Towards Digital Liminality:

Computational tools for 'beyond average' creative thinking

by

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Abstract

Renowned designer Kenya Hara writes: "Creativity is to discover a question that has never been asked". These questions are commonly discovered early in the design process; an often ambiguous and liminal experience where new information is explored and considered in non-obvious ways to reveal unexpected associations. 'Intelligent' digital technologies such as machine learning are increasingly employed in tools used in the early phases of the design process. These computational techniques undeniably surpass humans at quickly generating numerous designs and calculating 'optimised' responses, but their average-driven approaches are limited when it comes to embracing the serendipity that can inspire creative breakthroughs. How can we develop digital tools to augment this liminal period of the creative process and help designers discover unexpected ideas?

This dissertation explores this question through three new 'Beyond Average' systems that integrate ambiguity and serendipity into digitally-enabled design tools: the Reframe creative prompt tool that juxtaposes language from a designer's notes in surprising ways to provoke new associations between concepts in their project; the Looking Sideways inspiration exploration tool that presents a diverse range of content for each search query and suggests connections between the concepts discovered; and the digitally-augmented Design Daydreams ideation table and post-it note that seamlessly connects the physical and digital content that designers use in their creative processes. These systems were informed by field research and interviews with expert designers and their impact on the design process was evaluated through several interventions in which creative practitioners, entrepreneurs and technologists used the Beyond Average tools to inspire new ideas for their projects. These interventions highlighted that the creative disruptions these tools provoke cannot exist alone; they must be situated in a larger creative process that accommodates for serendipitous interjections and unanticipated ideas. Overall, this research demonstrates how embedding liminality into digital tools creates a space within the design process for serendipitous inspiration and helps designers apply these innovative ideas, pointing towards new questions to consider as we design the future of our creative work.

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Be careful what you wish for… when researching the storm of creativity, be prepared for a turbulent journey!

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Chapter 1.
Introduction

Renowned designer Kenya Hara (2007) writes: "Creativity is to discover a question that has never been asked". These are the questions that lead us to different interpretations, novel ideas and new schemas, or, as Coyne et al (1993) write, "entities that appear to cross over the boundaries between schemas." The further apart that these boundaries are and the more unrelated the ideas seem to be, the more important the new creative insight (Nielsen, 2011). If new ideas exist between these boundaries, how can we explore this threshold to extend our creativity?

1.1. Exploring A Digitally Liminal Creative Process

The liminal realm is the space between these boundaries where significant, transformational events can occur. Literally meaning "a threshold" (from the Latin līmen), liminality describes the quality of ambiguity experienced when we are standing on this edge of change; "betwixt and between" two worlds (Turner, 1974), able to step back to reflect on the status quo and explore the unknown (Howard-Grenville et al., 2011). It is in these transitions that "the normal limits to thought, self-understanding and behavior are relaxed, opening the way to novelty and imagination, construction and destruction" (Thomassen, 2016).

These liminal experiences contain whole worlds of possibilities; they are the seedbeds of creativity and new paradigms (Turner, 1974). They can also be a discomforting and unpredictable place; a space of questions over answers, imperfection over precision, unknown over known (Gray, 2016). If we are brave enough to wander through this ambiguous space, we can explore inspiring information, consider different meanings and reveal unexpected associations; activities that we often use in the early, nascent period of the creative process to discover new ideas.

Traditionally a very analogue process, we are increasingly using computational tools in our explorations for inspiring information and new ideas. In comparison to the playful ambiguity of the unpredictable liminal space, digital technologies often rely on discrete, predictable approaches. These computational techniques are very powerful at automating processes; genetic algorithms and machine learning programs can quickly generate a multitude of different design options and calculate 'optimised' responses to our questions. However, as Drucker (2009) writes, "bit by byte, the digital approach reinforces a mechanistic understanding" where "information takes on the character of that which can be parameterized through an unambiguous rule set." These artificial intelligent technologies can indeed help us find huge amounts of knowledge very quickly, but if we are not careful these machines can also pull us down very creatively problematic, average-driven, algorithmic rabbit holes.

The agendas of the digital tools we are increasingly using in our creative process tend towards predictability, not chaos. They are limited when it comes to embracing the ambiguity and unknowns of the liminal space; the unexpected possibilities that can often provoke the radical inspiration needed for creative breakthroughs. This dissertation explores this seeming paradox and asks: how can digital tools be developed to augment this liminal period of the creative process and help designers discover unexpected ideas?

1.2. Tools as Research Probes

> "[Tools] exist so that we may do more, see better, gather information, transform things, make decisions, investigate new frontiers, interact more fluidly and precisely, achieve higher forms of aesthetic satisfaction—extend our reach."
>
> –McCarty & McQuaid, 2015

Tools have been with us as long as humanity; ever since we picked up a stone and used it to crack open a nut. Paleoanthropologist Louis Leakey even considered that "the most significant step that ever was taken in human history, the thing that turns animal into man was this step of making tools to a set and regular pattern" (Meredith, 2011). They are among the first examples of human design (McCarty & McQuaid, 2015) and are integral to how we encounter our surroundings and "attain the results of our imaginings" (Decker in Piedmont-Palladino, 2007).

Tools are the material and intellectual extensions that can augment our physical and cognitive abilities (McCullough, 1998), and, as such, play a crucial role in all aspects of the creative process and in various forms. They can be the conceptual frameworks that provide "a vocabulary for constructively intervening in processes of meaning making" (Krippendorff, 2005) or the mechanical machines that help us expand the precision, complexity and scale of our work (Cardoso Llach, 2015). Their manifestation can vary from a general methodological representation of knowledge or processes such as a flow chart (Dubberly, 2004) or even games (Habraken & Gross, 1988) to a specific physical instrument in which certain affordances are embedded (Spier, 1970).

Their design and use may be abstract and ad hoc to fit into the early stages of the creative process (Mitchell, 1993) or more structured to integrate into discrete digital programs such as CAD (Loukissas, 2012).

Both for research and design, these tools can act as important catalysts to "realize what did not exist before, to introduce desirable changes in the world, to project the technological, social, and cultural consequences of a design" (Krippendorff, 2005). Being so closely intertwined with our creative process means these tools can have paradigm-shifting effects on the insights gathered and designs created. In the process of designing tools for a certain activity, we learn more about that experience, but also make decisions that shape the outcomes that we—and others who use our tools—produce. Especially today, when computation and digital technologies continue to play an increasingly important role in both society and our creative process, how can we understand the potential for change these tools have on our designs and the development of the very tools themselves?

1.2.1. Methodological Approach

In this dissertation, tools have both an inherent value in the design process and a methodological value in my research explorations; they are research probes. Cultural probes are a useful design research method when investigating relatively open-ended phenomena. Designed to provoke the user to engage with their everyday behaviours in new ways, the responses from these probes attempt to elicit dialogue, identify new opportunities and inspire further questions for my research. Like the creative process in general, their impact can be multi-layered and therefore difficult to analyse clearly; as their pioneer Gaver writes, these probes aim to "elicit inspirational responses from people—not comprehensive information about them, but fragmentary clues about their lives and thoughts" (Gaver et al., 2004).

Being a designer myself, my instinct is to transform even early research insights into practical experiments. Driven by a curiosity to understand the design process, many of these experiments have therefore been tools that both manifest and probe various aspects of creativity. The development of these tools was a process of iterative research-prototyping-feedback guided by grounded theory, where case studies and continual conversations shaped my understanding of both the creative process and the opportunities for new computational tools within it (Eisenhardt, 1989).

My overall methodological approach took primarily qualitative styles: semi-structured exploratory ethnographic field research and interviews, and more structured interventions where participants engaged with the tools I developed throughout this work as research probes. The exploratory research consisted of a six-week field research residency at the Cambridge (MA) studio of the design consultancy IDEO as well as one-off interviews with several professional designers throughout the course of this research. Conversations in these interviews were semi-structured, with questions ranging from: describe your design process; what outputs do you create throughout

your design process; what methods or tools do you use; where do you find inspiration; how would you change the technologies you use to improve your creative process? During analysis of these interviews and design project case studies, I used a loose coding structure to guide the identification of insights related to the types of activities that are underserved by current technology and develop a theory that could guide the development of new tools. Treating these Beyond Average tools as probes for understanding the role of digitally liminal tools in the creative process, I then carried out more structured interventions—ranging from 1-hour observed lab studies, to week-long unobserved 'in the wild' deployments, to semi-structured workshops and follow up sessions—to assess the usability of the tools as well as reflect on my underlying theory and assumptions for when, where, how and for whom these tools are most relevant. Open to the discovery of unexpected insights, I overlapped the collection and analysis of data throughout the studies to dynamically modify the methodologies of these interventions and ensure that the tools could become continually refined research probes.

1.3. Questions and Contributions

This dissertation presents a vision for a digitally liminal creative process and the tools that can augment it. Through field research, practical experiments and exploratory studies, I map out a new design space for digitally-enabled design tools and creative processes that employ ambiguity and serendipity to inspire new ideas. Guiding this research over the past five years were the following questions:

- What new frameworks can improve understanding of the role of computational design tools in the early phase of the creative process?
- What new computational design tools can be developed to explore how liminality can be better integrated into the digital tools used in the early phases of the creative process?
- How can these computational design tools influence and support new ways of thinking and the generation of novel ideas in the creative process?

Informed by field research and interviews with expert designers, these questions were explored through three new 'Beyond Average' systems: (1) the Reframe creative prompt tool that juxtaposes language from a designer's notes in surprising ways to provoke new associations between concepts in their project; (2) the Looking Sideways inspiration exploration tool that presents a diverse range of content for each search query and suggests connections for the concepts discovered; and (3) the digitally-augmented Design Daydreams ideation table and post-it note that seamlessly connects the physical and digital content that designers use in their creative processes. Using these tools as probes to explore my vision of a digitally liminal creative process, I evaluated their impact through several interventions in which creative practitioners, entrepreneurs and technologists used the Beyond Average tools to inspire new ideas for their projects.

This work led to the following contributions:

- An overview of the challenges of integrating liminality into computational approaches and a summary of the opportunities to augment the creativity these digital tools can provide within the design process.
- The introduction of three new 'Beyond Average' systems that integrate ambiguity and serendipity into digitally-enabled design tools: (1) the Reframe creative prompt tool that juxtaposes language from a designer's notes in surprising ways to provoke new associations between concepts in their project; (2) the Looking Sideways inspiration exploration tool that presents a diverse range of content for each search query and suggests connections for the concepts discovered; and (3) the digitally-augmented Design Daydreams ideation table and post-it note that seamlessly connects the physical and digital content that designers use in their creative processes.
- The development of the Beyond Average design space dimensions and application to a liminal ideation framework that shaped the evaluation methodology.
- Guidelines for designing tools for digital liminality, informed by findings from several multi-format interventions, and considerations for future exploration of the digitally-augmented creative process.

1.4. Dissertation Outline

Chapter 2 presents a brief introduction to the history of the relationship between computation and the design process and discusses the benefits and limitations of the current trend towards integrating certain computational technologies into the tools we use for design. Evaluating different models for the design process and how computational tools may be suited to the activities within them, I then frame the opportunity space for an alternative approach that will guide this research into developing more digitally liminal design tools. Chapter 3 builds on this approach with findings from field research and presents the design space dimensions that shaped the development of the 'Beyond Average' tools, described in Chapter 4. Chapter 5 then describes the interventions of the Beyond Average tools that were carried out to explore the different situations within the creative process in which these tools might be impactful. Finally, Chapter 6 distills the findings from these interventions into a set of guidelines for designing tools to augment a digitally liminal creative process and considers how this research can be extended to explore the future of the digitally augmented creative process.

Chapter 2.
Provocation Over Prescription

What is the best way to Larissa?

This is the question that Plato imagined his teacher Socrates and the Greek general Meno discussing (Plato). Since Meno was born in Larissa, he knew very well how to get there from previous travels. An inexperienced traveler could also use a map to make the journey most efficient. Or, as a tourist, he might wish to see the sites along the way and therefore take a less direct, but potentially more satisfying route. The more adventurous soul might just head out in the general direction and let chance guide her actions along the journey. The core of this dialogue is to question what knowledge is, but it also relates to an important consideration for any research into developing new computational design tools: how should they guide us?

After a brief introduction to the history of the relationship between computation and the design process, this chapter discusses the benefits and limitations of the current trend towards integrating certain computational technologies into the tools we use for design. Evaluating different models for the design process and how computational tools may be suited to the activities within them, I then frame the opportunity space for an alternative approach that will guide this research into developing more digitally liminal design tools.

2.1. A brief introduction to design and the computation of our creative process

Design has a long and diverse history. It ranges from the everyday things that we have always created to satisfy needs and organize our environments—design with a small 'd'—to more official disciplines that develop the mass produced artifacts and experiences that we are familiar with today—big 'D' Design (Margolin, 2015).

Probably the earliest definition of what a designer should know was described by Vitruvius in his treatise De architectura (ca. 15 BC): “Let him be educated, skilful with the pencil, instructed in geometry, know much history, have followed the philosophers with attention, understand music, have some knowledge of medicine, know the opinions of the jurists, and be acquainted with astronomy and the theory of the heavens.” Over the centuries since, design has transformed from this polymath definition to a set of more specialized disciplines: empowered by the printing press, graphic design practices were formalized; motivated by the growth of trade in the Renaissance period and the resulting need to scale, the design of artifacts became divided from the labour required to make them; responding to the technological advances in the Industrial Revolution and the desire for branded goods, the arts and crafts movement and mass-production techniques were combined through the practices of fashion and industrial design.

