familiar in the context of domestic energy* and 5 was an idea that was *highly novel with regards to domestic energy*; and *usefulness*: where 0 was an idea that would *fail to reduce peak domestic energy consumption* and 5 was an idea that would *effectively reduce peak domestic energy consumption*. This type of approach to assessing design products is discussed in more detail in section 3.2.3.

To check for statistically significant differences between conditions, a one-way ANOVA test followed by a Tukey test for significance between scores for each condition was performed.

7.4.3 Understanding the Design Process

In order to understand in a little more detail the way in which the different design artefacts were used during participants' design processes the video recordings of each workshop were analysed. In this analysis particular attention was paid to Activity 3 in which participants were generating divergent ideas. From these recordings I was able to determine: *the amount of time each group spent interacting with the design artefact they had been given*; *whether this interaction was collaborative or individual*; and *whether this interaction was immediately followed by, or included, the group generating and recording any new ideas on post-it notes*.

Following this, I undertook a microanalysis of key sections of video from workshops in the two conditions of primary interest, where participants were given one of the digital design artefacts. In this analysis participants' visible interactions with the iPad interface were captured, together with their conversation and those instances where they recorded ideas on post-it notes. This was in order to gain a more nuanced and detailed picture of the way that participants used each of the digital design artefacts.

7.5 Results

7.5.1 Supporting the People Designing

Participants' individual Creativity Support Index (CSI) ratings for the particular design artefact used in their workshop can be seen in Figure 37. These suggest that participants in condition C1, who used the interface designed to prompt creative cognition in an *analytical* way by visualizing smart energy data in a *traditional* style, felt most strongly that their creative processes were being effectively supported during the activities they undertook. Analysis using a one way ANOVA test shows a significant difference at p<0.001 between the final CSI scores for participants in condition C1, (M=83.64, SD=11.97), and those in condition C2, (M=40.99, SD=8.72), who used the interface designed to prompt creative cognition in an *intuitive* way by presenting photographs from Flickr in a *direct visualization* style.

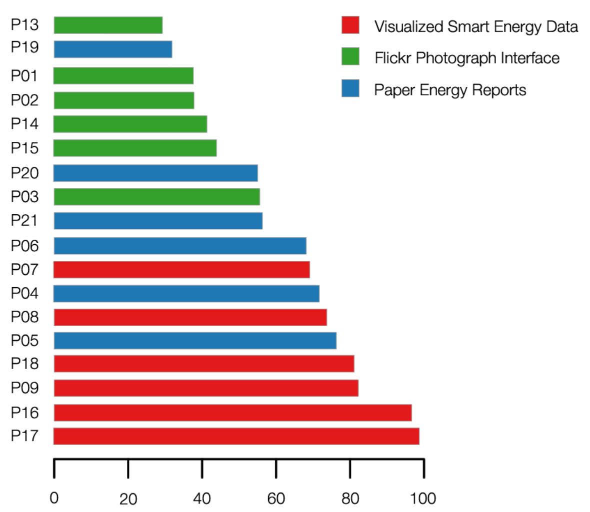

Figure 37: Individual CSI ratings given by each participant

The difference between the CSI rating for participants in condition C1, and those in condition C3, (M=59.94, SD=16.13) who used the printed energy reports, gave a result of $p=0.05$. This was not significant. The difference between the CSI rating for those in condition C2 and those in condition C3 was significant at $p<0.05$ indicating that participants in condition C2 felt the design artefact they were given was the least effective at providing support for their creative processes during the workshops' activities. Analysis of the aggregate scores given in the second part of the CSI indicates that *Exploration* and *Collaboration* were considered the most important creativity dimensions for participants undertaking these workshop activities. The aggregate score for each dimension is shown in Figure 38.

In addition to the CSI questions, I also asked participants two questions that directly addressed how important they felt that the relevant design artefact had been to their idea generation. Individual participant's ratings for the importance of the relevant design artefact to their idea generation are shown in Figure 39. These indicate that participants in condition C1, using the interface visualizing smart energy data, felt most strongly that the design artefact had been important to their idea generation.

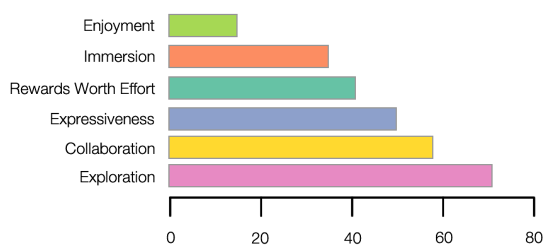

Figure 38: Aggregate scores for the different CSI dimensions of creativity

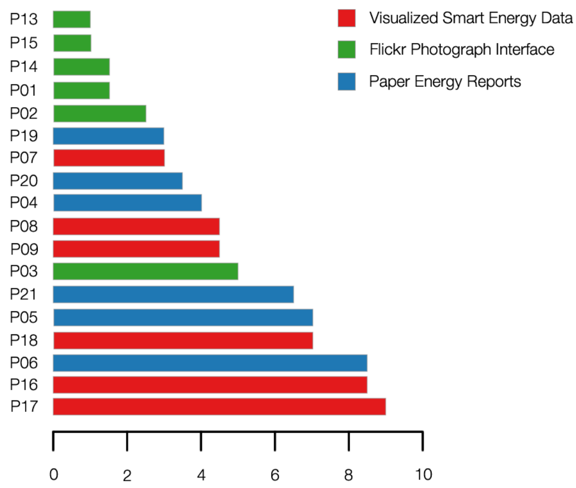

Figure 39: Individual participant's average rating for the importance of the relevant design artefact to their idea generation

Statistical analysis of participants' responses to these questions, using a one-way ANOVA followed by a Tukey test, shows a significant difference at $p<0.05$ between those participants in condition C1, ($M=6.08$, $SD=2.44$), and those in condition C2, ($M=2.08$, $SD=1.53$). The difference between those participants in condition C1 and those in condition C3, ($M=5.42$, $SD=2.22$), was not significant at $p=0.85$. Finally, there was a significant difference at $p<0.05$ between those participants in groups in condition C2 and those in condition C3, which indicates that those in condition C2, using the Flickr interface, felt least strongly that the design artefact had played an important role in their idea generation.

7.5.2 Assessing the Design Product

The number of ideas generated during Activity 3 in each workshop can be seen in Figure 40(a). Whilst there are large differences between the number of ideas generated in individual workshops, there was no significant difference between conditions found using a one-way ANOVA test, $p>0.05$. Analysis of the ratings given to the final outputs from each of the workshops also provides inconclusive results. Because there are only 8 solutions to compare across the 4 conditions, a statistical analysis such as that used above would not have been appropriate. However, if we look at the mean scores of each of the ratings for *creativity*, shown in Figure 40(b), *novelty*, shown in Figure 40(c) and *usefulness*, which can be seen in Figure 40(d), they indicate that, whilst there were differences in the ratings given for solutions from different workshops, there is no clear pattern of differences between conditions.

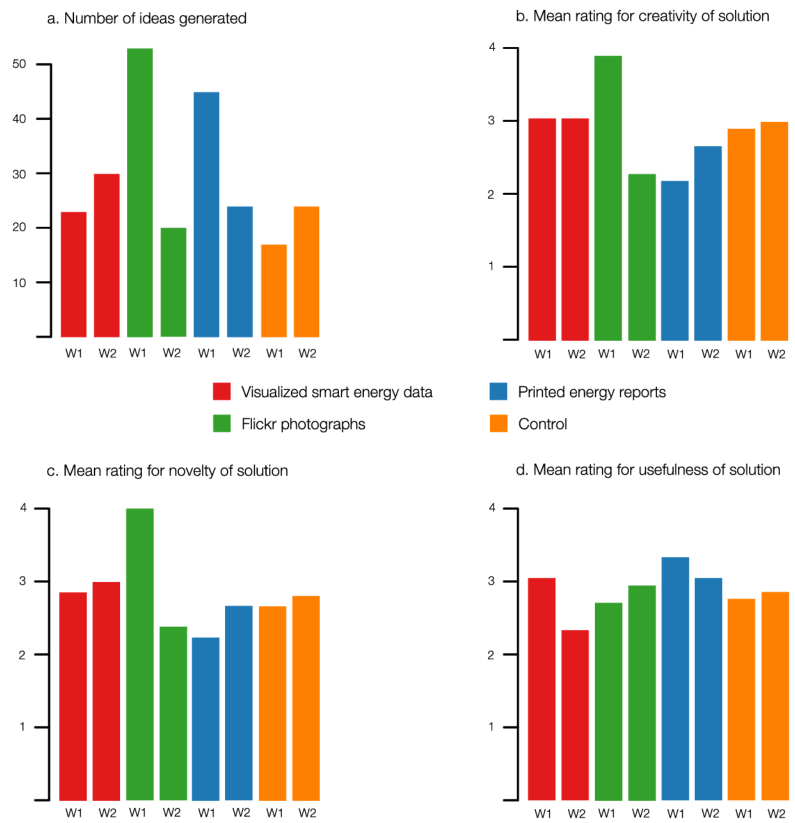

Figure 40: Graphs showing: a) the number of ideas generated during each Activity 2; b) the mean creativity; c) the mean novelty score; and d) the mean usefulness score; for final ideas.

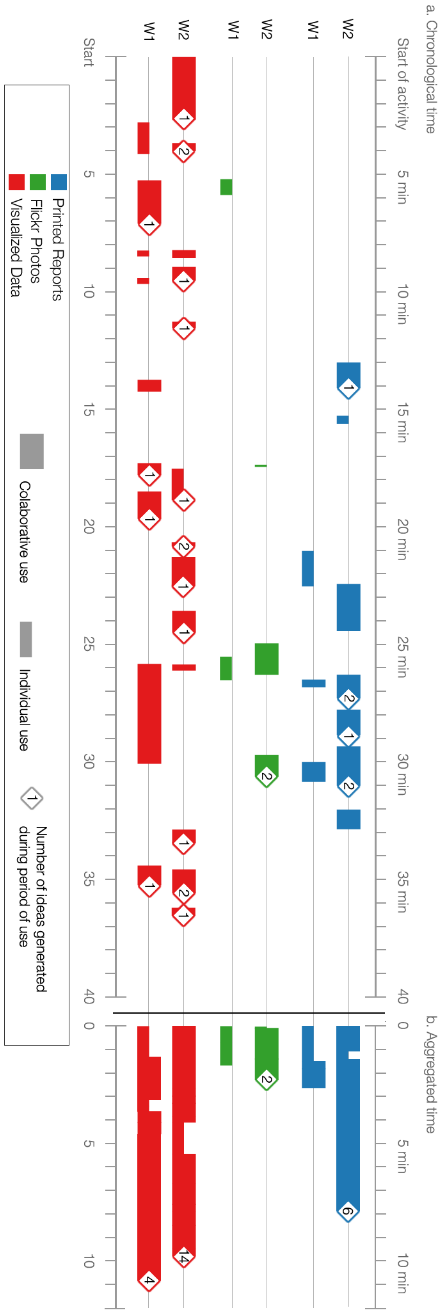

Figure 41: Graph showing how much time was spent with the different design artefacts during idea generation, together with the number of ideas recorded during that period of use: a) in chronological time; and b) in aggregate time

7.5.3 Understanding the Design Process

My initial analysis of the video recordings of Activity 3 in each workshop provides an overview that begins to reveal differences in the ways the different design artefacts were used. Figure 41 shows that in the workshops in condition C1 participants spent a greater amount of time interacting with the visualized smart energy data, and that much of this time was spent on collaborative exploration. Collaboration and exploration are important here because I found them to be the dimensions of creativity support that participants felt were most important when I looked at the aggregate ratings from the second part of the CSI analysis. This analysis also shows that during the workshops in condition C1 a greater number of ideas were recorded on post-it notes as part of, or directly following, use of the design artefact. In the workshops in condition C2 participants' idea generation seems to proceed with less direct reference to or interaction with the Flickr photo interface, and there appear to be fewer instances where ideas were recorded on post-it notes as part of, or directly following, use of the design artefact. The two workshops in the reports condition C3 do not show a consistent pattern of interaction, exploration and collaboration during participants' idea generation activities. One of these workshops appears to be most similar to the workshops in condition C1, where participants were given the visualized smart energy data, and the other being more like the workshops in condition C2, where participants were given the interface displaying Flickr photographs.

However, this overview analysis tells only a simplified story. The patterns of interaction, exploration and collaboration seen in the workshops in conditions C1 and C2 may simply reflect the intentional design decisions made in order for each interface to prompt creative thinking in either an *analytical* or an *intuitive* way. The microanalysis of key segments of video captures in closer detail the way the iPad was used by participants in the two conditions of primary concern.

7.5.3.1 Condition C1: Visualized Smart Energy Data

Figure 42 shows a detailed microanalysis of participants' idea generation during the second of the workshops in condition C1, workshop W2 in the bottom third of Figure 41. In it we can see that the structured, analytical way in which participants are interacting with the iPad interface and looking at different views of the smart energy data is an integral part of their process of developing and refining ideas. For example, at the beginning of the segment we can see P16 pointing at and interacting with the interface as he refines his idea about wet appliances such as clothes driers and washing machines. We then see how all three members of the group collaborate to develop this idea.

Following P16's suggestion about the clothes drier, P18 responds by interacting with the visualized data in the iPad interface to show that drier use is very different in summer and winter. P17, who is initially silent during this exchange, then contributes the suggestion for an Eco setting, again directing the other participants' attention to the interface, this time just by pointing at what is already shown. Initially P17 considers an Eco setting for the drier, but then modifies her idea as she realizes that such a setting might in fact be more appropriate for a dishwasher.

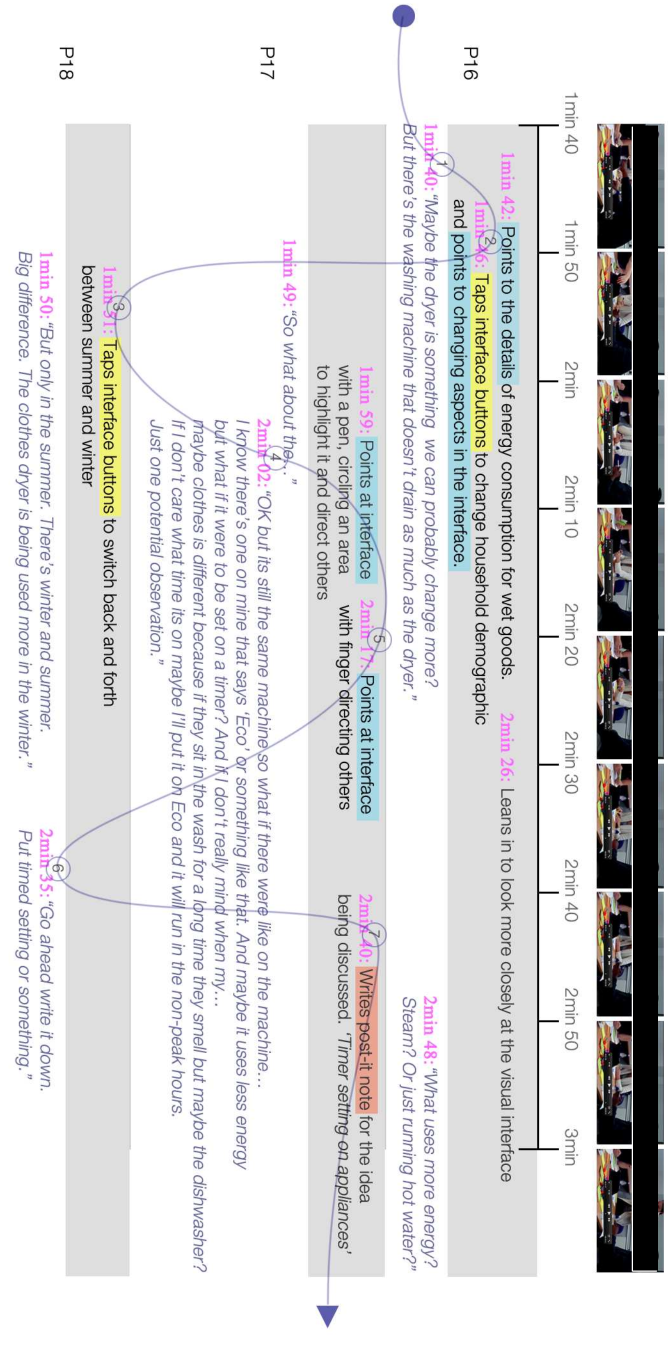

Figure 42: Video analysis of participants in condition C1 working with the interface in which smart energy data are visualized

The visualized smart energy data is being used as a source of specific insights, which participants combine with their existing domain knowledge, as the basis for generating and developing these ideas. These interactions, and the conversation that takes place around the iPad interface, result in P17 recording the idea '*Timer setting on appliances*'. Here we see the emergence of an idea, for saving energy when using wet appliances, which came about through a systematic and collaborative exploration of the information. This sequence involved all participants in both conversation and exploratory interaction with the digital design artefact. The interactions surrounding the development of this idea involved direct use e.g. tapping interface buttons to change the view of the data, and also reference to the data during conversation e.g. by pointing out information to underpin their contributions to the development of the idea.

This theme of saving energy whilst using wet appliances, which started with participants exploring the data to analyse where energy might be effectively saved, remained a focus for long periods of their idea generation, and this group generated many ideas that fitted this theme. These included ideas for communal washing and drying spaces that variously recycled the energy used in heating the water for washing, or used green houses to improve drying, and schemes for students in shared housing. It was a theme that became the key feature of the candidate design solution this group selected and developed during activity four of the workshop. This candidate solution involved an overnight community laundry service, which they felt would increase efficiency, and shift significant energy consumption away from peak hours. The visualized data also played an important role as a reference point during the selection, refinement and development of this idea in activity four of the workshop.

7.5.3.2 Condition C2: Flickr Photographs

Figure 43 shows a detailed microanalysis of participants' idea generation during the second of the workshops in condition C2 using the interface representing Flickr photographs, workshop W2 in the middle of Figure 41. Here, participants do not use the interface to facilitate a systematic and structured process of comparing alternatives as we saw them do in the previous example. Rather, they take inspiration in a more direct way with a riff of ideas resulting from a single image. This is a process that appears to rely more on unconscious creative connections, and which involve an element of surprise to the participants involved.

The initial stimulus to a period of effective idea generation is the image that prompts P13 to think about '*Science Fiction'*, and which in turn triggers P13 and P14 to discuss personal energy generators. This reference to personal generators then triggers P15 to think of the film *Back to the Future,* which he discusses with P14. The result of this discussion is an idea to use personal waste as a source of power. At the end of this brief period, two post-it notes recording new ideas are written. The first contains the idea '*Our own electricity generators*', and the second contains the idea '*Use our waste to generate electricity*'.

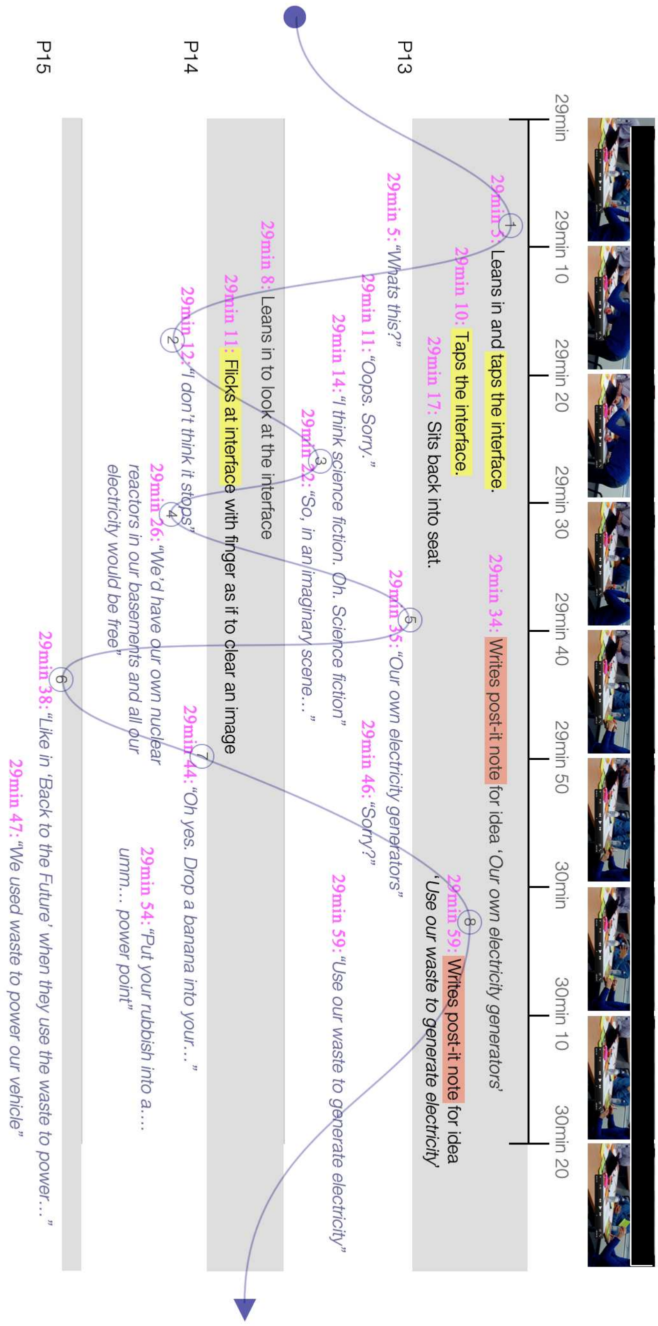

Figure 43: Video analysis of participants using the interface displaying photographs from Flickr, tagged with terms relevant to domestic energy consumption

This segment of analysis shows an effective period of participants' collaborative idea generation. However, in this description collaboration does not focus around participants using the iPad interface to systematically explore information. Instead, in this instance, the focus is on the way they share and build on the ideas and connections that are inspired by a single image. There is less interaction with the iPad interface, which acts as a trigger for the ideation process rather than forming an integral part of the way ideas are developed and refined. The ideas they generate appear to emerge from participants' imaginations in a more direct or intuitive way. In this segment we also see different pairs of participants collaborating and discussing their ideas rather than all three working together simultaneously with the iPad as a focus.

