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Where next for research on fixation, inspiration and creativity in design?

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This is a report from an international workshop focused on the future of design fixation research within the broader context of work on creativity and inspiration. Fixation studies have already generated many useful results but there are clear opportunities to better connect with work done on other related concepts and work done in other disciplines. This would allow fixation research to broaden and strengthen its methodological approaches, offering richer insights into how design ideas originate and how they subsequently evolve. Such knowledge could then be applied to influence the development of design education, training and tools. In this way, fixation research would maximize its potential to provide insights into the creative process, improve design practice and thereby support innovation.

Keywords: creativity, design behaviour, design fixation, research methods

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> "the mind fails to see the shortest solution for a given problem because of a fixation to one approach of solving a problem of that type"
>
> — Tracz (1979: p. 133), writing about the psychological challenges of computer programming

Designers of all disciplines are required to be creative if they are to arrive at new and useful solutions to the problems that they address. Design tools and design processes are often claimed to unlock this creativity by inspiring designers to undertake a wide-ranging exploration of the design space. Despite this, designers can still inadvertently restrict the range of ideas that they consider, limiting the way in which they interpret problems and explore possible solutions. In particular, potentially useful sources of inspiration or information can have the effect of constraining rather than freeing the designers' imagination (see Figure 1). As Tracz said in 1979, they would then be suffering from 'fixation', only seeing things in one particular way, even if there were a 'shorter', simpler or better approach.

For many years, psychologists have been describing and studying the kinds of blocks that can impede insight, often resulting from the counterproductive effects of prior knowledge. This phenomenon and its variants have been demonstrated in a number of now-classic experiments, including Maier's (1931) and Duncker's (1945: Ch. 7) demonstrations of how people's 'attachment' to the conventional function of artefacts inhibits their capacity to see new possible functions — referred to as 'functional fixedness'. Related to this are Luchins' (1942) demonstrations of the 'Einstellung effect', where people become mentally 'set' in a particular approach to solving problems.

Figure 1 Many descriptions of design fixation suggest that if designers have been exposed to existing design solutions (e.g. from their immediate environment) then this might unknowingly restrict the range of solutions that they explore (e.g. by repeating features of the existing solution)

The concept of 'design fixation' (also simply referred to as 'fixation' hereafter) was developed from these early psychological studies, with the term initially being used to refer to "a blind adherence to a set of ideas or concepts limiting the output of conceptual design" (Jansson & Smith, 1991: p. 3). This definition described what Jansson and Smith found in a number of experiments with participants working on creative design tasks. Student designers, working individually, had to generate ideas in response to different problems (i.e. design a car-mounted bicycle rack, a measuring cup for the blind, a disposable spill-proof coffee cup). Alongside the design briefs, some of the participants, were also presented with pictures of existing solutions. Jansson and Smith identified the occurrence of fixation in their experiments when it was observed that the designers exposed to those pictures tended to repeat key features of the solutions that were represented. This behaviour persisted even when participants received instructions to avoid repeating particular features of those example solutions. As these features were intentionally problematic (e.g. they contradicted the brief) this feature repetition was taken to be inadvertent and counterproductive.

Since 1991, the basic approach taken in Jansson and Smith's study has been adopted by many other researchers whose studies have manipulated different variables to provide a better understanding of why fixation occurs and how it might be mitigated. These studies are now sufficient in number that literature reviews have recently been published focussed solely on design fixation, investigating the concepts of interest (Youmans & Arciszewski, 2014), the findings obtained (Sio, Kotovsky, & Cagan, 2015) and the research methods used (Vasconcelos & Crilly, 2016). For detailed summaries of the experimental work conducted to date, readers are directed to these reviews and other recent publications on design fixation.

When surveying the research that has been conducted to date, five observations can be made about the current status of design fixation research.

1. *It's distinctive*. Research into design fixation is represented by a well-defined body of literature. Although there are some differences in the detailed definitions and methods used, there are strong underlying similarities in the concepts that are invoked and the general approach taken.
2. *It's productive*. Lots of experimental studies of design fixation have now been conducted, with different variables being manipulated to reveal more about the phenomena of interest. The concept of design fixation is also used to explain design behaviour outside of experimental settings.
3. *It's disconnected*. Although design fixation research is often explicitly connected to the psychological traditions that initially inspired it, it is disconnected from other relevant fields of research. Looking more widely might reveal other related concepts, appropriate methods and possible applications.

4. *It's uncritical*. Design fixation research has seldom been self-critical in terms of what is being studied, how it is being studied and how the resulting knowledge is being applied. Concerns can be raised over conceptual precision, methodological validity and potential impact.
5. *It's undirected*. Despite focussed and longstanding interest in design fixation, there is not (to our knowledge) a dedicated forum for those interested in the topic to exchange ideas and discuss possible future directions.

These observations about the status of design fixation research motivated the organisation of a workshop that would capture the perspectives of different people whose work is related to that topic (for an earlier event, see Cardoso & Badke-Schaub, 2011). The objective was to stimulate debate about future possibilities for design fixation research. This report presents the findings of that workshop, structured according to the main issues that were discussed.

1 The workshop

A one-day workshop was organised at Arts Centre Delft (The Netherlands) on March 4th, 2016.

1.1 Participants

Participants were invited to attend the event on the basis of their prior work on fixation, inspiration and creativity, or on the basis of their conceptual, methodological and practice-based expertise. The participants are listed on the title page. They self-identified as having expertise in the following areas:

- various branches of design, including engineering design, complex design, industrial design, fashion design and architecture, with special attention to design creativity, design fixation, inspiration in design, design cognition, design reasoning, design philosophy, design methodology, design processes, design models;
- various branches of psychology, including cognitive psychology, human factors psychology, health psychology and design psychology, with special attention to human mind and memory processes, problem solving, planning, expertise, habits and goals.

Collectively, the group therefore brought diverse perspectives to the discussion, allowing us to capture the history, development and state of the art in fixation research, survey the relevance of other disciplines and probe possible future directions.

1.2 Format

The workshop ran over a full working day and comprised a combination of small group activities and large group discussions. Two professional facilitators organised the session activities and chaired the discussions. The event was documented with audio recorders (two independent devices), hand written notes (from six participants, two per group), photographs (from two participants) and copies of all the visual materials produced in the group activities. In addition, one of the facilitators produced live 'visual capture' during the event, which inspired the illustrations included in this report.

1.3 Reporting

The notes and other recordings were summarised into draft reports which were circulated to all the workshop participants to elicit any suggestions or corrections. Others who were not able to attend were also invited to make additional contributions that refined or expanded the structure and contents. These other contributors are listed on the title page. With over twenty people providing their perspectives on the topic, the contents of this report are necessarily wide-ranging and do not always represent the views of all contributors. However, one issue that saw general agreement was that fixation should be considered in the broader context of creativity and inspiration, as reflected in the title of this report and in much of what is discussed in the pages that follow.

2 Key questions to address

The main findings from the workshop can be represented as a set of nine overarching questions that fixation research should address:

Q1. *Why are we even interested in 'design fixation'?*
Q2. *Why are we so fixated on one kind of fixation?*
Q3. *How does design fixation relate to other concepts?*
Q4. *Is fixation really always a bad thing?*
Q5. *Can you be creative and fixated at the same time?*
Q6. *What does fixation look like in the wild?*
Q7. *How can the experimental methods be improved?*
Q8. *What other research methods might be used?*
Q9. *How should knowledge about fixation be applied?*

In the sections that follow we elaborate on each of these questions, including the further sub-questions that they suggest and possible clues to how they might be answered. Each of the questions is posed and discussed independently, meaning that any given section can be read in isolation (with some points being repeated from one question to another where they are related).