Driven by the desire to automate the manufacturing of these mass-produced artifacts, computation entered the world of design in the mid-twentieth century. Instructions became the language of the day; instructions to direct a machine (Cardoso Llach, 2015); instructions that abstract the craft of the design process into models that use a more algorithmic logic (Alexander, 1966); instructions that parameterise and optimize virtual representations of artifacts using Computer Aided Design (CAD) software (Kalogerakis et al., 2012). The manner in which we ought to instruct and automate these systems started to be considered extensively in the field of cybernetics and provides useful insights into the challenges for integrating computation into the design process today (Dubberly & Pangaro, 2015).

Cybernetics comes from the Greek word kybernētēs (κυβερνήτης) meaning "to steer, navigate or govern". Originally defined by Norbert Wiener in 1948 as "the scientific study of control and communication in the animal and the machine” (Wiener, 1948), at its most basic, a cybernetic approach takes feedback from a system to understand how to reach a goal in the most efficient way. Building on Plato’s analogy, as a crow flying over the mountains of Athens, we could navigate our way to Larissa using compass bearings along the most direct route, modifying our movements to get to our end goal.

Around this time, these principles of cybernetics and systems were being translated into design practice by designers, theorists and cognitive scientists. Design started to be considered by some as a process of problem solving, reasoning and argumentation; a ‘design rationale’ (Rittel, 1988). In response to the increasingly complex, post-industrial world that designers were now working in, the Design Methods movement was founded to advocate for cross-disciplinary systems thinking as part of a more scientific design process (Cross, 2007). One champion of this model of design was Herbert Simon, whose book The Sciences of the Artificial expanded ‘design thinking’ into a rigorous framework for decision making (Simon, 1996). Mechanistic in its execution, the design process became a flow chart of narrow questions and prescribed answers; a language that could fit neatly into the discrete digital language that machines understand. Just as Taylor’s analysis and ‘programming’ of humans working in factories meant that their roles could easily be transferred

to machines, computer scientists integrated these computational models of the design process into software programs (McCullough, 1998).

One of these first programs was Ivan Sutherland's Sketchpad (Sutherland, 1964). Described as a 'robot draftsman', it could algorithmically store information about the topology of drawing created in the system, allowing the user to align, move, scale and associate different elements of the sketch; the beginnings of parametric design! Since then, the paradigms of computation used in the design process have changed dramatically throughout the development of CAD technologies. Early tools such as Pro/ENGINEER continued along the parametric path, allowing engineers to set clear parameters and relationships between a database of features, requiring designers to explicitly plan and describe their 'design intent'. In comparison, newer direct modeling CAD systems such as Autodesk Fusion 360 allow forms to be 'sculpted', enabling designers to integrate more of their implicit intuition into their creations (Tornincasa & Di Monaco, 2010).

These CAD tools contribute to one aspect of the design process; the rational representation of the physical information of a designed artifact. These are the tools used by industrial designers and engineers to virtually model and perfect the physical forms and functional mechanisms of their creations so that they can be produced by machines. Until recently, many of these tools essentially mimic the processes of analogue tools with digital means, requiring the user's full attention to explicitly dictate elements of the design and drive the creative process (Pieters & Winiger, 2016). More ubiquitous today are systems that have a greater agency in the creative process, using feedback loops to automatically generate and iterate through alternative forms, optimising very early abstract expressions into refined, and sometimes unexpected, designs that satisfy a set of parameters (Sjoberg, Beorkrem & Ellinger, 2017).

Today, however, the culture of design has, as Antonelli (2011) writes, "shifted from the centrality of function to that of meaning." Design as a practice is no longer constrained to the shaping of forms; in today's digitally dematerialised world, the interactions with an object's control system must be designed to include more than just ergonomic affordances and efficiently followed instructions. Pioneered by Suchman's conversations with a photocopier (1987), user experience design was born and flourished throughout the late-twentieth century with the proliferation of computers throughout our workplaces. Popularised by Norman (1988), user experience design is a cross-discipline process that considers the graphical and industrial design of the artifact as well as the interactions with the system and emotional experience of engaging with the design.

Evolving from solely determining the physical attributes of an object, design as a discipline now largely comprises the outlining of the more conceptual elements of an artifact, interaction and experience. It involves understanding people's needs and imagining the wide variety of ways to meet them, through physical products as well as digital interactions and even immaterial services (Dubberly, 2017). Ideas are the medium of this dematerialized design discipline and exploring the landscape of numerous possibilities is a key aspect of the process. While less advanced,

computation is increasingly playing a role in this aspect of today's design process too; tools that use statistically-driven techniques such as genetic algorithms and machine learning programs can search through and present hundreds of potentially relevant pieces of inspiration or ideas, slowly automating the decisions we make in our design process. These new technologies are increasingly automating how we can find the 'answers' to our design questions, but are the questions they are answering leading us to new ideas?

2.2. The limitations of average

What kind of questions should we ask of our design machines?

Not all questions are equal; some guide us to 'neat and tidy' answers; some help us more deeply understand our existing knowledge; some even provoke us to question our own beliefs. So far, our intelligently augmenting computational tools have mainly dealt in the realm of 'neat and tidy' questions such as "what possible solutions fit these goals & constraints?" (Case, 2018). The genetic algorithms and machine learning programs that can be used to generate thousands of designs for a chair (Rhodes, 2016), automatically design your website (Tselentis, 2017), select images for your ad campaign that are 'on brand' (Nanos, 2018) or even write the script for a new TED Talk (Lapowsky, 2016) use these directed 'deep reasoning' questions to converge on a few quantitatively better 'answers' (Eris, 2003).

These are the questions that will direct us most efficiently to Larissa. We can ask machines many of these types of questions about our designs and they can lead us to 'neat and tidy' answers. These computational 'oracles' are not infallible, however, and the truths they give us are not objective. Even when we present these machines with the directed questions that they are more capable of engaging with, how sound are the 'answers' that we are given? To address this, we must consider how these machines answer these questions. At the very core of many machine learning algorithms is an equation called the 'cost function' or mean squared error, essentially an average of the data points from which the program is learning. It is through repeating this equation, this average, that a local or global minima can be calculated and the quantitatively 'optimal' solution converged upon.

While these 'technologies of the average'—if we can call them that—can help us find huge amounts of content in search engines or quickly generate designs from sets of data, the efficiency-based approach to analysing information used by these systems means we are only presented with the average of this material. As Cardoso Llach (Cardoso Llach, 2015) writes, these machines can't run the gamut of creative solutions, they only offer "the freedom to create exactly what is afforded by the system's multiple geometric, material, and computational constraints". Generating a design for a bicycle frame using optimising CAD tools such as the genetic algorithm driven Autodesk Dreamcatcher may just present iterations similar to existing form designs, not challenge the paradigm of a standard bicycle shape. Intelligent graphic design and website development tools such as Adobe Sensei and Wix (Ungerleider, 2017) that use machine learning may make the

sometimes slow process of image editing, positioning, labeling and even curating more automatic, but the often inadequate data sets used to train the algorithms can also lead to clichéd, mediocre and often discriminatory results (Buolamwini & Gebru, 2018). Using search engines like Google to explore the concept of 'chair' will unlikely inspire new ideas for the future of seating; you will most probably just get a collection of pictures that look similar or adverts for websites for where you can buy a new armchair. Pinterest boards which select images based on visual similarity are often becoming collections of homogeneously sleek designs; so much so that designers suggest that we have reached the "Pinterest singularity" and are shunning using it to find inspiration images in an attempt to not create average-looking designs (Gong, 2018).

By relying on these optimising tools, the designs we generate are becoming repeatable, predictable and standardised (Gertz, 2015); the opposite of the unknowns searched for in the liminal process but unfortunately the very goal of the 'technology of the average'. Integrating this standardising notion of the average into the design process is not new (Rose, 2016): from its original application to understand the diversity in human sizes (leading to the Body Mass Index), to its use in the field of scientific management (or Taylorism) to operationalize the processes of factory workers, to integrating it into standardized ergonomic measurements to design mass-consumable objects (Dreyfuss & Dreyfuss, 1967). But just as its applicability was questioned when it was discovered that none of over 4000 pilots matched all of the 10 average body dimensions that cockpits were being designed for (Daniels, 1952), perhaps we should be questioning the suitability of technologies that rely on an efficiency approach used in the early phases of the creative process. Just as design has shifted away from a purely material discipline—one that better suited the Taylorist, mechanical approach—the tools we use in today's more conceptual design practice must also evolve.

In comparison to this current computational approach that prioritises efficiency, the early phases of the design process need a less logical exploration full of reflecting on experiments lead by 'hunches' (Schön, 1983) and open-ended 'generative design' questions (Eris, 2003); we are the adventurers who prefer the surprises you can discover along the scenic route to Larissa! Especially when dealing with the often ill-formulated 'wicked problems' that we are designing for today (Churchman, 1967), the beginning of the design process feels like aiming at a shifting target where we often don't fully understand the problem, let alone have a defined goal (Rittel, 1988). The design space we are exploring is not fully known; it is only by pushing the limits of this space to expand into unknown territory that we can discover a novel way of doing something (Shah et al., 2003). Appreciating this flexibility in the early phases of the design process is very important because, just as "we shape our tools and, thereafter, our tools shape us" (Culkin, 1967), the inspiration we can obtain to guide our designs is being shaped by the agendas of the algorithms that rule the machines we use to search for new ideas (Domingos, 2015). The averaging, monopolizing, homogenising effect that these algorithms can have on the information and

knowledge we are presented with by these tools can be very creativity problematic because, as Lynch writes, "it is fuel: fuel for our ideas, our actions, everything" (Lynch, 2016).

The argument for integrating these efficiency-based approaches into our design tools is one of convenience (Carter & Nielsen, 2017). But can outsourcing our creative tasks to these overly automated 'user-friendly' interfaces contribute to cognitive inertia? Part of the creative process can indeed benefit from the competence and efficiency that these intelligent tools can provide (Steinfeld, 2017), for example the latter stages of physical product design projects that require precision engineering or the rapid generation of hundreds of alternative graphic designs. However, radical breakthroughs come only from considering concepts more abstractly (Fulton Suri, 2008) and challenging the existing principles in our fields (Nielsen, 2016); a core component of the creative process of artists, entrepreneurs and today's more conceptually focused designers. What is an alternative approach to modeling the design process—one that moves beyond the efficiently productive assembly-line approach that guided the development of our computational tools until now—and how can these digital tools augment, not automate, our search for answers to our design questions?

2.3. Designing between logic and intuition

We are in the age of models. The 'technologies of the average' described above often apply a reductive first-order cybernetic model that would have us explicitly identify a goal and design a solution for it. But this abstraction of the creative process into a 'science of design' is, Margolin (2002) writes, "too remote from actual design situations." Despite advances in science enabling us to decode our bodies into a book's worth of numbers and letters, much of our interactions in the world—and the designs we make for it—are not mere compositions that can be assembled and disassembled. Just as Thomasina ponders while stirring her rice pudding in the play Arcadia (Stoppard, 1993), "the spoonful of jam spreads itself round making red trails like the picture of a meteor in my astronomical atlas. But if you stir backwards, the jam will not come together again. Indeed, the pudding does not notice and continues to turn pink just as before."

The nature of design now includes both the shaping of the physical world as well as imagining the more immaterial, experiential domain. While machine learning algorithms are good at marching around a rule-bound universe to converge on a quantified optimum for, say, the form of a new ergonomically-customised shoe (Stinson, 2015), designers exploring new concepts meander around actively looking for multiple peaks to climb, often building entirely new ones to explore as well. We want to diverge away from known facts, create new rules and completely regenerate the landscape of possibilities around us (Mitchell, 1993). How can tools be developed that balance the definite, deductive, logical attributes of computation and the indefinite, inductive, intuitive elements of the conceptual design process? We need a more liminal model of the design process that leaves room for unknown ideas to emerge.

2.3.1. An augmentable model of the design process

As described earlier, there has been much research into trying to define a more logical structure for the design process; Dubberly (2004) diligently collected a staggering 88 of them. However, overly operationalising the design process to the extent that it can be automated by a computer has its limits; not only due to the convergent nature of the optimising technologies we are increasingly relying on, but also because the very nature of design keeps growing, including everything from the shaping of physical objects to pushing pixels around our screens to the restructuring of whole organisations. As Buchanan (1992) writes, "design eludes reduction and remains a surprisingly flexible activity."

Despite this lack of agreement, the many attempts to review and synthesise different models of the design process into an overarching taxonomy (Mendel, 2012; Wynn & Clarkson, 2005) generally divide the overall process into four phases—discover, reframe and define, envision and develop, and create and deliver. These phases are often concurrent and cyclical (Lawson, 2006; Blessing, 1994), offering a greater flexibility for the model to be augmented based on the context of the project and the idiosyncrasies of the designer. This model—commonly called the Double Diamond (Council, 2007)—can offer structure and freedom, divergence and convergence; a more liminal model that I will be using to understand the different elements of the design process.