The themes of science fiction, personal energy generation and generating electricity from waste did not survive as a focus for this group, who ended up generating a variety of different ideas for reducing peaks in energy demand. The candidate design solution that this group selected was a web-based service to track households' electricity consumption; provide a forum for discussion; act as a repository for energy saving ideas; and be a place where competition between groups of friends or different localities can be arranged. The iPad played no immediately obvious role in the way this group selected their candidate design solution in activity four of the workshop.

7.6 Discussion

In this design experiment my aim was to compare participants' idea generation activities when they were given one of two different digital design artefacts, each of which takes a different source of domain-relevant information and presents it in a way that inspires creative thinking. The first of these digital design artefacts was designed to prompt creative thinking in an *analytical* way by visualizing smart energy data in a *traditional* style. The second was designed to prompt creative thinking in an *intuitive* way by presenting photographs from social media in a *direct visualization* style.

When we look at the analysis of the Creativity Support Index (CSI) (Carroll et al., 2009) questionnaire data we see that participants given the interface visualizing smart energy data felt significantly more strongly that their creative processes were being effectively supported by that interface during their idea generation activities, than those given the interface presenting the Flickr photographs. We similarly see that these participants also felt significantly more strongly that the interface played an important role in the ideas they generated. At first glance this may seem to suggest that interfaces visualizing quantitative data provide significantly more effective creativity support than those presenting qualitative data from social media sources. However, my additional analysis of the second part of the CSI data, which indicates that *exploration* and *collaboration* are the dimensions of creativity support most important to participants undertaking these workshop activities leads me to believe there could be an alternative explanation.

One of the key design decisions made when developing the digital design artefacts used in this study was to vary the degree of user-controlled interactivity between each of the two examples. The reasons for this are outlined in section 7.3.4. As Elmqvist et al.

outline in their discussion of *fluid interactions* for information visualization, providing users with well-designed user-controlled interactive features: *helps to promote flow*, *supports direct manipulation* and *minimises the Gulfs of Action* (Elmqvist et al., 2011). Each of these factors also supports participants' *exploration* of the information represented in the interface and *collaboration* with other group members. I would suggest therefore that it is likely to be the level of interactivity in the interface design that is the key factor in explaining the differences in the CSI ratings participants gave each of the digital design artefacts. A greater degree of interactivity in the interface may also promote feelings of agency and self-efficacy. This means that users can have a greater belief that, with their knowledge and skills, they are able to produce creative outcomes. This is known to be a key driver of individual creativity (Plucker & Makel, 2010), and may translate to this collaborative setting.

Investigating how participants might use an interface that presented domain-relevant images, such as the Flickr photographs, in a more interactive exploratory way, where they could select and retain things of interest is an obvious area for future research. Such an interface would arguably be more in keeping with my own previous use of photographs in the study reported in Chapter 5. It would also arguably be more in keeping with other approaches to using imagery as a source of inspiration during design workshops, e.g. (Sanders & Stappers, 2012, p.71; Halskov & Dalsgård, 2006).

The initial video analysis, in which an overview of the number and nature of interactions together with the number of new ideas recorded on post-it notes, also seemed to indicate that the interface visualizing smart energy data provided more effective support for participants' creativity during idea generation activities. However the microanalysis of the episodes of idea generation identified as being inspired by each of the digital design artefacts suggests that this might again be a reflection of the intentional design decisions made in their development. In this detailed view the differences between the ways the artefacts prompt and inspire creative thinking become more apparent.

Participants using the interface visualizing smart energy data interacted with the iPad in a structured and linear way, exploring different views of the data and systematically building on their ideas through the insights they found. They also remained much more closely focused on the same theme throughout their idea generation activity, and continued to return to the data in order to develop and refine their ideas. Participants using the interface displaying Flickr photographs on the other hand appeared to take inspiration more directly or even subconsciously from a single image. Whilst the interface was responsible for the initial prompt, the ideas developed because the participants riff off of each other's contributions. In this example we also see a degree of humour and surprise at the ideas that are being generated. Each of these descriptions of idea generation reflects the style of creative thinking that the particular design artefact was intended to prompt.

My analysis cannot describe the whole story of participants' creative ideation. The limitations, particularly of time and scope, associated with a relatively constrained design process, such as the one undertaken in these design workshops, meant that there were less opportunities for those ideas that bubble up over an extended period to emerge. These ideas are also more difficult to correctly identify and attribute through video analysis. In a similar way, those ideas that come as flashes of inspiration may be under valued, in comparison with those that follow longer periods of questioning, in an evaluation where time spent with the digital design artefact is one of the metrics for utility. Each of these elements is an important factor in assessing support for an *intuitive* style of creative thinking.

It is also perhaps unsurprising that the analysis of the workshop outputs should be inconclusive. With early-stage, exploratory design experiments there is often a limited understanding of the relationship between the processes at work and the outputs produced. For example, when Hilliges et al. (2007) compared the effectiveness of an electronic brainstorming system using an interactive tabletop and a large wall display with traditional paper and pen methods, they found no difference in the quality and number of ideas generated in each condition. Similarly, when Buisine et al. (2007) compared an interactive tabletop interface for mind mapping with a traditional paper-based approach they found that although both collaboration and subjective perceptions of the tool were higher when using the interactive tabletop, there was no real difference in the ideas produced. However, it remains important to collect and analyse data about workshop outputs in order to identify any early indications of possible impacts both positive and negative. Gaining an understanding of participants' individual cognitive styles, perhaps through pre-tests, might also help us to better understand differences in the number and quality of outputs between groups.

Returning to my reasons for undertaking this study, I found some initial evidence to suggest that different types of digital design artefact, representing different aspects of the design context, can be used to prompt and support different styles of creative thinking. The findings from this study also suggest the likely benefits of providing workshop participants with tools that prompt both *analytical* and *intuitive* styles of creative cognition. Indeed these styles of creative thinking, and the techniques that are used to prompt and support them, should be seen as being complementary rather than competing alternatives. This is the case in methods such as CPS (Isaksen et al., 2011), where each type of technique has its place during different stages and activities. It was also one of the reasons I had combined generative design activities with visualized data in the study reported in Chapter 5. Studying how these different types of digital design artefact can be used in conjunction with each other, and at which stages in the design process each might be more effective, is an area for future study.

7.7 Reflections

7.7.1 Research and Evaluation Methods

7.7.1.1 Benefits and Limitations of Study Design

In this study, comparison was made between two different iPad interfaces, both representing domestic energy consumption. Two additional conditions, one with printed reports and a control condition, were also included. This followed the recommendation of Cash et al. (2012). Unfortunately, these two additional conditions did not provide a great amount of help in understanding how the two digital artefacts were used. This was largely due to the effect of additional unknown variables impacting on participants' creative performance, which reduces reliability when comparing measures of creativity in different conditions. A full checklist of threats to the validity (Cook & Campbell, 1979, pp.37-95) of the results found in this study is included in Appendix D, Section 12.6. In addition, the control condition meant I had two workshops that did not provide CSI data, and this was an important metric. In similar circumstances, I think it better to include additional groups in the conditions of primary interest and do without these others. This would provide more CSI data and more examples in the videos for close microanalysis.

7.7.1.2 Limitations of Data Collection and Analysis

Having reflected on the design experiment reported in Chapter 4, the full Creativity Support Index (CSI) (Carroll et al., 2009) questionnaire was given to participants in this study. This enabled a more reliable comparison between participants' perceptions of the support provided by the different interfaces. In addition it also enabled me to identify which of the dimensions associated with creativity were most important to participants in the context of these workshop activities. However, as mentioned above, I was not able to use it with a control condition, which may be a future concern.

Analysis of video data allowed me to distinguish between individual and collaborative use of the different interfaces, and to identify those instances where a post-it note idea was part of, or directly followed, interaction with the interface. It also enabled me to investigate individual periods of idea generation in which the design artefacts played an important role more closely. Here the analysis was exploratory, looked to identify different patterns of use, and was represented visually to show the flow of interaction, collaboration and ideation. However, future study should included independent coding to help turn this exploratory investigation into a generalizable theory describing the different ways that ideas emerge. Video analysis only enables investigation of the visible aspects of participants' ideation activities. This is not the whole story, and finding ways to access the personal, introspective and even unconscious aspects of participants' creative ideation is a major research challenge e.g. (Busse & Mansfield, 1980; Dijksterhuis & Meurs, 2006; Whitfield, 2007; Zhong et al., 2008) that remains outside the scope of this thesis.

7.7.2 Takeaways

T7.1 *Exploration and Collaboration appear to be the dimensions of creativity support that are most important to co-designers during CoDesign With Data workshops*

T7.2 *Designing information visualization tools with interfaces that provide a high degree of user-controlled interactivity appears to support the Collaboration and Exploration dimensions of co-designers' creative processes.*

T7.3 *The parallels between 'analytical' or 'traditional' styles of information visualization design and 'analytical' categories of applied creativity technique; and between 'direct visualization' and 'intuitive' categories of applied creativity technique appear to offer the opportunity to present different sources of domain-relevant data in ways that prompt different types of design idea.*

8 Case Study: One Small Change

In this final case study I bring together the lessons learnt from the studies reported in the previous chapters. The CoDesign With Data approach that I have been developing is studied in a two-stage workshop.

8.1 Introduction

Design is a purposeful activity that can be said to conclude with a *"commitment to a plan that is meant to be carried out"* (Rittel, 1987). It can be described as a process of first identifying a problem and then generating alternatives as a means of finding a solution that matches satisficing criteria (Simon, 1996, pp.118-25). In addition, this process of identifying a design problem involves not simply accepting the problem space as given, but also includes a process of structuring and formulating that problem (Cross, 2006, p.p.77).

In this final case study, my aim was to take key elements of the CoDesign With Data approach and study them within a purposeful design process that was connected to a real world activity in which the co-designers had both an intrinsic interest and also a degree of domain knowledge. I also wanted this process to have two phases. First, a phase in which the co-designers would identify, structure and formulate the specific design problem under consideration. Second, a phase in which they would generate candidate ideas and propose a design solution. This was to investigate whether the tools and techniques I have been developing might be more effective in identifying problems or in generating and selecting design ideas.

8.2 Research Questions

This case study attempts to bring together and build on the lessons learnt during my previous studies in order to explore those aspects described above in more detail. The first phase's activities, leading up to the identification of a specific *Problem Statement*, would build on the case study held with E.ON that was described in Chapter 5, and less directly on the design experiment described in Chapter 4. The second phase's activities, where ideas for candidate solutions would be generated and a *Design Idea* selected, would build on the lessons learnt in the design experiment described in Chapter 7.

To investigate how effectively the CoDesign With Data approach uses domain-relevant data to support participants' insight seeking and provide inspiration for their creative design ideas during each of the two phases described previously, I set two research questions:

RQ8.1 *Would the CoDesign With Data tools and techniques support co-designers' insight seeking and help them gain a better understanding of the design context? During workshops in which they:*

A: *Identify and formulate a specific Problem Statement*

B: *Generate candidate solutions and select a Design Idea*

RQ8.2 *Would the CoDesign With Data tools and techniques support and inspire co-designers' creative design processes? During workshops in which they:*

A: *Identify and formulate a specific Problem Statement*

B: *Generate candidate solutions and select a Design Idea*

An opportunity to investigate these questions came through a project run as part of City University London Students Union's Green Dragons[28] initiative, in which I am working with members of City University's Environmental Champions network to design ways to reduce waste and encourage recycling. This project remains ongoing at the time of writing this thesis. The design proposal that resulted from this workshop, and which was put forward to the City University London Environmental team and the National Union of Students Green Dragons officers, is included in Appendix B.

8.3 Workshop Details

Tools used: *iPad Information Visualization Interfaces, Worksheets, Workshop Stationary*

Techniques used: *5WsH, Brainstorming with Behaviour Change Triggers, Brainstorming with Post-its, Insight Seeking*

8.3.1 Background

This case study describes a workshop held over two successive days for One Small Change, a project funded by the City University London Student Union's Green Dragons initiative. This initiative is a scheme to provide support and funding for City University students and staff who have identified opportunities to improve sustainability. The objective of the One Small Change project is to design a simple service that helps City University students to reduce waste, choose re-usable options or improve recycling, and in this way to make the green option the simplest or default option.

[28] www.green-dragons.co.uk

Figure 44: Participants in the One Small Change workshop generate candidate solution ideas

8.3.2 Participants

Seven co-designers were recruited for the One Small Change workshop. Three of these were in the age range 18-24; three were in the age range 25-34; and one was in the age range 35-44. There were four female and three male co-designers. Five co-designers were recruited from City University London's Environmental Champions Network, a network of student and staff volunteers from across the University who are committed to making it a greener place to work and study. These co-designers were recruited because of their domain knowledge and motivation. Another two co-designers with a background in user experience design and creativity research were also recruited to provide some domain independent design knowledge and experience. The second day's workshop had six co-designers, as one of the male co-designers was unable to attend. His data was discounted from the evaluation.

8.3.3 Workshop Materials

Co-designers were provided with the following workshop materials to help them during their design activities:

*Two **iPad Information Visualization Interfaces**, described in section 8.3.4*

*A selection of custom **Worksheets** designed to support individual activities, described below*

*A selection of standard **Workshop Stationary**, including coloured pens and post-it notes to record their ideas, blank flip chart sheets, and smiley face stickers for voting.*

The workshop took place in a large room with plenty of space to move around and tables to work at. Co-designers were provided with refreshments and each of the two phases of the workshop was videoed using two cameras. Examples of each of the materials used in this workshop can be found in Appendix C of this thesis.

The custom worksheets used to support co-designers during particular activities were as follows:

A0 sized hexagonal 5WsH worksheet used on Day 2 in Activity 8: Describe the Design Idea

A1 sized worksheets to collect and organise the outputs from:

Day 1, Activity 2: Examples of Waste

Day 1, Activity 3: Insight Seeking

Day 1, Activity 6: Problem Abstraction

Day 2, Activity 3: Behaviour Change Triggers

Day 2, Activity 7: Idea Validation

A2 hexagonal 5WsH worksheets to record ideas during:

Day 1, Activity 4: Opportunities for Change

Day 2, Activity 5: Design Intervention Ideas

A5 worksheets to record outputs generated during:

Day 1, Activity 3: Insight Seeking

Day 2 Activity 3: Behaviour Change Triggers

Day 2, Activity 4: Insight Refresher

8.3.4 Visualization Interface Design

Two custom information visualization interfaces were designed for the One Small Change workshop. The first visualized data reflecting student attitudes towards sustainability issues, this is discussed in section 8.3.4.1. The second visualized data reflecting the levels of contamination in different general waste and recycling bins around City University London, this is discussed in section 8.3.4.2. In both cases, the visualization interface was developed using the D3 JavaScript library (Bostock et al., 2011), and they were presented to co-designers using iPads. The reasons for using iPads in a workshop setting are discussed in section 2.5.2.2. In this study, three iPads were shared between the co-designers. This meant there was a single iPad for each small group, in the activities where the co-designers were divided into smaller groups of two or three. In this way it was similar to the studies reported in previous chapters.

8.3.4.1 Student Attitudes to Sustainable Behaviour

This interface visualizes data concerning City University London students' attitudes to sustainability and is available to use online.[29]

[29] www.grahamdove.com/greendragons/attitudes.html

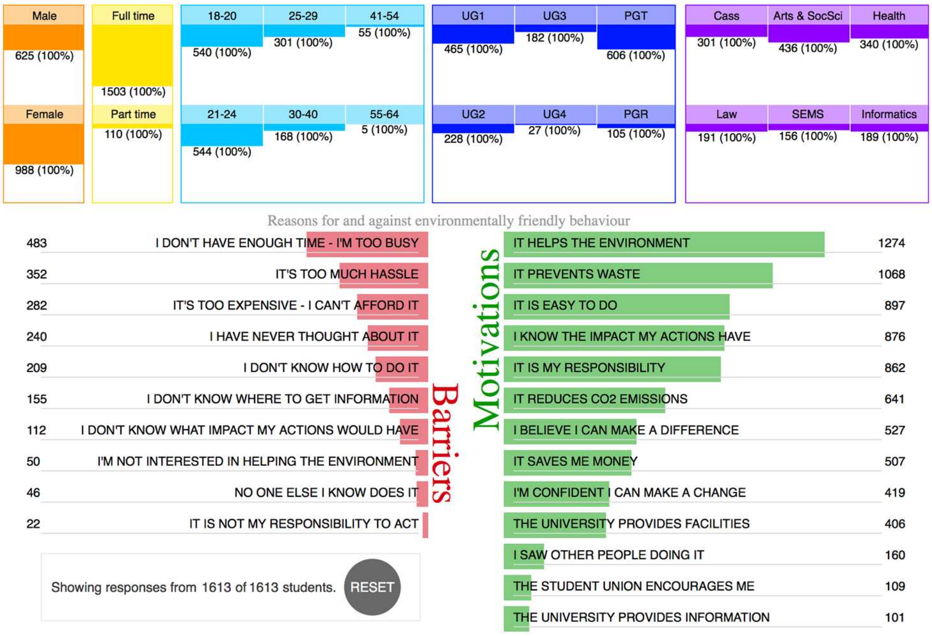

Figure 45: Screen shot of the interface visualizing student attitudes towards sustainability

8.3.4.1.1 Data

This interface visualizes data collected by the National Union of Students through an online quantitative survey, held during October and November 2011. These data were collected in order to better understand the environmental attitudes and behaviours of City University London's students. They provide the basis of the report '*How can behaviour change for pro-environmental behaviour be encouraged amongst students and staff at City University London?*'[30]. For this interface, a subset of the data relating specifically to waste and recycling were visualized. These data represent the responses of 1,613 students to a series of questions regarding motivations or barriers to environmentally friendly behaviour, and includes demographic data: *gender*, *age-range*, *full time or part time status*, *year of study*, and *school of study*.

[30] www.grahamdove.com/greendragons/nus_report.pdf

8.3.4.1.2 Visual Design

There are two main sections to the visual design of this interface (see Figure 45). The top section contains representations of the respondents' demographic data. Here, a series of simple rectangular area charts show the number and percentage of respondents that belong in the demographic for which the data are currently filtered. For example when all data are shown in Figure 45, the gender section shows 625 (100%) for *male* respondents and 988 (100%) for *female*, whilst in the year of study section we see 465 (100%) for *UG1*, 228 (100%) for *UG2*, 182 (100%) for *UG3*, 27 (100%) for *UG4*, 606 (100%) for *PGT* and 105 (100%) for *PGR*. In Figure 46 the data are filtered to show only female respondents, and we see 0 (0%) for *male*, 988 (100%) for *female*, 276 (59%) for *UG1*, 143 (63%) for *UG2*, 107 (59%) for *UG3*, 13 (48%) for *UG4*, 389 (64%) for *PGT* and 60 (57%) for *PGR*.