2.1 Why are we even interested in 'design fixation'?

Since Jansson and Smith's original study, design fixation has been defined in many different ways, sometimes as something that is just unintentional or inadvertent, but sometimes as something that is also inappropriate or counter-productive (e.g. see Youmans & Arciszewski, 2014). To permit a wide-ranging exploration of design fixation, we here propose a working definition that does not require the effects to be negative, as that judgement would, in any case, be a matter of perspective (see Section 2.4); we also propose a definition that is inclusive of many different kinds of design activity (not just conceptual design), many different sources of bias (not just example solutions) and many different consequences of that bias (not just limited design outputs):

> *design fixation is a state in which someone engaged in a design task undertakes a restricted exploration of the design space due to an unconscious bias resulting from prior experiences, knowledge or assumptions.*

According to this definition, design fixation can be seen as a cognitive 'error' because areas of the design space are inadvertently left unexplored. It is not that these errors are necessarily common − they might be quite rare − but by studying them researchers are provided with useful information about normal cognitive processes. Fixation is interesting because these cognitive processes are interesting, especially processes related to creativity, inspiration and information processing (see Figure 2).

Designers are frequently confronted with problems or opportunities that demand creative ideas. Prior solutions often exist, either in the same domain or in some other domain, and designers are often aware of those prior solutions or seek them out. In addition, designers are often aware not just of prior solutions, but also of prior interpretations of the problem and prior methods of developing solutions (Crilly, 2015). However, research suggests that these different forms of prior knowledge might not only have positive consequences (in terms of inspiration), but negative also (in terms of fixation). If fixation is seen as often having negative effects overall (see Section 2.4) then reducing fixation is a way to unlock creative potential, thereby improving design activities and the products (defined broadly) that result. In this way, fixation research (and associated activities) has the potential to provide insights into the creative

Figure 2 Studying design fixation allows researchers to explore many different aspects of design behaviour, especially aspects of design cognition

process, improve creative design practice and thereby support innovation. This might be achieved through research-driven interventions in practice, such as changes to educational programmes, training courses and design support (see Section 2.9).

Design fixation is often studied and described separately from other topics. However, fixation can be placed within a broader context, being just one of many phenomena relevant to the development of design ideas. As such, we might ask about the factors that influence that development, what role creativity plays in that process and what the impediments to creativity are. We might also ask how we can improve the development of design ideas, either by increasing creativity or reducing the impediments to creativity. It is within this broader context that design fixation is an interesting phenomenon, but we still might be prompted to ask a number of questions about what exactly is of interest.

- *Creative work*. Is studying fixation just a way to better understand design creativity? What is the relationship between overcoming fixation and being creative? Is inducing fixation a good context for studying the effectiveness of creativity tools such as SCAMPER, Synectics, Six Hats, etc. (e.g. Kowaltowski, Bianchi, & de Paiva, 2010; Michalko, 1991)? Why are we giving so much importance to fixation in comparison to all the other hindrances to creativity?
- *Mental content*. Is studying fixation just a way to better understand how designers bring content into their minds? Are design ideas special in this regard? How can we understand the interaction between internal mental states and external stimuli?
- *Information processing*. Is studying fixation just a way to better understand information processing in design? What information is being processed and how? Is fixation an instance of information not being processed enough or of it being overly processed?
- *Cognitive economy*. Is studying fixation just a way to better understand how designers balance efficiency with effectiveness? Does fixation occur because it requires too much cognitive effort to always think differently, creatively, divergently? Is fixation a cognitive coping strategy when there are too many things to think about? What other such strategies are we interested in?
- *Cognitive flexibility*. Is studying fixation just a way to better understand the trade-off between flexibility and commitment in design? Is fixation sticking with an idea ‘too much’, and if so how can we define ‘too much’ and what would it look like to not stick with an idea ‘enough’?
- *Analogical transfer*. Is studying fixation just a way to better understand how designers transfer information within and between domains? Such transfer is sometimes beneficial for creativity and solving a problem, and sometimes

not. Does a common process underlie analogical transfer irrespective of how the outcome is judged?

Whatever reasons we might have for seeking to understand design fixation, there are benefits to making those reasons more explicit. This not only connects the study of fixation to a wider context, but it invites other people interested in that context to interpret our findings and respond to them.

2.2 Why are we so fixated on one kind of fixation?

It has been suggested that fixation researchers should be wary of becoming fixated on what fixation is (Purcell & Gero, 1996). However, to date, the majority of fixation research tries to identify fixation behaviour in the early stages of a design process, especially during 'early ideation' or 'idea generation'. The design tasks that are assigned to participants are also relatively unbounded, with the requirement that they develop solutions to open-ended problems. In addition, both the background of the participants and the examples that are shown to them often suggest that physical or mechanical products are a viable or likely solution to the problem (see Figure 3). Exceptions to this do exist of course, with fixation-like effects also having been studied in software design (Goddard, 1976), interaction design (Hassard, Blandford, & Cox, 2009) and service design (Moreno et al., 2014).

A few exceptions notwithstanding, a rather narrow range of design activities provide the basis for most studies of design fixation and for much of the discussion that surrounds those studies. In fact, to date, the majority of fixation studies might more accurately be described as studies of 'ideation fixation'. This raises a number of questions about how the findings from fixation research might generalise to other kinds of design activity, and also questions about whether the design tasks being used offer the best basis for studying fixation. By considering a wider range of design tasks, researchers might address questions about how design fixation relates to the following dimensions of design practice.

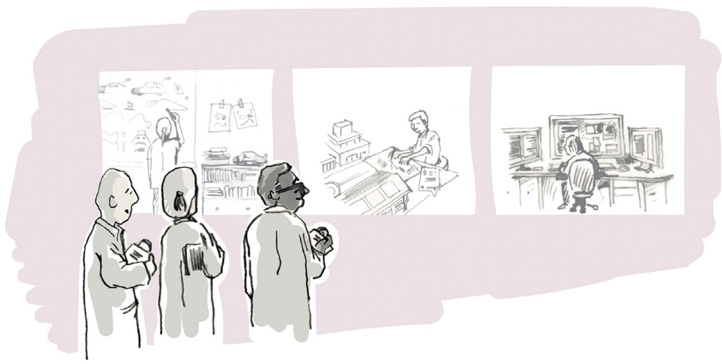

Figure 3 Design fixation might be exhibited in many different kinds of design practice (e.g. architecture, software engineering, etc.) but to date most of the empirical studies have focussed on industrial or mechanical design

- *Process stage*. Design processes are commonly divided into many different stages, e.g. clarification of the task, conceptual design, embodiment design, detail design (Pahl & Beitz, 1996). Many models of the design process exist, each with a different number of stages and different dependencies between those stages (Wynn & Clarkson, 2005; also see Dubberly, n.d.).
- *Problem type*. Design problems are often described according to the extent to which they are simple or complex, defined or ill-defined, wicked or tame, fixed or negotiable, etc. (e.g. Rittel & Webber, 1973; Simon, 1981). Alternatively, design problems might be described as requiring routine design, innovative design or creative design (Gero, 1990).
- *Design discipline*. Design is commonly divided into a great many different disciplines or domains, e.g. architecture, communication design, electronics design, graphic design, industrial design, interaction design, mechanical design, process design, service design, software design, systems design, etc. (e.g. see Eckert, Blackwell, Stacey, Earl, & Church, 2012).

With respect to process stage, 'conceptual design' was the explicit focus of Jansson and Smith's original study and has remained central to much fixation research since then. However, during task clarification, there are opportunities for creative reinterpretation of the design problem (Paton & Dorst, 2011) and therefore also opportunities to fixate on one interpretation of the problem (Pretz, Naples, & Sternberg, 2003). We might have similar expectations for other stages of the design process, with creativity required at every stage (Snider, Culley, & Dekoninck, 2013; Snider, Dekoninck, & Culley, 2016), and therefore fixation possible at every stage also.

Although design processes have traditionally been divided into a number of sequential stages, other approaches exist, such as agile product development (Martin, 2003). This raises questions about how fixation occurs in design processes where the cost of change is low and the rate of iteration is high, or where each of the traditional stages is performed continuously throughout the project. Either way, given that we might expect differences between how design processes are formally described (or prescribed) and how they are actually conducted, it is interesting to consider how fixation occurs in practice (see Section 2.6). For example, in many instances, designers may immediately imagine possible solutions to a problem statement before any task clarification activities are conducted, or before the brief is questioned.