Figure 1 shows a diagram representing the four phases of the Double Diamond design process model; two cycles of divergent and convergent thinking (Guilford, 1956), where many ideas are initially generated before being narrowed down to the chosen solutions. The discovery phase builds from initial hunches to collect diverse information and designers use their intuition to structure the often disparate data to reveal patterns and gather insights. In the reframe and define phase, designers take this information and use their imagination to juxtapose it in non-obvious ways to

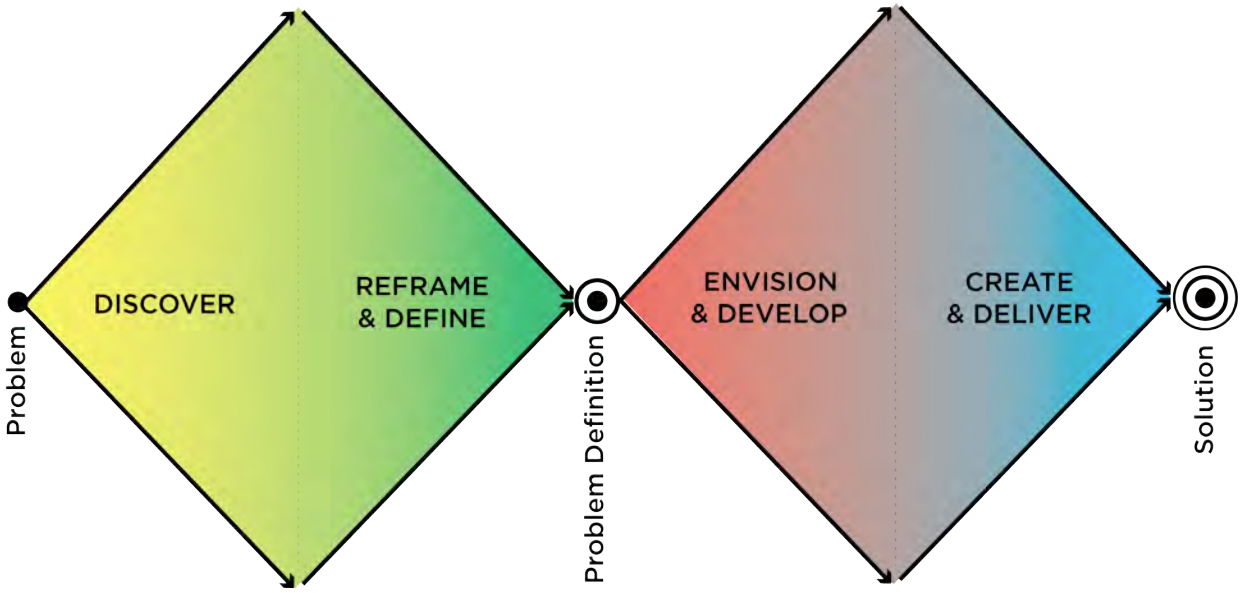


Figure 1. Double Diamond design process model (modified from Council, 2007)

"reveal new salience, relationships, and meanings" (Mendel, 2012). These are the opportunity areas which are the focal points for envisioning new designs, i.e. the creative brief to guide the next phases. Potential solutions or concepts are generated and evaluated in the next envision and develop phases, converging from many extreme envisionings to a few more concrete forms and final solutions in the final create and deliver phase.

Throughout these phases, designers go back and forth between considering concrete information and more abstract interpretations (Fulton Suri, 2008). Especially in the early phases that focus on design research and idea generation, designers bridge "the space in-between research and concept" (Robinson in Dubberly & Evanson, 2008). Moving between exploration and synthesis, designers use abductive reasoning—a form of logic that, unlike deduction or induction, allows intuition to guide the inference of new knowledge and insight (Kolko, 2010)—to translate models about what the current situation is into a future of 'what could be' through creating and playing with abstract concepts (Steinfeld, 2017).

This focus on more abstract interpretations in the early phases of the creative process may help to explain why there are fewer computational tools available to aid designers. Taking Gero's (1990) definition that design "can be modeled using variables and decisions made about what values should be taken by these variables", I suggest that it is in these first two phases that the 'variables' of the design are defined. They are where information is discovered and synthesised in new ways; the creative leap that crystallises the essence of an idea that then inspires a designer's imagination and creates variables to guide them throughout the rest of the project (Fulton Suri, 2008; Pahl & Beitz, 1996, in Wynn & Clarkson, 2005). These are the more tacit, human-driven moments of the design process where dreaming and playful exploration are used to "liberate thinking from old habits so as to break through to the Aha! moment of inspiration" (Schneiderman, 2007). The latter phases that assign values to these newly defined variables involve a more well-bounded deductive process which is better suited to the currently available computational tools that can iteratively test huge numbers of different values for those variables (Steinfeld, 2017).

In comparison, the early phases of discover and define contain these more tacit activities, such as collecting diverse information and reframing it in novel ways, that are not, as yet, served by many computational tools. Bernal, Haymaker & Eastman (2015) showed the dearth of computational tools in the activities in these early phases of the design process in Figure 2 shown below (modified to include the four design process phases); there are few dark grey and black squares (representing computer-aided activities) in the first two phases, mainly populated with white squares (representing human-based activities). They posit this is due to the fact that the explicitly-defined hierarchical data structures required for computer programs are limited in their ability to support the more heuristic, abstract thought processes and ad hoc methodologies present in the variable definition phase. This is the opportunity space for this research to explore new computational approaches suitable for these more abstract creative activities in which designers, artists and entrepreneurs discover new information and reframe it into conceptual ideas for their projects.

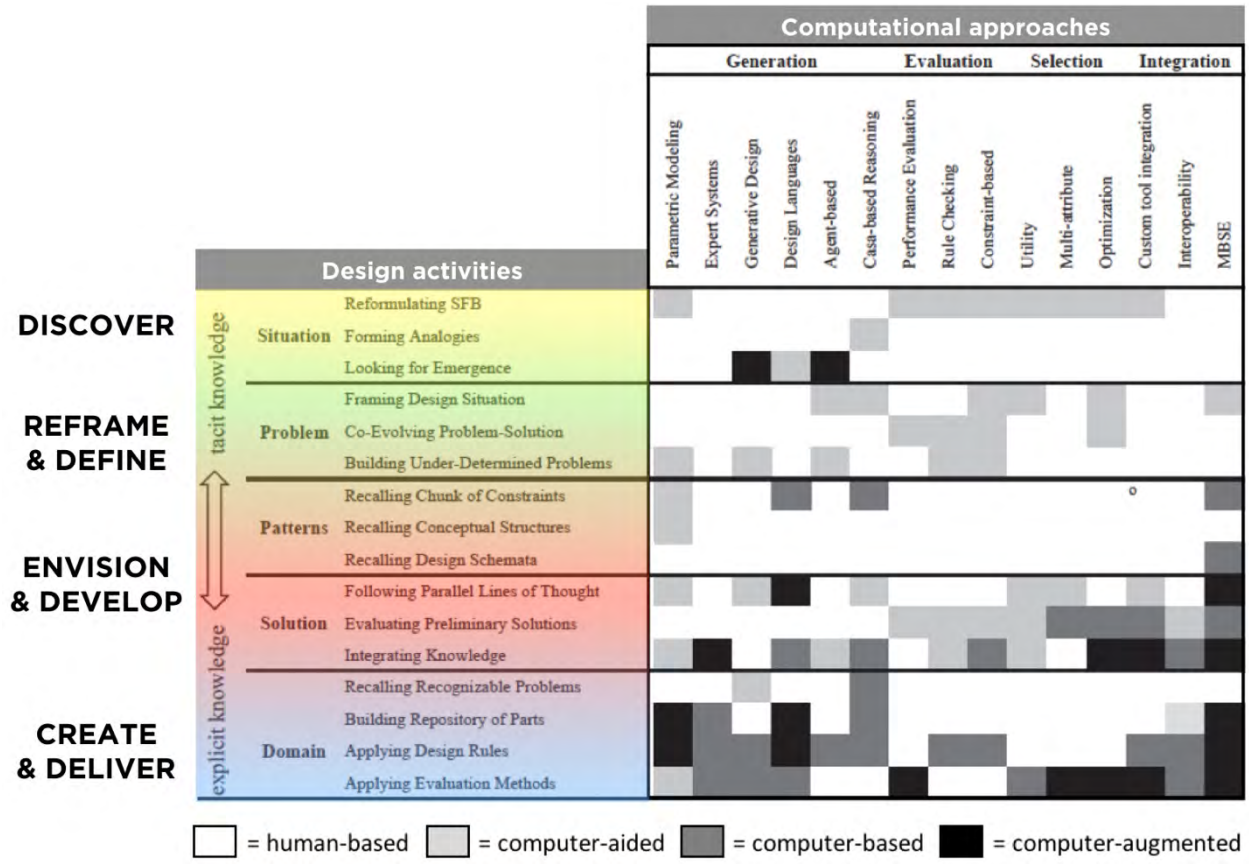


Figure 2. Bernal et al's (2015) diagram of human and computational tools available for the 'actions' in the design process with additional coloured bands added to show the four overlapping design phases

2.3.2. Computational approaches to augment the early phases of the design process

So what computational approaches, if any, can be useful in the early phases of the design process where new conceptual ideas are explored? In order to evaluate the landscape of computational tools available today, it is useful to identify some general activities and examples of tasks within those activities that are often carried out in the discover and define/reframe phases. A review of the literature collected a range of these activities and tasks (see Appendix 1), a summary of which are described in Table 1. This list is not proposed to be exhaustive; they are merely 'primary generators' (Darke, 1979) to act as a guiding structure for analysing which computational approaches may have potential in the early phases of the design process.

Table 1. Summary of design activities and tasks in the first two phases

Design Phase	**Design Activity**	**Design Task**
Discover	Gather disparate information	• Use initial insights to find related information • Think about initial insights and information in different contexts • Create divergence using associations, abstractions and analogies
	Sort information	• Collect information in a way that allows easy analysis and comparison, e.g. annotating, tagging and database structures • Decompose information into related attributes/categories • Use structure and categories to look for patterns and questions
Reframe/ define	Generate hypotheses	• Present and recompose information in many representations (word/image) to create stories for possible design alternatives • Allow for ambiguity in these hypotheses to encourage multiple interpretations
	Identify novel directions	• Use analogy or different contexts to interpret information in new ways • Recombine/mutate/substitute the information in new ways to create wildly unexpected inferences and moments of illumination

Reviewing various real world design projects and technology-driven art experiments through the lens of these design tasks, several computational approaches that can contribute to these early phase activities are described below.

Tools to find related information

The discover phase involves searching for and organising the information related to a design situation in unexpected ways; tasks that even advanced optimising parametric CAD tools such as SolidWorks or Autodesk Dreamcatcher do not provide extensive support for (Bernal et al, 2015). The computational tool that designers often use to help them find information related to their initial prompt is the now ubiquitous semantic search engine such as Google. In this technology, the machine learning technique of dimensionality reduction abstracts a large database that uses many dimensions to connect the information into a smaller, more manageable set of key features using linear and non-linear mapping (Barysevich, 2017); not dissimilar to how designers navigate information about their projects to learn from related fields (Finke et al, 1992; Mendel, 2012).

A tool that can execute these operations on a corpus of text, and one that forms the basis of many Natural Language Processing tools, is word2vec (www.tensorflow.org/tutorials/word2vec) (Mikolov et al, 2013). Words are assigned a number based on their connection to others, forming a vector that can be used to compare words in different contexts and find similarities through it's direction and location. A similar strategy can be used to compare images, with a popular algorithm being t- SNE (Maaten & Hinton, 2008); Figure 3 shows sketches from Golan Levin and David Newbury's (2018) Moon Drawings project sorted into similar styles (McDonald, 2016).

Taking this further, Yossarian (www.yossarian.co) adds a 'metaphorical distance' to this vector to return connected words and images with a more diverse interpretation of the initial word and image input by the designer (Figure 4). The details of the technology are not public, but we postulate it does this by adding a factor to change the distance or direction in the vector mathematics connecting the entities in the database. Working with poet Helen Mort to help provide inspiration to write a poem a day ("Helen Mort's poetry challenge with Yossarian", 2015), Yossarian allowed Mort to more quickly connect diverse themes, a crucial part of the early creative process (Minissale, 2013). This computational tool of dimensionality reduction with a vectorising factor to extend the metaphorical search capabilities could therefore potentially help designers find unexpected information in their search activities, leading to more novel design solutions.

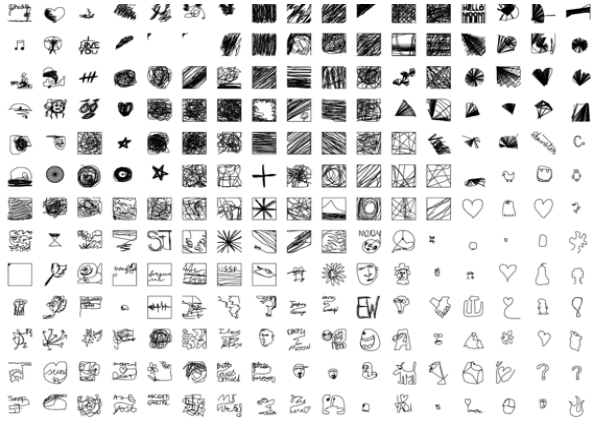


Figure 3. MacDonald's (2016) sorting of Levin and Newbury's (2018) Moon Drawings project sketches

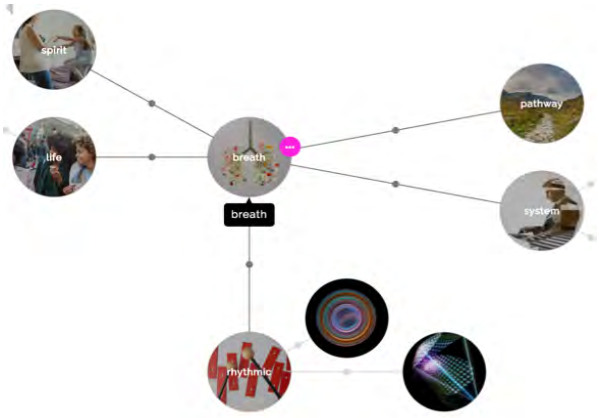


Figure 4. Yossarian metaphorical search engine

Tools to find analogous information

Traditional CAD tools often use very structured procedural knowledge and pre-defined geometric relationships to automate certain actions (Bernal et al, 2015), e.g. automatic patterning of shapes in SolidWorks or Adobe Illustrator. This limits the ability of these tools to integrate analogical information into their operations; an important feature to allow for divergent thought and idea generation in the discover phase (Gero & Maher, 1993).

