Science and Design: The Implications of Different Forms of Accountability

Chapter · January 2014

DOI: 10.1007/978-1-4939-0378-8_7

1 author:

William W. Gaver
Goldsmiths, University of London

SCIENCE AND DESIGN

THE IMPLICATIONS OF DIFFERENT FORMS OF ACCOUNTABILITY

William Gaver

Interaction Research Studio

Goldsmiths, University of London

Gaver, W. (2014). Science and Design: The Implications of Different Forms of Accountability. In Olson, J. and Kellogg, W. (eds.), *Ways of Knowing in HCI*. London: Springer, pp. 143 - 165.

INTRODUCTION

'Fools rush in where Angels fear to tread.'
- Alexander Pope

When I was working towards my PhD in psychology and cognitive science, I ran a series of experiments investigating whether people could hear the length and material of struck wood and metal bars. My curiosity was motivated by J. J. Gibson's (1979) ecological theories of perception. If, as he argued, our visual perception has evolved to 'pick up' information about the world conveyed by the structure of light, then, I surmised, our hearing might well be attuned to auditory information about sound-producing events. In my pursuit of an experimental demonstration of this, I spent months finding just the right kinds of metal and wooden bars, experimenting with recording conditions to capture just the right set of sounds, tinkering with experimental instructions and response scales, and running numerous 'pilot studies'. Finally, when I had everything working well, I collected my experimental data and spent more months trying out different analysis methods until I found several that seemed to give clarity to the data – and finally, the experiment was done.

Writing up the study, I used the canonical structure for reporting experiments. I set the scene both theoretically and in terms of related work, using that to motivate a set of hypotheses, describing my methods, stimuli and procedure, and then reported the data and discussed how they reflected on my initial hypotheses. What I didn't do – of course! – was talk about all the work done to achieve the final data set: the shopping I did in specialist hardwood stores, the improvising of foam mounts that would let the bars sound when struck, the ways I tried to get participants to listen to the right things, and so on. Instead, I told the story the way I had been taught, as a linear narrative from theory to experiment to data and back to theory, in which each step was logically connected to the previous ones and to those that followed.

Flash forward twenty years, and I am a designer working on another project. As part of a larger consortium that included computer scientists and sociologists, a team from my studio – itself quite interdisciplinary – developed a system called the Local Barometer and deployed it to a volunteer household. This involved installing an anemometer in the back garden so we could measure wind speed and direction outside the house, and using this to control an algorithm that searched for online advertisements originating upwind from the home. Text and images from the advertisements we found were displayed on a series of six small devices designed to be positioned on various shelves, racks and tables around the home, after some processing to remove overtly commercial references, emphasise the resemblance to poetry, and adjust aspect ratios. The notion was that the system, which had been inspired by a wide range of influences, might raise awareness of the sociocultural landscape around the home – but we were not committed to this idea either as a hypothesis or goal; instead we treated the notion as a potentially disposable guide for our thinking about the design.

Once we had everything set up and running in the household, we gave our primary contact, R, a 'user manual' and explained how the system worked. But we avoided telling him about how we thought he or his friends might use it or what our ideas were in developing it, since the point of the exercise was to see how they would interpret this situation on their own, without our help. Over the following month, we used a variety of means to see what R had made of the Barometers. Detailed reports were made by an ethnographer on our team, who visited the house, observed how R interacted with the system and had many long conversations with R about it. Another source of information was unexpected: the Barometers had a technical flaw (faulty garbage collection in the operating system of the mobile telephones we used for their implementation), which meant that they had to be rebooted every few days. R eventually learned to restart the devices himself, but until then our regular 'service' visits provided opportunities for informal chats about the devices that seemed particularly revealing because their ostensible purpose had nothing to do with assessment. Finally, we captured yet another perspective by hiring a professional filmmaker to make a documentary video about R's experiences with the devices. To ensure what independence we could, we did not tell the filmmaker about the devices or our intentions for them, but let him learn about them from R himself. Moreover, we were never present during filming, and explicitly told the filmmaker that we did not want a promotional piece, but instead his own potentially critical account.

Characterising Science and Design

In many ways, the two projects I've just described are quite similar. In each case, I was involved in devising and implementing a physical situation (vibrating bars, and the Local Barometer), which involved a great many pragmatic and exploratory activities. In both cases too, what I made was influenced by, and meant to be informative to, a body of ideas about people and the world (ecological psychology in the first case, designing for ludic engagement[1] in the second) that not only served to describe existing things but to suggest new avenues for exploration. Also in both cases, I created the physical situation in order to put it before people unconnected with my profession (the 'participants') to see what they would make of it. Finally, in each case I pursued these activities as a form of research – in other words, I did what I did to learn something new, and presented an account of the process and results to an academic research community (see Gaver et al. 2008; Gaver 1988).

Yet the two projects were also different in ways that I will suggest are important. The impact sound experiments were motivated by the possibility of applying Gibson's thinking about light and vision to questions concerning sound and hearing, not in an analogical or metaphorical way but as a logical extension of his analysis to a new domain. In contrast, the Local Barometer was inspired by a wide range of influences, all helping to shape the final result but without the closely linked reasoning that led to my recordings of impact sounds. Similarly, I had fairly specific hypotheses about the impact sound

[1] Ludic engagement refers to forms of interaction that are not utilitarian or task-oriented, but exploratory, provisional and curiosity-driven: playful in the broadest sense (see Gaver, 2009).

experiments: I expected, on the basis of theory and my analysis of sound-producing events, that people would be able to hear both the material and length of struck bars with a good degree of accuracy. In contrast, our expectations for the Local Barometer were much more nebulous – we hoped that people would find the system engaging, and told our stories about sociocultural texture, but in reality we had little idea how people might use or think about the system in their day-to-day lives. Nor did the vagueness of our expectations worry us: on the contrary, the prospect of inciting surprising forms of engagement was what motivated the study. In addition, although I constructed the apparatus and thus the sounds used in the impact sound experiment, they were interesting precisely because they were representative of phenomena that are wide-spread and well-known, and in that sense there was nothing new about them at all. In contrast, the Local Barometer was interesting precisely because it *was* novel: to our knowledge, it represented a form of electronic threshold between the home and its local environment that had not existed before.

In this chapter, I want to explore the differences between doing these kinds of projects – which I take as typical of research through science on the one hand, and through design on the other – in more detail[2]. To be sure, I am mindful of the perils of trying to characterise science or design as if either were a unitary endeavour. After all, disciplines that identify themselves as branches of the sciences range from particle physics to library sciences, and involve vastly different mixtures of quantitative and qualitative theory, experimentation and empirical observation, taxonomic classification, procedural know-how, and long apprenticeships. Equally, activities self-identified as design vary from those that rely explicitly on individual and group creativity to so-called design science, and practices ranging from work done directly for commercial clients, to that done in the design departments of large organisations, to entrepreneurial work with no client other than eventual buyers, to practices verging on the artistic whose 'clients' might include galleries and collectors. I don't want to argue about which of these constitute 'real' science, or 'real' design. Instead, I appeal here to design and science as categories identified not by a set of definitional criteria, but by features that each tend to have in common. From this point of view, a given activity is counted as a science, or as form of design, depending on its similarity to canonical examples of each. What I want to do here is characterise what I think are fundamental distinctions between science and design identified in this way. Given my appeal to a definition of science and design based on family resemblance, the test of these distinctions is not whether they hold for all examples of self-defined science and design, but rather whether they are recognisable for the kinds of activities we most readily identify as one or the other – a matter which readers will have to decide for themselves[3].