With respect to problem type, it seems that most of the design problems assigned in fixation studies could be understood as 'ill-defined' or 'open-ended'. However, we might question whether this is the most important (or the only important) problem type addressed in design practice. Designers also engage with problems that are well-defined or closed (even if those problems are not necessarily easier to solve).

With respect to design discipline, some design activities might lend themselves to studying fixation more readily than others. For example, some design tasks could impose a more constrained solution-space (e.g. the redesign of an electrical circuit) where the challenge lies in creatively designing within those boundaries, rather than freely reframing the whole problem or context. This would permit better comparison between participants' outputs because they would be within the same category, typology or domain (see Section 2.7). It would also permit more objective testing of the outputs because they might be subjected to consistent performance measures (e.g. using circuit simulators).

The opportunity to test solutions would not only allow researchers to assess performance more objectively, but could also allow designers to gain feedback on the design's performance as they perform their work (e.g. by testing a simulation of their current design). This feedback could be a variable that researchers manipulate, either by providing or withholding it during the task. Alternatively, it could simply be provided to make the task more realistic for those practices where iteration based on such feedback is important during design (e.g. where software simulations are used to assess fluid flow, structural integrity, thermal performance, etc.).

One of the difficulties that researchers face in designing experiments to study fixation is finding a 'natural' way to provide participants with an example solution to the problem (see Section 2.7). If this is not done in a subtle way, then participants might become confused, guess the subject under investigation, misunderstand the design task or more generally exhibit behaviour that is an artefact of the experimental setup. Instead of requiring free ideation, instructing participants to redesign an existing product (perhaps now with a new function or requirement) offers a logical basis for providing an example solution (the existing product), whilst also offering many of the benefits associated with having participants operate in a more constrained solution-space. Of course, there might also be benefits to studying fixation in response to unconstrained problems (for instance, when considering the effects of 'Need for Closure'), but such tasks are already being set in fixation studies.

Here, we have only briefly touched on the possibilities of research into design fixation looking beyond the narrow range of design activities that have typically been focussed on. A proper exploration of the variety of design activities that might be studied promises to yield much richer opportunities, both for what we might learn about fixation and what me might learn about how best to research it.

2.3 How does design fixation relate to other concepts?

Any review of the literature reveals that when it comes to the details, the term 'design fixation' can mean many things (see Youmans & Arciszewski, 2014, and Section 2.4 of this report). However, most of the things that are meant by the term relate to some form of oversight, bias or repetition. These general ideas of restricted search are also related to other well-established concepts that are discussed in design and elsewhere (see Figure 4). As originally formulated, design fixation was explicitly linked to traditional work on the Einstellung effect (or mental set) and functional fixedness (e.g. Luchins, 1942; Maier, 1931). However, contemporary studies of design fixation are seldom connected to contemporary studies of these phenomena despite the conceptual and methodological relevance of such work (e.g. see Bilalić, McLeod, & Gobet, 2008a, 2008b; German & Barrett, 2005).

In addition to looking deeper at the concepts that originally inspired design fixation research, there are many other concepts that are relevant but often overlooked. This raises questions about what fixation researchers might learn from attending to those disciplines that study fixation-like effects in other aspects of human behaviour. Certainly, those reviewing work on design fixation would benefit from broadening their own search to include work on concepts that are related to fixation in some way. These concepts might include, but are certainly not limited to, the following:

- *attentional blink* (e.g. see Raymond, Shapiro, & Arnell, 1992)
- *cognitive entrenchment* (e.g. see Dane, 2010)
- *confirmation bias* (e.g. see Nickerson, 1998)
- *convergent thinking* (e.g. see Cropley, 2006)
- *IKEA effect* (e.g. see Norton, Mochon, & Ariely, 2011)
- *inattentional blindness* (e.g. see Simons & Chabris, 1999)
- *hill climbing* or *local minima/maxima* (e.g. see Minda, 2015: p. 199)
- *local search bias* (e.g. Rosenkopf & Nerkar, 2001)
- *memory blocking* or *mental-rut* (e.g. see Smith, 2003)
- *paradigm-induced blindness* (e.g. see Kuhn, 1962)

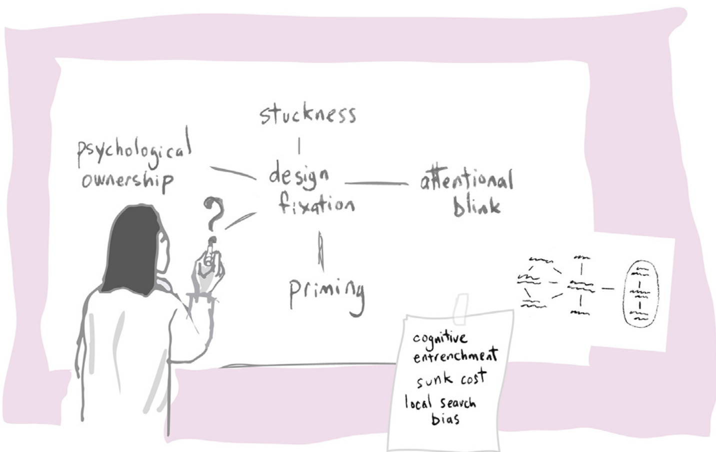

Figure 4 Design fixation is related to many other behavioural and cognitive phenomena that are described in other literatures, but the nature of those relationships has not been investigated

- *path of least resistance* (e.g. Ward, 1994)
- *premature commitment* (e.g. see Carroll, 2002)
- *priming* (e.g. see Tulving, Schacter, & Stark, 1982)
- *psychological ownership* (e.g. see Baer & Brown, 2012)
- *primary generator* (e.g. see Darke, 1979)
- *satisfaction of search* – SOS (e.g. see Berbaum et al., 1994)
- *subsequent search misses* – SSM (e.g. see Biggs, Adamo, Dowd, & Mitroff, 2015).
- *stuckness* (e.g. see Sachs, 1999)
- *sunk cost effect* (e.g. see Arkes & Blumer, 1985)
- *tolerance for ambiguity* (e.g. see Budner, 1962).

Many of the concepts listed above are related to the broad phenomenon of 'cognitive bias'. Situating design fixation research within the context of cognitive bias research encourages us to consider design activities in terms of a dual-processing model of cognition (e.g. see Kahneman, 2011). Many cognitive scientists suggest that cognitive processes are driven by two quite independent cognitive systems: 'System 1' and 'System 2'. System 1 is often described as rapid, parallel, innate, unconscious and 'old' in evolutionary terms, whereas System 2 is slow, sequential, abstract, conscious and 'recent' in evolutionary terms (see reviews by Evans, 2003, 2008). If these separate systems compete for control during inference and decision-making, then what aspects of a design scenario determine how that competition is settled? Is a dual-processing model useful for approaching the study of creativity, inspiration and fixation? How might this model inform the reinterpretation of prior findings, the design of future studies and interventions in practice?

In addition to various forms of cognitive bias and other related concepts, researchers should also consider fixation from the perspective of the more general behavioural issues with which it might be associated, for instance: inflexibility, stubbornness, inspiration, distraction, attention, focus and persistence. Conversely, fixation might be considered with respect to things that it is either negatively associated with or distinct from (e.g. design reuse, design freeze, intentional commitment, resource-limited search, divergent thinking, etc.).

However wide the net is cast, it would be useful for fixation research to have a survey of the most relevant concepts, showing what they are, how they are distinct from each other, where they come from and how they are applied. Generating a map of these concepts and their relations would make it easier for researchers to navigate through the different disciplines and literatures that collectively describe how people fail to search a space of alternatives. Such a map might be descriptive of the concepts and terminology already in use or might be more prescriptive, suggesting new classifications and terminology (see Bailey, 1994; Marradi, 1990). The benefit of a prescriptive approach would be that it could result in something more consistent and more complete, being free from the legacies of many independent traditions. One example of such conceptual work being performed elsewhere is research on the ‘semantic basis’ for system lifecycle properties (Ross, Beesemyer, & Rhodes, 2012). There, many concepts that would otherwise be difficult to distinguish from each other (because of overlaps or ambiguity) are all defined in the same terms with the distinctions drawn out. Put simply, applying this approach to fixation-related concepts might look something like this:

> “*Fixation type* F_x, the designer was fixated on [A] because of [B] as evidenced by [C] and having the effect [D].”