Computational tools with this ability are machine learning techniques such as convolutional (CNN) and recurrent (RNN) neural networks prevalent in image and language processing tools such as IBM's cognitive system Watson. CNNs are useful for image recognition as, after 'learning' patterns from a large training set of tagged images, they can distinguish parts of images related to different categories. RNNs use feedback systems to continually learn about the training set and modify the patterns they observe, making them good at parsing and generating new text.

'Living Sculpture' by SOFTLab is a project that used these tools to broaden the perspective of the designers while exploring and identifying trends in the materials, shapes and colours that Gaudi used in his work to influence development of a new sculpture (Lewis, 2017a). Feeding hundreds of tagged images of Gaudi's work, Barcelona and its culture into Watson's Visual Recognition tool taught the system how to recognise the components of those images that 'looked' Gaudi-esque and those that didn't. The system could then compare them to other unrelated images in the database to see if there were any similarities, e.g. it recognised that many of the Gaudi images had depictions of spiders in them. Similarly, Watson's AlchemyLanguage tool analysed various documents about Gaudi and his work as well as Catalan culture, nature and design to identify the most prevalent keywords and concepts. The concepts highlighted using these tools included objects such as 'waves', 'arches', and 'spiders' which were very obvious to the designers familiar with Gaudi, but Watson also helped identify less immediately apparent but very inspiring connections such as the forms, materiality and colours of 'crabs', 'shells' and 'candy' (Wiltz, 2017). The similarity of SOFTLab's work to these elements in Gaudi's designs can be seen in Figure 5.

SOFTLab designer Michael Szivos described how Watson's cognitive tools helped them to carry out the tasks they normally do without computers in the early conceptual design stage of a project such as "look at references and try to extract fundamental ideas that we then re-translate into a specific project" (Lewis, 2017b). Integrating these computational tools of CNNs and RNNs into design tools could help designers expand the initial information they explore but also quickly parse it to identify both expected and unexpected findings; a cybernetic design psychedelics of sorts!

Figure 5. Gaudi's Casa Batlló (left) by Amadalvarez (CC) and SOFTLab & IBM's Living Sculpture (right) showing similar iridescent patterns (SOFTLab, 2017)

Tools to annotate information

Collecting information in a way that allows easy analysis and comparison later in the design process is a useful strategy in discover phase. Computer assisted qualitative data analysis (CAQDAS) tools to aid the tagging (or coding), sorting and analysis of information collected during research in a design project, such as ATLAS.ti and NVivo, allow researchers to search and pull out common themes from their data, but also require a very manual coding process (Saldana, 2009); the computational tools described above, on the other hand, only require some of the data to be tagged. A subset of these techniques called unsupervised learning algorithms help automate this process; tools that use CNNs and RNNs, such as the Clarifai application (www.clarifai.com), can learn from a training set of data to automatically tag a wider corpus of images or video and understand the categories present.

Overlapping coding with other stages of the research process can help generate new hypotheses (Eisenhardt, 1989). What if the tools that helped us code the research could also inspire new ideas? An interesting development of this technique created by Fito Segrera is The Treachery of [Soft] Images (2016); a homage to Magritte's painting of similar name where an image of a pipe is described as not being a pipe (Figure 6). Here, images found on the internet are put through a neural network that labels them with humorous—and potentially inspiring—misinterpretations.

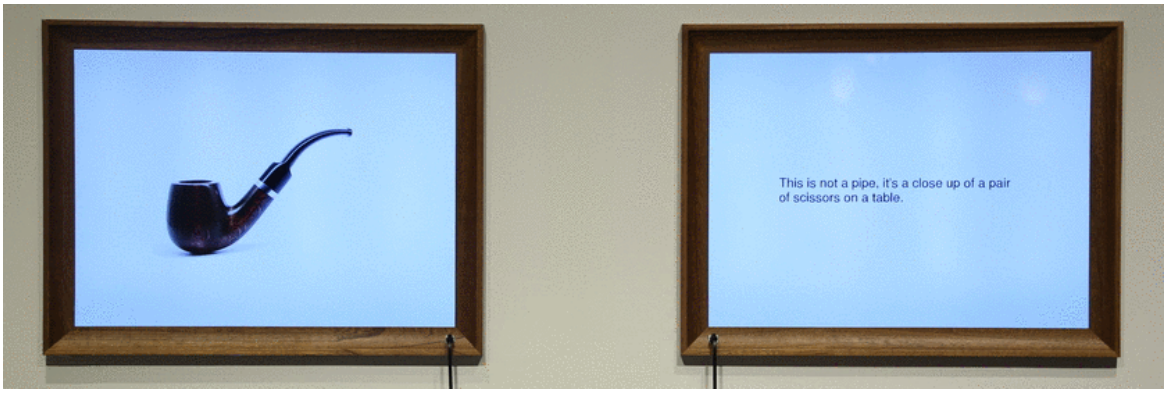


Figure 6. A still from Fito Segrera's installation The Treachery of [Soft] Images (2016)

Tools to identify patterns in information

Traditional CAD systems such as SolidWorks often require a design to be decomposed into its underlying attributes, often limited to geometric properties, in order to store and relate them to each other parametrically, e.g. specifying the points which make up a curve (Tornincasa & Di Monaco, 2010); the decomposition required in the early design process requires different computational tools to identify attributes, find patterns and inspire related categories.

As with the projects described above, it is the combination of CNNs with a dimensionality reduction algorithm that can help decompose and structure the text and image-based information used early in the design process. One such tool is t-SNE (Olah, 2014) which allows an image to

be assigned a numerical description associated to the different categories that it is related to. This numerical description can then be compared to others and the images grouped on their visual and contextual similarities (as Karpathy (n.d.) has shown in Figure 7). Taking this further, McDonald (2016) has used t-SNE to place all of the underlying categories of the images in a database next to each other, showing what objects are often found in similar contexts despite being visually different, e.g. pill bottle, band aid and lipstick are grouped closely due to them being found in bathrooms (Figure 8). These tasks—understanding the underlying attributes of images and sorting them based on their classifications—are currently very human-based; integrating this computational technology into a design tool could help designers more quickly structure their research into constructive categories.

Figure 7. Karpathy's (n.d.) visualisation of the similarity of images

Figure 8. McDonald's (2016) representation of the similarities of image categories

Tools to recompose information

In the early phases where ideas are being defined, designers often imagine how the information collected in the discovery phase could be considered and recombined in new ways to inform future design solutions. Chance has played a large role in this method of generating new ideas for centuries and creative writers and artists—most notably the Dadaists and Surrealists—have often used tools that purposefully incorporate non-predictability and provoke ambiguity or absurdity and help them to generate new possibilities for their work (Gaver & Dunne, 1999; Dorin, 2013). Accessing the higher powers through the I Ching, the ancient Chinese method of interpreting a divination text through the random throwing of sticks or dice, has also been used to inspire creative paths for artists such as John Cage and Philip K Dick (Mountfort, 2016). Absorbing these stochastic muses into the digital world, algorithmic artists such as Vera Molnar and Frieder Nake generated art using computers, finding a balance between controlling the structure of the macro-aesthetic and allowing randomness to make decisions about the micro-aesthetics (Nake, 2005).

Computational tools that integrate these chance processes to provoke new design ideas include story generator algorithms (Gervás, 2012) where a predefined structure of a short story or letter or plot is randomly assigns nouns, verbs, adjectives etc. provided by the user into appropriate places (https://www.plot-generator.org.uk/). Despite being so simply structured and often generating ridiculous, unrefined compositions, the ambiguity of the output creates very unexpected and inspiring juxtapositions of concepts and themes. Taking this further, the short film Sunspring used a RNN machine learning algorithm to learn the structure and style of sentences used in dozens of sci-fi screenplays and then generate the content of the script from scratch (Newitz, 2016).

Considering how we might recompose information related to images, much can be learned from the field of data visualisation (Tufte & Robins, 1997). CAQDAS systems integrate some simple visualisation features but are limited in the creative explorations that designers require in these early phases (Bhowmick, 2006). Data visualization artists such as Jared Tarbell have created tools that explore more creative ways of representing data using computational processes that randomize the fonts, sizes and positions of text and images (Figures 9, 10 and 11). These computational tools could help designers juxtapose unexpected concepts from their research by allowing them to intuitively 'find' the elements that inspire them, like gazing at Leonardo's paint stained wall that inspired deliberate accidents (Turner, 2011) but with more purposeful information embedded in it. These visualisations could even become an immersive experience as CAD systems that integrate virtual and augmented reality technologies become more readily available (Arnowitz, Morse & Greenberg, 2017).

Figure 9. Cylinder Image Display by Jared Tarbell (http://www.levitated.net/daily/levCylinderImage Display.html)

Figure 10. Text Space by Jared Tarbell (http://www.levitated.net/daily/levTextSpace.html)

Figure 11. Emotion Fractal by Jared Tarbell (http://www.levitated.net/daily/levEmotionFractal.html)

Tools to mutate information

Once the diverse information related to a designer's initial ideas has been collected, and categories have been identified and presented in novel ways, it must all be synthesised into original ideas that can guide the design as it is developed. These new ideas often come from reframing, recombining or mutating the original information and categories into new contexts or interpretations (Gero & Maher, 1993). Despite the real-time manipulation and generation that direct modelling and generative CAD tools such as Autodesk Fusion 360 and Dreamcatcher respectively offer, they merely present a range of options that hope to provoke the 'Aha' moment of inspiration; the human designer is still needed when engaging with these tools to think critically about what is being designed and 'nudge' the algorithm in the preferred direction (Bernal et al, 2015; Bruner, 2016).

The lack of accuracy in predictions generated by the computational tools discussed above can actually help provoke a more inspiring range of design ideas related to the information collected in the discovery phase. Google's Quick, Draw! App (https://quickdraw.withgoogle.com/) is a tool that runs a CNN in real time while the user is sketching a picture and offers many speculative guesses as to what is being drawn (Figure 12); like a game of Pictionary. As the system continually provides guesses of incomplete images, the user is presented with a range of interpretations not associated to the initial intent of the drawing. This creative misinterpretation is not an unfamiliar activity in the design process; a designer's colleagues may see a half drawn sketch and interpret it as something different to the designer's original intent, often inspiring a new idea for their design (Stacey, Eckert & McFadzean, 1999).

Figure 12. Google's Quick, Draw! app showing interpretation of a cat sketch also as a spider, airplane, campfire, etc.

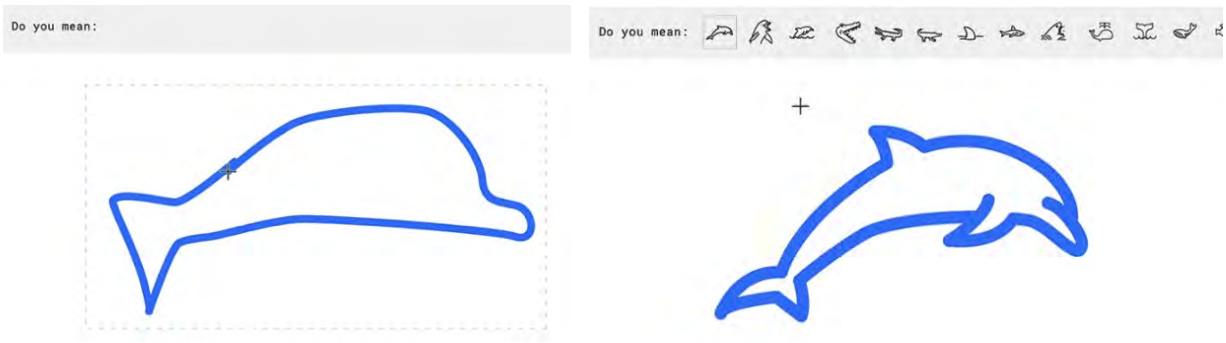


Figure 13. AutoDraw suggesting alternative illustrations for a sketch of a dolphin

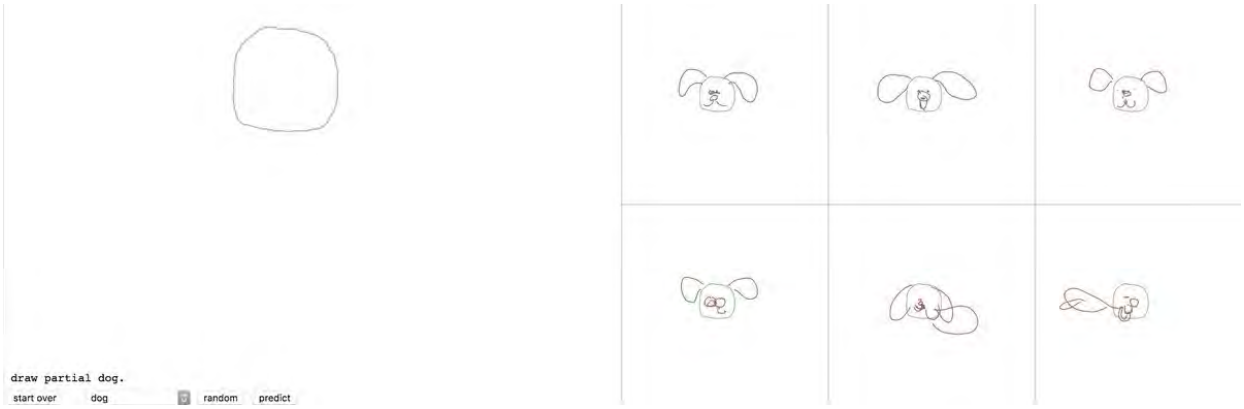


Figure 14. Magenta's sketch-rnn generating sketches of a dog from an initial basic sketch

Taking this idea further, the AutoDraw app (https://www.autodraw.com/) guesses what the user might be drawing and then uses CNN to find many different illustrations of a similar context from a database (Figure 13). Again, this offers the designer an interesting real time interpretation of the information they are inputting into the system. Adding RNN to this tool, as in Magenta's sketch-rnn demo (https://magenta.tensorflow.org/sketch-rnn-demo), allows these alternative illustrations to be generated from the actual sketch that the user draws (Figure 14).