[2] Many others have discussed whether and how design and science are distinct approaches, as well as whether they should be or not. I do not present a survey here, but see e.g. Cross et al. 1981; Louridas, 1999; Schön, 1999; Cross, 2007; Stolterman, 2008; Gaver, 2012; and particularly Nelson and Stolterman, 2003.

[3] To make matters worse, I am purposely not distinguishing design in general from 'research through design' in what follows. Such a distinction is neither simple nor productive, in my view. For instance, people have suggested that research through design is different from 'real' design in not having a client, or clear problem to solve. But researchers

With those provisos, it's time to rush in, and discuss the differences between science and design.

A MATTER OF ACCOUNTABILITY

Reflecting on my experiences working as a scientist, and later as a designer, a core difference in pursing research from these traditions has to do with the issues that must be addressed in defending each kind of work from the criticisms and questions of colleagues.

Presenting scientific research such as the impact sound study, I would expect to be asked a series of questions, all of which amount to variations on a single one: '*how do you know what you say is true?*'. These are questions about process, including conceptual and practical moves and the linkage between the two. How did my experiments operationalise the theory I was testing? Did I control for any potential confounds? How many participants were there? Were the stimuli presented in random order, or perhaps using a Latin Square design? Would an alternative explanation render my results inconclusive? And so on. How interesting my results were – whether they were counter-intuitive, or shed new light on a phenomenon or theory, or simply displayed a pleasing sense of elegance and order – were secondary concerns. To be sure, the topicality, novelty or potential benefits of a given line of research might help it attract notice and support, but scientific research fundamentally stands or falls on the thoroughness with which activities and reasoning can be tied together. You just can't get in the game without a solid methodology. The most astonishing finding is without scientific merit if its methodology is suspect. Conversely, the most pedestrian result is scientifically valid if it can be shown to be the result of a meticulous approach.

The situation is different for design. The basic question here is '*does it work?*' The issue of whether something 'works' goes beyond questions of technical or practical efficacy to address a host of social, cultural, aesthetic and ethical concerns. Is it plausible to think that people will engage with a system that isn't guided by pre-defined tasks? Can you really scrape information from the web that way? Does the form and colour fit the context, with the appropriate functional, social, cultural and aesthetic connotations? Does the design tend to stereotype the people and places it addresses? To be sure, questions of process might enter the discussion – how did you come to think of your user group in such a way? Why did you choose to use that form of input? – but such questions are not grounds in and of themselves for judging a design successful or unsuccessful. Instead, they are asked to elicit answers providing resources for better appreciating a design's intentions and plausibility. They may help critics to 'get it', perhaps by allowing

---

do have their clients, including research funders, academic audiences, and the people who might encounter their work, and these are not so different from the managers, colleagues, other departments, purchasers and end users that 'real' designers have to please. Equally, many 'real' designers don't solve problems so much as they explore new configurations of materials and form in an endless conversation with each other and the surrounding culture, while practitioners of research through design commonly *do* address problems, such how to reflect the full range of human experience.

interpretation from other perspectives, or by reassuring clients that an idea responds to needs of potential customers – or they may fail to help a design that is slow to convince. Still, it is perfectly possible, even common, for a compelling, eye-opening design to emerge from a process that is idiosyncratic and even a bit mad. We talk of 'inspired' ideas with more enthusiasm than we talk of 'informed' ones. And successful designs validate new methods and conceptual perspectives, rather than the other way around. In design, even the most meticulous methodology will not redeem a bad design, and even the most hare-brained processes will not ruin a good one.

The distinct sorts of questions asked of science and design manifest the different kinds of *accountability* that apply to each - that is, the expectations of what activities must be defended and how, and by extension the ways narratives (accounts) are legitimately formed about each endeavour. science is defined by epistemological accountability, in which the essential requirement is to be able to explain and defend the basis of one's claimed knowledge. Design, in contrast, works with *aesthetic accountability*, where 'aesthetic' refers to how satisfactory the composition of multiple design features are (as opposed to how 'beautiful' it might be). The requirement here is to be able to explain and defend – or, more typically, to demonstrate – that one's design *works*.

In suggesting that science is epistemologically accountable, and design aesthetically accountable, I do not mean to suggest that other concerns are completely irrelevant to these pursuits. As I have suggested, the topicality, intrigue and potential impact of a given scientific research project can have a huge influence on whether it is lauded at conferences and attracts multi-million dollar funding, or languishes in the back corridors of some university. But before questions of timeliness, interest and relevance even arise – the prerequisite for them making any sense at all – the scientific validity of the project must be established. The most eloquent narrative about potential impacts (increasingly demanded by funding agencies) will not redeem a proposal judged to be unscientific by reviewers; equally, the most feted, faddish, and even effective diet plan may be derided as unscientific if there is insufficient evidence to validate it. The epistemological accountability of scientific projects is *essential*, while being interest and impact are not definitional of science. And the converse is true for design's accountability to 'working': the ability to talk a convincing game about the mind-blowing conceptual flights and hundreds of person-hours behind a given design may help draw attention to it, but this will not make it a valid design if it is incoherent, unfinished or implausible. Its aesthetic accountability – its ability to integrate functional, formal, material, cultural and emotional concerns (for instance) – is *essential*, while arguments based on process are, at best, secondary.

Mechanisms of Progress

The different systems of accountability for science and design – the need to be able to defend one's knowledge, on the one hand, and that one's productions work, on the other – parallel the different strategies the two endeavours use to proceed.

For science, the logic of day-to-day research – what Kuhn (1970) called 'normal science' – revolves around an iterative process of using theory to understand observations of the world, and observations to test and extend theory. Theory, usually taking the form of an ontology of entities and the causal connections amongst them, embodies an explanation of phenomena of interest and potentially allows their prediction. There are two basic pathways to theory expansion. The researcher may gather observations of a body of phenomena that appears theoretically salient, or which simply happens to seem interesting. Gathering repeated observations allows induction of new hypotheses that may modify relevant theory. The more stereotypically 'scientific' route, however, goes the other way, relying on theory's nature not only to explain phenomena and their relations that have already been observed, but, through its mechanism of entities and connections, to have implications about things that have not yet been seen. Where those implications are not so close to established fact as to be axiomatic, or where the theory is unclear in its implications (and note that identifying either condition relies on the scientists' experience and skill) a set of hypotheses may emerge about a possible state of affairs suggested by the theory. So, for example, thinking about how ecological psychology might be applied to auditory perception led me to hypothesise that people might be able to hear the physical attributes of sound sources. In order to test hypotheses such as these, they need to be operationalised in the form of a set of experiments or observations that simultaneously reflect the hypothesis and can yield unequivocal data. Operationalised hypotheses allow salient phenomena to be assessed empirically to see whether they fit the theory. This typically involves the situating of general hypotheses in particular contexts (e.g. specifying that everyday listening might apply to hearing attributes of impact events), the contrivance of experiments or other data-collecting activities, and the analysis of data, all deployed not only to determine whether the observed phenomena agree with the theory, but to elaborate the theory or even modify it.