The variables A, B, C, D (and possibly more) would each have lists of possibilities associated with them, which in different combinations would define fixation types F_1, F_2, F_3, etc. Approaches such as this might be used to develop a sort of ‘periodic table’ of fixation: a representation that has predictive power, indicating the possibility of fixation types even if they have not yet been observed or studied.

Of course, the construction of a semantic basis is only one approach to achieving conceptual clarity. When defining fixation-related concepts, it would also be beneficial to explore the different types of definitions that are possible (Gupta, 2015), and how those might be suited to the different types of work that could be done with them (see Sections 2.7 and 2.8). For example, researchers looking for evidence of fixation in professional practice might have different requirements of a definition to those designing an experiment or those developing a design support tool. Thus, we might consider the following types of definition to be useful: *formal definition* (a definition that sets out the meaning of the term as in a dictionary); *definition by example* (an example that captures the essential features of that which is being defined); *definition by exception* (clarification of a definition by indicating what that definition does not include, but which might otherwise be mistakenly thought to be included); *definition by operationalisation* (definition of a phenomenon by describing the way it can be measured).

To be clear, it is not just that different interpretations of design fixation would lead to different (formal) definitions, but also to different ideas about the kinds of definition that would be useful. When this thinking is extended to the other related concepts listed earlier, there is the potential for achieving much greater conceptual clarity for fixation research.

2.4 Is fixation really always a bad thing?

Discussions about design fixation often raise the question, *is fixation always a bad thing?* This is difficult to answer because of the different ways in which fixation is defined, and confusion between how it is defined and how it is identified in fixation experiments.

Some definitions of fixation state that it is a behaviour that is either 'blind' or 'inadvertent' on the part of the designer (e.g. see Jansson & Smith, 1991). If designers are unintentionally or unknowingly 'conforming' to precedent then this need not necessarily lead to bad outcomes but it clearly might (Smith, Ward & Schumacher, 1993). Or at least, the outcomes from such acts might be worse than the outcomes from acts that are more intentional. Other definitions of fixation state that it is either 'negative' or 'counterproductive' (e.g. see Moreno, Yang, Hernández, Linsey, & Wood, 2015). The only way that these concepts of fixation might permit fixation to be good is if fixation is bad in some ways but not in others. For example, it could be that fixation prevents some good solutions from being considered (which might be bad), but if fixation encourages a deep exploration of a narrow set of viable solutions this might save time (Bilalić, McLeod, & Gobet, 2008b; Luchins, 1946; Schwartz, 1982), thus reducing the cost of a design project (which might be good). Of course, all the points above involve someone making a judgement about what is good and what is bad, and such judgements can be expected to vary from person to person and from one context to another. Nevertheless, there are various questions that ought to be considered.

- *Mixed consequences*. What are all the consequences of fixation (good and bad)? What effect does fixation have on the time it takes to complete a design task? What effect does it have on group dynamics? What effect does it have on designers' satisfaction with the process and the solution?
- *Measurement methods*. How can we measure the different consequences of fixation (beyond simply assessing the solutions)? Are those different consequences evident within similar timeframes or are some more immediately realised (or short-term) than others?
- *Relative costs*. On balance, what is the true cost of fixation, once the good and bad consequences have been considered? How do different stakeholders (interested in different aspects of the project) see the relative costs of fixation?

Although fixation is defined in different ways, the occurrence of fixation is identified in the experiments in a relatively consistent manner, as the repetition of features from a prior solution. The degree to which feature repetition is unintentional or inadvertent is often not assessed, but feature repetition might result from consciously or unconsciously copying a feature (Youmans & Arciszewski, 2014). We might ask, therefore, whether the feature repetition measured in the experiments is always bad.

There may be many benefits of repeating solution features during design, including decreased time, increased confidence and improved stakeholder acceptance (if the prior solution was conventional). Especially in craft-based design practices, the re-use of good, standard product features is often acceptable or preferable because knowledge of how to shape the product is embedded in prior examples. If contemporary products reflect many years of product refinement and exhibit good performance, the features that contribute to that performance and the reasons behind them might not be fully known to those attempting redesign (Lawson, 2005: pp. 19–23). Similarly, in some industries, (e.g. aerospace, healthcare, pharmaceuticals) the cost of design change might be very high, either in terms of risk, scheduling, tooling, testing or re-certification (Eckert, Stacey, & Earl, 2005). As such, there are scenarios, where even the *unknowing* repetition of features might have positive consequences (see Figure 5). That is not to say, however, that repeating such features *knowingly* would not result in equally (or increased) positive consequences. Methodologically, this gives rise to some interesting questions.

- *Differentiation*. How can we distinguish between the different causes of feature repetition? How can those causes be identified in design processes (e.g. observing meetings) or design outputs (e.g. analysing product evolution)?
- *Transition*. What happens when designers become aware that they have been fixated? Do they overcome the idea that they were unintentionally biased towards and then think more widely? Or do they then intentionally commit to that idea?
- *Risk*. Do fixation behaviours differ between those practices that are risk-focussed and those that are opportunity-focussed? Do designers in safety-critical industries think about fixation differently to those in other sectors?

Just as there may be pragmatic benefits to a narrow but deep exploration of the solution space, there may also be creative benefits. This is especially the case where that limited exploration forms the foundation for the more expansive

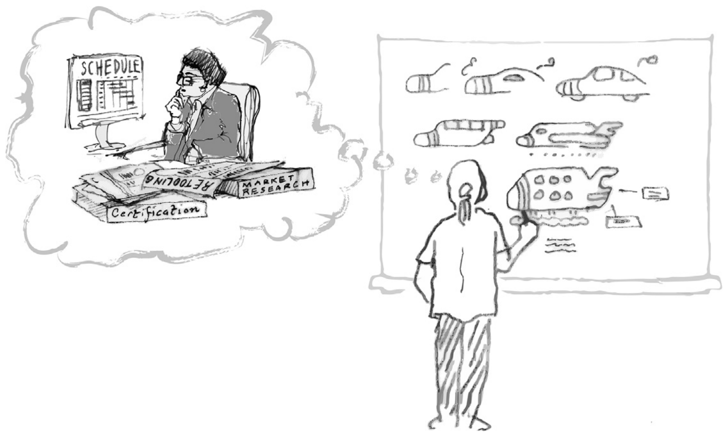

Figure 5 Although design fixation results in conservative designs, a less restricted exploration of the solution space might give rise to new risks associated with change

exploration that follows. This requires taking a longitudinal view of design behaviour, where fixation might appear to be present at one moment, but creativity might be evident the next (Moreno et al., 2014). A designer may explore the design space in a systematic way, making only incremental moves that are not typically associated with creative thinking. However, once obvious ideas have been scrutinised and discarded, creative ideas may emerge. This cognitive behaviour has been termed ‘the persistence pathway’, in contrast to ‘the flexible pathway’, a creative thinking mode where people switch more flexibly between approaches and categories, and more easily use distant associations (Nijstad, De Dreu, Rietzschel, & Baas, 2010). However, both pathways play a complementary role in creative thinking: the flexibility pathway facilitates the discovery of new approaches to design problems; the persistent pathway triggers a systematic exploration of such approaches and associations (also see discussions of divergent and convergent thinking, e.g. Cropley, 2006). As such, persistence (which might be mistaken for fixation) can be important for creative design. Being aware of this raises some challenges for fixation research.

- *Persistence effects*. If designers are explicitly required to exhaustively explore a small part of the design space, what effect does this have on their subsequent exploration of the wider space? What other effects does persistence have on design behaviour (e.g. on confidence or group coordination)?
- *Avoidance effects*. If designers are explicitly required to not reproduce a small part of the design space (e.g. to avoid patent infringement), what effect does this have on their exploration of the remaining space? Do they consciously avoid any proximity to the prohibited solution or do they work right up to the edges of that solution?
- *Temporal effects*. What does fixation behaviour look like over the longer term? Can alternating episodes of persistence and flexibility be identified? What relationships exist between persistence, flexibility, creativity and fixation?