A more advanced version of these sketching tools are the style transfer algorithms like Google's DeepDream that have become popular in the last few years (Steinfeld, 2017). In these "design by example" tools, CNNs are used to detect the set of context and style features in different images and a feedback technique is used to slowly change the style features of one so that the difference between the two images is reduced (Tejani, 2016). McDonald (2016) has explored this technique extensively, transforming an image of Marylin Monroe and Mount Fuji into versions that could have been painted by all of the artists throughout history (Figure 15). Refining this technology, Korsten and Flores (2016) 'learned' the style of 17th century master painted Rembrandt and generated a completely new artwork in his style. Integrating more of the user's input for which areas should be 'transferred' between images, Champandard (2016) uses visual analogy to demark areas that have certain categories in the style image, e.g. marking a tree with brown pixels. The

user then 'paints' a new composition using the same colour scheme and the CNN transfers the style learned from that section of the image to those areas of the new composition (Figure 16).

What is exciting about these computational tools is that these techniques are not unfamiliar to artists, who have been learning, integrating and modifying other artist's styles for centuries. While not achieving the standards of a professional artist, these algorithms provide enough of an idea of what one image in another style would be like—similar to the analogies that designers often apply in their early experiments (Hey et al., 2008)—to inspire the aesthetics and 'feeling' of the design that they will develop.

Figure 15. McDonald's (2016) style transfer studies (see more at www.kylemcdonald.net/stylestudies/)

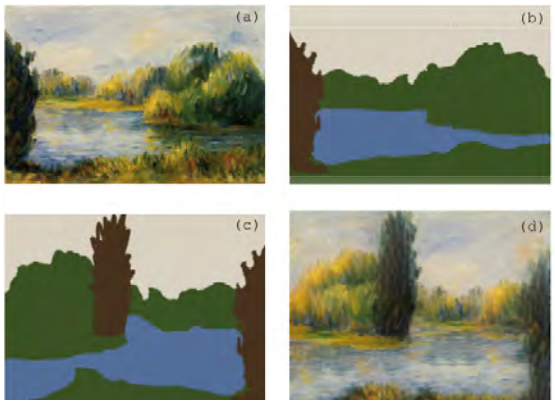


Figure 16. Champandard's (2016) analogy style transfer examples, (a) Original painting by Renoir, (b) semantic annotations, (c) desired layout, (d) generated output.

From this analysis, some key computational mechanisms stand out as opportunities to contribute to the development of computational tools applicable to the early phases of the design process. In the discover phase, the activities involve gathering and sorting disparate information. Machine learning algorithms are excellent computational mechanisms to parse and categorise the initial information that a designer inputs into a design tool, such as their design research notes, interview transcripts or even inspirational images. Integrating factors that allow for a looser connection between the classification of the data can particularly help the system to search for more analogous information, extending the range of material that the designer can be inspired by. In the reframe/define phase, the activities focus on generating hypotheses and identifying novel directions. In these design tasks, computational mechanisms using stochastic processes to juxtapose the information from the discover phase in new ways, e.g. using visualisation tools that play with the position, size and style of the text and images, could help designers to imagine unfamiliar concepts and novel design ideas. Simple randomising functions and more advanced machine learning algorithms used in story generators and style transfer algorithms can also be used to generate new design 'prompts' for designers to consider and hopefully be inspired by.

2.4. Embracing Uncertainty

From this review of tools, it appears that, unsurprisingly, the activity of 'sorting information' in the discover phase is well served by current computational technologies. However, to generate truly paradigm-shifting 'creative' designs, this early exploration relies on "the introduction of new variables into the design process, variables which were not originally considered by the designer or design system" (Gero, 1990); a task that computational technologies do not well serve at present. Recombining existing and new design elements in unexpected ways to discover new variables that can shift the direction of the design development is a particularly human skill and enabling computational tools to "trigger unpredictable inferences" is a key area of development identified by Bernal et al. (2015).

The tasks in the 'Gather disparate information', 'Generate hypotheses' and 'Identify novel directions' activities involve the often serendipitous creative challenges that humans are very good at: considering different contexts, finding new interpretations, embracing ambiguity and seeming irrelevance, and finding new associations through our innate desire to find patterns and analogies. Purposely integrating noise into the very predictable and controllable systems we are so familiar with can "create a margin of error in which creative interpretation and misinterpretation might thrive" (Bernes, 2017). If we are open to exploring these moments of creative reinterpretation, we might discover entirely new approaches to a design problem and invent "ways of thinking which haven't yet been invented" (Nielsen, 2016).

Perhaps we don't always need these intelligent tools to be that 'smart' or provide us with such optimised, unambiguous responses. Rationality is powerful when we want to be able to understand and repeat a process but can, as Jones (1980) writes, all too easily become "a toolkit of rigid methods that obliges designers and planners to act like machines". The ambiguity provided by imperfect technologies and randomness delivered by 'dumb' AIs can actually augment our human smartness, and potentially even our creativity (Shirado & Christakis, 2017).

This was something that I learned first hand through the development of an earlier project called the EmotiveModeler CAD tool, a plugin for the Rhinoceros CAD software that allowed users to use expressive adjectives to manipulate 3D forms (Mothersill & Bove, 2015). While the EmotiveModeler project was successful in constructing a simple shape grammar for stereotypical perceptions of emotive character in objects, the rationalist database approach I took was very limited when situated in the early more exploratory phase. This would have been compounded if the tool only presented one 'answer'. The surprising learning came through inclusion of an interactive toolbar which allowed designers to change the levels of emotions connected to a word to modify the resultant shape to one that they preferred. The designers suggested that the output of the EmotiveModeler didn't need to be perfect as they preferred this conversational style that prompted them to examine their hunches and consider new approaches. What started as a more traditional industrial design tool to aid the rational representation of a physical object became more

of a tool to help designers consider the overall meaning of engaging with the artifact; a conceptual design tool that provoked different interpretations and new ideas.

These unexpected creative possibilities that an imperfect liminal process can illuminate were embraced by psychologists and creativity researchers Edward de Bono and William Gordon. Bono (1970) coined the now famous creative practice of lateral thinking, which utilised the fact that the human mind is very efficient at recognising patterns; if we are presented with information which does not immediately seem relevant, we naturally try to 'make sense' of it. A large part of a more liminal design process is, therefore, "inseparable from perception and interpretation (that is to say, from experience)" (Cardoso Llach, 2018); an approach also embraced by early computational design researchers in shape grammar theory (Stiny, 1998). Taking this further, lateral thinking actively welcomes chance intrusions, irrelevance, and ambiguity in order to provoke the restructuring of information and synthesis of new patterns and ideas (Bono, 1970). Adopting processes and tools that provoke less literal analogies and metaphors that "systematically [disorganise] the common sense of things—jumbling together the abstract with the concrete, the physical with the psychological, the like with the unlike—and [reorganise] it into uncommon combinations" (Geary, 2011) can, therefore, help push our abductive sensemaking to new horizons. Gordon embraced this strategy in the practice of synectics—literally meaning "the joining together of different and apparently irrelevant elements" (Gordon, 1961)— where 'perfect' ideas are rejected in favour of the non-rationality that can generate more evocative metaphors and seeds of inspiration.

If ambiguity and openness to chance interventions are important aspects of the early phases of today's more conceptual design process that can help us discover new ideas, then a promising direction to explore is the unpredictable creativity that can happen when the tools we use in those design activities exist in the space between the logical structure of a database and the intuition of a human designer. In contrast to the drive for quantification, optimisation and 'intelligence' in current technologies derived from traditional physical and precision-driven computational design tools (Sjoberg et al., 2017), this research explored how the more serendipitous principles of creativity—those of seeming irrelevance and ambiguity—can be used as an approach for creating new computational tools more applicable to today's increasingly conceptual, product and service design disciplines. The following sections describe the 'Beyond Average' approach I have taken to develop more digitally liminal design tools and the evaluations carried out to understand how they can be used to generate new ideas.

Chapter 3.
Structured Serendipity

Once upon a time, three princes of Serendip went on an adventure. On this adventure, they used their keen powers of observation to help a fellow traveller find his missing half-blind, one toothed, butter-carrying camel by considering how the patterns of chewed grass, footprints and spilled cargo could be connected. This Persian fairy tale of how the princes were "always making discoveries, by accidents and sagacity, of things they were not in quest of" (Andel, 1994) was the metaphor used by British aristocrat and art historian Horace Worpole to explain a fortuitous unsought finding in a letter to a friend in 1754; and so the term 'serendipity' was born.

The above chapter describes how our current digital tools can limit our ability to discover these serendipitous unsought findings, a quintessentially ambiguous yet crucial part of the early phases of the design process (Merton & Barber, 2011). As Zuckerman (2013) writes, this offers a great opportunity for how we can design our future technologies: "In the next ten years, I expect that tools that enable serendipity, that help us stumble on unexpected and helpful information, will become as important a utility as search engines and social networks are today." But how do we design for serendipity? In this chapter, I discuss how field research with expert designers led to design space dimensions that shaped the development of the 'Beyond Average' tools.

3.1. Designing the 'Aha!' moment

To further investigate the tools and techniques designers use in their creative process to find inspiration and develop these ideas into final designs, I conducted ethnographic research during a six-week residency at the design consultancy IDEO and interviews with several professional designers at small digital design agencies. Analysis of these 18 conversations with designers from a range of disciplines—industrial design, interaction design, communications design, design

research, design engineering, business design, web development—resulted in case studies of several real world product design projects, whose final outputs included research-inspired concepts, physical objects, digital communications websites and apps. These case studies were synthesised into maps representing the different activities carried out by the designers and what type of tools or knowledge—declarative i.e. general design facts, procedural i.e. general design methods, situational i.e. contextual application of facts, and strategic i.e. situational application of methods (Ahmed et al., 2005)—they used to develop their ideas (two are shown in Appendix 2).

Consistent with the above literature, this research revealed the lack of a generalisable overall process. Despite this, many of the design activities—such as 'metaphorical inspiration' or 'extreme themes'—were present in all the projects. The types of knowledge and tools used were also more general across projects, with declarative and situational knowledge used earlier in the design process and strategic and procedural knowledge towards the latter stages, concurring with previous research (Gero, 1990).

A cycle that was often described was one of searching for inspiration then synthesising it into design decisions. Some designers were aware that in some projects *"everyone ends up talking about the same things"*; to avert this inertia they actively try to find radically different inspiration sources and analogous research experiences that *"present opportunities to think differently and challenge existing perceptions, perspectives, or biases"*, e.g. interviewing extreme user groups. Introducing these seemingly irrelevant, often non-computational experiences into the design process provide provocative questions and clues from which the designers can build new ideas: *"you go along for the ride [because] the frustration [of considering seemingly irrelevant information] is ok because you trust it will lead to a good end point"*.

Searching out ambiguous inspiration sources often provides the designers with surprising observations that provoke their curiosity. As Merton (1968) writes, this is a key part of the serendipitous discovery process as "it stimulates the investigator to 'make sense of the datum', to fit it into a broader frame of knowledge." This broader frame of knowledge that guides the synthesis of ambiguous inspiration is often the context of the project; moodboards and design principles and product concepts are developed by considering the inspirational material through the lens of the particular elements of the product being developed, often using widely used computational design tools such as Adobe Creative Suite. Like the princes of Serendip, the process these designers are using—that of observing a surprising fact and correctly 'abducting' its relevance—is that of serendipity (Andel, 1994).

Understanding the importance of balancing these divergent, ambiguous, imaginative explorations and convergent, realistic, contextual syntheses (Heath, 1993), these designers have developed a process of 'structured serendipity'. Described as *"design jazz"* by one interviewee, it is a process that flows between structure and freedom where *"inspiration comes from random but purposeful inputs"*.

3.2. A 'beyond average' approach

It is these tensions of ambiguity and context that informed the design space dimensions that guided the development of the 'Beyond Average' tools.

Interpretability

This dimension determines how direct or ambiguous the information or creative guidance provided by the tool is; is it a prescription or a provocation? This dimension can also relate to the agency that the user has when using the tool. Examples of tools with low interpretability are search engines like Google where a user enters a specific request and the tool returns very directly related information that requires little additional interpretation; the user is very active in choosing a specific concept to explore but more passive when interpreting the information. An example of a tool with a higher level of interpretability is Eno and Schmidt's (1975) Oblique Strategies card deck that does not require the user to choose an initial concept but relies on their active perception and imagination to 'make sense' of the more ambiguous information.