There is a set of core values that characterises the pursuit of scientific knowledge, whether through induction or hypothesis testing, which the methods developed for pursuing knowledge in these ways seek to realise. Perhaps most important is that scientific knowledge should be *replicable*, able to be reproduced by others, both to allow it to be built upon and as a fundamental guarantee of its epistemological accountability. This means it should be *objective*, with a truth-value independent of individual experimenters. It should be *generalisable*, in the sense that scientific phenomena are expressed and understood abstractly enough that instances of them can be found in a wide variety of circumstances. Scientific theory is ideally *causal*, explaining the connections amongst related phenomena as a matter of necessity rather than correlation or coincidence. Theory should not only *explain* phenomena that have already been observed, but *predict* new ones. And so on. Perhaps the most essential value is *definiteness*. Being able to say *what* you know - precisely, and ideally quantifiably – and *how* you know, and *when* or under what conditions what you know is known to be true – these are the hallmarks of science.

Of course, as those versed in the sociology of science, science and technology studies, and similar fields have shown, these values are not simply given or received; they have to be *achieved* in the doing of science. Latour (1987), for instance, points to the 'Janus faces' of science: if one looks at science after the fact, then the account above may fit, but if one looks at science as it is happening, things look very different. As numerous empirical studies have shown, scientists do not proceed in any simple mechanical way from theory to hypotheses to tests to conclusions. As my own introduction illustrated, a huge amount of work behind the scenes is done to produce the simplest experimental demonstration. Moreover, a great deal of post-hoc rationalisation goes into aligning empirical data, hypotheses, and theory. Scientists rarely or ever explain their methods sufficiently to allow replication, and anyway few scientists ever bother to replicate work done elsewhere. On top of that, the success of any given scientific endeavour will depend on the way that (from the perspective of the received account of the scientific method I gave above) 'extra-scientific' agencies can be marshalled: for example, whether or not a given line of research will be supported by employers and funding bodies, find sympathetic reviewers and take a significant place in webs of citation depends on the technical resources to demonstrate its merit, as well as its authors' reputations, social-professional networks and potential for reciprocal influence (c.f. Latour, 1987). In the end, the so-called 'scientific method' outlined above is an *achievement*, an account hewn from processes that are far more complex and embedded in the pragmatic politics of science than it admits.

Nonetheless, the core values of replicability, objectivity, generalisability and so on remain central in this process, because they serve to *guide* the efforts, to provide a goal for what should be achieved. Even if the 'scientific method' is a simplification of what science in action is actually like, it is a simplification that is upheld as an integral ritual in the doing of science. Whether or not science actually proceeds according to the logic from theory to hypothesis to data to analysis to theory, that is how it is *presented,* in academic articles, in conferences, in job talks and in funding applications. It was not by accident that when I wrote up the struck bar experiments, I omitted details about how they came to be – the shopping for wood, the cutting and sanding, the fabrication of a mechanism to strike them – and the way they came to be analysed – playing with the parameter space of a time-varying Fourier analysis, the different 2- and 3D visualisations I tried, and so forth. Nor did I leave these details out to save space or avoid boring readers. No, I didn't report those details because they were irrelevant to the clear causal flow between logic, materiality, events and their interpretation I needed to establish, and thus needed to be omitted from the project's official history muddy lest that flow be muddied. For it is in terms of that stream of logic that scientific research is formally *assessed* by reviewers. Conference committee meetings may give rise to any number of discussions about how boring or wrong-headed a piece of scientific research is, but when it comes time make a formal decision then methodological weaknesses, not aesthetic (or cultural, or political) shortcomings, are the resources panel members use to justify rejection. Funding agencies and recruitment committees may turn down an applicant on the grounds that a given line of research is outside their scope, or that its impact will be minor, but the surest path to rejection is by failing to establish epistemological accountability, whether because of faulty reasoning, a misjudged method or a simple lack of clarity about the logic and activities used to pursue a topic. Researchers know this, of course. They know they must outline a research plan that follows scientific logic if they want to gain funding, and they know they must present a completed piece of research according to the logic of science if they want to be published. And because of this, no matter how much extraneous backstage activity may go unreported, and no matter how post hoc the account may be, then unless they are out-and-out frauds there will be, running through scientific researchers' day to day research activities, the skeleton of the scientific method presented above. As a post-hoc rationalisation, the logic of scientific method may seem to be a fiction, or even a lie, but if so it is a lie by omission not commission, and a fiction that guides and constrains real scientific activity.

For design, the logic of activity is different. The designer encounters a world, which crucially includes designed artefacts as well as people and physical phenomena, and has the job of fashioning something new that works for that world. A significant step on this journey is the development of a proposal, or proposals, about what might be built. Proposals may vary widely in their specificity, from evocative and unrealisable sketches, to abstract representations of intention, to relatively complete specifications or scenarios. In each case, the role of design proposals is both to create and constrain. On the one hand, they suggest things that might be made, things that have not hitherto existed. Simultaneously, their collection implicitly limits the myriad possibilities for design offered by a given situation by focusing attention on one or a few more-or-less concrete configurations. For instance, the Local Barometers came about when, after some time exploring ideas for a project in which we knew, simply, that we would develop new technological artefacts for the home, one of us started exploring notions of information being carried into the home by the wind. Once a proposal is agreed on, this serves as a brief for further elaboration and refinement of what the artefact *will* and *will not* be. Typically this involves a combination of progressively more focused design explorations and proposals, including what Schön (1983) calls a 'conversation with materials', as a myriad of decisions are made (Stolterman, 2008) and the artefact that will actually be built is resolved. Finally, the finished artefact is assessed through some combination of critique, commercial success or failure, and empirical study of what people do with it and how it might affect their lives, until accounts about it settle down, and it is ready to take its place in the world and its artefacts to serve as a context for new designs.