Figure 46: Screen shot of the visualized student attitudes data, filtered to show responses from only female respondents

In Figure 47, where the data are filtered to show only responses from first year undergraduates, we see 189 (30%) for *male*, 276 (28%) for *female*, 465 (100%) for *UG1* and 0 (0%) for all other years of study. In each case the percentage value reflects the percentage of that demographic being shown, i.e. 276 is 28% of the total female respondents, and the area of the coloured rectangle reflects the proportion of the filtered data, i.e. 276 as a proportion of 465 first year undergraduates.

The second section of the interface, below this, shows the number of respondents in the currently filtered data that agree with the different statements regarding motivations or barriers to environmentally friendly behaviours. These are displayed using two simple horizontal bar charts from the centre outwards, motivations in green to the right and barriers in red to the left.

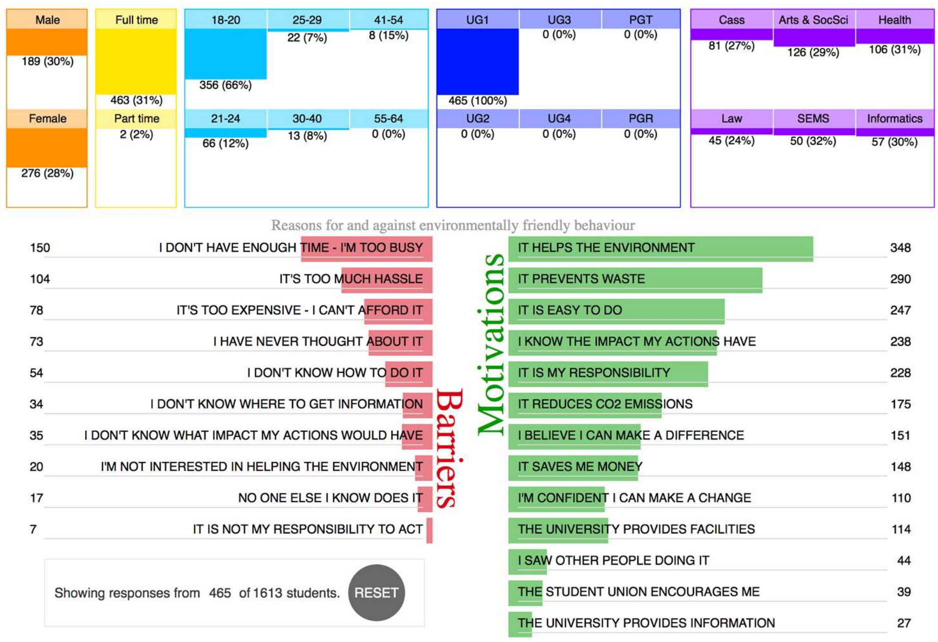

Figure 47: Screen shot of the visualized student attitudes data, filtered to show only the responses of first year undergraduates

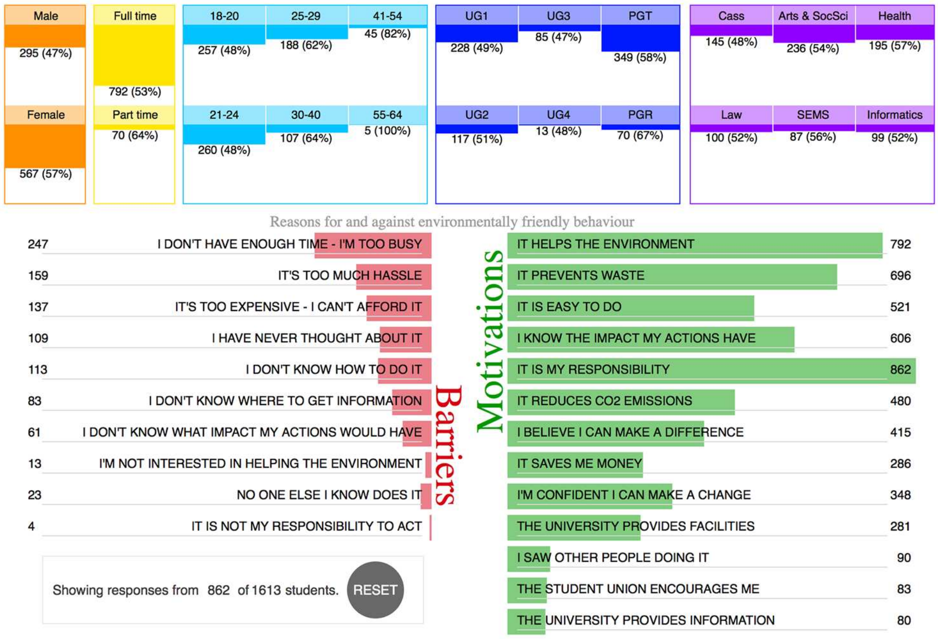

Figure 48: Screen shot of the visualized student attitudes data, filtered to show the details of respondents who agreed that behaving sustainably is their responsibility

In Figure 45, where all data are shown, we see 1274 respondents agreed that helping the environment is a motivation, and 483 agreed that being too busy is a barrier to their behaving in an environmentally friendly or sustainable way. The length of the bar reflects the proportion of respondents in the currently filtered data that agree with the statement. In Figure 48 we see that 862 is the total number of respondents who agreed that a sense of responsibility is a motivation for sustainable behaviour. The colour scheme used in this interface is based upon recommendations for qualitative schemes made in (Harrower & Brewer, 2003).

8.3.4.1.3 Interaction

This interface adopts a direct manipulation of the data approach to interaction, which means that the visual elements representing the data are also the interaction elements that control how the data are filtered. For example, to filter the data so that only the responses from female students are shown the user clicks on the box showing the number of female respondents (see Figure 46). Similarly, to see the responses of first year undergraduates, the user clicks on the box showing the number of UG1 respondents (see Figure 47). In each case, the data that are visualized are updated to reflect the filter selected. In addition to filtering on student demographics, the data can be filtered on responses to individual questions. In Figure 48 the data are filtered to show details of only those respondents who agreed that a sense of responsibility was one of their motivations for behaving sustainably. Similarly Figure 49 shows the data filtered for those respondents who felt that a lack of knowledge was a barrier to their behaving sustainably. The interface includes a *Reset* button to remove any filters and show all the data. Next to this, the number of respondents reflected in the current filter is shown.

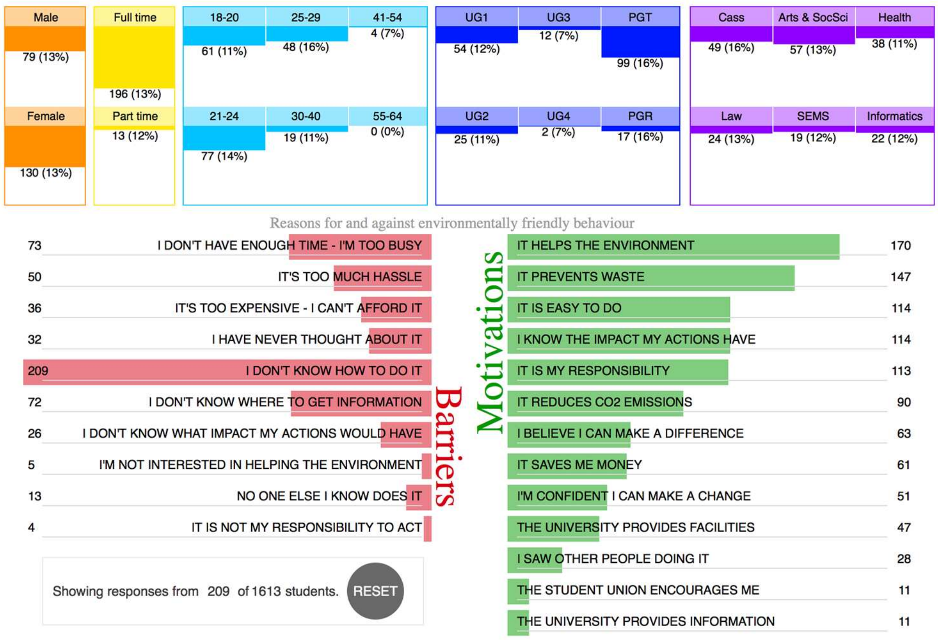

Figure 49: Screen shot of the visualized student attitudes data, filtered to show the details of respondents who agreed that a lack of knowledge was a barrier to their behaving sustainably

8.3.4.2 Contamination in Bins

This interface visualizes data recording the amount of contamination found in different types of waste bin at City University London. It is available to use online[31].

8.3.4.2.1 Data

These data represent the amount of contamination found in *general waste*, *food waste* and *dry recycling* bins, positioned in different locations around City University London. Contamination might be food waste or recyclables in a general waste bin; non-recyclable waste or food waste in a dry recycling bin; or any non-food waste in the food waste bins. They were collected by a visual inspection of the bins measuring how full the bin was at the time of the inspection and the amount of contamination present. The data are sorted into twenty groups, each representing a value to the closest 5%.

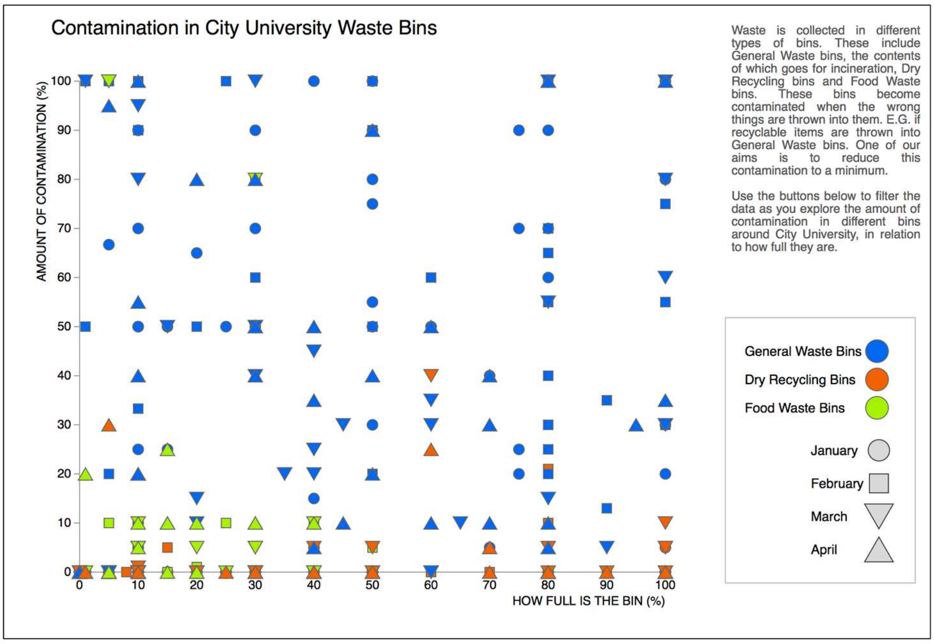

Figure 50: Screen shot of the interface visualizing bin contamination data

[31] www.grahamdove.com/greendragons/contamination.html

8.3.4.2.2 Visual Design

The visual design of this interface uses a familiar scatterplot technique, perhaps the most widely used graphical representation of data (Tufte, 1983, p.47), the origins and early developments of which are discussed in (Friendly & Denis, 2005). It uses a simple combination of visual variables (Bertin, 2011, p.42), utilising shape to represent the different months, and colour to represent the different types of waste bin. The colour scheme used in this interface is based upon recommendations for qualitative schemes made in (Harrower & Brewer, 2003).

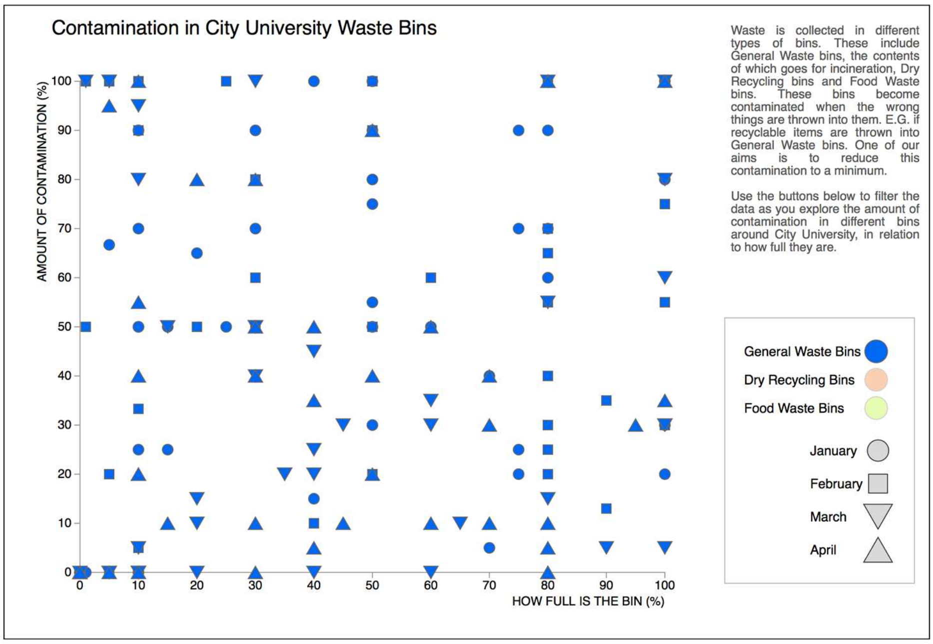

Figure 51: Screen shot of the visualized bin contamination data, filtered to show only the general waste bins

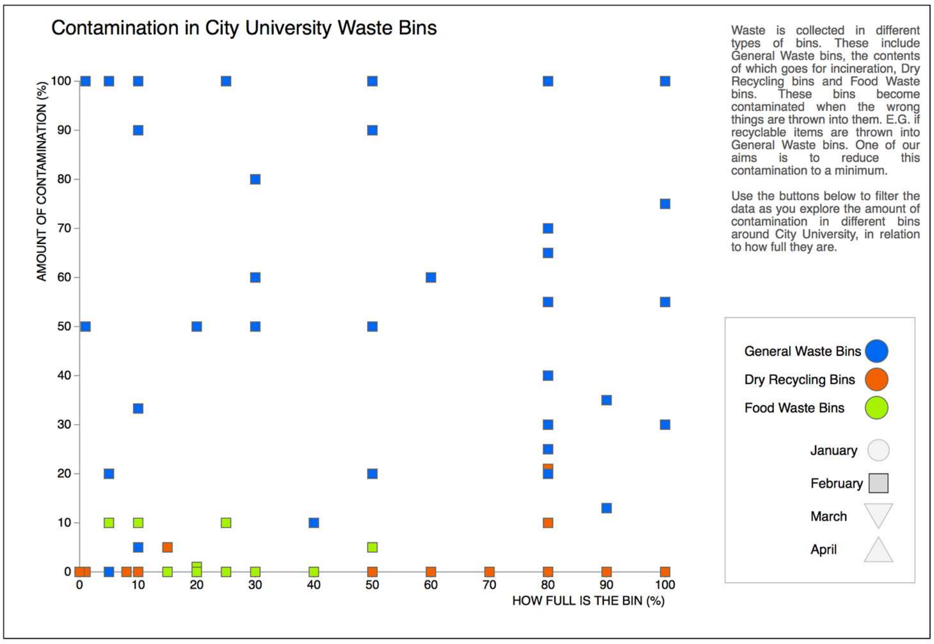

Figure 52: Screen shot of the visualized bin contamination data, filtered to show the data from February

8.3.4.2.3 Interaction

In this interface, the data are filtered using a series of graphical buttons found in the lower right hand corner. Through these buttons, any combination of the three types of waste bin can be viewed for any combination of the four months for which data were available. For example, Figure 50 shows the interface without any filters in place, and therefore with all the available data visualized. Figure 51 shows the data for the general waste bins over all of the four months. Figure 52 shows the data for all of the different bin types from February. Finally, Figure 53 shows the data for dry recycling and food-waste bins, from January, February and March.

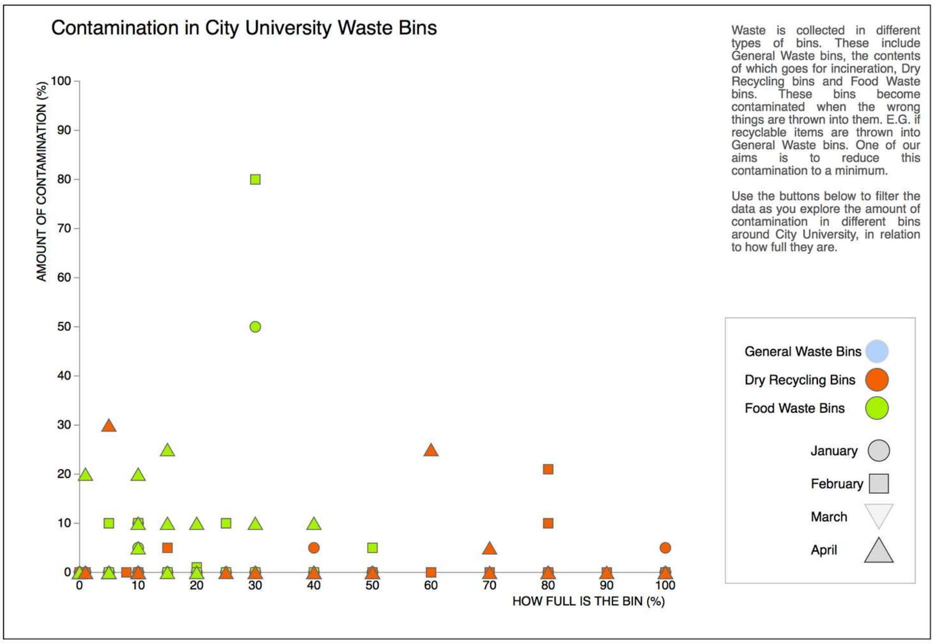

Figure 53: Screen shot of the visualized contamination data, filtered to show a combination of Dry Recycling & Food Waste Bins in January, February & April

8.3.5 Workshop Activities

The One Small Change workshop described in this case study, was held over two consecutive days. The objective of the first day was to identify and define a *Problem Statement*. The objective of the second day was to generate candidate solutions and select a *Design Idea*.

8.3.5.1 Workshop Day 1: Define the Problem

The purpose of the first day's activities was to investigate the problem space being considered by the One Small Change project. That is to help reduce waste and increase re-use and recycling. Its objective was to define a statement reflecting the aspect of this problem co-designers felt could be addressed most effectively. The activities lasted a total of approximately two hours, including fifteen minutes to complete the post-workshop evaluation questionnaires.

8.3.5.1.1 Activity 1: Introduction to the Design Challenge

In this activity, co-designers were given a brief introduction to the design challenge they were being set, and to the scope of each of the workshop's two days. As part of this introduction they were read the following guiding statement:

"The One Small Change project aims to design a simple service that helps City University students to reduce waste, choose re-usable options or improve recycling. In this way the greenest option becomes the simplest or default option. In today's workshop we will be thinking about the things that are disposed of at City University, how these things end up in the bins that they do. What motivates City University's students to act sustainably? And what are the barriers that stop them from doing so? At the end of today's workshop we will have identified a clearly stated problem. In tomorrow's workshop we will be generating ideas for potential solutions to this problem."

This statement was also printed so that co-designers could refer to it as they wished. This activity took approximately 5 minutes.

8.3.5.1.2 Activity 2: Examples of Waste

In this activity, co-designers were first asked to work individually and suggest five examples each of things that might be thrown into the waste or recycling bins at City University London. Each example was written on an individual post-it. Co-designers then shared their ideas, which were organised by the facilitator on a flip chart sheet. Following this, there was a round of further suggestions in which co-designers worked collectively to build on the initial ideas. This activity took approximately 15 minutes.

8.3.5.1.3 Activity 3: Insight Seeking

In this activity, co-designers were asked to work in small groups of two and three to explore the visualized student attitude and bin contamination data using the iPads. They were asked to record any insights they gained into how waste is disposed, what contaminates bins, and into the factors that motivate or are a barrier to sustainable behaviours. Each insight was recorded on a separate A5 worksheet, each of which contained one of the three guiding questions listed below. After approximately twenty minutes, these insights were collected, shared and organised on three custom A1 worksheets, one for each guiding question. The activity took approximately 25 minutes, and was guided by the following three questions:

'What are the barriers to reducing waste? Or to re-using items instead of recycling or disposing of them?'

'How might we motivate people to choose a re-usable option? Recycle more effectively? Or simply generate less waste?'