Contextuality

This dimension assesses the amount of contextual information—or seeming irrelevance—that the tool or method uses to guide the collection, generation and reviewing of inspirational information and design outputs. This dimension can also relate to the 'smartness' of the tool. A tool with a high contextuality integrates a lot of advanced computation such as the machine learning analysis of extensive data sets to calculate a contextually 'optimised' and relevant response, e.g. as used in a search engine such as Google or Pinterest. In contrast, a tool or method with low contextuality is one that embraces tangential information, such as analogous research experiences, or uses much simpler algorithms such as randomness, hence doesn't generate recommendations learned from previous uses and can often provide seemingly irrelevant responses.

Chapter 4.
'Beyond Average' Tools

The design space dimensions described above create a framing through which to consider how computational design tools can influence the creation of new ideas in the early phases of the design process. Informed by the above research, this chapter presents three new 'Beyond Average' systems that embed ambiguity and serendipity into examples of more 'digitally-liminal' design tools: (1) the Reframe creative prompt tool; (2) the Looking Sideways inspiration exploration tool; and (3) the digitally-augmented Design Daydreams ideation table and post-it note. Figure 17 shows my proposed positioning of the 'Beyond Average' tools on the design space dimensions, with Google included as a benchmark of current tools.

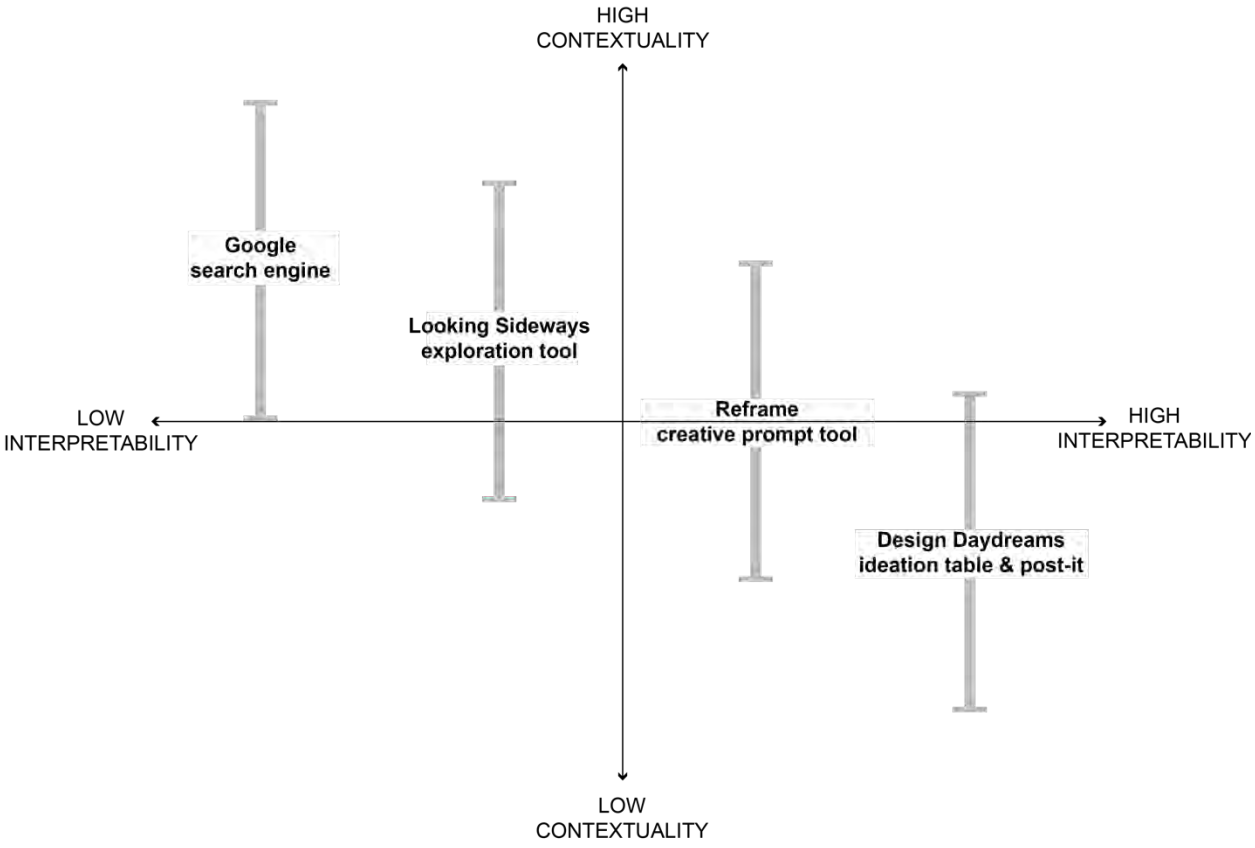


Figure 17. Existing and 'Beyond Average' tools proposed mapping onto design space dimensions

4.1. Reframe: a creative prompt tool

Reframe is a creative prompt tool that juxtaposes language from a designer's notes in surprising ways to provoke new associations between concepts in their project. Inspired by my field research at IDEO, it was originally developed as a card deck to help designers integrate some 'structured serendipity' into their design process during early concept brainstorming sessions, not dissimilar to Eno & Schmidt's (1975) Oblique Strategies (Mothersill & Bove, 2017). Reframe specifically tries to help introduce new variables into a designer's creative habits; as one interviewee said, *"every designer has their 'moves' that they work through to test out ideas"* and it can be inspiring to try something different occasionally. The user can generate a prompt by randomly selecting cards for these variables or 'moves': the artefact to be designed, e.g. an object, image, service etc; an inspiration source, e.g. senior citizens, nature, cities etc; the experience evoked e.g. responsive, discrete, approachable; and the medium used e.g. paint, CAD, card and tape. Figure 18 shows an early prototype of the card deck and Figure 19 shows examples of ideas inspired by it.

Extending this concept into a digital tool afforded many benefits: many more designers could access the tool and the words included in the prompts could be more easily customised to specific projects. Instead of shuffling cards, users can now quickly generate a whole new randomised prompt or change individual words within the prompt until they find one they prefer. The digital Reframe tool also includes a 'save' button for users to capture an image of any prompts they find inspiring, 'screensaver mode' that automatically generates new prompts every 8 seconds, and an 'upload' feature that enables designers to customise the words included in the prompts (Figure 20).

Figure 18. Reframe card deck prototype

Figure 19. Idea created with Reframe card deck

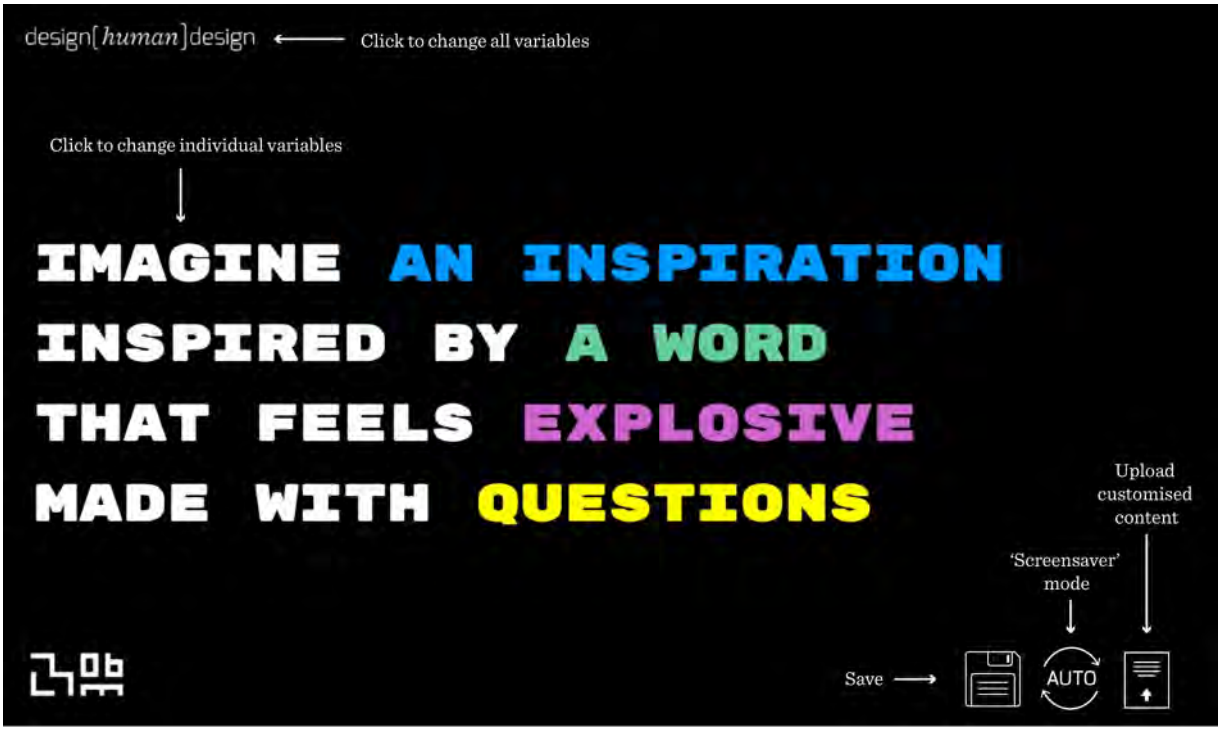
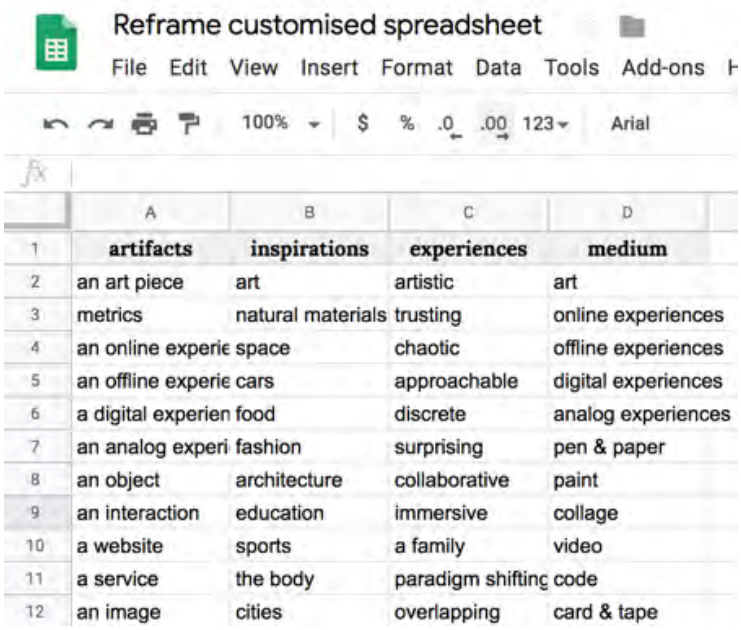


Figure 20. Reframe digital tool with annotated features



	A	B	C	D
1	**artifacts**	**inspirations**	**experiences**	**medium**
2	an art piece	art	artistic	art
3	metrics	natural materials	trusting	online experiences
4	an online experie	space	chaotic	offline experiences
5	an offline experie	cars	approachable	digital experiences
6	a digital experien	food	discrete	analog experiences
7	an analog experi	fashion	surprising	pen & paper
8	an object	architecture	collaborative	paint
9	an interaction	education	immersive	collage
10	a website	sports	a family	video
11	a service	the body	paradigm shifting	code
12	an image	cities	overlapping	card & tape

Figure 21. Customised spreadsheet

The words that Reframe includes in the prompts are stored in a Google spreadsheet (Figure 21). By appending the unique spreadsheet ID to the Reframe website address, users can create prompts that include their own words. These words can be entered manually into the Google spreadsheet or automated through the 'upload' feature (detailed in Figure 22). Users can copy and paste text, upload pdf documents and add website links to customise the database of words stored in the spreadsheet. The system uses Python Natural Language Toolkit (Loper & Bird, 2002) to parse the text in this uploaded content, sort the words into nouns and adjectives and add parts of speech e.g. indefinite articles and plural endings. WordNet, a lexical database (Miller, 1995), is also used to find synonyms and antonyms of the uploaded words to add unexpected content to the database. Once the uploaded content has been parsed, the words are sorted by frequency and a randomly distributed sample of up to 50 selected to be transferred to the Google spreadsheet. I made the design decision to only transfer this subset of uploaded content after feedback on early prototypes suggested that including all of the parsed words led to an overwhelming variety of concepts in the prompts generated by the tool.

Figure 17 shows the position of Reframe on the design space dimensions. Due to the relative simplicity of the prompts, I posit that the Reframe creative prompt tool has medium interpretability; a user has to use their own creative agency in order to 'make sense' of the often ambiguous conceptual juxtapositions presented. The contextuality of the tool can range from relatively low to medium-high, depending on how much additional content is uploaded by the user to customise the prompts.