It is tempting to see parallels between the basic mechanisms of science and design progress described here. Aren't design proposals like hypotheses, suggesting possibilities that might be investigated – in the case of a scientific hypothesis, the possibility that a certain supposition may be true; in the case of a design proposal, the possibility that a certain artefact (or kind of artefact) might 'work'? And aren't products like experiments, contrived to allow empirical test of the conjectures embodied by design proposals? For that matter, aren't scientific experiments themselves designed products, artefacts that must be invented and refined just like a new chair or an interactive website? Of course they are – and yet, like any analogy, the focus on similarities between science and design obscures as well as reveals. Worse: the analogy of science and design is positively dangerous, because it obscures the very features that give each endeavour its specificity and potency. For where scientific hypotheses sprout from a ground of theoretical or empirical confidence, design proposals are inventions that spring up under the influence of a potentially unlimited number of influences that include, but are by no means limited to, theoretical frameworks or empirical observation. Where scientific hypotheses are uncertain because they project tentatively from truths confidently held towards those that are conjectural, design proposals are vague because they are tools for imagining things that don't yet exist. Scientific studies are contrived to *control and hold apart* the factors that potentially cause phenomena of interest;designs are arranged as configurations in which elements *merge and blend* like ingredients in a recipe. Finally, scientific activities seek to discover, explain and predict things that are held to pre-exist in the world, whereas design is fundamentally bent on creating the new.

Design and the New

science uncovers what exists, and design creates the new. This might seem the most profound difference between the two endeavours, and given how many other commentators suggest that this is the case, it may seem strange that I haven't highlighted it before now. And indeed, this distinction does seem to underlie much of what is different about science and design. science is based on realism, a deep assumption that things exist apart from our thinking of them, and further that they interact in non-arbitrary ways, with the complexity we normally experience resulting from a smaller number of underlying principles. The goal of science is figure out how the world works by dismantling its complications, teasing out its separate elements, and figuring out how they interlock to operate together. The fundamental assumption of design, in contrast, is that new things can – and should – be made. The goal of design is to make the world work in new ways by producing new complications, assembling elements in new ways, and crafting them to work together. Design can work with the world as found: it does not have to concern itself with realism in any deep way, nor does it have to get to the bottom of how things really work. It may do so, of course, and often designers are adept at finding radical new ways of understanding materials, people and processes in the course of their work. But this is not a requirement for good design, because design is not responsible for explaining the world as it is, but for producing new artefacts that work.

design's concern for creating new things leads to a different set of values than those for science. Good science is characterised by replicability, objectivity, generality and causal explanations. Successful design artefacts, in contrast, are characterised by *working* – by functioning efficiently and effectively, by solving problems neatly or reconfiguring them insightfully, by using materials and production processes in elegant ways, and so forth. Beyond this, some designs – perhaps many of those that succeed in the ways just described – embody other values that make them as powerful in opening new understandings of the world as scientific discoveries are. Think of Durrell Bishop's answering machine (Crampton-Smith, 1995), in which messages are represented by RFID tagged marbles, allowing them to be manipulated, relocated, and used with other devices. This opened the world of tangible computing by showing how the affordances of the physical world could be harnessed to communicate those of the digital one. Or remember the way the iPod superseded portable media players not only through its elegant product design, but by its ability to merge and detach from an online world of commercial and uncommercial media (Levy, 2006). Or consider the Brainball (Hjelm and Browall, 2000), in which winning a contest requires being more relaxed than one's opponent, simultaneously demonstrating neurological interaction and playfully subverting competition to create an entertaining and thought-provoking game. Such designs have *individuality*: they possess their own character, which is not only original, but integrated and with a clear personality or style. They *resonate*, reminding and energising and speaking to a wide and potentially incommensurable variety of influences, issues, artefacts, phenomena and perspectives, both natural and cultural. They are *evocative*, stimulating new possibilities for design, whether similar, compatible, extended or even counterbalancing. And perhaps most of all, they are *illuminating*, reaching out beyond their immediate functionality to suggest new ways to perceive and inhabit the world.

designs' values are deeply bound to its fundamental undertaking of realising new possibilities, but it is only this in combination with its aesthetic accountability that distinguishes it most surely from science. Design's concern with the new, and science's with the existing, may distinguish them from each other, but it is not enough to distinguish them from other kindred disciplines. Literary fiction, poetry, the arts, documentary filmmaking, and at least some strands of the humanities can all offer insights into 'what is' while eschewing scientific methods and embracing aesthetic accountability. Engineering and other forms of applied science, on the other hand, routinely use scientific theories, methods and findings to construct 'what might be' using a form of epistemological accountability ('how do you know it won't fall down?'). It is the *combination* of accountability plus orientation to what exists that best captures the differences between science and design. And in my view, it is their contrasting accountability that allows their most characteristic – and productive – differences to be best appreciated.

DESIGN METHODS AND PRODUCTIVE INDISCIPLINE

The reason I suggest that design's aesthetic accountability is more useful as a focus than its orientation towards the new in understanding how it operates differently from science is because of the methodological implications of that accountability. sciences' epistemological accountability, its commitment to being able to answer questions about how one knows one's assertions are true, constrains its methods towards those that tend to be empirical, specified in advance, standardised, replicable, independent of the observer and (ideally) quantifiable. Design's aesthetic accountability, in contrast, means that its methods do not necessarily have to have any such characteristics. They may, of course – aesthetic accountability doesn't imply that scientific methods are out of bounds – but equally, design may thrive on information that is fictional as well as factual, and on reasoning and activities that are improvised, unrepeatable and highly personal. Design methods often exhibit a *productive indiscipline* thanks to their freedom from epistemological accountability. That is, design processes are not bound to particular theoretical or methodological rationales, but can borrow from all disciplines or none. Even more subversive, from a scientific point of view, all this can be left unclear. Knowing whether something is true or not, or whether things have changed, or whether a view is idiosyncratic or widely shared may simply not matter when it comes to design. On the contrary, in some cases a lack of knowledge (and meta-knowledge) leads to just the sort of conceptual space in which imagination seems to thrive. We might say that, where science relies on epistemological *accountability*, design can often work from a kind of epistemological *ambiguity*.

Many of the design methods used in my studio illustrate the kind of fluid flow between certainty and speculation that design allows. In this section, I discuss some of these methods, organised according to the typical project trajectory we use for describing our projects. In this account, design projects typically progress through four stages linked by different sorts of activity. Most projects start with the identification of a *context* for design, which is elaborated, specified and investigated through further work. This informs the development of numerous *proposals* for what might be made, which act as landmarks to create and expand a space of possibilities for design. A turning point is reached when a specific direction is chosen, at which point activity turns towards the refinement of a realised *prototype*. Finally, this is assessed using various means to reach *conclusions* about its success and, more importantly, the lessons to be learned from the project. This trajectory is typical of many, many descriptions of design process, and like most it implies a kind of waterfall model in which stages are encountered sequentially (with the possibility of iteration). In reality, design projects rarely proceed in such an orderly manner. Important insights from contextual studies may seem to disappear from the following design proposals, only to become salient late in the development of a prototype. Proposals may be inspired by seemingly unrelated sources, or may spin off to different projects, or become the context for new proposals. Development work might transmute to contextual research. And so on. Nonetheless, this trajectory is not entirely fictional – our projects do tend to proceed through these phases in this order, and moreover it plays a role in how we attend to their progress – and thus for the sake of organisation I will describe some of our approaches in the sequence it suggests.