Answering questions about whether fixation is always bad requires a focus on exactly how fixation is being defined. However, such questions often get at the matter of whether a restricted exploration of the design space has benefits, and what the costs are of a more expansive exploration. This suggests questions about how we represent a design space and the exploration of that space. Being better able to indicate the many dimensions of a design space and the different levels at which it is being explored (either with persistence or flexibility) might be key to obtaining a better understanding of fixation and creativity.

2.5 *Can you be creative and fixated at the same time?*

Connected to the question of whether fixation is always a bad thing is the question of whether a designer can be creative and fixated at the same time (see Figure 6). Many definitions of creativity require the production of novel and appropriate ideas (Runco & Jaeger, 2012; also see; Sternberg & Lubart, 1999, p. 4; Taylor, 1988), with some additionally requiring that the idea be non-obvious or surprising (e.g. see Howard, Culley, & Dekoninck, 2008; Newell, Shaw, & Simon, 1962). Novel, non-obvious and surprising ideas are incompatible with the repetition of prior solutions (although they might permit the incorporation of such solutions into a larger whole). As such, some notions of creativity and fixation exclude the possibility that a designer could be creative with respect to the same aspect that they are fixated on. For example, if a designer is fixated on the location of a certain component, then that designer is not being creative with respect to the location of that component (or perhaps even the very presence of that component).

Although fixation and creativity might be mutually incompatible when researchers only consider one single aspect of design, the situation clearly becomes more complicated when the bigger picture is considered. Fixation might be observed at one level whilst creativity is observed at another. Interesting research questions might therefore be asked about this 'tension' between fixation and creativity.

- *Multi-level fixation*. What are the different levels at which fixation might occur? For example, fixating on the problem *vs.* fixating on the goal *vs.* fixating on the process *vs.* fixating on the solution; fixating at the component-level *vs.* fixating at the system-level; fixation in individuals *vs.* fixation in groups *vs.* fixation across a larger community.
- *Creativity/fixation trade-offs*. What happens when fixation is challenged at multiple levels (e.g. problem, goal, process *and* solution; components *and*

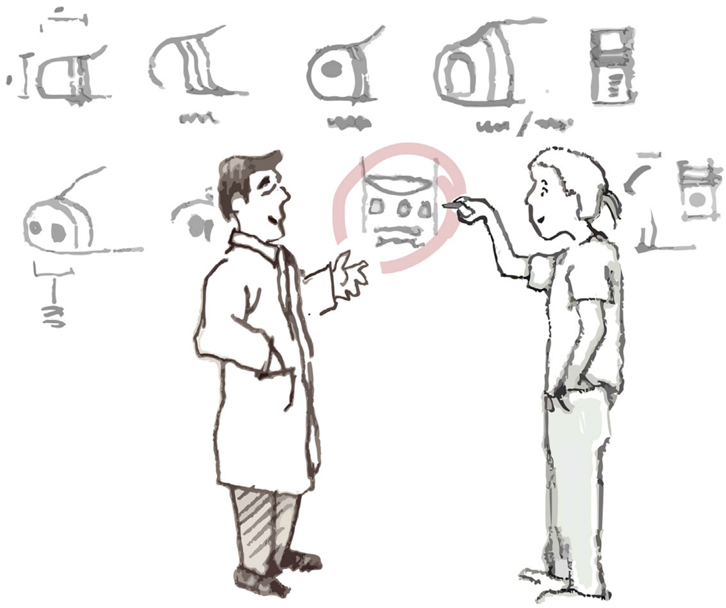

Figure 6 Even if design fixation restricts the space of ideas that designers explore, it could be that designers still exhibit creativity within that restricted space, perhaps arriving at ideas that would not have been developed in the absence of fixation

systems)? Is creativity possible at more than one level at the same time? Is some form of fixation required at one level for creativity to be possible at another? If so, how might we determine the level at which designers could be beneficially fixated and how might that fixation best be induced?

- *Interaction effects*. What is the interaction between fixation and creativity at different levels? Does fixation (at one level) free up the cognitive resources to permit creativity (at another)? Does the perception of creativity at one level prevent people from recognising the presence of fixation at another?

Designers must often balance competing requirements for novelty, safety, cost, timescales, legislation and many other factors. Because of this, both wide-ranging *and* restricted exploration of different areas of the design space might be expected. As such, if we wish to develop a better understanding of creativity and fixation in design then we should investigate their co-occurrence even if that is with respect to different levels.

2.6 *What does fixation look like in the wild?*

There are a few accounts of fixation-like episodes occurring in real design and development projects (see Figure 7). For example, French (1985) describes how engineers at Rolls-Royce developing gas turbine blades were fixated on the geometry of the preceding technology (steam turbine blades), leading to a long delay in changing that geometry and thus adopting materials that could perform better in the new context. Similarly, Barker (1994) describes how technologists at Sony developing the Compact Disc were fixated on the size of the preceding technology (the LP record) even though their new technology had a much higher information density, leading them to temporarily abandon the project due to the perception that there would be no market for a recording media that would store so much music. Whilst these brief stories (and others like them) are an interesting counterpoint to the data reported in fixation

Figure 7 Many studies of fixation eliminate contextual factors that might be relevant in professional practice, including other projects, workload, deadlines and teamwork

experiments, they are also of limited value. The stories are reported in the form of anecdotes rather than research accounts and as such, we know nothing about whether the accounts are accurate, what data supports them, how that data was collected and whether the accounts that are offered would be recognised or accepted by those involved.

As discussed earlier (Section 2.8), much of the fixation research to date has been conducted under laboratory conditions rather than out in the real world. However, we might expect many differences between how design activities occur 'in the lab' and how they occur in the 'in the wild' (Cash, Hicks, & Culley, 2013). Considering what fixation looks like in the wild raises a number of questions. At the most basic level, we might ask what forms of fixation occur, under what circumstances, how often, for how long and to what effect? Digging deeper, there are many aspects of design practice that are typically absent from the experiments (or tightly controlled in them).

- *Workplace*. What role does the physical workplace play in fixation? If designers are surrounded by images, models and products, what effect does this have?
- *Process*. What role does design process play in causing or mitigating fixation? What role do chance, random occurrences play in comparison to systematic or calculated approaches?
- *Groups*. What role do groups play in inducing or overcoming fixation (e.g. in brainstorming sessions)? How does fixation propagate through networks of individuals? Is it best to treat fixation at the individual level or to manage it as a concern of the group?
- *Teams*. What does fixation look like in teams, especially in long-established teams where the team roles are pre-defined and well practiced? Do established teams better anticipate, manage and mitigate collective fixation?
- *Feedback*. What effect does feedback have on fixation? What feedback effects occur when designers are testing, simulating and sharing design ideas? Is operating in a feedback-rich environment helpful? What kind of feedback is most effective, and when?
- *Technology*. What role does technology play in fixation? Is fixation more or less likely when designers work with pencil and paper, digital tools or physical models (see Robertson & Radcliffe, 2009)? What aspects of the technology are influential in this regard?
- *Communication*. What role does the communication of design ideas play in fixation? In comparison to sketches and discussions, do ideas become more definite and less provisional when represented for asynchronous (mediated) communication?
- *Domain knowledge*. What effect does domain knowledge have on fixation? Does domain knowledge exacerbate or mitigate fixation? Which forms of expertise are most helpful for particular fixation scenarios?

- *Multidisciplinary teams*. What effect does team composition have on fixation? What is more effective in combatting a team's fixation, adding another domain expert or adding someone from a different discipline?
- *Creative knowledge*. Do experienced designers become expert in problem solving (generally)? Can someone be expert in creative methods? Does this influence the occurrence of fixation?
- *Inducing fixation*. When (if ever) would it be beneficial to induce fixation in real design projects (see Section 2.4)? How could this be achieved most reliably? How could this fixation be verified as resulting from the intended cause?
- *Awareness*. How much awareness of fixation do professional designers demonstrate (see Crilly, 2015)? What meta-cognitive strategies do designers employ to tackle fixation and how effective are these? Are designers aware of balancing the need to remain flexible in exploring ideas and yet committed to the solutions that they are developing?
- *Management*. Do fixation episodes have positive side effects (e.g. problem understanding, team cohesion) that managers should encourage (see Section 2.4)? Are designers better able to identify and manage their own individual fixation or that occurring in others?
- *Scale*. Is fixation only visible at the level of an individual designer, or also at the level of the group or a broader community? Is collective fixation essentially the same phenomenon as individual fixation?
- *Language*. How does the naming of the problem or the solution (or parts thereof) constrain thought? For example, product components might be named according to functions or according to forms (Malt & Sloman, 2007: pp 95–96). Do different naming practices influence fixation?
- *Exceptions*. Which design scenarios suffer from the least or the most fixation (see Section 2.2)? What is it about these scenarios that cause them to be different? What can be learned about fixation by studying such exceptions to the norm?