'What items are likely to be causing the contamination in different bins? And why might these bins become contaminated?'

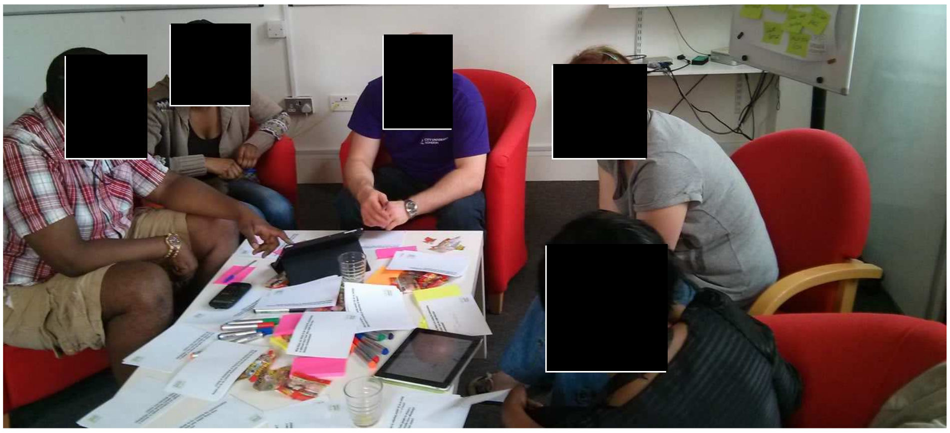

Figure 54: Co-designers seeking insight in the visualized data during the One Small Change Workshop

8.3.5.1.4 Activity 4: Opportunities for Change

In this activity, co-designers again worked in small groups of two and three. They were asked to identify and describe opportunities for making student behaviour more sustainable at those touch points where waste is being generated or disposed of. Co-designers were instructed to continue using the information visualization interfaces to build on the insights identified during the previous activities. Each idea was recorded on a separate A2 sized 5WsH hexagonal worksheet. After approximately twenty minutes, these ideas were shared and pinned to the wall. This activity lasted approximately 25 minutes, and was guided by the following five questions that were printed on the worksheets:

‘What is the situation we would like to change?’

‘Why might it be happening?’

‘When does the problem become apparent?’

‘Where does the problem originate?’

‘Who do we need to engage in order to change this situation?’

‘How significant would the impact of changing this situation be?’

8.3.5.1.5 Activity 5: Opportunity Selection

In this activity, co-designers voted to select their favoured opportunity ideas. Each co-designer was given three smiley face stickers to place on the hexagon or hexagons they selected. Voting was based on two criteria: *how simple it would be to address* and *how significant the impact on sustainability would be*. This activity lasted approximately 10 minutes.

8.3.5.1.6 Activity 6: Problem Abstraction

In this activity, all co-designers worked together to further investigate the *Opportunity for Change* that had received most votes. To do this, co-designers were asked to brainstorm numerous contributing factors in answer to the question '*Why might it be happening?'* (where *it* was the opportunity in question). Following this, the most promising answer was selected and used to describe an *Opportunity for Change* at a different level of abstraction. Co-designers were then asked to brainstorm answers to the '*Why might it be happening?'* question for this opportunity too. This activity lasted approximately 20 minutes.

8.3.5.1.7 Activity 7: Select the Problem Statement

In this activity, all co-designers worked together in a facilitated discussion to define and select the *Problem Statement* that they considered most effectively and appropriately described the situation they would like to address in the following day's workshop. This activity lasted approximately 10 minutes.

8.3.5.2 Workshop Day 2: Generate and Select Design Ideas

The purpose of day two's activities was to take the *Problem Statement* defined at the end of day one and generate candidate solutions before selecting their preferred *Design Idea*. The outputs and workings from the first day were displayed around the workspace, and were therefore visible and available for co-designers to refer to or use. The activities lasted a total of approximately two and a half hours, including fifteen minutes for co-designers to complete evaluation questionnaires.

8.3.5.2.1 Activity 1: Recap

In this activity, the facilitator provided a brief recap of the previous day's activities. This was to re-introduce the *Problem Statement* that had been agreed upon, and to remind co-designers of key landmarks in the process through which it had been reached. This activity lasted approximately 5 minutes.

8.3.5.2.2 Activity 2: People To Engage

In this activity, co-designers initially worked alone to identify candidate people or organisations within City University London who might need to be engaged in any solution devised. After five minutes these initial ideas were collected and shared. Following this there was a brief round of collective work in which all co-designers worked together to build on the initial suggestions. This activity lasted approximately 10 minutes.

8.3.5.2.3 Activity 3: Behaviour Change Triggers

In this activity, co-designers used a series of behaviour change triggers as prompts for brainstorming ideas for situations in which possible candidate solutions might exist. Using triggers to stimulate and guide participants' brainstorming is based on the technique of Creativity Triggers, which has been used effectively in creative requirements gathering workshops (Jones et al., 2008) and is discussed in section 2.5.4.2. The behaviour change triggers used in this activity were derived from a set of publicly available *behaviour change strategy cards* produced by design company Artefact Group (Artefact Group, 2012).

The activity started with five minutes of individual work, in which initial ideas were individually recorded on A5 worksheets, each printed with one of the following behaviour change triggers:

'What can we do to increase the sense of control, ownership and personal identification?'

'How might we emphasise gains and reduce losses?'

'How can we set up positive expectations and provide feedback to reinforce commitment?'

'What can we do that will focus attention, reduce uncertainty and minimise decision-making?'

After the initial five minutes work, the ideas were collected, shared, organised and displayed on one of four A1 worksheets; each printed with one of the behaviour change triggers. Following this, all co-designers worked collaboratively to build on these initial ideas. This activity lasted approximately 20 minutes.

8.3.5.2.4 Activity 4: Insight Refresher

The purpose of this activity was to refresh co-designers' understanding of the visualized sustainability data and to remind them of the insights they had gained exploring the information visualization interfaces in the previous day's workshop. Once again, new insights were individually recorded on A5 worksheets. After approximately ten minutes work in small groups of two or three, the additional insights gained were collected and shared on A1 worksheets. This activity lasted approximately 15 minutes and was guided by the same questions used in the previous day's activity:

'What are the barriers to reducing waste? Or to re-using items instead of recycling or disposing of them?'

'How might we motivate people to choose a re-usable option? Recycle more effectively? Or simply generate less waste?'

What items are likely to be causing the contamination in different bins? And why might these bins become contaminated?'

8.3.5.2.5 Activity 5: Design Intervention Ideas

In this activity, co-designers worked in pairs to generate initial ideas for interventions that would respond to the projects' overall objective of designing a new service to change student behaviour and reduce the amount of waste being generated. To achieve this, co-designers were asked to think of ideas that might respond to the *Problem Statement* they had defined at the end of the first day. They were asked to use the data visualized on the iPad interfaces, together with insights and ideas from earlier in the workshop to help inspire them. To describe these interventions, co-designers used A2 5WsH hexagonal worksheets. After approximately twenty minutes work the ideas they generated were shared and displayed. This activity lasted approximately 25 minutes and was guided by the following questions printed on the worksheets:

'What is the change you would like to make?'

'Why might this change be effective?'

'When does the change take place?'

'Where does the change take place?'

'Who will be affected by this change?'

'How does this change respond to students' motivations and barriers?'

8.3.5.2.6 Activity 6: Idea Selection

In this activity co-designers voted to select their favoured design intervention based on two criteria: *how simple it would be to implement* and *how significant its impact on sustainability would be*. Each co-designer was given three smiley face stickers to place on selected hexagons. This activity lasted approximately 10 minutes.

8.3.5.2.7 Activity 7: Idea Validation

In this activity, co-designers were asked to validate their selected design idea. To achieve this they worked in a single group to interrogate their selected solution by brainstorming responses to each of the following questions in turn:

'In what ways will this idea be effective?'

'What are its limitations?'

'What unique qualities does this idea have?'

'How can the limitations be overcome?'

Co-designers were asked to use the visualized sustainability data and insights gained during previous activities to help them answer these questions. This activity lasted approximately 25 minutes.

Figure 55: Co-designers vote for their favoured solution ideas during the One Small Change workshop

8.3.5.2.8 Activity 8: Describe the Selected Design Idea

In this activity, all co-designers worked together to describe their selected service design idea in greater detail. To help structure this description, they were given an A0 sized 5WsH hexagonal worksheet on which they could write or sketch to describe elements of the service experience. This activity lasted approximately 20 minutes and was guided by the following questions printed on the worksheet:

'What is the service idea?'

'Why should this service be developed?'

'When will this service be used?'

'Where will this service be used?'

'Who will benefit from this service and who will implement it?'

'How will this service increase environmentally friendly behaviour?'

8.3.5.2.9 Activity 9: Describe the Selected Design Idea to Camera

In the final activity of the workshop the selected *Design Idea* was presented to camera. This activity lasted approximately 5 minutes.

8.4 Evaluation Methods

My aim with this case study was to evaluate the emerging CoDesign With Data approach as a design process with two distinct phases. This was to compare the effectiveness of the tools and techniques during each phase. To answer my research questions, see section 8.2, I collected data from pre- and post-workshop questionnaires, and Reflection Postcards given to co-designers after each day's activities. I also asked three domain experts to rate each of the day's final outputs, and I collated the outputs from individual activities to trace the provenance of the *Problem Statement* generated on day one and the *Design Idea* selected on day two.

The questionnaire I gave to each co-designer prior to the start of the first day's activities collected their demographic information and asked them to rate their knowledge on selected aspects of the design context. The questionnaires I gave co-designers at the end of each day's activities included the questions required for the Creativity Support Index (CSI) (Carroll et al., 2009); two questions addressing their insight seeking; two questions addressing the impact of the information visualization interfaces on co-designers design ideas; and the questions relating to knowledge of the design context asked in the pre-workshop questionnaire. The questionnaire given to co-designers after the second day's activities additionally asked them first to rate the importance of each of five workshop dimensions to the development of their ideas, and then for any other comments they might wish to share. A follow up questionnaire was also sent to co-designers one week after the workshops in which I asked them about the role that the information visualization interfaces had played in their individual thinking and in their group discussions. The Reflection Postcard given to co-designers after each day contained the same prompt in order to compare their thoughts at each phase. The first day's postcard was returned at the start of the workshop's second day. The second day's postcard was returned by post.

As in my previous case studies the evaluation methods and data collected will be discussed in terms of *Supporting the People Designing* and *Assessing the Design Product*. This choice of structure is explained fully in section 3.2.

8.4.1 Supporting the People Designing

To assess the effectiveness with which the CoDesign With Data tools and techniques supported co-designers' creative processes during their design activities in the One Small Change workshop, I once again used the questions from the Creativity Support Index (CSI) (Carroll et al., 2009). As in the evaluation reported in section 7.4, the questions were slightly reworded from the original questionnaire to refer directly to the information visualization tools being used. Again similarly to the evaluation reported in section 7.4, the total of the scores given in response to each dimension in the second part of the CSI questionnaire was used to assess the relative importance of the different creativity support dimensions to co-designers. The CSI is discussed in detail in section 3.2.1.

To assess how effectively the information visualization tools supported co-designers' insight seeking and helped them to gain a better understanding of the topic under consideration, the questionnaire given to them after each day's activities included the following two questions:

My understanding of the topic under investigation improved as a result of using the iPad information visualizations.

I was better able to answer questions regarding the topic under consideration as a result of using the iPad information visualizations.

These were presented as statements with Likert scale agreement ratings ranging from 1 *strongly disagree* to 9 *agree strongly*. This is the same format as the CSI questions are presented. In my analysis I calculated the mean of the rating given to these two questions by each person, for each day.

To assess how effectively the information visualization tools provided inspiration for co-designers' idea generation, the questionnaire given to them after each day's activities included the following two questions:

I had many ideas as a result of using the iPad information visualizations

The iPad information visualizations played an important role in the ideas I had

These were also presented as statements with Likert scale agreement ratings ranging from 1 *strongly disagree* to 9 *agree strongly*. In my analysis I calculated the mean of the rating given to these two questions by each participant, for each day.

To assess whether co-designers had gained an improved understanding of the design context, as represented in the data, three questions were included in the questionnaire given to them before the start of the first day, and also in the questionnaire given to them after each day's activities. Co-designers were asked to rate their knowledge, in each case, from 1 *minimal knowledge* to 7 *deep knowledge* in response to the following statements:

The things that would make City students more environmentally friendly

The things that prevent City students' environmentally friendly behaviour

How students use the different types of bin available at City to dispose of things

Responses to these questions were collated at each stage they were asked, and the results graphed.

To assess the relative importance of different aspects of the workshop in the development of their design ideas, co-designers were asked to rate each of five different workshop aspects on a scale from 1 *unimportant* to 7 *very important*. These aspects were: *Time spent thinking about the subject matter individually; Discussions with other group members; The expertise of other group members; Doing activities with information visualizations; and Workshop facilitation*. To analyse this data, the responses were collated and the mean, median, range and standard deviation calculated. This provides an overall picture regarding which of these aspects participants had found effective. Each co-designer's response to these questions was graphed to highlight emerging patterns.

In addition to my questionnaires, the degree to which the workshop activities had helped co-designers gain a better understanding of the design context and the relative importance of different aspects of the workshop were both addressed by the prompt in the Reflection Postcard given to each co-designer after each day's activities:

Please reflect on your involvement in today's workshop. Write a few sentences thinking in particular about whether your understanding of the subject matter has increased and if so which were the particular elements of the workshop that helped you gain this improved understanding.

To analyse the responses co-designers gave on the Reflection Postcards, they were first transcribed and the responses to each part of the prompt separated. They were then ascribed to one of five conditions: *Totally positive; Partially positive; Neutral; Partially negative; or Totally negative.*

Following my initial analysis of the questionnaires, I wanted to evaluate how important the information visualization tools were in stimulating and focusing co-designers' individual thinking and group discussions during the workshop's activities. To do this co-designers were given a follow-up questionnaire a week after the workshop, in which they were asked two open questions:

To what extent did the information visualizations stimulate and focus the group discussions you had?

To what extent did the information visualizations stimulate and focus your individual thinking?

To analyse these, the responses were first transcribed and each question separated. These were then ascribed to one of five conditions: *Totally positive; Partially positive; Neutral; Partially negative; or Totally negative.*

8.4.2 Assessing the Design Product

To assess the design product, three domain experts were given a document outlining the *Problem Statement* participants had defined together with a description of the *Design Idea* they had selected. These domain experts included the member of University staff with responsibility for managing recycling and waste, the student union official running a major national student waste and recycling initiative, and an associate editor of the UK's leading materials and recycling magazine with over ten years experience. The document briefly described how the *Problem Statement* had been arrived at during the first day's activities, and how the *Design Idea* had developed during the second. Some examples of how the *Design Idea* might be implemented were also included. The domain experts were asked to rate the *Problem Statement* on three measures: from 1 *unimportant* to 5 *very important*, on how important they thought the problem it describes is; from 1 *very familiar* to 5 *very novel*, on how novel they thought the problem it describes is; and from 1 *uncreative* to 5 *very creative*, on how creative they thought the co-designers had been in identifying this problem. The same three domain experts were also asked to rate the *Design Idea* on three measures: from 1 *ineffective* to 5 *very effective*, on how effective they thought it would be in reducing waste and improving recycling; from 1 *very familiar* to 5 *very novel*, on how novel they thought the solution was; and from 1 *uncreative* to 5 *very creative*, on how creative they think it is. The rating given by each domain expert for each assessment factor was then collated for each day's final output. In addition, the domain experts were also asked for any other thoughts or comments they might have. These were transcribed, and ascribed to one of five conditions: *Totally positive; Partially positive; Neutral; Partially negative; or Totally negative.*

To trace the provenance of the *Problem Statement*, and understand its development, I worked backwards through the collated outputs of the first day's workshop, starting with the *Problem Statement* itself. For each activity I identified the outputs that had contributed to the development of the ideas represented in the *Problem Statement*. A similar process was carried out to analyse the provenance of the *Design Idea*. In this case I started with the *Design Idea* itself and worked backwards through the activities of both days of the workshop in turn.

8.5 Results

8.5.1 Supporting the People Designing

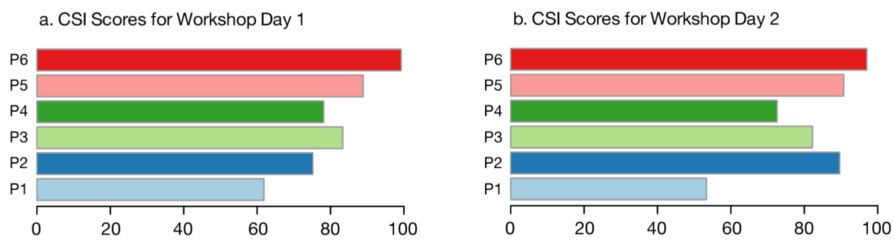

Figure 56: Creativity Support Index scores for: a. Workshop Day 1: Define the Problem; and b. Workshop Day 2: Generate and Select Design Ideas

Figure 56 shows the Creativity Support Index (CSI) (Carroll et al., 2009) scores calculated from co-designers' questionnaire responses. These range from 62 to 99 after the first day's activities, with a mean of 81 and a standard deviation of 12.72. Scores calculated from responses to the CSI questions after the second day's activities range from 53 to 97, with a mean of 81 and a standard deviation of 15.9.

In Figure 57 we see the dimensions of creativity that co-designers thought were most important to the activities undertaken in this workshop. After the first day's activities, the two considered most important were *Exploration* with a total score of 28 and *Collaboration* with a total score of 18. The same two dimensions were also considered to have been the most important after the second day's activities, however this time *Expressiveness* was considered equally important to *Collaboration*. *Exploration* had a total score of 24, whilst both *Collaboration* and *Expressiveness* had total scores of 17.

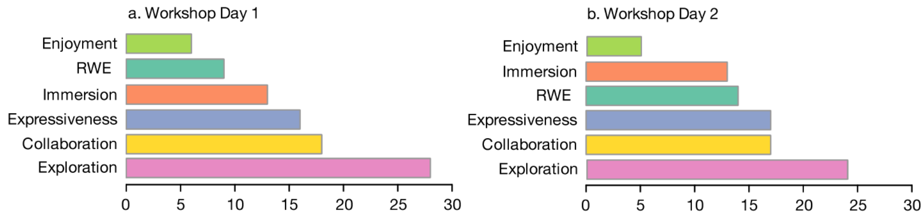

Figure 57: Aggregated scores for the importance co-designers gave to each CSI factor: a. Workshop Day 1; and b. Workshop Day 2

Figure 58 shows the mean of the ratings each co-designer gave in response to the two questions regarding how important the information visualization interfaces were in helping them understand the topic under consideration. This reflects how well their insight seeking had been supported. These ratings range from 6.5 to 8, from a possible scale of 1 to 9, after the first day's activities. These ratings have a mean of 7.2 and a standard deviation of 0.6. After the second day's activities, the ratings ranged from 3 to 8.5, and have a mean of 6.5 and standard deviation of 2.1.

Figure 59 shows the mean of the ratings each co-designer gave in response to the two questions regarding how effectively the information visualization interfaces provided inspiration for their idea generation. This reflects the degree to which their creative processes were inspired. These ratings range from 7.5 to 8.5, from a possible scale of 1 to 9, after the first day's activities. These ratings have a mean of 7.8 and a standard deviation of 0.6. After the second day's activities, the ratings ranged from 4 to 9, and have a mean of 7.5 and standard deviation of 1.8.

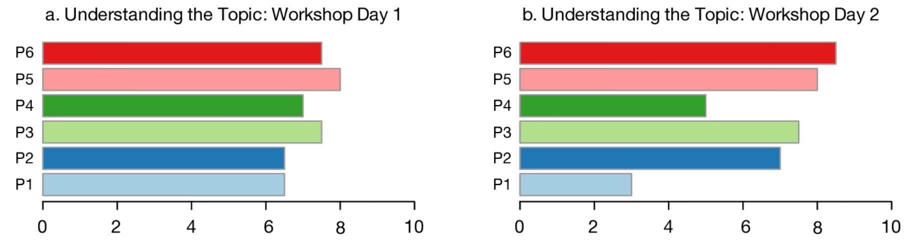

Figure 58: Co-designers’ ratings of the importance of the information visualization interfaces to understanding the topic in: a. Workshop Day 1; and b. Workshop Day 2

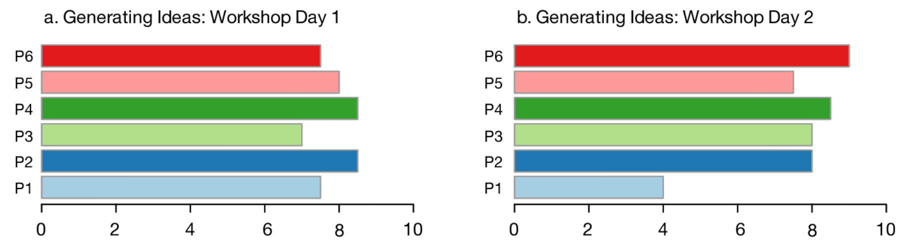

Figure 59: Co-designers’ ratings of how effectively the information visualization interfaces provided inspiration for their idea generation.