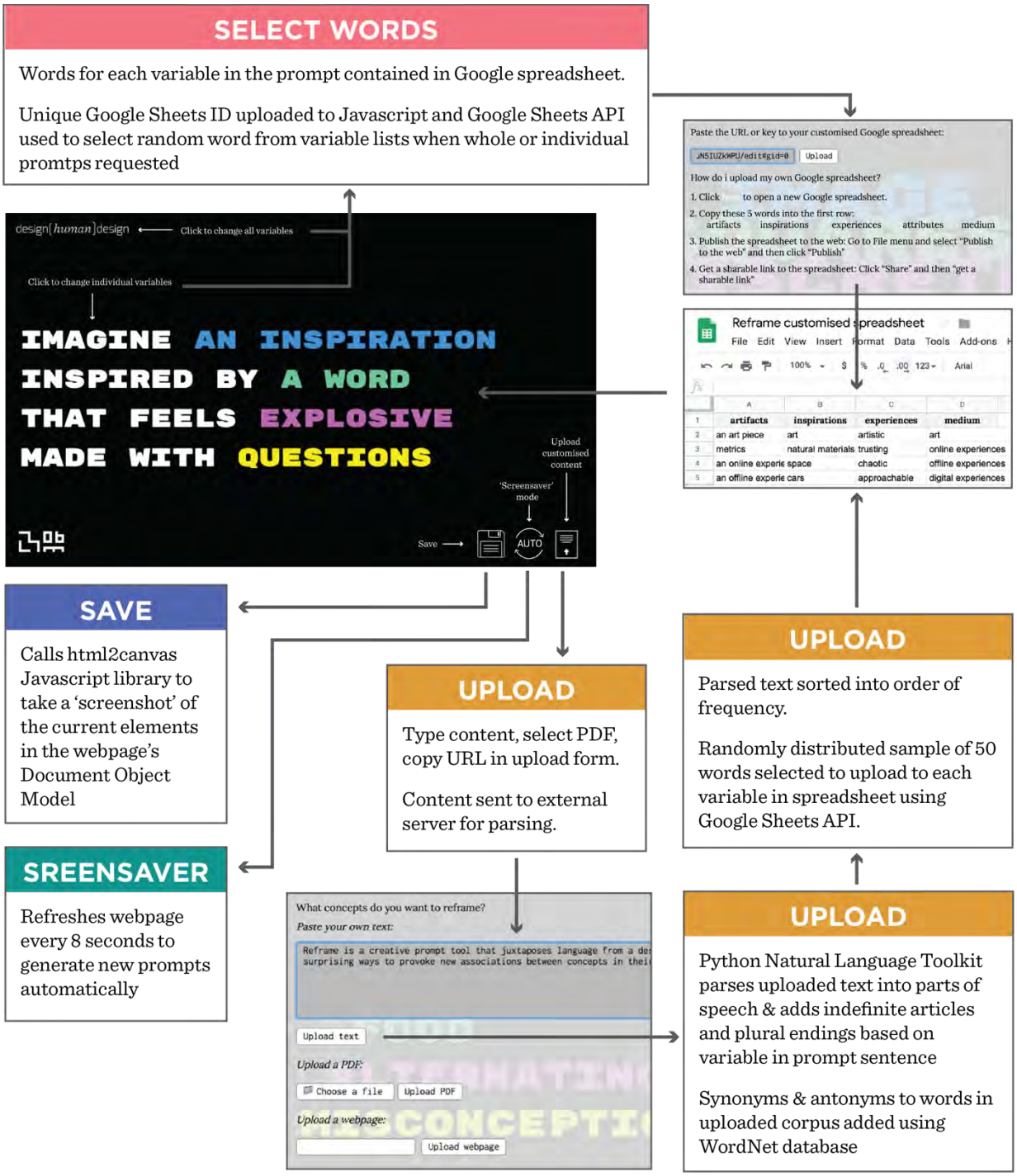


Figure 22. Reframe creative prompt tool features flowchart

4.2. Looking Sideways: an inspiration exploration tool

Looking Sideways is an online inspiration exploration tool that presents a diverse range of content for each search query and suggests connections for the concepts discovered. It was inspired by considering how designers could more deeply explore the concepts provoked by the Reframe tool by searching for information or visual content related to the words in the prompts, using the many different *"creative watering holes"* that they visit to find inspiration for their designs, e.g. Pinterest, Dribbl, Google, magazines, books, art galleries, films etc. An excellent analog example of this process is the book The Art of Looking Sideways (Fletcher, 2001); an "inexhaustible mine of anecdotes, quotations, images, curious facts and useless information, oddities, serious science, jokes and memories" collected over 20 years by designer Alan Fletcher. This content is loosely collected into 72 chapters that position, for example, quotes from scientists next to a doodle of robots next to a modernist poem next to a description of a chess move; reading it is an exercise in lateral thinking in itself!

Similarly, the designers I spoke to often talked about how the act of making mood boards by hand helped them loosely synthesise this vast array of inspiration that they had collected; it presents the *"landscape of different possibilities [from which] new combinations"* can be discovered. The Looking Sideways tool aims to make searching for inspirational content online feel like this lateral thinking experienced when jumping between 'creative watering holes' or juxtaposing content on a mood board.

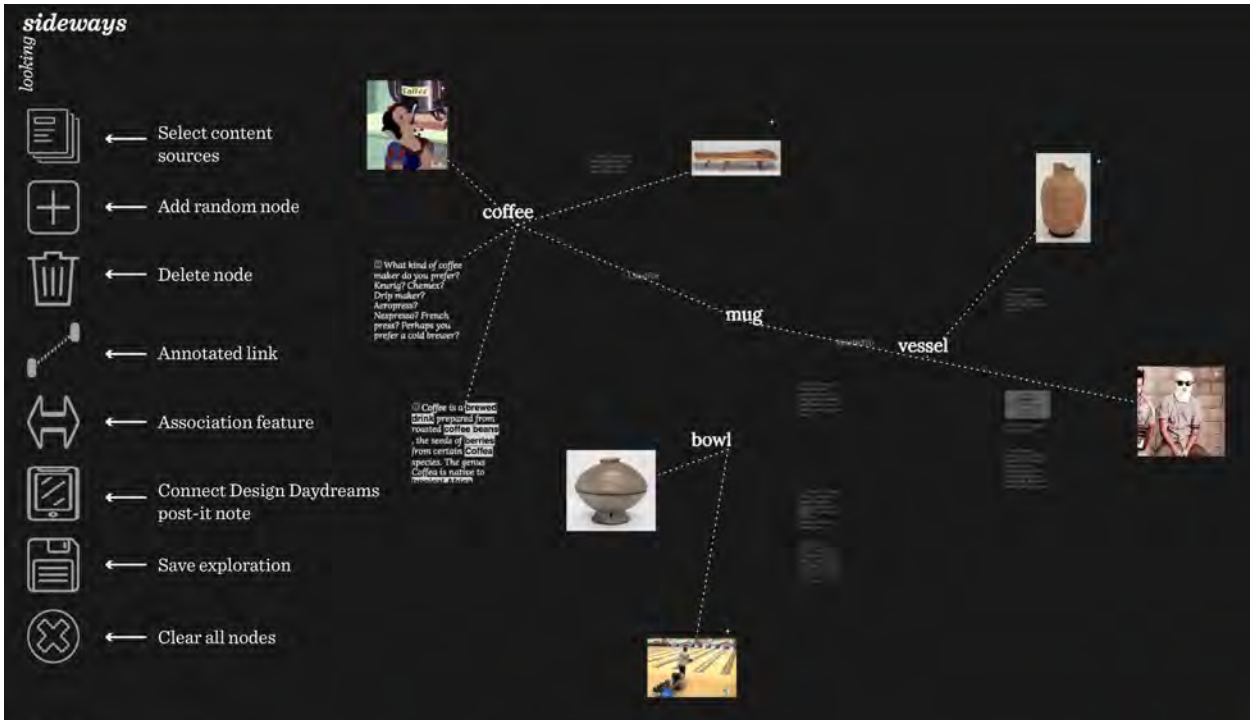


Figure 23. Looking Sideways inspiration exploration tool with annotated features

At its core, Looking Sideways is a search engine. Yet, unlike other search engines it does not attempt to optimise the content presented to the user. For every search query, Looking Sideways collects content from a diverse range of online databases—Wikipedia, Wiktionary, Harvard Art Museum, Cooper Hewitt Design Museum, Giphy animated images, news, National Geographic, and New Scientist—and presents users with a random selection of that image or textual content (Figure 23). Clicking on these 'nodes' activates another search query based on the metadata of that content.

With this semi-random selection of both visual and text-based content, Looking Sideways provides a more visual accomplice to Reframe's semantic juxtapositions. However, unlike Reframe, Looking Sideways has a feature that can aid in the abductive leaps that helps users find associations between the seemingly disconnected content presented. The 'association feature' (detailed in Figure 24) uses the ConceptNet commonsense semantic knowledge graph (Speer et al., 2017) to offer suggestions for concepts that can connect two words, e.g. 'vessel' is related to 'mug' which is used for 'coffee'. Other features include: selecting or adding specific content from the available content sources, adding annotated links between content nodes, deleting nodes, saving the exploration, and connecting content found on Looking Sideways to the Design Daydreams post-it note (described below).

Figure 17 shows the position of Looking Sideways on the design space dimensions. I posit that Looking Sideways has a lower level of interpretability than the other tools due to the user's more active engagement with it, i.e. they can enter their own search queries and delete or further explore the nodes of their choice. At its most simple state, it has a medium level of contextuality, however if the databases that the tool is searching are customised to a certain topic or personal 'creative watering holes', the level of contextuality could become quite high.

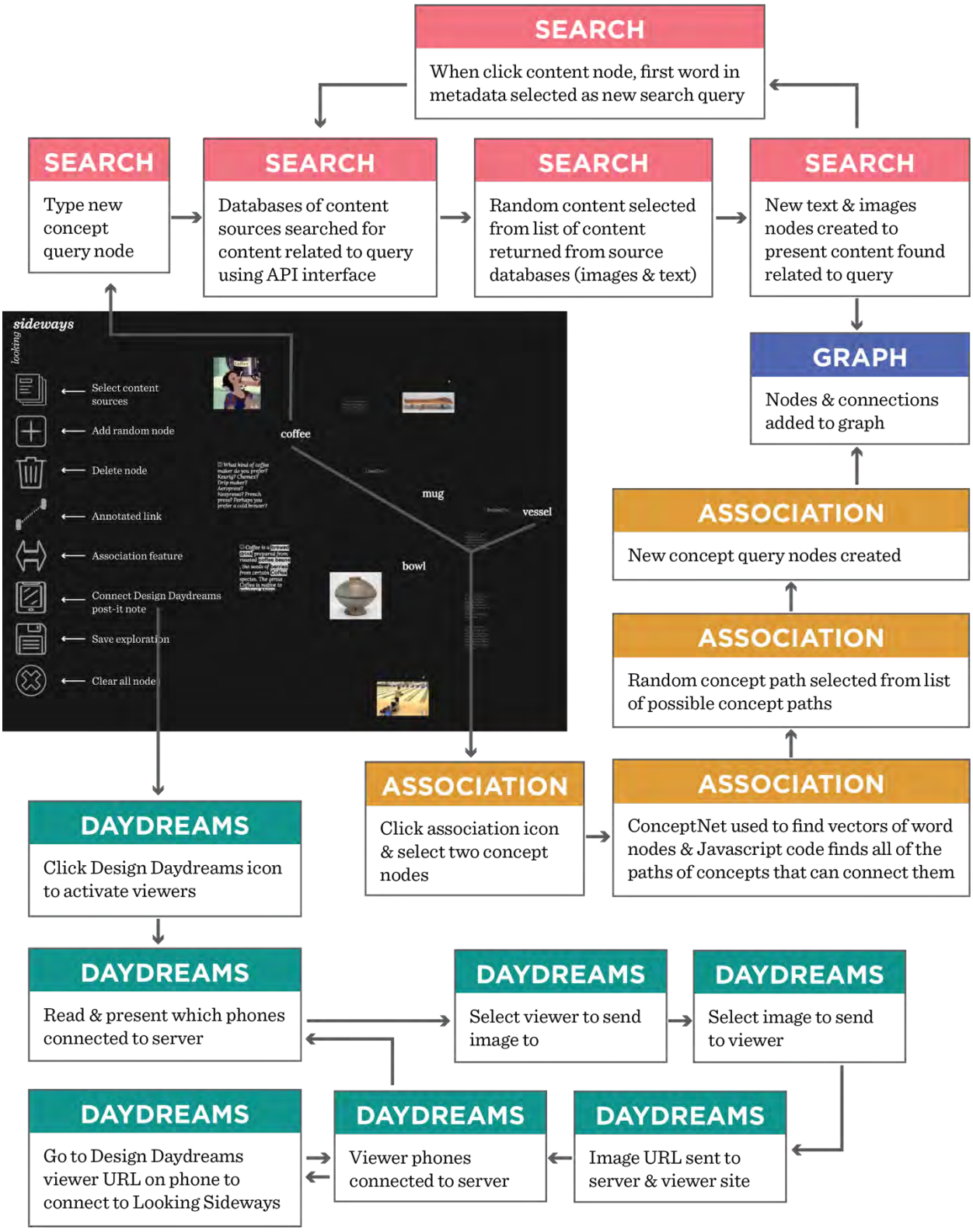


Figure 24. Looking Sideways exploration tool & Design Daydreams post-it note feature flowchart

4.3. Design Daydreams: a digitally-augmented ideation table and post-it note

Design Daydreams is a digitally-augmented ideation table and post-it note that seamlessly connects the physical and digital content that designers use in their creative processes. It was motivated by the limitations that designers I spoke with found when using digital tools and screens in more exploratory creative activities; in more collaborative settings such as brainstorms, they preferred to interact with each other and their collections of inspirational content around tables, using paper, post-it notes and physical inspiration material. This exploratory brainstorming workspace is one of collage and bricolage; bringing together a plethora of inspiring physical and digital content and tools to be used as and when the designers need.