Exploring Context

Our design projects are almost always set in an explicit or implied context, and early design activities will usually be concerned with better understanding the people and situations for which we are designing. This involves elaborating and enriching information about the setting, but can also require particularising or specifying examples of a context that is initially only broadly or vaguely defined. Considered instrumentally, our goal in this phase is twofold: first, to build an understanding of the setting that is rich enough to allow design ideas to be checked for plausibility and likely problems, and second, to find inspiration for design directions. These two objectives can pull in different directions. On the one hand, trying to ensure that designs will be appropriate and fit for purpose suggests gathering as complete and veridical account as we can. Inspiration, on the other hand, often comes from particularly striking facts about the context, or idiosyncratic views on it, even if these are unrepresentative or unconfirmed. Balance is crucial: too little contextual information can lead to free-floating speculation, but too comprehensive an account can smother creative ideas and lead to predictable responses. Thus in our approaches we tend to gather a great deal of eclectic material about the contexts for which we design, but to appreciate both gaps and questionable perspectives as leading to the kind of interpretative speculation that leads naturally to invention.

For instance, the Local Barometer described at the beginning of this chapter was developed for a project initially defined as exploring how merging the digital and the physical could produce new technological products for the home. In order both to enrich and focus the topic, our initial external research included academic publications from disciplines spanning the sciences and engineering, psychoanalysis and social science, the humanities, cultural studies and philosophy. We looked to examples from design and from the contemporary arts, including artists such as Sophie Calle (Calle & Auster,1999), Ilya Kabakov (1998) and Gillian Wearing (e.g. Ferguson, De Salvo & Slyce, 1999) who make social and cultural interventions, or those such as Gregory Crewdson (Crewdson & Moody, 2002) and Gordon Mata-Clark (Crow, Kirshner, & Kravagna, 2003) who offer surprising new views of the domestic. We looked to a range of sources from the popular or tabloid press, dealing with topics such as journalists who search peoples' trash for intimate information, as well as niche publications such as pamphlets about how to hide money and weapons in the home (e.g. US Government, 1971). Taken together, these resources allowed us to amass a multi-faceted appreciation of 'the home' in which academic respectability was less important than developing a richness and narrative depth that we felt nurtured our design.

In addition, we ran a Domestic Probes study with twenty volunteer households from the greater London area to uncover orientations and activities that might undermine any stereotypes we might bring to the project. The Probes, an approach invented by Tony Dunne and myself for an earlier project (Gaver, Dunne & Pacenti, 1999), are, from my point of view, all but defined by their unscientific nature. We recruited volunteers by advertising in a variety of popular publications including a local newspaper, a publication of classified advertisements, and a magazine for the 'horse and hound set', taking people on a first-come-first-served basis and making no attempt to achieve demographic representativeness (though our volunteers ended up represented a wide range of ages, backgrounds and socioeconomic status). We gave each household a Probe package containing a dozen tasks designed to be intriguing, but seldom clear about what information we were asking for or how the results might be interpreted. These included, for instance, a disposable camera, repackaged to remove it from its commercial origins, with requests for pictures such as 'a view from your kitchen window', 'a social gathering', 'the spiritual centre of your home', and 'something red'. A drinking glass was included with instructions indicating that it should be held to the ear to listen to interesting sounds, with observations to be written directly on the glass with a special pen enclosed in the package. Pages with graphics including, for instance, a cricket game, a wooded slope, and Dante's Heaven and Hell were provided for people to diagram their friends and family circles, a knowing perversion of a traditional social science approach (e.g. Scott, 2000). Finally, a small digital recorder was repackaged with instructions to pull a tab when waking from a vivid dream, at which point a red LED lit up and the participant had ten seconds to tell us about the dream before the device shut off, offering no facility for replaying or editing the dream, only the choice of whether or not to return it to us.

Tasks such as these provide a puzzle to participants about how to react, and their responses – hundreds of photographs, notes and drawings – defy easy summary or analysis. Our probes are purposely designed this way, not least to disrupt assumptions for all of us about the roles of researchers and 'subjects'[4]. Moreover, we emphasised their atypical nature with reassurance that not all materials need to be completed, and by suggesting that participants should feel free to tell us stories – or simply lie – if they wished. By blocking expectable lines of questioning, and even approaches to answering, the Probes force both participants and

[4] Others design 'probes' to avoid such disruption; see Boehner et al. (2007).

us to struggle for communication, and in so doing produce surprising angles and perspectives on our participants. At best, the returns achieve a balance between inspiration and information. They are fragmentary, elusive and unreliable, but they are also real, offering numerous small glimpses into the facts of peoples' lives. Taken together, their ambiguity – their very lack of scientific validity – evoke for us as designers the kind of grounded curiosity, empathy and conjecture that we find useful in our work.

Developing A Design Space

A natural and desirable (though sadly not inevitable) consequence of an evolving understanding of a design situation is the emergence of speculation about what might be made that will work in that situation. Like most designers, we externalise ideas through sketching, but as we move towards sharing them with one another we usually develop more finished design proposals using combinations of collage, diagrams, computer drawing and rendering, and written annotations. Once we have amassed enough of these – and fifty is not unusual for a given project – they are often collected into a workbook, arranged into a set of post-hoc categories to indicate the shared themes that are beginning to become clear.

One might imagine that the proposals would be based fairly directly on the returns of Probe studies. Having collected Probe returns, we might use them to draw up a contextual account featuring a set of key issues, recommendations or requirements, which could lead relatively directly to a set of designs. This is not what happens. Not only are Probe returns difficult to analyse or summarise, but we prefer to avoid mediating representations of the returns, or summaries of contextual research in general. Instead, proposals emerge seemingly spontaneously, and may reflect any number of influences including ones that seem completely unrelated to anything that has gone before. This does not suggest that Probes are irrelevant or a waste of resources. They can help us better understand the context for which we are designing, help us in assessing whether it is plausible that given proposals will work, and even inspire ideas relatively directly. But they are not *responsible* for doing so. Freed from epistemological accountability ('how do you know this is the right design proposal?') we can pursue ideas without worrying about explicitly justifying them with previous research.

design proposals are seldom detailed or elaborate. Instead, they are often comprised of an evocative image or two, annotated with captions ranging from a few words to a few paragraphs. Rarely, if ever, do they include technological details or sequential scenarios of use, or even much in the way of detailed functionality. Succinct as they are, however, sketch proposals can be remarkably rich in pointing towards configurations of motivations, functionality, technologies, emotional or cultural qualities and the anticipated effects or experiences that make up a direction for design. Moreover, when gathered together as a workbook, collections of proposals allow a *design space* to emerge, making clear a bounded range of possibilities characterised by a range of dimensions we are interested in exploring. Individual proposals play a dual role in this process: they both represent (more or less) specific configurations for further development, but also, and often more importantly, landmarks in a space from which other ideas may be developed.