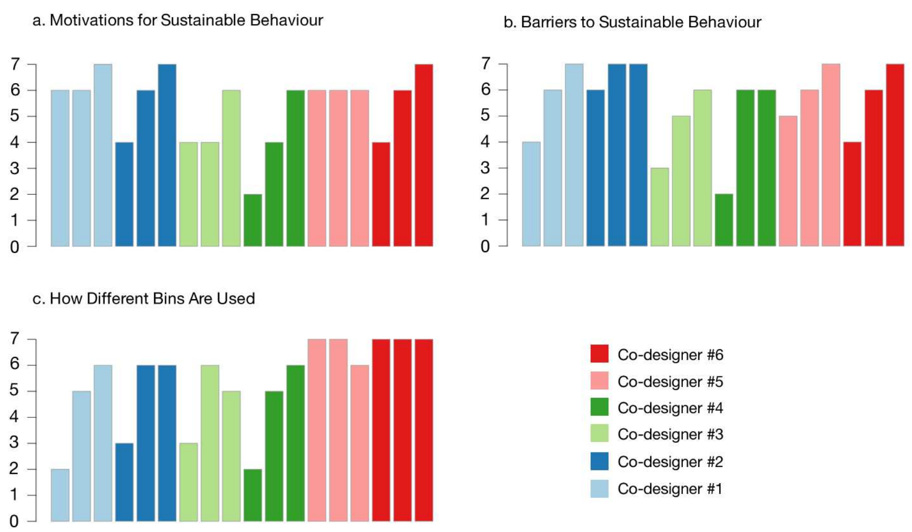

Figure 60: Changes in co-designers' self-reported level of domain knowledge: a. motivations for sustainable behaviour; b. barriers to sustainable behaviour; and c. knowledge of how different types of recycling and waste bin are used. Bars represent pre-workshop, post day 1 and post day 2 questionnaires for each co-designer (in order left to right).

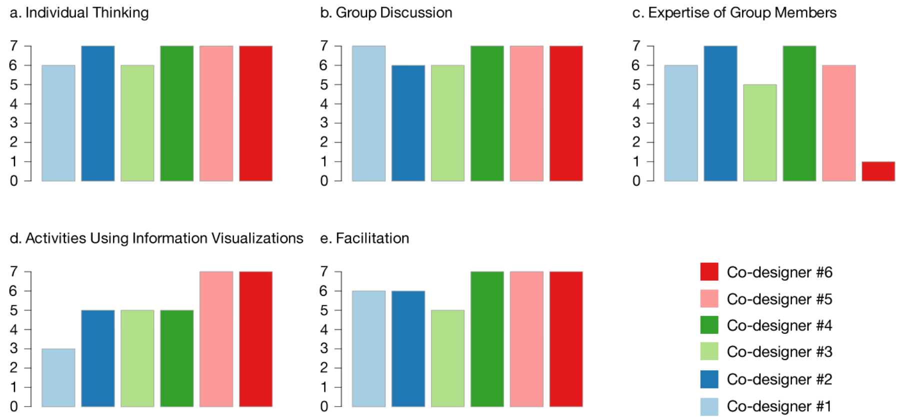

Figure 61: Co-designers' views of the importance of different aspects of the workshop: a. Individual Thinking; b. Group Discussion; c. Expertise of Group Members; d. Activities Using information Visualizations; e. Facilitation.

Figure 60 shows the collated scores for co-designers' self-reported level of knowledge of the design context, as expressed in the data represented in the information visualization interfaces. Here we see that in the vast majority of cases this knowledge increases, and often between every stage that the questions were asked. Figure 61 shows the different workshop aspects that were identified by co-designers as being important in the development of their design ideas, together with the number of co-designers identifying each of these factors as important. Table 12 shows the mean, median, minimum, maximum, range and standard deviation for the collated scores given by co-designers.

	Individual Thinking	Group Discussion	Group Expertise	Information Visualization	Facilitation
Mean	6.67	6.67	5.33	5.33	6.33
Median	7	7	6	5	6.5
Min	6	6	1	3	5
Max	7	7	7	7	7
Range	1	1	6	4	2
S	0.52	0.52	2.52	1.51	0.82

Table 12: The importance of different aspects of the workshops to co-designers

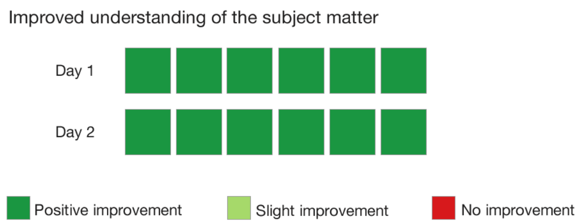

Figure 62: Co-designers' responses on the Reflection Postcards with regards to improvements in their understanding of the subject matter being considered

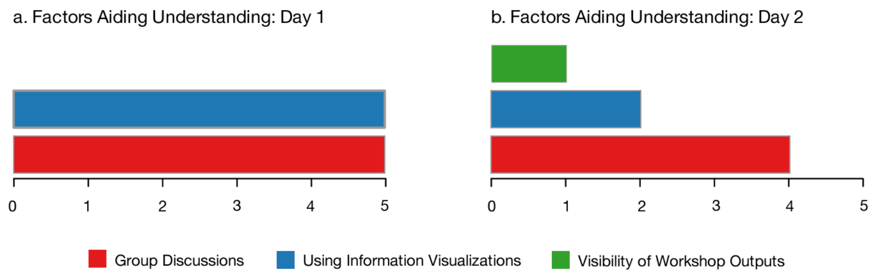

Figure 63: Workshop factors that helped co-designers to gain an improved understanding of the subject matter, as highlighted in participants' Reflection Postcard responses

Figure 62 shows the analysis of the Reflection Postcard responses made by co-designers with regards to improvements in their understanding of the subject matter under consideration, i.e. the design context. Here we can see that there was a *Positive improvement* in understanding recorded by all co-designers after both days of the workshop. Figure 63 shows which of the different aspects of the workshop co-designers highlighted as being important to their ability to gain a better understanding of the design context in their Reflection Postcard responses. Individual examples of these responses provide detail to this analysis:

"My understanding of the subject matter has increased and this was due to: a) listening to other peoples' ideas; b) using the iPad visualizations which helped us to understand the barriers / motivations people associate with recycling and they acted as foundations for pinpointing problems or finding possible solutions." Co-designer #2, Day 1.

"The iPad visualization allowed me to see how a different combination of aspects affected peoples' involvement in recycling. Also hearing other peoples' experiences improved my understanding of some of the issues. The discussions were insightful." Co-designer #3, Day 1.

"My knowledge of the subject matter has increased, mainly because I was sitting next to someone from the environment team who told me all about it." Co-designer #4, Day 1.

"The visualization on the iPad provided insight on what are critically damaging to the process of effective recycling." Co-designer #5, Day 1.

"The greatest way in which my understanding increased was by gaining insight into the different perspectives of the other participants." Co-designer #1, Day 2.

"My understanding of what we can do to address the subject matter has definitely improved and increased. The collaboration really helps. Also because we had the same data, it enabled us to focus on the problem better and come up with solutions." Co-designer #6, Day 2

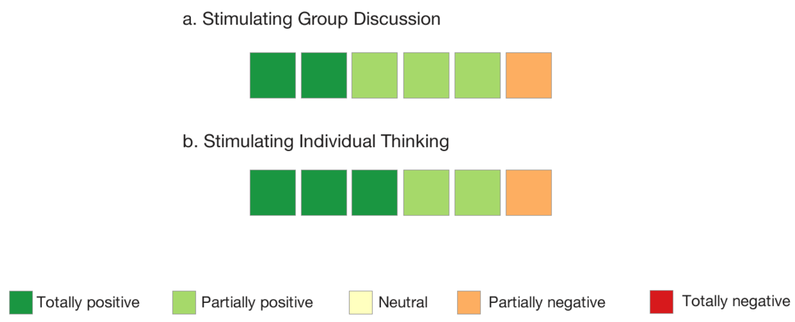

Figure 64: Co-designers' view of the degree to which the information visualizations stimulated group discussion and individual thinking, from the follow up questionnaire

A follow up questionnaire was sent to co-designers one week after the workshop to address questions that had arisen during my initial analysis of the data about which aspects of the workshop were important and influential to their design activities. Figure 64(a) shows that the majority of co-designers responded positively when asked to comment on the role the information visualization interfaces played in stimulating and providing a focus for group discussions. Individual responses show that the visualized data provided a platform for them to share their thoughts, and a space where they felt confident that they were talking about similar subjects.

"The visualizations allowed the group to ask specific questions about trends that were noticed and created a level playing field where everyone could contribute to the discussion without feeling like they were not experts." Co-designer #6

"In the second workshop, when trying to come up with the different ideas to put on the wall in the different categories, I feel that the visualisation helped spark ideas and perhaps answer 'why' certain ideas may work since they provide reasons and show which barriers and motivations were most prevalent." Co-designer #2

However, not all of the responses were positive, one co-designer thought that a better focus could have been gained by distilling the visualized data down to simple statements.

"Whilst the visualisation did stimulate group discussions, I think focus would have been better gained just with simple statements, for example, saying x% of general waste bins are contaminated, and an explanation of what contamination was in this context." Co-designer #4

Figure 64(b) shows that most of the co-designers also responded positively when asked to comment on the role the information visualization interfaces played in stimulating and providing a focus for individual thinking. Individual responses show how the visualized data triggered co-designers to think again about the subject.

"It also helped me to present ideas that gave reasons for why people may not recycle." Co-designer #5

"The visualisations made me question some of my own ideas." Co-designer #3

Again there was a partially negative aspect to one of the responses. In this instance, Co-designer #1 highlighted that the information visualizations did not help his original thinking, but rather that they were more useful in helping communication and sharing.

"The information visualizations largely reinforced my gut feeling on this particular matter – they did not have a substantial effect in stimulating or focussing my original thinking, but they did allow me more easily to draw attention to specific ideas by pointing to the visualization rather than needing to communicate and explain in great detail." Co-designer #1

8.5.2 Assessing the Design Product

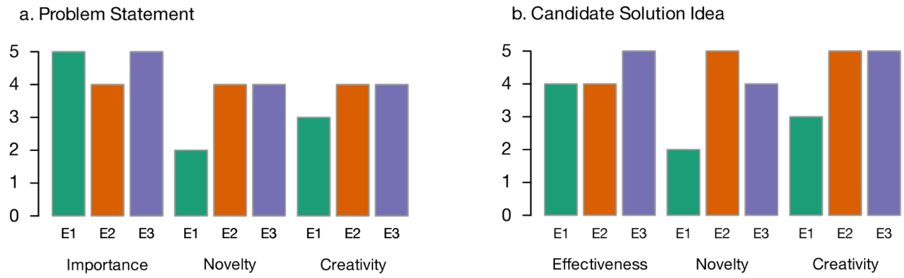

Figure 65: Evaluation ratings from domain experts for: a. the Problem Statement output from Workshop Day 1; and b. the Design Idea output from Workshop Day 2

Figure 65a shows the ratings given for the *Problem Statement*, which was defined at the end of the first day's activities, by each of the three domain experts for each of the three factors under consideration. For *importance*, the scores range from 4 to 5 with a mean of 4.66. For *novelty*, the scores range from 2 to 4 with a mean of 3.33. For *creativity*, the scores range from 3 to 4 with a mean of 3.66. Figure 65b shows the ratings given for the *Design Idea*, which was defined at the end of the second day's activities, for each of the three factors under consideration, by the same three domain experts. For *effectiveness*, the scores range from 4 to 5 with a mean of 4.33. For *novelty*, the scores range from 2 to 5 with a mean of 3.66. For *creativity*, the scores range from 3 to 5 with a mean of 4.33. The additional comments provided by domain experts are also informative. The *Problem Statement* was viewed particularly favourably. For example, domain expert E1 said:

"You are right to try and prevent waste in the first place, such as encouraging people to use their own mugs, food containers etc."

"Having fewer general waste bins and more recycling bins may help with shifting away from general waste being the default bin."

Whilst domain expert E2 said:

"The problem identified in the workshops (how to make general waste for incineration the bin of last resort) is certainly an important one and quite relevant for us at City. The proposed solution to this particular problem is quite novel and creative and has the potential to be quite effective."

"Reducing the number of general waste bins is just part of the actual problem at City. The other equally important problem is that people tend to contaminate the recycling bins with food/liquid waste."

Domain expert E3 said:

"Simple and very effective!"

"Another thing would probably be to reduce the number of bins for general waste for incineration and mainly have recycling bins available around the campus."

The *Problem Statement* that was the final output of the first day's activities was: ***In what ways might we make general waste the bin of last resort?*** Tracing the provenance of this output shows that it was arrived at through the following steps, clearly indicating the passage from insights to ideas.

On investigating the visualized data during Activity 3, co-designers had noted that people were *too busy* or that *it took too much time* to behave sustainably. This meant that there was a lack of *convenience* and that *carrying things around is annoying,* also that there was *too much thinking about what goes in what bin*. Amongst the reasons for this were *different bins in different places*; *the right bin is not where you are or where you are going*; *labelling on bins is unclear*; and that there are ***more general waste bins***.

Following this, the selected *Opportunity for Change* from Activity 4 was ***Too many general waste bins and not enough recycling bins***. The *Opportunity for Change* receiving the second largest number of votes was "*People putting recyclable waste in the general waste bin*". In this 5WsH hexagon, the *Why* was ***General waste implies 'everything'***. The problem abstraction exercise in Activity 6 started with the situation of there being "*Too many general waste bins*". This led to the situation that "*General waste is considered default*". Co-designers went on to identify the general waste bins as the "*any*" bin. This, they said, was making general waste bins the easiest option for both provision and use, or the *bin of first resort*. This was then turned around and made into a *Problem Statement* that could be addressed the following day: ***In what ways might we make general waste the bin of last resort?***

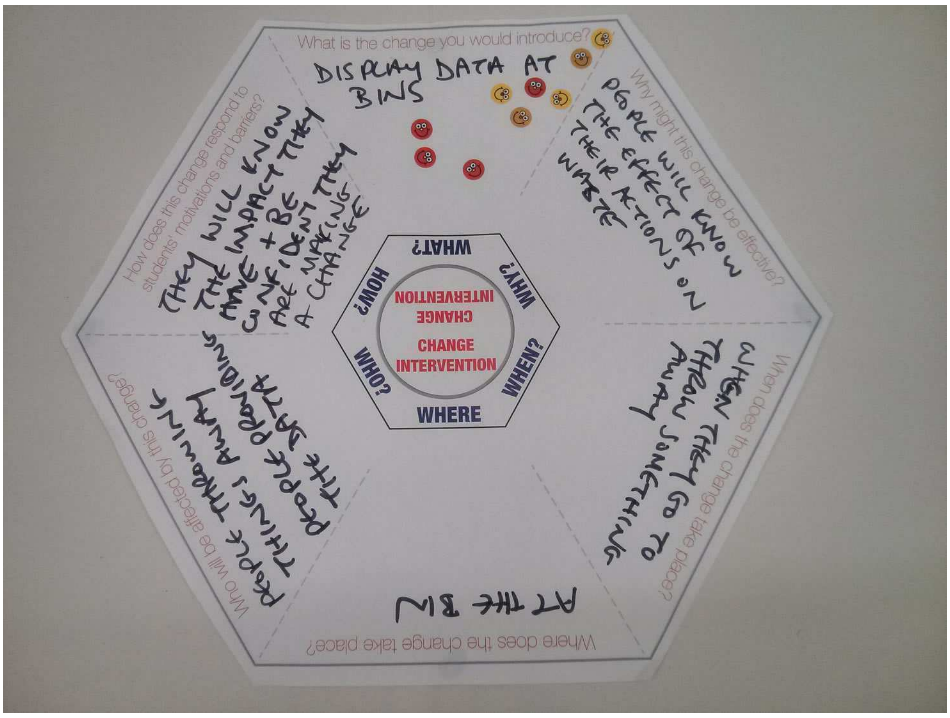

Figure 66: Selected change intervention hexagon, describing co-designers' idea to display data about waste and recycling at the site of the bins

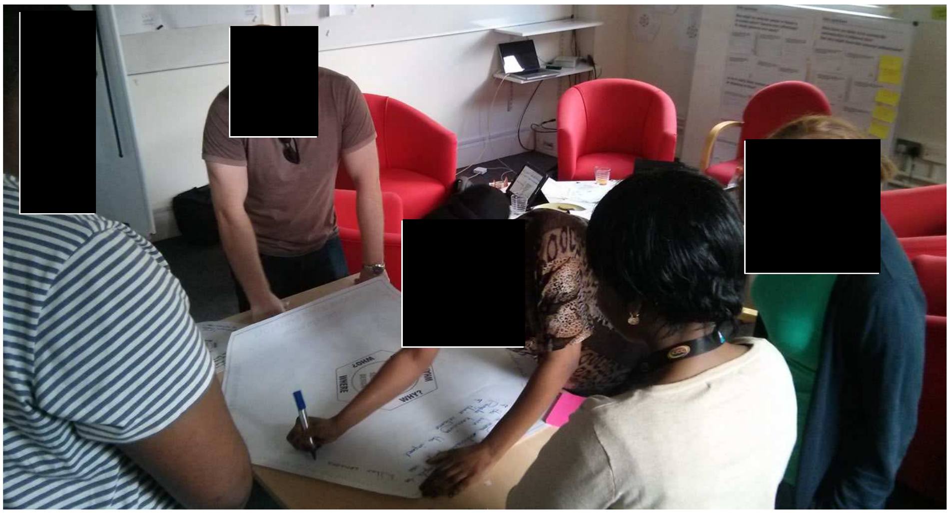

Figure 67: Co-designers describe their selected candidate solution using the large A0 size hexagonal worksheet

The *Design Idea* selected by co-designers was to ***Display data information points by bins***. This idea was developed through the following steps.

In Activity 3 co-designers had brainstormed initial solutions using *behaviour change triggers* as prompts. One of these triggers was "*What can we do that will focus attention, reduce uncertainty and minimise decision-making?*". One of the responses to this trigger was "*Display data by bins on the amount of contamination of bins*". Activity 4 was a refresher to reacquaint participants with the data displayed in the information visualization interfaces. Following this, in Activity 5, co-designers described their suggested *Change Interventions*. The *Change Intervention* that was then selected was "*Display data at bins*". This can be seen in Figure 66. The purpose of this intervention, the *Why* on the 5WsH hexagonal worksheet, would be so that "*People will know the effect of their actions on waste*". Following Activity 7's validation, in which this *Why* was explored in more detail, the final *Design Idea* was described on a large 5WsH hexagonal worksheet, see Figure 67. This idea was considered to be effective because it is a "*Simple way to encourage people to make a more extensive/proper use of the bins*". This idea was furthered developed into the proposal that is presented in Appendix B of this thesis.

8.6 Discussion

My aim with this case study was to investigate how effectively the emerging CoDesign With Data approach's use of domain-relevant data would support co-designers' insight seeking and provide inspiration for their creative design ideas during each of two distinct design phases. The first phase would lead up to co-designers defining a *Problem Statement*. In the second co-designers would generate candidate solutions and select a final *Design Idea*. This case study would also bring together and build on the lessons learnt in my previous studies.

When we look at the ratings given by the independent domain experts to the final output from each of the phases we see that the tools and techniques used during the workshop activities led to co-designers successfully identifying a specific problem to address and defining it in a *Problem Statement* domain experts considered *important*. The same domain experts also considered that the *Design Idea* co-designers developed was likely to be *effective*, and that co-designers had been *creative* in its design. This can be considered positive evidence for the effectiveness of the CoDesign With Data approach.