In considering all these questions, one overarching methodological issue is pertinent: we don't know how to study fixation in the wild. Whilst there are some clues to how this might be done (see Section 2.8), there are also many practical issues that have not so far been the concern of most fixation studies: how to gain access to the right settings, how not to overly influence the phenomena of interest and how to ascertain if it is really fixation that is being observed. Unlike the traditional experimental studies, approaches to studying fixation in the wild are unlikely to focus solely on the final outputs of design activities, but on the activities themselves, as they are manifest throughout the project.

2.7 How can the experimental methods be improved?

Since the publication of Jansson and Smith's original paper, many other fixation researchers have used a similar experimental method. Those researchers have primarily focussed on manipulating different variables related to the design task or the conditions under which that task is performed. They have also developed new metrics for design performance and new approaches to analyse the data collected. However, the general experimental setup has largely remained the same as that implemented by Jansson and Smith. As such, the studies have typically exhibited a number of common features: *open-ended* design problems are set (early stage ideation); *simple outputs* are requested (basic sketches); *limited time* is provided for design activities (often around an hour); *example solutions* are provided to participants (often represented visually); *inexperienced participants* are recruited (typically students); *design outputs* are analysed (focussing on outcomes rather than process); *subjective assessment* of design ideas is performed (usually by researchers).

Clearly, these features (and others that might be identified) present a number of challenges in conducting the studies and interpreting the results. Looking forward, what opportunities are there to improve the experimental methods that are used to study design fixation? Some of the questions that we might ask of current and future methods are listed here (some quite general and some more specific).

- *Ecological validity*. What kinds of design practice are the experiments intended to simulate? At what point in turning real world design scenarios into lab sessions does the essential nature of the task get lost? What alignment is there between the experimental results and naturally occurring design behaviour, and is this alignment always the same?
- *Theory development*. How far can lab sessions enable the identification of the underlying cognitive mechanisms at play when design fixation occurs (see Figure 8)? Can researchers develop a rigorous theoretical framework for design fixation that allows hypotheses to be formed and tested? Can the experiments be more theory-driven, distinguishing between competing explanations or possibilities? (For broader context, see Cash, Stanković, & Štorga, 2016.)
- *Control conditions*. How can robust control conditions be developed and implemented in the absence of strong theory? What would it look like to have a 'perfect control condition' in a fixation experiment? How should we distinguish between baseline and control conditions in fixation experiments?
- *Task constraints*. How constrained can a design task be whilst still permitting creative solutions and thus permitting fixation to be observed? What are the methodological benefits of setting constrained design problems? How does this affect data capture and data analysis?
- *Output uniformity*. For the purposes of assessment, how can researchers ensure that participants present their ideas in the same format even if they are in different conditions (e.g. see Vasconcelos, Neroni, & Crilly, 2016). Should design outputs be reformatted later by researchers (for

instance by redrawing their designs) so that the ideas are assessed without influence from the quality of representation (e.g. see Finke, 1990; Kudrowitz, Te, & Wallace, 2012)?

- *Data capture*. Are there better ways to capture design activities during fixation experiments? Would the use of digital design tools permit unobtrusive continuous (real-time) data capture? How could continuous data be analysed with respect to fixation? What else can researchers elicit from participants during a design task? For instance, can researchers implement self-assessment activities at different points in the design process (perhaps by asking, 'How clearly do you understand the problem now? How many ideas do you have at the moment?')?
- *Physiological measures*. Just as brain scanning and eye-tracking have been applied to the study of other phenomena, how might direct physiological measures be used in fixation research (e.g. see Smith, Youmans, Bellows, & Peterson, 2013; Bilalić & McLeod, 2014)? Can any physiological measures (individually or in combination) capture the moment when a new idea appears or when an old idea reappears (e.g. brain activity, pupil dilation, heart rate)?
- *Participant response*. How can researchers find out if participants' constrained exploration of the design space is truly 'blind' or whether it is a conscious or even intentional behaviour (e.g. through concurrent or retrospective protocols or post experimental interviews, see Chrysikou & Weisberg, 2005)? How can researchers capture ideas that participants think of but reject before communicating them? If, after the experiment, participants are made aware that there were other (unexplored) parts of the design

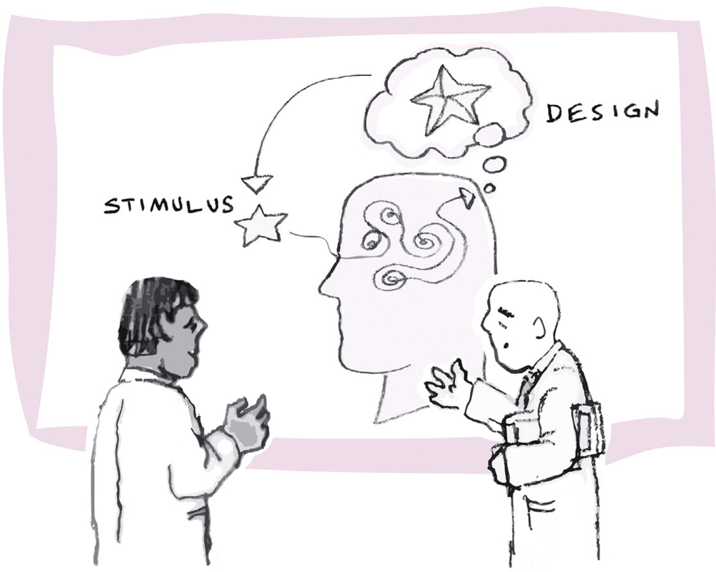

Figure 8 Experiments might be designed according to a better understanding of the underlying cognitive mechanisms that drive fixation or might be designed to allow such an understanding to be developed

space (see Luchins, 1942: pp. 25–48; Bilalić & McLeod, 2014: p. 77), how might researchers capture and analyse participants' responses to this?

- *Demand characteristics*. Although standard experimental practice requires that participants be blind to hypotheses (Orne, 1962), certain aspects of typical design fixation studies (e.g. providing example solutions) may provoke participants to draw inferences about what the researchers are studying (e.g. see Luchins, 1942: pp. 31–39). How can researchers best assess whether participants were influenced by knowledge of the hypothesis? How can experiments be designed so as to minimise the likelihood that participants suspect the kind of phenomena being investigated?
- *Stimuli introduction*. In typical design fixation studies, the stimuli (i.e. the example solutions) are explicitly presented to participants by the researchers (e.g. as an instruction for how ideas should be represented). This experimental manipulation of an independent variable (participants' momentary state of knowledge) allows logical inferences to be made about cause and effect. However, must fixating stimuli be introduced by experimenters? What happens if the stimuli are presented to the participants in an implicit way (e.g. when another team member sketches an idea)?
- *Fixation decomposition*. How can issues relevant to design fixation (e.g. underlying cognitive mechanisms, mitigation approaches) be broken down into components so that each component can be studied separately? Rather than considering these various components altogether, how could we disentangle the working elements behind them? (For an example from the domain of health psychology see Abraham & Michie, 2008.)
- *Individual differences*. How can researchers evaluate the role of individual differences in design fixation? What is the effect of different cognitive styles and processes (e.g. divergent and convergent thinking, cognitive flexibility, task switching, metacognition)? What is the effect of different personality variables (e.g. motivation, confidence, risk aversion)? Can we identify individual characteristics that might predict fixation results?
- *Design context*. How can researchers evaluate the role of context in design fixation? What role does context play in influencing how designers solve a problem but also the way in which they interpret and approach the problem? What is the effect of different physical environments, time pressure, rest periods, fatigue, concurrent activities, etc.?
- *Fixation metrics*. How can researchers establish standardised fixation metrics? What should be measured and how should it be measured? Are fixation metrics the same as creativity metrics (e.g. quantity, quality, novelty, variety, utility)? What can we say about fixation for each one of these metrics? What studies might be conducted specifically on design fixation metrics?
- *Objective measurement*. How can fixation effects be measured or reported in a more objective way? Is it the similarity between solutions that should be measured or the route taken from one solution to another? What opportunities are there for representing the exploration of a design space in ways

that are formal, automated, statistical or information-theoretic (e.g. see Cai, Do, & Zimring, 2010; Gero, 2011; Hanna, 2007; Kan & Gero, 2008)?