Similarly to the Probes, workbooks balance concrete factuality with an openness to reinterpretation . As externalisations of design ideas, and moreover ones which are presented slightly more formally than sketches, they have a reality that is relatively free from an identifiable authorial hand, and thus available for critique and change. Achieving this may require specifying aspects previously left unconsidered, or they may inherit the connotations of the resources used to create them (e.g. images used for collage, or the style of renderings). At the same time, proposals are often indicative rather than detailed representations. Collages may use images that hint at dimensionality, appearance and materials, while retaining enough of their (unconnected) origins to indicate they are not to be taken as literal representations. Renderings and illustrations are often diagrammatic, clearly leaving elements unspecified or unresolved. The basic concepts themselves are often 'placeholders', gesturing towards design directions rather than specifying them. Thus proposals are deeply provisional, allowing a great deal of room for elaboration, change or development (Gaver, 2011). Because they are aesthetically rather than epistemologically accountable, they do not need to be part of a longer chain of argument from an initial setting to a final design, but need only 'work' in the sense of suggesting potentially topical and compelling possibilities.

Refinement and Making

Workbooks are a means of developing understanding of what actually to make. After some period – often months – of developing a design space through contextual research, one or several collections of proposals, and associated technical experimentation, it becomes time to focus efforts around one or a few directions to take forward. This might involve the progressive development of an existing proposal, but often a new proposal will emerge which integrates and consolidates the thinking embodied in a number of other ones. At best, when this happens there is a kind of 'audible click' as consensus quickly forms around an agreed direction for development, and other proposals and possibilities are deferred or fade away. The new proposal serves as a design brief, and from this point efforts are turned towards detailing, refining, and making the new design.

The evolution of a design from a proposal to an actual artefact is, literally, a slow process of materialisation. At first the work tends to be symbolic in nature, involving tens or hundreds of sketches and later diagrams and CAD renderings. This is soon accompanied by physical explorations, as form models are made from cardboard or foam, and fabricated using rapid prototyping machines. Materials such as plastics or wood or metal are sourced and tested for their aesthetic and functional properties. Components such as displays or buttons are gathered and evaluated for their appearance and tactility, with many being abandoned and a select few retained. Computational and electronic experiments are performed, not in the scientific sense of testing hypotheses, but in the sense of trying out a set of arrangements to see whether they hold promise. New processes of making are explored and refined. Over time, larger and more complex configurations are constructed, as when a computer display is mounted in a cardboard form study, until the first working models appear and a final specification is finally drawn.

During this process, hundreds of decisions are made – in the case of the Local Barometers, for instance, to base the design on a partially deconstructed mobile phone, to use a variety of shapes to afford different placements in the home, to scroll text vertically, to use brightly coloured card over a plastic structure, to use separate devices for text and images, and so on – and the final design resolves as its features slowly become definite (c.f. Stolterman, 2008). Each decision embodies the designers' judgements about a potentially multitudinous range of concerns, from functionality and cost to emotional tone and cultural connotation. Moreover, each is made in context of the other decisions that have been or will need to be made, and is situated in the circumstances of development, including both those of the setting for which it is devised and those of the designers that make it. In the end, the final design, if well made, is the result of a tightly woven web of judgements that are contingent and situated, and shaped by an indefinite mix of practical, conceptual, cultural and personal considerations. Yet the result, a highly finished product, is an 'ultimate particular' (Stolterman, 2008), as definite and precise as any scientific theory.

The practice of resolving a design from an agreed proposal to a finished product is an essential aspect of design, bringing into play the full range of expertise and skills of its designers. Nonetheless, this aspect of design is seldom reported in detail (though see Jarvis, Cameron & Boucher, 2012), perhaps because the myriad of decisions involved are difficult to organise to provide a coherent account. It is through the process of making that a great deal of understanding – of a domain, of people, of conceptual issues – is both exercised and furthered. It is the product itself, however, that typically serves both as the report of that understanding and as the means by which it is assessed.

Assessment and Learning

As decisions combine with one another to form a complete and highly finished design, it is as if an elaborate theory is constructed, embodied by the emerging design, about the important factors and configurations in designing just such a device in just such circumstances, a theory as definite as the physical components used to construct it. Moreover, the design will imply, with a varying degree of specificity, how people are expected to engage with it and what their resulting experiences may be. This is not like a scientific theory, however. Instead it is dependent and localised. It does not arise by necessity from any preceding contextual research or design space explorations, though of course it would be likely to reflect them. Moreover, the 'theory' embodied in a design is not articulated by it. Not only is it impossible to 'read' an artefact unequivocally for its conceptual import, but designers themselves may be unable to explicate the full rationale for their decisions, many or most of which are a matter of 'feel' rather than explicit reasoning (c.f. Carroll & Kellogg 1989).

Nonetheless, the 'theory' of a new design begs to be tested by exposure to the people who might use it. For specifically targeted designs – a potato masher, for instance, or a word processer – laboratory based 'user testing' based on scientific experimentation may seem adequate. Even in these cases long-term, naturalistic field tests may be better at uncovering the subtle aesthetic, social and cultural aspects of the experiences they offer; the ways they are talked about, displayed or hidden away, used and misused. In the case of the designs we produce in our studio, certainly, the best way we can find out what a design is really 'for' is to allow people to use them in their everyday environments over long periods of time, since our designs are purposely left open to multiple interpretations. Deploying our designs allows us both to discover the questions we should ask about their use, and some of the answers to those questions.

Because this form of assessment does not involve the testing of specific hypotheses so much as the discovery of multiple possible forms of engagement, it benefits from a variety of views rather than a single summary judgement. Given that designs can be appreciated from a number of different perspectives, and that different people may find different ways to engage and make meaning with them – or fail to do so – multiple, inconsistent and even incompatible accounts may all be equally true. For instance, the Local Barometers were variously regarded as aesthetically intriguing artefacts for the home, as representing a dangerous form of subliminal advertising, as offering gifts, as unique and cutting-edge designs, and as annoying bits of broken electronics. To focus on one of these accounts over the others, or to amalgamate them without regard to the way they accumulate, combine and change over time and from place to place, would not produce a more general or abstract account, but one that flattens the experiences afforded by the designs.

Thus we use a number of tactics to gather multiple accounts, and invite distinctive perspectives to reach the full range of possible orientations. Our methods range in the degree of technical specialism they require. A great deal of information comes simply from informal chats with the volunteers who live with our designs, and especially those occasioned by unconnected activities such as routine maintenance or visits to document the devices in situ. For academic credibility, ethnographic observations and interviews often form the backbone of our assessment, with their mixture of empirical observation, interpretation and storytelling providing a coherent account of how people orient to and engage with the products we make, and some indication of the range of those engagements. (See Chapter X in this volume.) Finally, we often draw on the specialised expertise of 'cultural commentators' (Gaver, 2007) who are independent of our Studio, and whose disciplines and institutional ties are independent of our own. I have already described how we commissioned a documentary film of the Plane Tracker. We have also solicited the interest of independent journalists to write stories of deployments, ideally to be published as an indication that they have been written for their purposes, not ours. We have hired a poet to write about two of our prototypes in their settings, with results that were sometimes opaque, and sometimes extraordinarily moving. From the mundane to the artistic, each of these forms of description provides a new point of view, a new approach into the ways that designs are experienced and used.