Investigating the provenance of each of these outputs shows that the *Problem Statement* can be clearly traced back to insights regarding the greater number of general waste bins and the barriers to sustainable behaviour, which co-designers discovered through exploring the visualized data during Activity 3's insight seeking. The origins of the *Design Idea* co-designers selected also reflect the importance of the data to their thinking. However, here we see the important influence of wider thinking too, particularly that initiated by the behaviour change triggers.

The Creativity Support Index (CSI) (Carroll et al., 2009) ratings calculated from co-designers' questionnaire responses range from 62 to 99 after the first day and from 53 to 97 after the second. The mean rating was 81 after both days. These figures are comparable with those calculated from responses given by participants who had used the interface visualizing smart energy data in a design that aimed to prompt creative thinking in an analytical way during the design experiment reported in Chapter 7, see section 7.5.1. This offers additional evidence for the effectiveness of this type of interface in CoDesign With Data workshops. Also similarly to the findings reported in section 7.5.1, the dimensions of creativity support that co-designers considered most important were again *Exploration* and *Collaboration*. This suggests that those findings and the factors relating to interaction discussed in section 7.6 may be generalizable to many instances of similar workshops. This is an important consideration for the way information visualization interfaces and workshop activities are designed and used in CoDesign With Data workshops.

Findings from the other questionnaire data and the Reflection Postcard responses suggest the workshop's activities were effective in helping co-designers gain a better understanding of the design context, and that the visualized data contributed inspiration to co-designers' ideas. However this data also point to the importance of group discussions and sharing other co-designers' knowledge in this respect. When we look at the questionnaire data relating to which aspects of the workshop were important in the development of design ideas, *group discussion* and *individual thinking* were considered important by all co-designers. When we factor in the Reflection Postcard responses, this appears to have been particularly the case for the second day's activities.

Responses to the follow-up questionnaire suggest that for most co-designers exploring the domain-relevant data visualized in the iPad interfaces provided a focus for and stimulated both of these aspects. One thing of note is that the co-designer who was most familiar with the details of the design context before the workshop was the one most positive about the role of the visualized data in the group discussions. This was co-designer #6 whose role at the University includes managing the Environmental Champions Network on a day-to-day basis. Co-designer #6 highlights how the data "*allowed the group to ask specific questions",* and "*created a level playing field where everyone could contribute".* This can be compared with co-designer #4 who had thought "*simple statements*" might have been better, and whose Reflection Postcard response on the first day had said "*My knowledge of the subject matter has increased, mainly because I was sitting next to someone from the environment team who told me all about it*". Co-designer #4 was the co-designer with least detailed knowledge of the domain context. She was also the co-designer whose self-reported level of domain knowledge was lowest at the start and showed the greatest increase by the end.

This suggests that the information visualization interfaces may have been being used as a common ground where information and opinions could be shared. In this way they were performing a role analogous to that ascribed to *boundary objects* (Star, 1988; Star, 2010). The term *boundary object* is used to describe objects that have a meaning or purpose that can be shared by groups who are collaborating or cooperating without consensus. Importantly though, a *boundary object* should also have an existing, more specific purpose for at least one of the groups, which precedes the more vague or ambiguous shared purpose. In this workshop, the information visualization interfaces were artefacts specifically given to participants in order to perform particular workshop activities. It would therefore be incorrect to refer to them specifically as *boundary objects*.

Using the term boundary object analogously is still potentially useful though, because it relates to an important factor in the relationships between co-designers, and between co-designers and the tools they are given. Fischer and Shipman (2013) and Arias and Fischer (2000) discuss something similar in participants' use of novel digital systems they call '*domain-oriented design environments*' during collaborative or social creativity. Carlile provides examples of design artefacts, such as sketches and models, acting as *boundary objects* in new product development (Carlile, 2002). Here the artefacts are used to transform knowledge as well as to share it between representative design engineers, manufacturing engineers, sales representatives and production staff. Further study is required of this collaborative aspect of using information visualization interfaces in workshops.

Returning to the research questions asked in section 8.2. Were there differences in the support provided for co-designers' insight seeking between the two days of the workshop? Responses to the questionnaires and Reflective Postcards would suggest there were, and that the information visualization interfaces played a more significant role when defining the *Problem Statement* on day one than when generating candidate solutions and selecting a *Design Idea* on day two. Similarly, it also appears to be the case that the information visualization interfaces were a more important source of inspiration for co-designers' creative design process on day one than on day 2. These factors suggest that the tools and techniques for working with domain-relevant data, particularly those using information visualization techniques to prompt creative thought in a structured and analytical way, developed during this research are likely to be particularly well suited to identifying and formulating design problems. However, confirmatory investigation is needed.

8.7 Reflections

8.7.1 Research and Evaluation Methods

8.7.1.1 Benefits and Limitations of Study Design

This case study enabled me to compare Reflection Postcards and questionnaire responses at the end of each phase of a two-phase workshop held over consecutive days. It also provided an output from each phase that could be assessed by independent domain experts. However, a large number of activities were included in a limited timespan, which led to a degree of compromise. In particular, the selection and validation of the final *Design Idea* were truncated. Future workshops might therefore follow the Creative Problem Solving (CPS) method (Isaksen et al., 2011) in having three distinct phases.

My comparison of the evaluation data at different stages is informative and highlights possible areas where the methods under investigation might be particularly effective. However, it should be remembered that this case study involves a single workshop with a particular set of participants and therefore the reliability of attempting to transfer the findings to other contexts is limited.

I had also thought that separating the two phases over consecutive days would be important to provide time for co-designers' ideas to incubate overnight. Such periods of incubation have been identified as a key stage in creative processes e.g. (Lubart, 2001), and they are considered an important and effective element in the Creativity Workshops discussed in section 2.4.1. However, there was no obvious way to assess the effectiveness of providing a period of incubation when studying a single workshop, and so it was not something explored in detail. This is perhaps a factor that could usefully be studied in a future design experiment.

8.7.1.2 Limitations of Data Collection and Analysis

In this case study I gathered evaluation data from multiple sources in an attempt at triangulation, and to mitigate any threats to the validity and reliability of any findings. The combination of Creativity Support Index (CSI) (Carroll et al., 2009) ratings, other questionnaires and Reflection Postcards provides a comprehensive account of participants' self-reported perceptions of the effectiveness of the workshop's activities. This could be augmented with participant interviews, but any added value should be weighed against the extra demands placed on those taking part. To support this evidence, I also asked independent domain experts to rate each day's final output. This provides an alternative assessment of the workshop's effectiveness, and one that is an accepted and useful measure of their success (Dean et al., 2006; Jones et al., 2008), even if it does have limitations with regards to consistency (Christiaans, 2002).

The major limitation in the evaluation data gathered during this case study was the failure to gather video data. In the design experiment reported in Chapter 4, detailed analysis of the video recordings of participants' use of the different information visualization interfaces enabled me to gain an understanding of the sensemaking processes that were taking place. Similarly, in the design experiment reported in Chapter 7, detailed analysis of the video recordings of the activities surrounding participants' idea generation, enabled me to gain a picture of the differences in the way participants were inspired by the different design artefacts.

My intention had been to undertake a similarly close and detailed analysis of the video recordings of the activities undertaken during this workshop. However, here the workshop setting was less controlled, activities were not situated around a single table, and the dynamic changes between small and large group working meant that even with two cameras the video recordings I made did not capture the necessary interactions sufficiently well. This was a failing in my approach, and finding alternative ways to capture video data is an important consideration for future research. It may prove effective to use the forward facing camera on an iPad to record the conversations that the users of that particular iPad have, and combine this with a log of their interactions with the visualized data. However, this might also require a significantly longer development time when building information visualization interfaces.

8.7.2 Takeaways

T8.1 *Interactive interfaces that visualize domain-relevant data appear to provide a common ground on which workshop co-designers are able to share their knowledge and develop creative design ideas.*

T8.2 *Activities in which co-designers seek insight in visualized domain-relevant data, using interactive interfaces designed to prompt creative thinking in a structured analytical way, appear to be particularly well suited to identifying and formulating design problems.*

9 Discussion

At the outset of this thesis, I described design as being a process by which "*courses of action aimed at changing current situations into preferred ones*" (Simon, 1996, p.111) are devised through a "*reflective conversation with the materials of a design situation*" (Schön, 1992) and where to "*design with future use activity in mind means to start out from the present practice of the future users*" (Bødker et al., 1988). I also explained how domain-relevant data, generated during everyday activities, offer new ways to gain an understanding of possible future users' current activities.

9.1 Research Question

To investigate this opportunity, I set myself the following research question:

How can seeking insight into domain-relevant data help participants in early-stage co-design workshops gain a richer understanding of the context under investigation, and provide inspiration for creative design ideas?

9.2 Contribution

In response to this question, I have been developing the CoDesign With Data approach to early-stage design workshops, in which working with domain-relevant data is the key distinguishing feature. This has been the primary contribution of the research detailed in this thesis. During a CoDesign With Data workshop participants take part in a series of activities using the tools and techniques I have developed to help them: *seek insight into domain-relevant data*; *share their individual knowledge to gain an improved understanding of the possible contexts these data might come from*; and *use the insights gained as a source of inspiration for creative design ideas*. This research has been exploratory and the CoDesign With Data approach remains a work in progress. However, this research has received validation through peer-reviewed publication at international conferences. These publications, reproduced as Appendix A, include studies of the tools, techniques and methods developed, and discussion of a new method of evaluating creativity support during workshops using Reflection Postcards.

9.2.1 Tools, Techniques, Methods and Approach

In section 2.3, I introduced a framework of ***tools***, ***techniques***, ***methods*** and ***approach*** that has been used to structure the different aspects of a participatory design workshop (Sanders et al., 2010). I adopted this framework to organise the different aspects of the workshops described in this thesis, and I will now use it again to structure the contribution made by this research in more detail. The level of ***approach*** describes an overall mindset or guiding philosophy. The level of ***method*** refers to specific combinations of tools and techniques that have been brought together to meet the goals of a particular workshop. The level of ***tool*** describes different material elements of a workshop, including visualized domain-relevant data. Finally, at the level of ***technique*** I am describing how these tools might be used during a workshop activity.

9.2.2 Contribution at the Level of Approach

The contribution made by this research at the level of design *approach* has been first to identify the opportunity offered by domain-relevant data, data which describe aspects of potential future users' current practice; and second to demonstrate how these data can be used as a raw material through which co-designers are able to explore the domain context of a design situation, and use the insights they gain as inspiration for creative design ideas. Findings from each of the studies reported in chapters 4, 5, 7, and 8 indicate that co-designers find exploring visualized domain-relevant data to be not only useful and engaging, but also a source of inspiration for creative design ideas. This offers a new approach through which human-computer interaction design researchers might investigate activities of interest, frame design problems, and stimulate co-designers' creative ideation.

9.2.3 Contribution at the Level of Method

At the level of workshop *method*, the main contribution of this research has been the empirical evidence, gained through analysis of Creativity Support Index (Carroll et al., 2009) data, which shows that *exploration* and *collaboration* are key creativity parameters to support during this type of workshop. This finding, from the studies reported in chapters 7 and 8, reflects the importance to co-designers of developing, sharing and validating alternative ideas about what might be happening during the activities represented in the data. These alternative ideas are important because they go on to form the basis of an improved understanding of the domain context, and provide a source of inspiration for design ideas.

Supporting exploration and collaboration therefore becomes an important guideline when designing a workshop, one that underpins the development and selection of the tools and techniques used during its activities.

9.2.4 Contribution at the Level of Technique

At the level of workshop ***technique***, the contributions of this research are as follows. Findings from chapters 7 and 8 suggest that important parallels can be drawn between *analytical* (Kosara, 2007) or *traditional* (Manovich, 2011) methods of visualizing information, and structured activities that prompt an *analytical* style of creative cognition (Couger et al., 1993; Shah et al., 2000). We can therefore develop workshop activities that prompt and guide co-designers' exploration of suitably visualized quantitative data, using an analytical style of creative cognition, which lead them to find insights about the domain context of a design situation, and which in turn inspire useful design ideas. Findings from Chapter 5 suggest that interactive information visualization interfaces can also be used effectively in combination with *generative design* techniques (Sanders, 2000), such as making collages. Findings from the study reported in Chapter 8 suggest that using creativity techniques to explore visualized domain-relevant data can be an effective way to identify and formulate design problems. Finally, findings from the studies reported in chapters 5 and 6 suggest that generative design activities can help co-designers' interpret and resolve ambiguities in data, and therefore increase their understanding of the domain context in which data are generated.

9.2.5 Contribution at the Level of Tool

The contributions of this research at the level of workshop ***tool*** are as follows. Findings from the studies reported in chapters 4, 5, 7 and 8 all indicate that co-designers find interactive interfaces that visualize domain-relevant data, and which are presented using an iPad, to be an engaging tool that supports their collaborative design activities. The study reported in Chapter 5 suggests that this may be true for a broad range of the public. Findings from the study reported in Chapter 4 suggest that these interfaces should not represent domain-relevant data with a visual encoding that increases ambiguity, as this will have a negative impact on co-designers' sensemaking and subsequently reduce the appropriateness of their design ideas. Findings from the study reported in Chapter 7 suggest that these interfaces should be designed with a high degree of user-controlled interactivity, as this appears to support their collaborative exploration. Findings from the study reported in Chapter 8 suggest that these interfaces can provide a common ground on which co-designers are able to share their knowledge and develop creative design ideas. Findings from the study reported in Chapter 5 suggest that collections of domain-relevant images or photographs can help co-designers interpret ambiguity in data and in the domain contexts where data are generated.

9.2.6 Comparison to Other Design Approaches

To further demonstrate the contribution of this research to the field of human-computer interaction design, comparisons can be made with other design approaches used in the field. Section 1.2.1 introduced the question that guided this research and described two key relationships it assumes. I will use these two relationships again now to frame my comparison with other design methods. First is the relationship between data and context, and how exploring domain-relevant data, and thinking about the context of the activities being undertaken when these data are generated, can provide insight into design problems. Here I will compare the Codesign With Data approach to Contextual Design (Beyer & Holtzblatt, 1997). Second is the nature of inspiration, and how insights from exploring domain-relevant data can provide inspiration for possible design solutions. Here I will compare the CoDesign With Data approach to the Inspiration Card Workshop (Halskov & Dalsgård, 2006).

It is also worth noting here that when I talk about design context or domain context I am discussing the possible contexts in which the activities represented in the domain-relevant data might have taken place. An alternative understanding of design context is the context in which the design process is taking place. This is discussed in (Svanaes & Gulliksen, 2008), and is not something I am directly making reference to in this thesis.

9.2.6.1 Data and Context

Contextual Design (Beyer & Holtzblatt, 1997; Beyer & Holtzblatt, 1999) is a method that covers the entire front-end of the design process, through a series of structured phases. It is an information-based method that is heavily influenced by close study techniques imported from the applied social sciences, such as ethnography. It results in a highly detailed understanding of the domain context of future customers' work that is well suited to the custom design of software and systems for a particular work environment. This means that even in its agile incarnation (Beyer et al., 2004) it is both time and labour intensive. In contrast, CoDesign With Data is relatively lightweight with a focus on creative workshop activities. However, whilst not equivalent, both approaches take data as a starting point and can be said to follow a basic principle of *designing from data*. The way in which each gathers and treats data will be the basis on which comparison can be made.

The data used for Contextual Design are gathered during the initial contextual inquiry phase, when one-to-one field interviews and observations of customers and their work are conducted. For Contextual Design, "*the principle of* ***context*** *tells us to go to the customer's workplace and see the world as it unfolds*." Because "*All the richness of real life is there, able to jog the customer's memory and available for study*" (Beyer & Holtzblatt, 1997, p.47). Here, context is something experienced by the design researcher who is acting like an apprentice in order to learn about work tasks with the aim of relating the data she collects to concrete instances rather than abstract examples. Typical contextual inquiry interviews might last two to three hours each. Interviews will be held with two to three people for each identified work role. This may result in around twenty interviews. For commercial software systems this might be repeated in six different businesses (Beyer & Holtzblatt, 1997, pp.75-76). The result of this is large amounts of qualitative data, such as notes and sketches detailing interviews and observations, each referring to specific instances of work practice.

The analysis of Contextual design data is a process that turns these concrete instances of work practice into abstractions and models, such as workflow diagrams, sequence models, cultural models and physical environment models. Following the creation of individual models, a consolidation process in which designers attempt to "*develop a sense for a whole customer population from particular instances and events*" through affinity diagrams and consolidated work models takes place (Beyer & Holtzblatt, 1997, p.151). It is the insights gained from abstracting these data into models, and then consolidating and interpreting these models that leads to initial design ideas. During a Contextual Design process it could be said that design ideas emerge as the data are transformed from individual instances into abstract representations.

The data used during a CoDesign With Data workshop may be of different kinds, both qualitative and quantitative, and can come from any number of sources. In most cases these data are likely to have been generated or collected for a previous purpose, other than the current design process, and include domestic and social data as well as work place data. For example, smart meter and smart plug energy data are generated to measure everyday energy consumption, whilst Flickr and social media data are generated so that people can share images, thoughts, ideas and feelings with each other. The visualized representations of these data used in a CoDesign With Data workshop can be thought of as collated abstractions of the different instances of current practice taking place when they were generated. This might offer a view on the activities of larger numbers of people, over longer periods of time, and in a wider range of settings than is practical during a Contextual

Design process, albeit at the cost of being at a much courser granularity.

The activities undertaken during a CoDesign With Data workshop aim to employ stakeholder knowledge and creativity to share ideas, based on participants' own experiences, which describe possible instances in which these data might have been generated. Stakeholders are being asked to interpret the data through the lens of their own experience, use this to provide insights into the domain under consideration, and use these insights to inspire creative design ideas. During a CoDesign With Data workshop it could be said that design ideas emerge as the data are transformed from abstract representations into individual instances.

In a Contextual Design process, the decision has already been made to design *something*. Here data are collected and analysed to ascertain exactly what form that thing should take. The story these data tell is in the form of a documentary, accurately describing the context of customers' current work practices. Whilst this is also possible with CoDesign With Data, it is not always necessarily the case. At times, data might be a starting point, and the aim of the workshop might either be to generate ideas that use these data to address a known issue, as in the case studies reported in chapters 5 and 8; or simply to investigate whether these data can be combined or repurposed to increase their value, as in the case study reported in Chapter 6. In this way CoDesign With Data can be a more speculative endeavour than Contextual Design. Here, understanding the domain context becomes exploratory, and data are used to tell a more imaginative story. I do not believe that these two ways of understanding domain context are incompatible, rather that they are different and hopefully complementary. A detailed contextual enquiry into the domain is a likely next step in developing design ideas generated during a CoDesign With Data workshop.

9.2.6.2 Inspiration

As well as potentially offering a different way of understanding the domain context of a design situation, the insights gained exploring domain-relevant data during a Co-Design With Data workshop also offer a new source of inspiration for creative design ideas. With this in mind it is instructive to compare CoDesign With Data with the Inspiration Card Workshop (Halskov & Dalsgård, 2006) that was described in section 2.4.3. Taking the Inspiration Card Workshop as a case study, Halskov identifies four different strategies through which sources of inspiration are related to design ideas: *selection*, in which some particular feature of the inspiration source is identified for future use; *adaptation*, in which a selected feature of the inspiration source is taken and modified in some way; *translation*, in which a selected feature of the inspiration source is taken and placed into a new context; and *combination*, in which previously unrelated features from different inspiration sources are combined to make something new (Halskov, 2010). These four strategies reflect the generative activities undertaken during the Inspiration Card Workshop. Here participants' creativity is harnessed through making activities, and pre-selected cards showing domain and technology images provide the primary source of inspiration. These strategies also reflect that the Inspiration Card Workshop is largely a process of convergent thinking in which design concepts are developed. In the Inspiration Card Workshop, the bulk of divergent creativity takes place in the pre-workshop phase where the Domain and Technology cards are prepared.

A CoDesign With Data workshop includes an explicit phase of divergent creative thinking prior to convergence activities. In each of the studies reported in chapters 4, 5, 7 and 8 of this thesis we have seen how visualized data can be a source of inspiration for these divergent ideation activities. During these periods, participants' *insight seeking* plays an important role. These insight seeking activities highlight two strategies for relating sources of inspiration to design ideas that differ from those described above, and provide evidence of the novel contribution of the CoDesign With Data approach in this area.

The first of these can be understood as being *Pattern Recognition*. *Pattern Recognition* describes the strategy of identifying visually salient aspects of an interface that are likely to relate to some structure or pattern in the underlying data. The second can be understood as *Sensemaking. Sensemaking* describes the strategy of relating the visually salient patterns found in the visualization interface, first to the underlying data, and through this to the activities that these data represent. These two strategies are closely linked, and in many cases *Sensemaking* will follow *Pattern Recognition* just as *Adaptation*, *Translation* or *Combination* may follow *Selection* in the Inspiration Card Workshop.