- *Methodological transparency*. Are there key experimental details or challenges that are not reported in the published studies? For example, how were the stimuli introduced to participants, and how was the introduction of those stimuli explained? Had the participants designed in response to this problem before? How was the idea assessment process conducted? How were the assessors briefed or trained? Were the assessors blind to the hypotheses or the experimental groups? Have the results been replicated, whether by the original researchers or others (for discussions of replication see Pashler & Wagenmakers, 2012)?
- *Procedural consistency*. Can agreements be reached for establishing a common set of design tasks, sample sizes, assessment procedures, reporting standards, etc.? Would this consistency permit better comparisons across studies or reveal where other variables have not been controlled or reported? Is this standardisation something that is important to achieve now or should researchers first conduct more exploration into how best to investigate design fixation? (For a related discussion of field-wide method development in software engineering see Kitchenham et al., 2002.)

Looking through the points above, it is clear that efforts to improve the experimental methods might take many different forms, whether that is through coordinating research efforts, incorporating new technologies, requiring different activities from participants or attending to different aspects of those activities. Any or all of these approaches would provide alternatives to the traditional methods used, whether they are used in combination with those methods or ultimately replace them.

2.8 What other research methods might be used?

All research methods have limitations and so using only a single type of method to study a phenomenon will inevitably yield limited results (Greene, Caracelli, & Graham, 1989). However, as is clear from any review of the design fixation literature (e.g. Sio et al., 2015; Vasconcelos & Crilly, 2016; Youmans & Arciszewski, 2014) that the majority of studies contributing to knowledge in this area employ experimental methods (see Section 2.7). That said, there are a few qualitative (Crilly, 2015) and mixed methods studies (e.g. Cai et al., 2010; Chrysikou & Weisberg, 2005; Hassard et al., 2009) focused on design fixation. There are also a broader set of qualitative studies in which fixation concepts are used to describe aspects of design behaviour, even if that is not the focus (e.g. Busby & Lloyd, 1999a, 1999b; Candy & Edmonds, 1996; Cross & Cross, 1996; Cross, 2011; Darke, 1979; Eckert et al., 2005; Herring, Chang, Krantzler, & Bailey, 2009; Robertson & Radcliffe, 2009; Robertson, Walther, & Radcliffe, 2007; Rowe, 1987; Roy, 1993).

Even when considering the work mentioned above, it is clear that research into design fixation is heavily biased towards the use of experimental techniques (see Figure 9). By not embracing a wider range of methods, fixation research stands in contrast to other areas of creativity research (and behavioural research more generally) where many different methods are applied (e.g. see Tashakkori & Teddlie, 2010). Furthermore, when considering the variety of methods that are used to study related concepts such as ‘cognitive entrenchment’ and ‘psychological ownership’ (see section 2.3), design fixation appears very methodologically restricted (for arguments against ‘mono-methodological’ approaches see Peer, Hakemulder, Hakemulder, & Zyngier, 2012). This restriction is unfortunate because a wider range of methods would help with understanding the contexts within which fixation occurs and the scale of the problem in practice (see Section 2.6). Such information would be useful independently of the experimental studies, but might also yield hypotheses that later experiments are designed to test (for related discussions in management studies see Eisenhardt, 1989; Eisenhardt & Graebner, 2007).

If design fixation is defined in a way that is independent of the methods that might be used to study it (see Section 2.3), then many possible methods might be considered, either individually or in combination. Some of these are discussed below.

- *Observational studies*. Research could observe fixation in naturally occurring settings, whether in professional or educational contexts. A challenge with such methods would be identifying the occurrence of fixation if design acts were not being verbalised. However, researchers could focus on design interactions that require verbalisation (e.g. meetings), or combine

Figure 9 Whilst fixation research has traditionally adopted an experimental approach, researchers might usefully consider many other research methods, which might be applied either individually or in combination

observations with interviews. (For a study of cognitive biases that includes observational techniques see Dodge & Frame, 1982.)

- *Interview studies*. Conversations with designers might focus on their awareness of fixation, their attitudes towards it and their accounts of naturally occurring examples (Crilly, 2015). Such studies are often subject to various forms of bias, including those related to recall and self-presentation. However, this might be mitigated by conducting interviews with groups and conducting interviews 'about' a set of drawings or other documents (see *Document analysis* below).
- *Questionnaire methods*. Surveys could be employed for gaining responses from large populations, especially for the generalisation of findings from existing studies or to see what factors those findings might vary with. This requires the participants to be able to reflect on the phenomena of interest, which poses challenges for studying fixation. However, collecting designers' accounts of the fixation episodes they have observed in others (e.g. colleagues, clients) could be informative. (For an example of a questionnaire focussed on cognitive biases see Peters et al., 2013.)
- *Document analysis*. Studies could focus on how existing sketches, models, reports, meeting minutes and other documents reveal evidence of design fixation. Such analysis might be more fruitful, where the 'rationale' for design decisions is recorded alongside the design outputs such as sketches (see Bracewell, Wallace, Moss, & Knott, 2009).
- *Action research*. Researchers might act to influence a design project with the aim of reducing fixation in a given context. For example, they might implement a change to the working practices of designers and document the effects of those changes. By working with designers (whether in education or professional settings), researchers would be able to intervene in creative work, recording both the effect that those interventions have and the way in which those interventions are accepted or resisted (see Section 2.6).

Many of the methods outlined above are qualitative, involving reflection on the part of the participants. This raises questions about whether fixation is something that designers become aware of after the fact (perhaps once alternative ideas have become apparent). We might also ask what relationship exists between the progress that designers are making and their perception of that progress? In the study of insight tasks, participants' perceptions of their proximity to a solution have been associated with *incorrect* solutions (Metcalfe, 1986), and it would be interesting to understand how this might relate to designers' perceptions of their design space exploration.

For those methods that are more naturalistic, fixation-related phenomena might be most easily identified when some form of communication occurs. The subtle aspects of how design spaces are explored might be difficult to identify in the practices of a designer working in isolation, but in design meetings these might become more explicit. This corresponds with related work in science studies, where Dunbar's (1997) investigation of analogy use in molecular biology focussed on presentations and meetings rather than other, more private activities. A similar approach might be applied to the study of design fixation, focussing on contexts in which designers communicate amongst themselves or with those outside the team, such as clients or manufacturers.

Broadening the range of methods applied to design fixation would yield a number of benefits:

- *Methodological Triangulation*. Because fixation research is dominated by psychology experiments, there are good opportunities to compare results across studies, but always studies with the same basic method. Employing more diverse methods would allow for comparison of results across studies that have fundamentally different data and where that data was collected in different contexts. Similarities and differences in the results might reveal things about fixation itself and also about the methods by which it is investigated.
- *Longitudinal approaches*. Fixation experiments typically only require short-duration design tasks and thus don't capture the temporal effects associated with concept generation (Tsenn, Atilola, McAdams, & Linsey, 2014) and concept development (Goldschmidt, 1992). By adopting methods that can be applied to the study of long-term projects, researchers might better investigate how design ideas arise, persist and develop over time (see Ball, Evans, & Dennis, 1994). New contributions could be made by studying design fixation not at one moment in time or over a short period, but in the context of an entire project or over the course of many projects (whether they are in sequence or concurrent).
- *Plurality of Concepts*. Because fixation is typically studied with experimental methods, the definition of fixation and related concepts has often been implicitly biased towards those methods. A broader, more inclusive set of concepts might arise when other types of study are conducted and other types of result are being interpreted.
- *Diversity of Researchers*. The bias towards experimental methods in fixation research biases participation towards those with a background in, or an aptitude for, experiment design and statistical analysis. Encouraging fixation studies to be conducted using other methods would also encourage participation from researchers with different backgrounds, theories, assumptions and skills.