What Designers Know

What can designers claim to know during and after this process? Given the indiscipline that I argue characterises design processes, productive or not, what can we claim to have learned?

From a scientific point of view, the answer is 'not a lot'. The complex, idiosyncratic and interpretative nature of design means that there is little epistemological accountability in the results. The processes used in the course of design may be replicable, but the ways designers respond are not. Equally, an individual design artefact is of course replicable, but only after the fact, with a different history from the original (not least because of the original's existence): identical designs are seldom if ever produced independently, nor would designers want them to be (Fallman & Stolterman, 2010). Granted, certain design themes or tropes may be exercised repeatedly, but this is a much weaker and more contingent form of replicability, however, than that found in science. Replicability, a key characteristic of scientific knowledge, is largely unavailable through design.

Similarly, the understandings achieved through design research are of limited generality, or at least become increasingly dilute the more they are generalised. This contrasts with regularities found in the sciences – such as the law of gravity, for instance, or the 7± 2 limit of short term memory, or Fitt's Law – which remain equally specific over a wide range of domains and scales. Because design is a matter of integrating myriad considerations, any given abstraction tends to be situated and contingent, and alters as it is applied to new domains or new scales (c.f. Louridas, 1999). Moreover, design is in constant conversation with itself, changing the ground on which it operates, so that many of the approaches that have succeeded in the past will find that their motivating circumstances have changed or simply fallen out of fashion. The result is that design theories tend to be indicative and aspirational, rather than explanatory of stable phenomena. This does not necessarily make them ineffectual, but the 'knowledge' they embody is of a different order than scientific knowledge.

What design *does* have to offer, what we *can* know, are the artefacts that design produces – not only the finished designs themselves, but the probes and probe returns, the sketches and workbooks, the technical experiments and form models. These are real, tangible things that have the definitiveness and detail that eludes attempts to conceptualise design. As the result of the many judgements that designers make to produce them, they embody a host of ideas about the conceptual, material, social, technical and philosophical issues they address. Moreover, they realise those ideas in material form: they serve as existence proofs of particular configurations of perspectives and stances. Of course, for many of the sketches and proposals and form studies produced in the course of design, these existence proofs are themselves unproven; they may not be viable or desirable or even technically possible. Nonetheless, they exist: they establish a position and thus help define a space for a design. Moreover, when a design is complete and well finished, and found to 'work' by appropriate criteria, then it can serve as a landmark for future design, an example of what can be done and a way to go about doing it. It concretises the kind of truth that design can produce, and that designers can use to inspire their own work.

The truths embodied by the artefacts of design do not speak for themselves, however. The features of interest, the commitments of the designer, the configurations that count, all may remain opaque or open to an indefinite number of contrasting interpretations. Thus designed artefacts are typically accompanied by explanatory comments, whether in the form of their designers' descriptions, advertisements pointing out their unique features, user manuals that explain how they are to be used, or critical reviews that compare them to other related designs. Much the same thing happens in presenting research through design: in the explanatory and conceptual accounts we give of our work, we point out new achievements, relate the designs we produce to theoretical work, and situate them in a context of related research. We *annotate* our designs, commenting on them to explain how they work and are related to matters of concern[5].

designed artefacts are too complex to be fully annotated, however. With the hundreds of detailed decisions that go into their making, ranging from their philosophical or political commitments to the speed of scrolling deemed optimal, it is practically impossible to comment completely on every detail of a design, much less on exactly how these are configured together. Moreover, a great deal of design knowledge is tacit and unspoken, or the product of hand-eye-mind coordination that is exceedingly difficult to articulate. Gathering a number of designs to form a *portfolio* can help to focus on a set of themes, features and configurations. Related by their concern with common issues, groups of designs define a space of possibilities, define a set of salient design dimensions within that domain, and take positions – some successful, some less so – within that space. Appropriate annotations can highlight and explain those dimensions and configurations, and moreover by maintaining a link with a portfolio of design artefacts, annotations can avoid the dilution that comes from unanchored generality.

Annotated portfolios may capture best what we can know through design. Attempts to abstract and generalise the knowledge produced through design runs afoul of its situated, multilayered, configured and contingent nature. A great deal of what designers learn is tacit, part of their lived experience, and shared in the culture of their fellow designers. Their knowledge is manifested, however, in the form of the artefacts they produce. It may not be possible to read these artefacts unequivocally, but any ambiguity in their interpretation may be useful in inspiring new designs. Moreover, when articulated through annotation, the knowledge they encapsulate may be exposed, extended, and linked to the concerns of a domain of research. This gives the learning produced by research through design a different nature from that produced by science, which, though not completely separable from the experiments, observations and measurements that give rise to it, can nonetheless be crafted to travel much further without distortion (Latour, 1989). Design knowledge is most trustworthy when it stays close to designed artefacts.

Design as (In)Discipline

Neuroscience, sociology, fine arts, literature, computer science, experimental psychology and theology have all met, at one time or another, in design. Design provides a useful meeting point both because one of its core activities is the synthesis of diverse concerns, and because it is more concerned with creating things that work than battling over facts. But while design can benefit from, and contribute to, a wide variety of academic discourses, it need not inherit their forms of discipline. Unconstrained by epistemological

[5] Much of this section is based on Gaver, 2012, Bowers, 2012 and Gaver & Bowers, 2012.

accountability, design often exhibits a *productive indiscipline*, borrowing from all disciplines or none to claim extraordinary methodological freedom. This does not imply that design is undisciplined, however. The relaxation of truth claims in many of the processes of design may suggest a kind of free-for-all, in which anything goes and there is no basis for discrimination. But aesthetic accountability – the responsibility to make things that work – is a demanding discipline of its own. It may benefit from a kind of playfulness of thinking that thrives on the methodological indiscipline I have described, but it also requires the ability to fit together ideas, materials, technologies, timings, situations, people and cultures. Designers need to have enough self-indulgence to become passionate about their ideas, while maintaining the ability to take a critical perspective on the things they are producing. They have the liberty to eschew traditional methods, but in avoiding the responsibilities these imply they also relinquish the reassurance that comes with following well-understood paths. Most of all, designers have to wait until late in the process to discover if their designs *work*, if all the bets they have made along the way, the myriads of decisions they have made, have finally paid off.

It can be tempting to avoid, or at least mitigate, the uncertainties that come with aesthetic accountability by imposing methodological frameworks to design, as an a approximation of the step-by-step assurance that scientific methods seem to offer. Both in research through design and in design education, it may seem legitimate to structure the space of potential processes by introducing methods that have been used successfully before – brainstorming, personas, probes – in the hopes this will optimise the chances of producing successful work. Such an approach may indeed be useful in introducing students to the overall 'feel' of doing design, and in reducing the overhead for more experienced designers of developing bespoke approaches to projects. The danger, however, is that in avoiding the terrors that come with indiscipline one also loses its advantages: the possibility of situating methods to the particularities of a project or people, and to find idiosyncratic and personal approaches to projects that can lead to innovative results.