The close video analysis undertaken for the studies reported in chapters 4 and 7 illustrates examples of both *Pattern Recognition* and *Sensemaking* strategies. In Chapter 4, Table 10 shows an example of the *Pattern Recognition* strategy unfolding. It includes statements like "*It's 5 across here, 4 up and down*", "*So the colour is* *the same… colours… yes. Just the amount… the circles*" and "*So there's a green up in here and a green down here…*", each of which show how participants are looking for structure and pattern in the visualization interface. Again in Chapter 4, Table 11 shows an example of the *Sensemaking* strategy unfolding. Here we see statements such as "*On Thursday people are washing their...*", "*And on Sunday*" and "*Is this one persons consumption? Do you think? Because they didn't do anything on those days. What about fridge-freezer? That one's continually on*", which show participants trying to understand the activities represented by the data that are visualized in the interface. In Chapter 7, Figure 42 shows another example of participants using a *Sensemaking* strategy. This includes statements such as "*Maybe the dryer is something we can probably change more?*" and "*There's winter and summer. Big difference.*". Again, participants are responding to the visualization interface by trying to understand the activities represented in the underlying data and finding inspiration for their ideation.

9.3 Recommendations for Design Practice

In addition to making a contribution to academic knowledge, it is my aim that the research detailed in this thesis also benefits design practice. With this in mind, some key guidelines for using domain-relevant data as a design material have emerged. These are listed below.

9.3.1 Guidelines for CoDesign With Data Workshops

G1 *Exploration and collaboration are key dimensions of co-designers' creative processes to support.*

G2 *Visualizing domain-relevant data on an iPad is engaging for co-designers, and compatible with their other design activities.*

G3 *Combining visualized data with generative design activities and applied creativity techniques inspires creative design ideas.*

G4 *Representing quantitative data unambiguously in an interactive interface prompts creative thinking in an analytical way well suited to formulating design problems.*

G5 *Interfaces and generative toolkits that present a large number of domain-relevant photographs help co-designers interpret ambiguity and understand the contexts data are drawn from.*

G6 *Custom worksheets help co-designers structure the ideas they generate using visualized data and applied creativity techniques.*

These key guidelines have been derived from the *design practice takeaways* that end each of the chapters 4 to 8. These takeaways are recommendations based on the research findings from each of the individual studies, and are listed in full below.

9.3.2 Recommendations from Individual Studies

T4.1 *Designing interfaces that visualize domain-relevant data with an intentionally ambiguous visual encoding appears to have a negative impact on co-designers' sensemaking, and reduces the appropriateness of their subsequent design ideas.*

T4.2 *Interactive interfaces in which domain-relevant data are visualized appear to provide an engaging tool for co-designers.*

T4.3 *Presenting visualized data to co-designers on a tablet device such as an iPad appears to provide a form factor that supports their collaborative design activities.*

T5.1 *Workshop activities that combine generative design techniques with seeking insight in visualized domain-relevant data appear to inspire useful design insights.*

T5.2 *Interactive iPad interfaces in which domain-relevant data are visualized appear to provide an engaging tool for co-designers who are members of the public, in a real world setting.*

T5.3 *Presenting visualized data on a tablet device such as an iPad appears to provide a form factor that is suitable for co-designers collaborative design activities during generative design.*

T5.4 *Generative design toolkits, which include items such as photographs, appear to be an effective way of helping co-designers interpret the ambiguous contexts that domain-relevant data are drawn from.*

T6.1 *Workshop activities that combine applied creativity techniques, such as 5WsH, with generative design activities, such as mapmaking, appear to help co-designers gain an improved understanding of the data available to a design situation, which in turn can help inspire creative design ideas.*

T6.2 *Custom worksheets, such as the hexagonal worksheets used with the 5WsH, appear to help participants structure the ideas they generate using applied creativity techniques.*

T7.1 *Exploration and Collaboration appear to be the dimensions of creativity support that are most important to co-designers during CoDesign With Data workshops*

T7.2 *Designing information visualization tools with interfaces that provide a high degree of user-controlled interactivity appears to support the Collaboration and Exploration dimensions of co-designers' creative processes.*

T7.3 *The parallels between 'analytical' or 'traditional' styles of information visualization design and 'analytical' categories of applied creativity technique; and between 'direct visualization' and 'intuitive' categories of applied creativity technique appear to offer the opportunity to present different sources of domain-relevant data in ways that prompt different types of design idea.*

T8.1 *Interactive interfaces that visualize domain-relevant data appear to provide a common ground on which co-designers are able to share their knowledge and develop creative design ideas.*

T8.2 *Activities in which co-designers seek insight in visualized domain-relevant data, using interactive interfaces designed to prompt creative thinking in a structured analytical way, appear to be particularly well suited to identifying and formulating design problems.*

9.4 Research Methods

In section 3.1 I introduced the research methods adopted for the studies reported in this thesis. I then outlined the mixed methods approach to evaluation that I adopted. I also outlined Archer's (1995) criteria for judging whether an investigation qualifies as research suitable for academic recognition. The studies reported have been one of two types: chapters 4 and 7 reported small-scale design experiments; and chapters 5, 6 and 8 reported case studies. Each has merits and drawbacks, which will be discussed separately in the following two sections. However, in combination they provided what I believe has been an effective way to structure this exploratory research. In each case, my studies have been described in sufficient detail that another researcher could repeat the activities, evaluation and analysis methods. The caveat with exploring creativity support, particularly in a collaborative context, is that there are a vast number of variables, many beyond the knowledge and control of the researcher, that impact on participants' performance and outputs, and that might ultimately lead to different results. Mixing the methods of study and evaluation used in this research was an attempt to mitigate this.

9.4.1 Design Experiments

The aim of the design experiments reported in chapters 4 and 7 was to explore the practice and performance of design teams in an empirical study where variables of interest are, as far as possible, controlled, while other factors remain as representative of real world design contexts as possible. Cash et al. (2012) argue that such experiments can be very useful in showing possible trends and giving valuable insights into particular design contexts.

Each of these studies meets Archer's requirements:

They were pursued according to a detailed and clearly laid out plan that included research questions that I intended to answer

Detailed descriptions of the tasks, their objectives and the evaluation methods that would be used to assess them were given

The findings, whilst including useful information that could be applied to practice, also included new knowledge and provided details of how our understanding can be applied to new contexts

The findings were presented in a way intelligible to academic human-computer interaction and design research audiences. In the case of the study reported in Chapter 4 this was validated by *the acceptance of a paper reporting this design experiment in the ACM DIS 2014 conference* (Dove & Jones, 2014(b)).

9.4.1.1 Threats to Validity

Design experiments, such as those reported in chapters 4 and 7, can be seen as quasi-experimental. Cook and Campbell (1979, pp.37-95) provide a classification scheme for assessing the validity of the findings of this type of research, consisting of four main types of validity: *Statistical Conclusion Validity*; *Internal Validity*; *Construct Validity* and *External Validity*. Whilst these experiments have been exploratory and small-scale, they have resulted in some important initial findings. Key threats to the validity of these findings are detailed below. A checklist for all threats to validity for each of these studies is included in Appendix D of this thesis.

9.4.1.1.1 Statistical Conclusion Validity

These design experiments were exploratory and small-scale with relatively few participants in each condition. This raises the threat of a *Type II Error* due to *Low Statistical Power*. Rating design outputs for measures of creativity, whichever method is used, is subjective and therefore introduces potential issues for *The Reliability of Measures*. These threats are mitigated through the multiple different approaches to evaluation adopted throughout this research. Having multiple evaluators mitigates the reliability of the ratings given to design outputs. In these design experiments there are a large number of variables interacting in complex ways such that some of what is happening within the situation being studied may remain entirely unknown. This failure of knowledge is of the type identified within medical practice as *necessary fallibility* by Gorovitz and

MacIntyre (1975). This necessary fallibility brings with it threats of *Random Irrelevancies in the Experimental Setting* and *Random Heterogeneity of Respondents*. There is a degree to which the second of these can be mitigated through pre-screening and assigning participants. However, in such small-scale exploratory research they must be accepted as inevitable and reported as such.

9.4.1.1.2 Internal Validity

For reasons relating to the necessary fallibility described above, threats to the internal validity due to *History*, *Maturation* and *Selection* are also possible. Again, whilst these may be mitigated to some degree by pre-screening and assigning participants, the exploratory small-scale nature of the design experiments undertaken during this research means that in practice these threats should be accepted and reported. Possible threats due to *Compensatory Equalization of Treatments*, *Compensatory Rivalry by Respondents Receiving Less Desirable Treatments*, and *Resentful Demoralization of Respondents Receiving Less Desirable Treatments* in the study reported in Chapter 7 have all been mitigated through careful experimental design and workshop design. Activities undertaken in each condition were in all key aspects, apart from those under consideration, the same. In addition, participants were not made aware of the precise nature of the investigations or of the differences between conditions, and therefore had no reason to consider themselves as "*underdog*" or in a "*deprived condition*".

9.4.1.1.3 Construct Validity

The design experiments undertaken during this research use information visualization interfaces as material representations of the constructs under investigation: ambiguity in Chapter 4, analytical and intuitive styles of creative thinking in Chapter 7. As a result there are possible threats to construct validity due to *Inadequate Preoperational Explication* of *Constructs, Mono-Operation Bias*, and *Confounding Constructs and Levels of Constructs*. Critique of these interfaces by visualization experts in City University London's giCentre offers some mitigation to these threats. However, the practical requirements of differentiating interfaces for different experimental conditions means that these constructs are by necessity simplified. This threat to construct validity is recognised and means that further investigation should be undertaken to confirm findings. Threats to construct validity due to *Evaluation Apprehension* are mitigated by careful consideration of scene setting and through the design of workshop activities. Threats due to *Experimenter Expectancies* are mitigated through data checking by other researchers and supervisors. The design experiment reported in Chapter 4 had a within subjects design, threats to construct validity due to *Interaction of Different Treatments* are mitigated here by counter balancing the order of presentation.

9.4.1.1.4 External Validity

In all research in which participants are recruited through voluntary response to advertisements there is the threat to external validity due to *Interaction of Selection and Treatment*. Where design experiments are held on University premises, and with members of the student population recruited as participants, there is a threat to external validity due to *Interaction of Setting and Treatment*. In this research, such threats are mitigated by the case studies that were used to investigate the issues under consideration in real life settings with wider populations. However, the limitations of small-scale design experiments, and the exploratory nature of the investigations undertaken during this research mean that these threats must to some extent be expected, accepted and reported.

9.4.1.2 Lessons for Future Design Experiments

There were also other valuable lessons that will inform future studies. The first of these lessons is practical. Each of the workshops that I ran for the two design experiments lasted between two and three hours, and each workshop required a minimum of three participants. It is challenging to recruit sufficient participants, and to arrange to have them in the same place at the same time, for the required amount of time. The practical effect of this is that screening and pre-testing for psychological factors, such as problem solving style (Selby et al., 2004), is not always possible. This can reduce the reliability of the findings.

Similarly, Cash et al. (Cash et al., 2012) argue strongly for the use of a placebo as well as a control condition to increase reliability. However, on reflection, using the printed reports in this fashion during the study reported in Chapter 7 may not have been the best approach. I feel I would have probably learnt more by having a greater number of groups in the two conditions of primary concern so that I could gather more video data to study the detailed use of the different design artefacts more closely.

Each of these means that the findings from small-scale exploratory design experiments remain initial, should be treated with caution, and therefore backed up by additional study in a real world setting. Given these caveats, design experiments are a useful technique for initial studies exploring the impacts of novel interventions. For example, the ambiguity studied in Chapter 4, which intentionally imposed difficulties inhibiting participants' design activities.

9.4.2 Case Studies

To assess whether studies involving enquiry through practitioner activity, such as the case studies reported in chapters 5, 6 and 8, constitute valid academic research, Archer (1995) suggests we ask seven questions. These I will address in turn:

1. *Was the activity directed towards the acquisition of knowledge?*

Each of the case studies undertaken for this thesis was guided by clear research questions and had a detailed evaluation plan that aimed to produce new knowledge.

2. *Was it systematically conducted?*

Each was also pursued according to a detailed and clearly laid out plan that included research questions, descriptions of the activities undertaken, and the evaluation methods used.

3. *Were the data explicit?*

The types of data collected, details of their evaluation, and examples of these data are all reported clearly.

4. *Was the record of the conduct of the activity "transparent", in the sense that a later investigator could uncover the same information, replicate the procedures adopted, rehearse the*

argument conducted and come to the same (or sufficiently similar) conclusions?

Each case study contains a workshop plan that includes details of the participants, the data collected and the methods used to evaluate these data. These should provide a clear guide for any later investigator wanting to repeat the process and test the findings and conclusions reached.

5. *Were the data employed, and the outcome arrived at validated in appropriate ways?*

The evaluation methods used to collect data and validate the outcomes were selected for their suitability according to relevant literature, and their effectiveness is discussed in detail in the reflection sections of the individual chapters and in a more general sense in section 9.5 below.

6. *Were the findings knowledge rather than information?*

In section 9.3.2 there were examples from each case study showing that the findings of this research included useful information that can be applied to practice, new academic knowledge, and details of how to apply current understanding to new contexts.

7. *Was the knowledge transmissible to others?*

The findings in each of chapters 5, 6 and 8 are presented in a way intelligible to academic human-computer interaction and design research audiences. In the case of the study reported in Chapter 5, this is validated by the acceptance of a paper in the ServDes 2014 conference (Dove & Jones, 2014(a)).

9.4.2.1 Threats to Validity

Case study research is also subject to threats to validity. These can be categorised as *Construct Validity*, *Internal Validity*, *External Validity* and *Reliability* (Riege, 2003; Runeson & Höst, 2009).

9.4.2.1.1 Construct Validity

The assessment of evaluation data gathered through Reflection Postcards, and evaluations of generative and other design outputs, each include a necessary degree of subjective interpretation. This is to some degree mitigated through discussion with other researchers and supervisors. Further mitigation comes through comparison with the findings from design experiments.

9.4.2.1.2 Internal Validity

The case study reported in chapter 6 was purely exploratory and its findings are reported as preliminary and in need of further investigation. No causal relations are reported. The case studies reported in chapters 5 and 8 explore interventions, which were previously tested in design experiments, in a real-world setting. Their purpose was to provide supporting data to that already obtained during the design experiment. Whilst there may be threats to the internal validity of the findings in individual case studies, these are mitigated by the multiple sources of data obtained throughout this research.

9.4.2.1.3 External Validity

The case studies reported in this research were small and within restricted domains. Even given the mitigation of comparison with the findings in the design experiments and with findings in related literature, there is an obvious threat to external validity and generalizability. Further study in other domains is required so that the initial findings reported here can be validated. Such future work is discussed in more detail in section 9.6.

9.4.2.1.4 Reliability

As discussed previously, this research was undertaken in accordance with recommendations made by Archer (1995) and should be easily repeatable by a future researcher, who given the caveats discussed earlier, should come to similar results. This mitigates threats to the reliability of this research.

9.4.2.2 Lessons for Future Case Studies

Similarly to the design experiments discussed previously, there were practical constraints placed on what was achievable in the case studies undertaken. These were not case studies in which a researcher investigates design practice by making a longitudinal study of the normal working practice of participants, an example of which can be found in Onarheim's study of engineering firm Coloplast (Onarheim, 2012). This research required participants to give up their time voluntarily to take part in workshops. It was therefore not always possible to try out all the interventions I would have liked, and the workshop design was typically shorter than would have been ideal. In future it would be beneficial to test the particular combinations of tools and techniques used over multiple instances of a workshop, with different sets of participants. This would provide greater confidence in the reliability of any findings. However, it should also be remembered that in design practice cost, time and access to participants are all real considerations, and so methods should be flexible and adaptable.

9.5 Evaluation Methods

To evaluate the tools, techniques and methods used during this research I have followed Cross (1999) and investigated three factors: the *people designing*, including empirical studies of designer's behaviour; the *design processes they undertake*, including the development and application of techniques to help the designer; and the *design products* that result. In the sections below I discuss the main evaluation techniques used. My aim in using multiple methods to evaluate these different factors was to provide evidence from a number of supporting sources that builds a richly descriptive story, and which helps us to understand and explain the reasons that the tools and techniques used in the CoDesign With Data workshops are successful or not.

9.5.1 Creativity Support Index

The Creativity Support Index (CSI) (Carroll et al., 2009) is a standardised survey metric for evaluating the effectiveness with which a given tool provides support for it's user's creative processes. It is discussed in detail in section 3.2.1. In the design experiment reported in Chapter 4, I used a simple questionnaire that was partly based on the questions asked in the CSI as a measure of support for insight seeking and creativity. A key reflection from this study was that, in the context of a design experiment, the simpler questionnaire was not powerful enough and that it would be much more effective to use the CSI in full, which I did in the studies reported in chapters 7 and 8.

During my evaluation of the design experiment reported in Chapter 7, the CSI data I collected provided an important comparison between conditions, and highlighted clear differences between the interfaces. In addition, I also used the CSI data in a simple but novel way that enabled me to identify which were the dimensions of creativity support participants thought most important during the CoDesign With Data workshop activities. The CSI data I collected during the case study reported in Chapter 8 allowed me to make a comparison between each day of the workshop. In addition, it also enabled me to make a comparison with the data collected during the previous design experiment, which strengthens the reliability of the findings in both studies.

The CSI was developed to measure the specific creativity support provided by different computer-based tools. In this research I have been measuring the support provided by combinations of tools, both digital and analogue, and techniques. Future research should investigate whether this metric could be adapted or extended in response to this change in context.

9.5.2 Evaluating Generative Design Outputs

The creativity expressed in the outputs made during activities using Generative Design toolkits does not reflect fully formed ideas or highly finished artefacts. In the studies reported in chapters 5 and 6 I assessed these outputs for evidence that the tools and techniques participants used had prompted insight and inspired creativity. This analysis was subjective, based on my interpretation of the artefacts co-designers had made, and was further influenced by my understanding of participants' intentions. In these exploratory investigations such an approach was adequate for my needs. For future studies, a method of evaluating these outputs by independent domain experts, which could be used with a similar confidence to the ratings given to written design outputs, should be developed.

9.5.3 Rating the Creativity of Design Outputs

Independently rating the creativity of design outputs generated during workshop activities was undertaken in two main ways. First I calculated the number of ideas generated and recorded during activities in the divergent phase of workshops to give a measure of creative fluency (Guilford, 1966). Second, the creativity of selected design outputs was measured through the ratings provided by domain experts (Hocevar, 1981). Here, a rating for *appropriateness* and a rating for *novelty*, two key dimensions of creativity (Sternberg & Lubart, 1999), where provided. This follows an approach outlined in Dean et al. (2006) and used in Jones et al. (2008). In the studies reported in chapters 7 and 8 a rating for *creativity* was also given. This follows Amabile, who has argued that assessors are able to consistently rate creativity using their own consensual definition (Amabile, 1983).

These ratings provide a useful measure with which to compare the outputs of groups in different conditions of a design experiment, and also a simple measure indicating the creativity of the ideas co-designers generate during case studies. However caution should be taken over the use of this method in isolation, as there have been questions raised about how reliably it can produce replicable results from different domain experts (Christiaans, 2002). Also, because there are inevitable differences in the creative performances of individual participants, and also between the collective performances of different groups, many different factors can impact on the ratings given to these design outputs. Pre-screening individual participants for cognitive style and creative performance, and then balancing groups accordingly might mitigate this. Kurtzberg and Amabile review creative performance in individuals and groups, and begin to outline the complex dynamics of diversity and conflict in team-level creativity (Kurtzberg & Amabile, 2000). Isaksen and Aerts discuss the impact of different problem-solving styles on creativity and what this means for fostering creative environments (Isaksen & Aerts, 2011). Each of these offers pointers to how, given the resources, such mitigation might be achieved. However, in practice I believe it better to counter the possible effects of individual and team creative performance by taking additional measures, such as the CSI, and by studying the processes being undertaken through video recordings and looking for evidence of success or difficulty. It might also be useful in future studies to ask co-designers to provide their own rating of the creativity of their design outputs as a way of measuring creativity within the individual, or *p-creativity* (Boden, 2004, p.2).