On this last point, one way to encourage a variety of researchers to participate in studying fixation would be to capture and distribute a common dataset for analysis. One point of reference for this would be the Design Thinking Research Symposium (DTRS) series of events (e.g. see McDonnell & Lloyd, 2009). Capturing data that includes fixation-related phenomena and inviting participation by researchers who collectively specialise in a broad range of methods might be one way to open up the subject. Ultimately, the inclusion of other methods will bring with it other people and other perspectives, which can only serve to strengthen the study of fixation.

2.9 How should knowledge about fixation be applied?

Given the wealth of design fixation research that has been conducted, it is perhaps surprising that there has not yet been widespread application of the findings. This is a situation quite unlike that observed in other areas of design research, where enquiry into design practice has resulted in tools and methods that have been adopted in design practice (e.g. see Bracewell et al., 2009). Fixation researchers might look to other parts of design research or to other disciplines altogether to understand how best to move from studying phenomena (whether in the lab or in the wild) to applying the resulting knowledge in the real world (see Figure 10).

If knowledge about fixation could be formalised and communicated appropriately, then it could be applied in different ways, with each of those possible applications raising a number of unanswered questions.

- *Education*. What opportunities are there for explicitly identifying and introducing the concept of fixation in design education, and how effective is this (see Chrysikou & Weisberg, 2005)? Is it beneficial to induce fixation in students so that they become more aware of fixation risks? Should students be educated in how to recognise and manage fixation, whether in themselves, colleagues, clients or others? What design methods and creativity methods

Figure 10 Research findings from fixation studies might ultimately be applied in the form of interventions in design practice (e.g. in the form of training sessions for designers)

might be more effectively taught when they are reframed as approaches for combating fixation? (For an example of how education about fixation might reduce its occurrence in design students see Howard, Maier, Onarheim, & Friis-Olivarius, 2013.)

- *Training*. For practicing designers, what courses or workshops might be developed to introduce the concept of design fixation and ways to avoid it or mitigate it? Is encouraging designers to reflect on fixation an effective way of dealing with fixation (see Lane & Jensen, 1993; Luchins, 1942)? What other metacognitive strategies might be employed in combatting fixation? What design-based activities could be developed to encourage groups to recognise their individual and collective propensity to fixate? (For a discussion of how medics are encouraged to reflect on the cognitive biases that might influence diagnoses, see Kassirer & Kopelman, 1989; Croskerry, 2003; also see Morewedge et al., 2015.)
- *Tools*. What tools could be developed to better support designers in avoiding or overcoming fixation? Can tools be developed to provide designers with feedback on when they are becoming fixated? What tools might cause or exacerbate fixation and how might those tools be redesigned to change this? Can tools be developed to provide designers with feedback on when they are becoming fixated? What measurements (e.g. physiological measures) or other data would be required for this? (For a suggestion about the potential to develop physiological indicators of creative effort, see Silvia, Beaty, Nusbaum, Eddington, & Kwapilet, 2014.)

On this last point of informing design 'tools', one clear possible application of fixation knowledge is supporting the development of software that provides designers with inspirational stimuli. A prominent example is the 'Ask Nature' website (Deldin & Schuknecht, 2013), where users can request information about how biological entities realise certain functions (e.g. adhesion, cleaning, propulsion, etc.). Examples of biological systems are then provided, illustrated with photographs, diagrams, graphs and text, and with links to additional sources of information. These stimuli are intended to unlock designers' creativity, provoking them to think of new ways of solving technical challenges. In a similar vein, design researchers have developed computer support tools that assist in the construction and application of cross-domain analogies (e.g. Chakrabarti, Sarkar, Leelavathamma, & Nataraju, 2005; Shu, 2010; Vattam & Goel, 2011; Cheong & Shu, 2013; Goel, Vattam, Wiltgen, & Helms, 2012) and within-domain analogies (e.g. Barber et al., 1992; Maher, Balachandran, & Zhang, 1995; Pearce et al., 1992).

The development of computer-based design support tools might be improved if it were informed by detailed knowledge of design fixation. In particular, tool developers need to understand how the information they provide and the interactions they permit will enhance or constrain the creativity of designers (Töre Yargin & Crilly, 2015). As such, there is a need for knowledge about how many stimuli should be shown, what types of representations should be used, the effect of verbal cautions about fixation, the role of distantly-related stimuli, and so on (for discussions of 'distance' see Fu et al., 2013; Goldschmidt, 2011; Gonçalves, Cardoso, & Badke-Schaub, 2013). This is the type of knowledge that fixation researchers should be able to generate and then package up in a form that is useful to tool developers.

In providing guidance for tool developers, fixation researchers would be undertaking a form of Human Factors research, where the humans under study are designers (who are the users of the resulting tools). Despite its close relation to design research, Human Factors is a field of study that has not yet been extensively applied to the investigation of design fixation. Human Factors knowledge is typically applied to the study of how designs are used rather than the study of how designs are created. However, much of the conceptual and methodological apparatus that Human Factors researchers employ can be applied to the study of designing (as a human activity that is prone to error). For an interesting example of how this might look, see Thimbleby's (2016) analysis of the design of the Enigma machine, a design process which exhibited persistent failures to seek out more effective designs.

Irrespective of the specific ways in which fixation knowledge is applied, realising those applications would challenge fixation researchers to consolidate and communicate their findings. This would raise awareness of where gaps in knowledge are, where research results conflict or where confidence in those results is low. It would raise questions about the generalisability of those results, possibly requiring studies of how context-dependent these findings might be (whether they are specific to particular design disciplines, problem types, experience levels, etc., see Section 2.2). If fixation researchers were able to address these issues then they might be able to offer prescriptions for design practice that are well founded and well supported (see Vermaas, 2016).

Another benefit of seeking to apply fixation knowledge would be the development of a community of 'users' of fixation knowledge (e.g. those delivering educational courses, running training sessions and developing software tools). Such users might give feedback on what works and what doesn't, as well as making requests for new types of knowledge that they require to perform their work. Applying fixation knowledge would also provide new research opportunities for studying fixation. Research projects might be implemented to better understand the development of specific applications (e.g. classes, workshops and websites), the experiences of those involved and the eventual impact on design practice. Perhaps most interestingly, we might also find out the 'efficiency' of fixation interventions, studying whether efforts to avoid fixation outweigh the costs of becoming fixated. In summary, working towards the application of design fixation knowledge has the potential to impact practice and shape future research.

3 Final remarks

The workshop reported here was motivated by the observation that design fixation research is identifiable as a distinct area of study, an area that has been very productive and yet somewhat isolated and uncritical, lacking a forum for discussing future directions. By reporting on the outputs from the workshop, we hope that new opportunities for fixation research can be identified. Our intention is that the nine questions outlined here might stimulate renewed thinking about fixation and promote debate about where research should head next. We believe that such considerations are important if design fixation research is to realise its potential in providing a window into creative processes and providing knowledge that is actionable in improving design practice.

Whilst the workshop was extremely useful in opening up the discussion about where fixation research might go next, there is room for further exploration, either in response to this report or independently. At the workshop, some opportunities for such exploration were proposed, including specific conference tracks, position papers, shared data-set research workshops, and research-and-response articles in the style of those published in *Behavioural and Brain Sciences*. Adopting any or all of these approaches would encourage fixation research to move beyond the publication of individual research articles and towards the development of a coherent body of knowledge. Ultimately, by opening up opportunities to understand what is possible within the study of fixation, researchers have the opportunity to demonstrate the types of behaviour that they celebrate in creative design work: wide-ranging exploration and the avoidance of premature commitment. Only then can the most productive directions be identified and developed further.

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