CONCLUSION

Distinguishing science and design in terms of their different forms of accountability appears the clearest way of understanding the tenor of these two forms of endeavour. The need for science to defend the basis of its claims each step of the way provides it with a remarkable mechanism for achieving clarity, replicability and generalisable abstraction. To be sure, the actual doing of science can be far more messy and bound in worldly power-politics than such an account suggests, but the rituals surrounding the presentation of scientific work as empirically accountable has allowed it to transcend its pragmatic realities and to produce a body of methods, theories and analytic tools that is arguably our most effective means for producing generalisable knowledge of the world. In its adherence to aesthetic accountability, in contrast, design is arguably our best strategy for producing things that that *work*, not only in the sense of being functional, but meaningful and inspiring as well. Freed from the shackles of certainty, designers are at liberty to speculate, experiment, dream and improvise – as long as they do so in ways that are accountable as design. The processes themselves are not effective at producing new *facts*, in the scientific sense, mired as they are in interpretation, ambiguity, imprecision and contingency. But they can be powerful in producing new *understandings*, based in experience, interpretation, and particular settings. Moreover, design produces new *artefacts*, each it embodying its own truths, just as real as those discovered through science, which can be articulated and extended and used as the foundation for yet newer creations.

One of my purposes in describing science and design in these ways is to emphasise that these two endeavours should be seen as distinct from one another, each with its own logic, motivation and values[6]. It would be a mistake to compare the two approaches to the detriment of either. Design is not a poor cousin of science. Instead, it is an independent approach with its own expertise and knowledge (c.f. Stolterman, 2008; Nelson & Stolterman, 2003). Research through design, similarly, should not be seen as an attempt to bring the principles of science to design, but as an autonomous approach that uses projection and making as tools for learning about people, technologies and the world.

ACKNOWLEDGEMENTS
This discussion is an updated version of keynote addresses delivered to DIS'00 and HCIC'10. The research was supported by European Research Council's Advanced Investigator Award no. 226528, 'ThirdWave HCI'. I am grateful to John Bowers, Eric Stolterman, Kirsten Boehner, Anne Schlottmann, Wendy Kellogg, Judy Olson, and John Zimmerman for their comments on this chapter, though it must be admitted that few if any of them would fully agree with the result.

REFERENCES
Boehner, K., Vertesi, J., Sengers, P., & Dourish, P. (2007). How HCI interprets the probes. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 1077-1086). ACM.

Bowers, J. (2012). The logic of annotated portfolios: communicating the value of research through design. In Proceedings of the designing Interactive Systems Conference (pp. 68-77). ACM.

Calle, S., & Auster, P. (1999). Sophie Calle: Double Game. Violette Limited.

Carroll, J. & Kellogg, W. (1989) Artifact as theory-nexus: hermeneutics meets theory-based design. Proc. CHI'89, 7-14.

Crampton-Smith, G. (May/June 1995). The hand that rocks the cradle. I.D. magazine, 60–65 .

Crewdson, G., & Moody, R. (2002). Twilight: Photographs by Gregory Crewdson. Harry N Abrams Inc.

Cross, N. (2000). Design as a discipline. Reprinted in Cross, N. (2007) *Designerly Ways of Knowing.* Basel: Birkhäuser.

[6] Of course science and design may be intertwined in practice; what my argument here suggests is the importance of being clear about the form of accountability claimed for different aspects of the process and results.

Cross, N. (2001). Understanding design cognition. Reprinted in Cross, N. (2007) *designerly Ways of Knowing*. Basel: Birkhäuser.

Cross, N. (2007). *Designerly ways of knowing*. Birkhäuser Basel.

Cross, N., Naughton, J., & Walker, D. (1981). Design method and scientific method. Design studies, 2(4), 195-201.

Crow, T. E., Kirshner, J. R., & Kravagna, C. (2003). *Gordon Matta-Clark*. C. Diserens (Ed.). London & New York: Phaidon.

Fallman, D., & Stolterman, E. (2010). Establishing criteria of rigour and relevance in interaction design research. Digital Creativity, 21(4), 265-272.

Ferguson, R., De Salvo, D. M., & Slyce, J. (1999). *Gillian Wearing*. Phaidon.

Gaver W., Boucher A., Law A. Pennington S., Bowers J., Beaver J., Humble J., Kerridge T., Villar N., Wilkie A. (2008). Threshold Devices: Looking Out From The Home. Proc. CHI 2008.

Gaver, B., Dunne, T. & Pacenti, E. (1999). Cultural probes. *interactions*, 6(1), 21-29.

Gaver, W. (2007). Cultural commentators: Non-native interpretations as resources for polyphonic assessment. International journal of human-computer studies, 65(4), 292-305.

Gaver, W. (2011). Making spaces: How design workbooks work. Proc. CHI'11.

Gaver, W. (2012). What should we expect from research through design?. Proc. CHI '12, 937-946.

Gaver, W., (1988). Everyday listening and auditory icons. Doctoral dissertation (University Microfilms No. 8908009).

Gaver, W., (2009). Designing for Homo Ludens, Still. In *(Re)searching the Digital Bauhaus*. Binder, T., Löwgren, J., and Malmborg, L. (eds.). London: Springer, pp. 163-178.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Lawrence Erlbaum.

Hjelm, S. I., & Browall, C. (2000, October). Brainball-using brain activity for cool competition. In Proceedings of NordiCHI (pp. 177-188).

Jarvis, N., Cameron, D. and Boucher, A. (2012). Attention To detail: Annotations of a design process. In Proceedings of NordiChi.

Kabokov, I. (1998). *A Palace of Projects*. Artangel, London.

Kuhn, T (1970). *The Structure of Scientific Revolutions*. London: University of Chicago Press.

Latour, B. (1987). science *in Action*. Cambridge, Mass: Harvard University Press.

Levy, S. (2006). *The perfect thing: How the iPod shuffles commerce, culture, and coolness*. Simon and Schuster.

Louridas, P. (1999). Design as bricolage: anthropology meets design thinking. Design Studies, 20(6), 517-535.

Nelson, H. G., & Stolterman, E. (2003). *The design way: Intentional change in an unpredictable world: Foundations and fundamentals of design competence.* Educational Technology.

Schön, D (1983). *The Reflective Practitioner: How Professionals Think*. New York, Basic Books.

Schön, D. A. (1999). *The reflective practitioner*. Basic books.

Scott, J. P. (2000). *Social Network Analysis: A Handbook* (2nd edition). Thousand Oaks, CA: Sage Publications.

Stolterman, E. (2008). The nature of design practice and implications for interaction design research. International Journal of design 2(1) 55 - 65.

US Government (1971). Hiding and Storing Stuff Safely.