9.5.4 Reflection Postcards

Reflection Postcards are a novel method for evaluating creativity support during workshop activities. The method was developed during this research, and is a secondary contribution of this thesis. The Reflection Postcard method was initially developed for the case study reported in Chapter 5 as a workshop activity that gathered evaluation data in a creative way, conducive to maintaining a positive atmosphere. Later, I used the postcards in different ways. For the case study reported in Chapter 6 I asked participants to complete the postcards at the end of the workshop. For the case study reported in Chapter 8 I asked participants to take the postcards away and complete them at home, and participants were given stamped and pre-addressed envelopes with which to return the postcards.

On a positive note, the Reflection Postcards provide an effective alternative to asking open questionnaire questions, and break up the evaluation process with a change of format. However, in isolation, the data they provide is limited and so they should always be used in conjunction with other evaluation methods. In future, I would again use the Reflection Postcard method during a dedicated workshop activity, where the contrast with evaluation questionnaires is most pronounced. For reflections at a greater distance from the activities in question, I would again provide stamped addressed envelopes and give them to participants to take away.

Throughout this research I have been developing ways to use information visualization tools and applied creativity techniques to encourage participants' *reflection-in-action* (Schön, 1995, pp.49-69), so that they consider the context of data as they seek insight and develop design ideas. Reflection Postcards are a method that aims to prompt participants' *reflection-on-action* (Schön, 1995, pp.275-79), so that I can gain a better understanding of their creative processes, and draw appropriate lessons for how best to support them within CoDesign With Data workshops.

9.5.5 Video Analysis

To better understand participants' creative design processes, key segments of the video recordings of the design experiments reported in Chapter 4 and Chapter 7 were studied. I used a thematic analysis (Braun & Clarke, 2006) based on theories of sensemaking (Pirolli & Card, 2005; Russell et al., 1993) to gain an understanding of support for insight seeking (Chapter 4). I undertook a close study of the interactions with and around different interfaces during critical incidents (Flanagan, 1954), to understand how ideas emerge (Chapter 7). This analysis enabled me to gain an initial understanding of what was taking place, and provided important insight into the creative design processes taking place. Such an understanding is sufficient for the exploratory research I have been undertaking here. However, in future this video analysis would benefit from independent coding by multiple researchers. In Chapter 7, I introduced a novel method of representing this analysis of short segments of video in which I aim to represent the flow of interaction, collaboration and ideation. The usefulness and reliability of this type of representation should be investigated further during future studies.

9.5.6 Additional Evaluation Methods

In addition to the methods outlined above, I also used questionnaires to assess individual aspects of the CoDesign With Data approach, such as their influence on and inspiration for participants' design creativity. I also analysed the outputs of individual activities to trace the provenance of ideas and to assess participants' sensemaking and insight seeking processes. As the research developed and I more clearly understood the factors I was looking for, my evaluation became more detailed. This is particularly evident in the development of the questionnaires I used. Examples of each of these questionnaires can be found in Appendix C.

9.5.7 Summary of Evaluation Methods

Each additional evaluation method provided new data that helped to build up evidence in support of my findings. Using this type of multi-layered approach is important when undertaking exploratory investigations into the effectiveness of novel workshop methods because, taken alone, individual methods might be unreliable. This is evidenced in the design experiment reported in Chapter 7. Here it is the story that emerges from multiple evaluation methods that allows us to appreciate the different ways that creative ideas emerge when using each of the digital design artefacts.

The need to develop particular methods of evaluating creativity support environments, such as the tools and techniques used in design workshops, is the subject of ongoing study (Kerne et al., 2013). The ethnographic methods that HCI has imported from the social sciences are not appropriate to use in isolation during the case studies I have reported, because the workshop activities are not part of the normal daily lives of participants. Also, the design experiments I report do not evaluate individual user's interactions with a technology whilst undertaking well defined tasks. This means that measuring factors such as the time taken to complete a task, the number of mistakes made whilst undertaking that task, or other quantitative measures of task performance recorded in controlled user studies is also not an appropriate mode of evaluation. This research has contributed to the investigation of evaluation methods for creativity support environments in a small way through the Reflection Postcard method, and also through the detailed descriptions of the way that multiple evaluation methods can be combined to present evidence that helps us understand design processes and creative performance.

9.6 Limitations & Future Work

This research has been undertaken through a series of small-scale exploratory studies. These studies had only a small number of participants and each group of participants took part in only one workshop. In addition, the domains studied and data used during these studies have been closely similar. This has allowed me to gain an initial understanding of the important issues under consideration, but at the same time it limits the reliability and generalizability of any findings. This research has also focused on using data as a key design material within a co-located workshop setting. This is not the only approach possible. Because these data are digital, and because they can easily and effectively be visualized online, there is an opportunity to explore crowd sourcing as an alternative method of eliciting creative design ideas from co-designers. Here we might take inspiration from open innovation platforms such as Open Ideo[32]. For this to be the case, future research should be undertaken to investigate how workshop activities and techniques for inspiring and prompting creativity can be translated into an online, asynchronous setting. Extending this research to an online crowd

[32] www.openideo.com

sourced setting also offers one possible route to expanding the number of participants that can be included in studies.

The case study, reported in Chapter 8, had a workshop design that was divided into two distinct parts held on consecutive days. These two parts were, first a problem identification phase, and second a phase to generate and select a candidate solution. The second phase included a single activity of idea validation, which in practice allowed little time for testing the efficacy of different solutions with reference to insights found in the visualized data. This was a definite limitation, all be it one that was due to the practical constraints of time and participant availability. The Creative Problem Solving method identifies three distinct phases: *Understanding the Challenge*, *Generating Ideas* and *Preparing for Action* (Isaksen et al., 2011, pp.31-32). Similarly, the UK Design Council's '*double diamond*' model of creative design processes identifies four phases: *Discover*, *Define*, *Develop* and *Deliver* (Design Council, 2007, pp.6-8). In both cases, there is specific work undertaken during the final phases in which candidate solutions are iteratively subjected to validation, improvement, selection or rejection.

Intuitively, the insights that can be gained from exploring domain-relevant data seem likely to be helpful during a validation process. Indeed, during the study reported in Chapter 7 there was some evidence of this in action. The group whose interactions with the analytical style interface visualizing smart meter data are pictured in Figure 42 not only used the visualized data to focus their idea generation but also repeatedly referred back to the data to check their insights and think about the possible impact of their candidate ideas whilst they were selecting and developing their proposed solution. Future iterations of the CoDesign With Data approach should include a period dedicated to selecting, testing and validating candidate solution ideas against insights found in the domain-relevant data. Future research should investigate how effective the tools and techniques developed for the CoDesign With Data approach, or variations on them, might be during an extended phase of idea validation and selection.

In the study reported in Chapter 5 a decision was taken to visualize data generated from a model of typical energy consumption rather than use the smart meter data being generated within the technology trial that participants were recruited from. This was partly in order to explore typical rather than specific consumption behaviours, but also because the data generated from the trial was anonymised, which meant that I was unable to match particular data to individual households and ask for informed consent. These issues of privacy and consent can be a key concern when working with domain-relevant data, as it may be of a personal or personally identifiable nature. Even in data that has been anonymised or pseudo-anonymised people can often be uniquely identified from combinations of simple demographics (Sweeney, 2000).

However, it could also be true that working directly with participants' own personal data might have a positive impact on their levels of intrinsic motivation, which is known to be a contributing factor in creative performance (Amabile, 1996, pp.115-19). There are many issues with regards to the ethics of personal data that will be important to using the CoDesign With Data approach in practice. Particularly as one of the domains where data are becoming increasingly available or easy to collect is personal health and fitness. Therefore, identifying ways of working effectively, ethically and creatively with participants' personal data is an important area for future research.

The design outputs that participants have created in each of the studies reported in this thesis often appear to score well on measures of appropriateness, but less well on measures of novelty. The CoDesign With Data approach is not alone in this, as human-centred design practice in general has been criticised for only resulting in incremental innovation (Norman, 2010). Whether or not this is inevitable in human-centred design remains open to debate. In any case, future research should be undertaken to investigate if there are combinations of tools and techniques that can increase the novelty of the design ideas that result from CoDesign With Data workshops.

My experiences in the studies reported here suggest an area that appears promising in this regard. Following the studies reported in chapters 5 and 7 I suspect that a workshop in which participants undertake activities designed to prompt different styles of creative thinking offer the best route to more radically creative design ideas. This would likely include activities to prompt an *analytical* style of creative thinking, through visualizing quantitative data and using techniques like 5WsH, alongside activities that prompt an *intuitive* style of creative thinking. This intuitive style of creative thinking might be achieved using interfaces that present social media data in combination with techniques such as Brainstorming with Triggers, or through generative toolkits that include a variety of domain-relevant photographs. Future studies should investigate whether this is the case, and if so whether this can be utilised to inspire unexpected creative connections and innovative design ideas.

Norman and Verganti (2014) suggest that radical innovation comes from exploring and understanding changes in technology and/or meaning. Future CoDesign With Data workshops might use information visualization techniques to represent technological and cultural change, for example through timeline style interfaces, and explore the meaning of these changes with participants. Another way to achieve this might be to import tools and techniques from other design approaches, such as writing Design Fictions (Sterling, 2009). These might be based on insights found visualizing and extrapolating trends in domain-relevant data. Finally, there are applied creativity techniques, such as the Imagery Trek (Isaksen et al., 2011, pp.101-02), which intentionally take participants on a journey into different places in an attempt to open them up to ideas outside their normal sphere of thinking. Future CoDesign With Data workshops might also investigate how these techniques can be adapted to working with domain-relevant data as a way of inspiring greater novelty in participants' design ideas.

9.7 Concluding Comments

The research undertaken for this thesis has been exploratory. It is often reporting initial findings that are contingent on confirmation or qualification through future study. The process of developing the CoDesign With Data approach remains an ongoing, iterative conversation with the domains of design research and design practice, and with data as a design material. This process follows a pattern in which exploratory studies are undertaken in design experiments, the findings tested in a real-world setting, and each of these subjected to peer review through publication. It has not been my aim to suggest definitive answers, but rather to contribute to an ongoing discussion that I hope informs the practice of design. In this spirit, the final contribution of this thesis will be an outline of the next iteration of the CoDesign With Data approach. I offer this as my take on the current state-of-the-art with regards to planning a collaborative early-stage design workshop in which domain-relevant data are the key distinguishing design material.

9.8 CoDesign With Data: February 2015

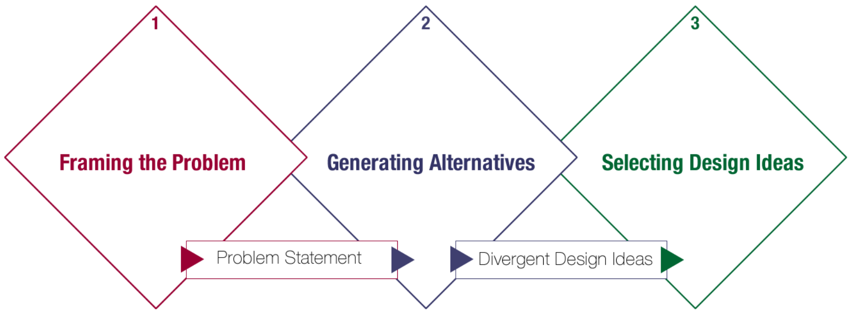

Figure 68: CoDesign With Data (February 2015) overview

Figure 68 shows an overview of the next iteration in the development of the CoDesign With Data approach. In this iteration we see a three-phase workshop. The first phase, in which the design problem is formulated, is closely based on the first day of the One Small Change workshop described in Chapter 8. It is updated to include the 5 Whys technique for problem abstraction to improve the activity described in section 8.3.5.1.6. The second phase, in which a wide range of possible design ideas are generated, is partly based on the second day of the One Small Change workshop. It is adapted to include inspiration from social media data using an updated version of the iPad Flickr Photograph interface described in section 7.3.4.2. I had wanted to include this type of interface and insight seeking in the One Small Change workshop but time constraints did not allow for the additional activities. This interface would be updated to include a greater degree of user-controlled interactivity, as discussed in section 7.6. The third phase is a new element, building on the final activities of the One Small Change workshop and the E.ON workshop reported in Chapter 5, in which the different possible design ideas generated in phase two are evaluated, and preferred ideas selected and described in detail. This was discussed in section 9.6.

9.8.1 Phase 1: Framing the Problem

Tools: *iPad Information Visualization Interface, Worksheets, Workshop Stationary*

Techniques: *5WsH, 5 Whys, Insight Seeking*

In Phase 1 co-designers seek insights in quantitative domain-relevant data. The data are visualized in an interface designed to prompt an analytical style of creative thinking, with an unambiguous visual encoding and user-controlled interactions. Co-designers use the 5WsH creativity technique and hexagonal worksheets to describe possible design problems. Co-designers use the 5 Whys problem abstraction technique (Couger et al., 1993) to find the root of selected design problems. The output of Phase 1 is a well-described *Problem Statement*.

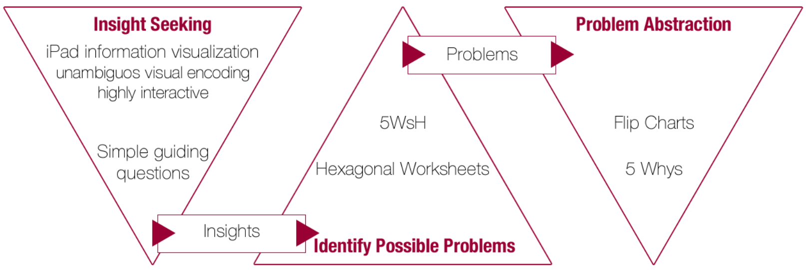

Figure 69: CoDesign With Data - Phase 1 Framing the Problem

9.8.2 Phase 2: Generating Alternatives

Tools: *iPad Flickr Photograph Interface, Worksheets, Workshop Stationary*

Techniques: *5WsH, Brainstorming with Behaviour Change Triggers, Combinational Creativity, Insight Seeking*

In Phase 2 co-designers seek insight in social media data. Flickr photographs are presented in an interface that uses a direct visualization style, and that is designed to prompt an intuitive style of creative thinking. Photographs are selected randomly using metadata tags but users are given some control to select and retain them. Co-designers use the Brainstorming with Behaviour Change Triggers technique to suggest opportunities for design interventions. Design ideas are generated using a Combinational Creativity technique and described using 5WsH and hexagonal worksheets. The output from Phase 2 is a divergent range of Possible Design Ideas.

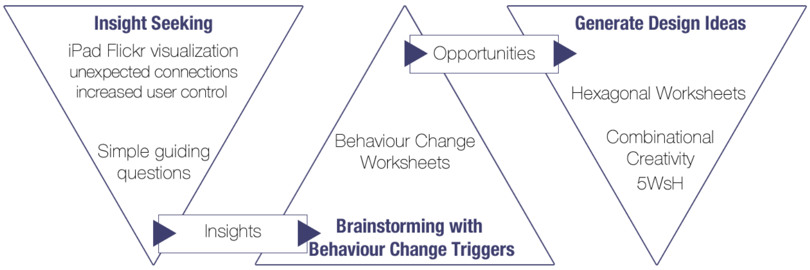

Figure 70: CoDesign With Data - Phase 2 Generating Alternatives

9.8.3 Phase 3: Selecting Design Ideas

Tools: *iPad Information Visualization Interface, Worksheets, Workshop Stationary, Generative Design Toolkit*

Techniques: *5WsH, ALUO, Combinational Creativity, Generative Design*

In Phase 3 co-designers use the same information visualization interface that was used during Phase 1 with the Advantages, Limitations, Unique Qualities, Overcoming Limitations (ALUO) (Isaksen et al., 2011, pp.46-47) technique. ALUO is used to help co-designers structure the selection and evaluation of design ideas generated during Phase 2. Co-designers use Combinational Creativity techniques and Generative Design tools and techniques to develop and describe their final Candidate Design Idea.

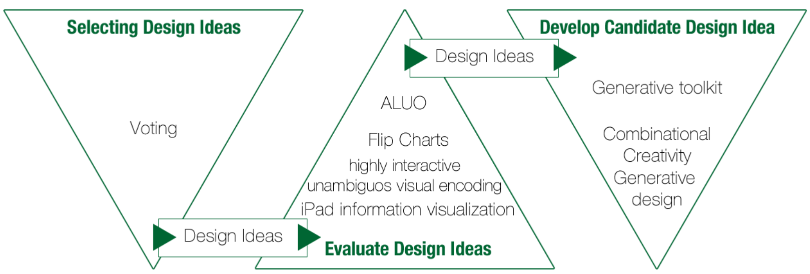

Figure 71: CoDesign With Data - Phase 3 Selecting Design Ideas

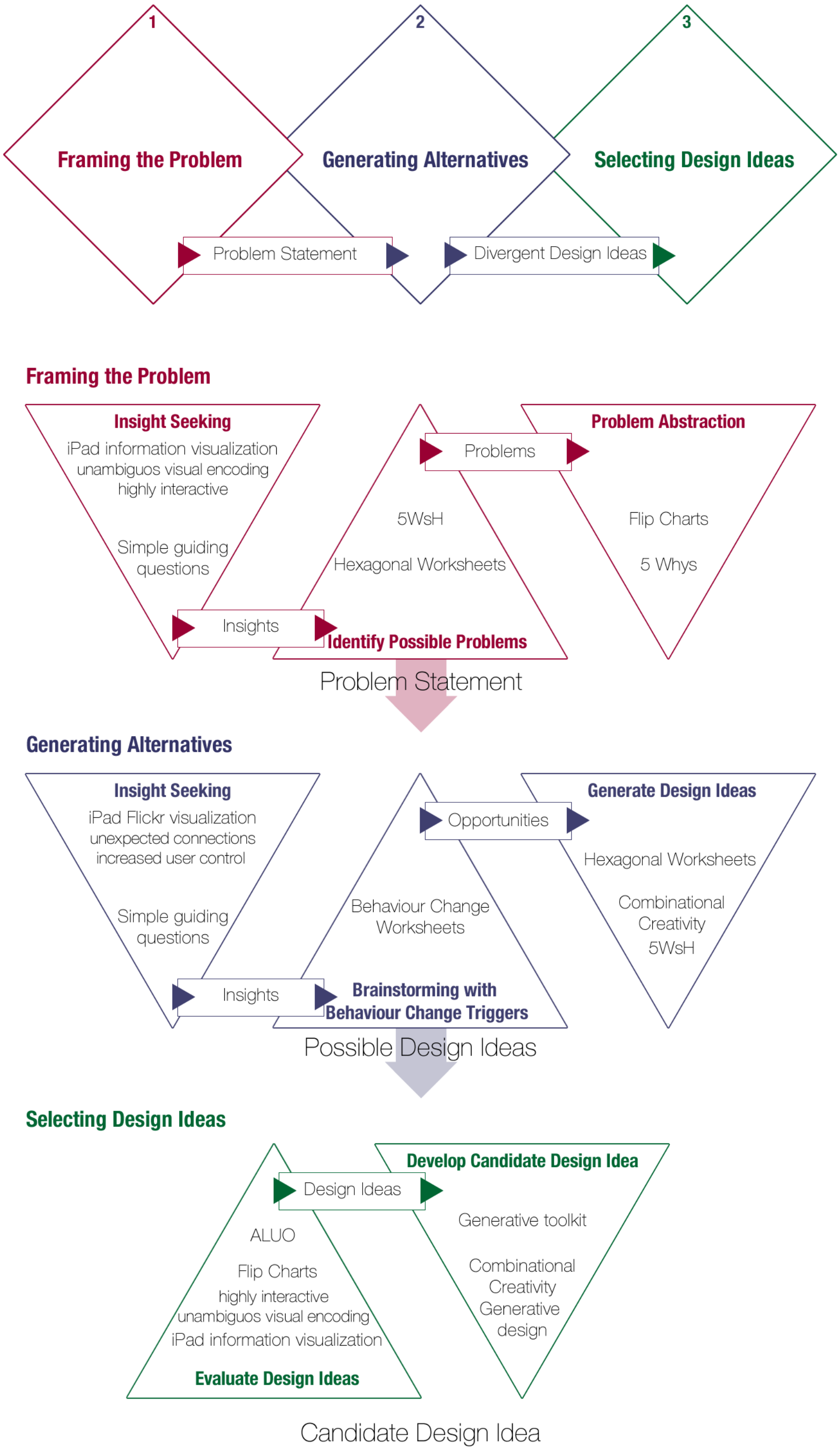

Figure 72: CoDesign With Data (February 2015)

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