In order to bring the rich digital inspiration material from the Reframe and Looking Sideways tools off the screen and back onto the brainstorming table to create even more inspiring juxtapositions, I experimented with several technologies: projection mapping, commercial AR headsets and mobile AR apps. However, as other researchers have noted (Saakes & Stappers, 2009), while these systems allow for detailed tracking of the objects they are augmenting with high-resolution imagery, I found them to be cumbersome and inaccessible to most designers. I wanted these digital inspirations to feel like the proverbial 'post-it note'; fragments ideas quickly encapsulated visually on simple pieces of paper that can be juxtaposed to other media and ideas, similar to Weiser's iconic 'scrap computing' Pads (Weiser, 1991).

I therefore chose relatively low-tech approaches to developing a more seamless interface for the Reframe and Looking Sideways tools. For the ideation table, a projector is placed underneath a clear plastic surface covered in paper to project the tools onto a 'screen'. Modeled after the shape of a drafting table, users can interact with the digital content displayed on the angled upper section of the table using a wireless mouse and keyboard and write notes with pen and paper on the horizontal lower section (Figure 25 and Figure 26).

Figure 25. The Design Daydreams digitally-augmented ideation table

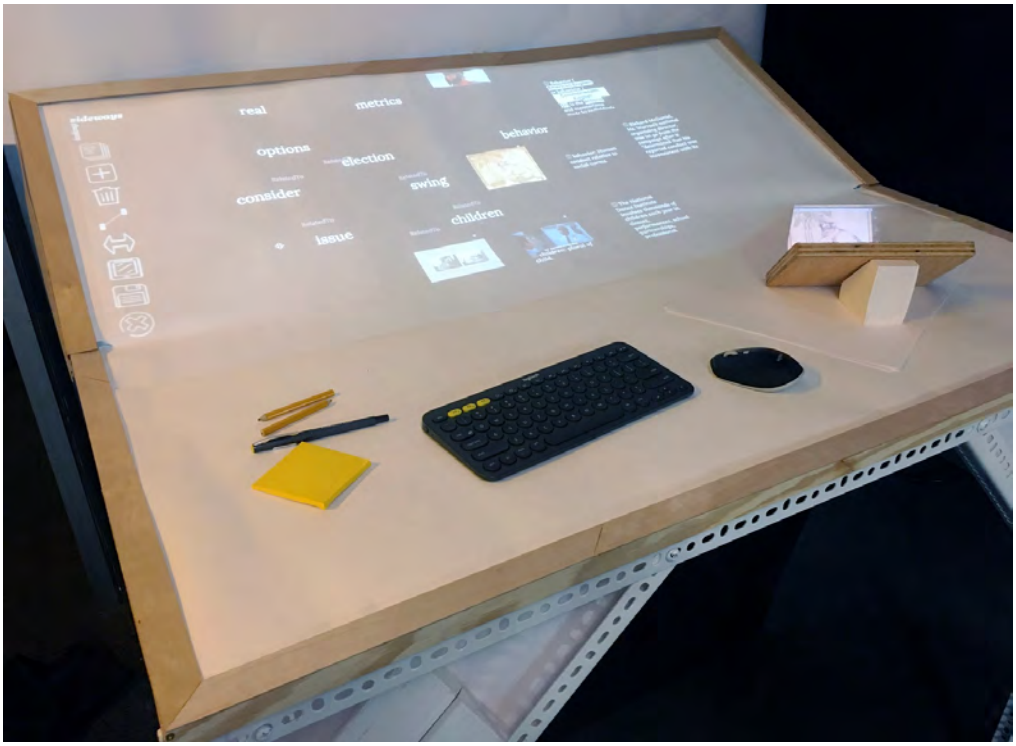


Figure 26. The Design Daydreams digitally-augmented ideation table & post-it note (close up)

Extending this digital table-top interaction, the Design Daydreams post-it notes uses the low-tech AR technique using the Pepper's ghost illusion (De Angeli & O'Neill, 2015) to overlay digital images found in the Looking Sideways tool on top of sketches and objects in the surrounding environment (detailed in Figure 24; Design Daydreams viewer feature in Looking Sideways exploration tool shown in Figure 28). Using a mobile device in a simple carved wooden holder with a transparent film positioned at 45 degrees to the screen (Figure 27), users can create the illusion of overlaying digital images or text on their mobile device onto objects viewed through the film. Designers can position the holders horizontally, vertically and with the film at a distance from the holder to manipulate how the augmented image interacts with the physical objects behind the viewer (Figure 29). Styled to feel more like an object a designer would have on their desk than a piece of technology, this low-fidelity format is more accessible and feels as instantaneous and creative as how designers intuitively use post-it notes to record and assemble fragments of ideas in a brainstorm.

The Design Daydreams augmented drafting table and post-it note has the highest level of interpretability as it involves interacting with a wide and very unpredictable array of physical objects that the designer wishes to introduce to the tool (Figure 17). At its most simple, it has a low level of contextuality as the information presented can be completely unconnected to the designer's search queries. However, if the content shown on the table and through the viewers is connected and customised to a certain topic or personal 'creative watering holes', the contextuality becomes medium-to-high.

Figure 27. Components of Design Daydreams augmented post-it notes (clockwise from top left): wooden holder, 45 degree wedge, transparent film with concrete corner weight, 3D shapes on which to overlay images, mobile phone

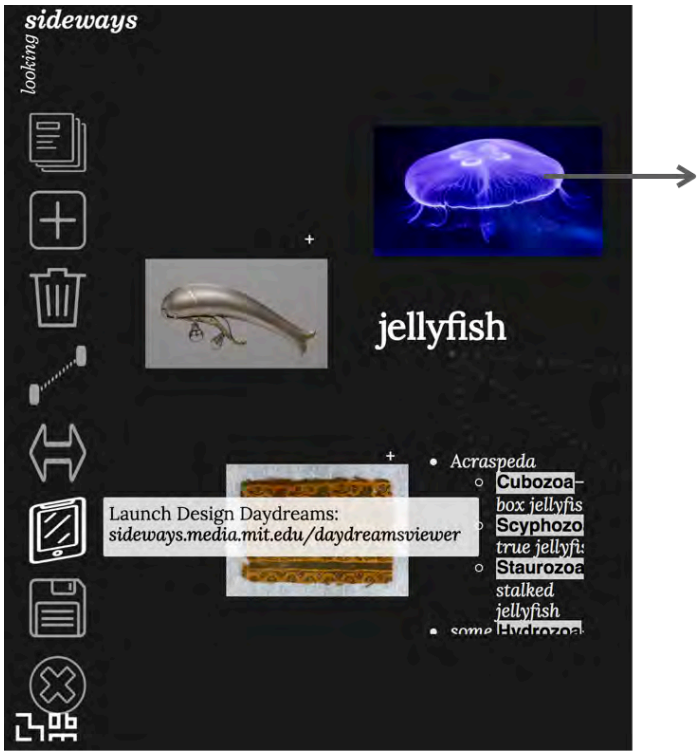


Figure 28. Design Daydreams viewer feature in Looking Sideways exploration tool

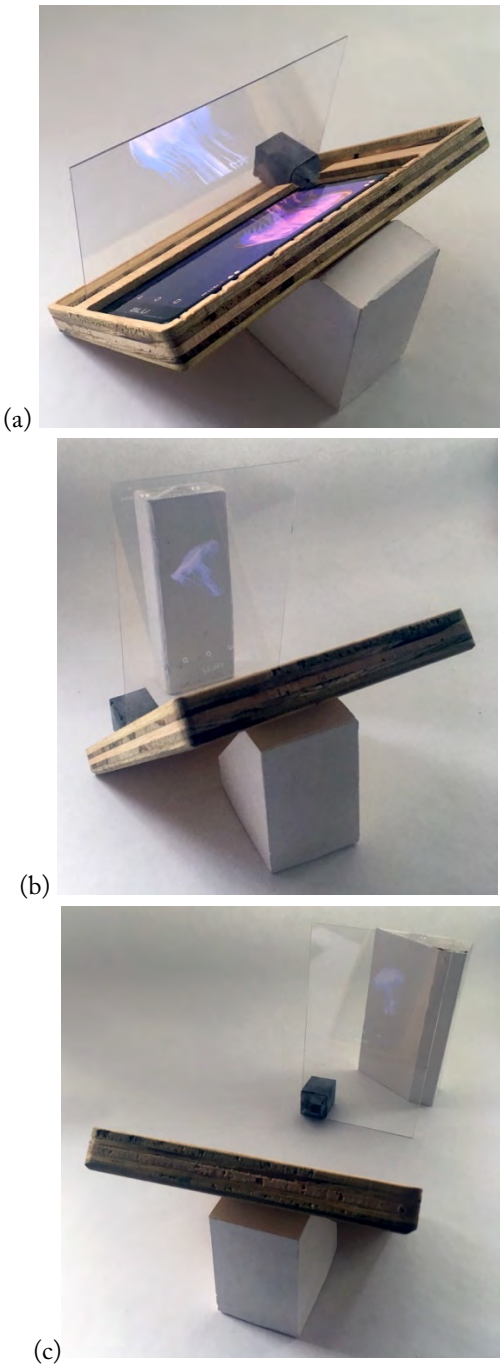


Figure 29. Design Daydreams holder in (a) horizontal, (b) vertical & (c) separated positions

Chapter 5.
Situated Serendipity

My field research confirmed long-standing knowledge that the creative process is a contextual endeavor (Redström, 2017). Especially in the early phases, designers often take a bricolage approach, using methods and tools as and when they deem appropriate to discover new questions or explore potential solutions. The artifacts, methods and tools we use throughout the design process can therefore "change their meanings as they travel through different uses, different situations, different times, and different people's lives" (Krippendorf, 2005). Any new tools developed are consequently situated in these specific contexts.

This contextual nature of creativity highlights the dilemma for studying the impact of new tools in the design process; any interventions are inevitably relatively subjective and not easily repeatable. As it can be hard to draw generalisable quantitative findings from these types of studies, I chose to use more qualitative techniques to evaluate the impact of the Beyond Average tools; specifically, a concurrent embedded mixed methods approach (Creswell & Creswell, 2017). This inductive approach aims to draw findings by interpreting participant's descriptions of their experiences. Additional quantitative questions that ask participants to rate elements of their experiences and analysis of the outputs of their processes using existing creative ideation metrics aim to demonstrate general trends—as opposed to definite answers—that can extend the analysis of these qualitative insights.

Three interventions of the Beyond Average tools were carried out to explore the different situations within the creative process in which these tools might be impactful: (A) a structured intervention that compared the creative impact of the tools to each other; (B) an unobserved intervention that tested the performance of the tools 'in the wild'; and (C) a semi-structured intervention that provided gentle guidance for using the tools in real world projects. This chapter describes these situated interventions and the insights gathered from them.

5.1. Intervention A: Beyond Average tools as part of a larger toolbox

In the latter phases of the design process, designers can often become bound to using one tool due to a lack of interoperability (Bernal et al. 2015). Conversely, in the earlier, more bricolage explorations designers visit many 'creative watering holes' and flit between many different tools and methods to discover new ideas. As such, the Beyond Average tools are not designed to act alone; I envision them to be but one element in a bulging toolbox that designers can use to find inspiration. This initial evaluation of the Beyond Average tools explored the creative potential that they can offer when finding inspiration for a new project idea, both as individual tools and as part of a suite of tools that can influence each other.

5.1.1. Methodology

As this intervention was the first structured evaluation of the Beyond Average tools, I chose to conduct an observed 'lab' study where the data collected could be more controlled and repeatable. 18 participants—10 male and 8 female professional and student designers and engineers—were asked to generate creative responses to one of two themes ("automated systems (in the home, work, city etc.) that we trust" and "the future of wellness (in the home, work, city etc.) that is integrated") using the Reframe and Looking Sideways tools to provide inspiration. The text corpus that the Reframe tool drew from was customized for each theme using words from relevant Wikipedia pages and articles. The results pages (including images, news, shopping etc.) from Google's search engine was used as a control tool. In this intervention, the Design Daydreams ideation table and post-it note was not used as an interface for Reframe and Looking Sideways; the participants accessed the tools on a laptop. The participants had 10 minutes to use each tool to explore the themes and generate ideas based on the inspiration they provided, noting down any ideas or sketches using pen and paper. As learning from previous tools was inevitable, the order of the tools was randomised across participants. Finally, participants completed a survey that asked questions related to the potential of each tool to provide unexpected creativity.

Shah, Smith and Vargas-Hernandez's (2003) metrics for measuring ideation effectiveness—novelty, variety, quality, quantity—as well as metrics relating to Bono's (1970) analysis of lateral thinking— whether ideas are of immediate usefulness, areas for further exploration or new approaches to problem, and if they are vertically or laterally related—were integrated into questions that participants rated on a 5 point Likert scale. Overall comments about how the tools influenced the participants' generation of new ideas, how the tools could integrate into their creative practice and any suggestions for modifications were also collected.

5.1.2. Intervention findings

Figure 30, Figure 31 and Figure 32 show examples of the inspiration material discovered by one participant and the resulting ideas they generated for the "automated systems (in the home, work, city etc.) that we trust" theme.

Overall, the participants indicated they had a similar experience using the tools as I expected. Google was considered to give very direct, highly contextual responses, which was reflected in the relatively specific, form based ideas that most participants generated (Figure 30). The Reframe creative prompt tool was considered to have the most interpretability and medium contextuality; this type of inspiration led to a more fragmented selection of ideas and loose mapping of general concepts (Figure 31). The Looking Sideways exploration tool was considered to give mediumly ambiguous and contextual responses (slightly lower than my expectation, likely due to technical limitations with the prototype tested in this intervention); interestingly, this type of inspiration led to ideas with a thought-provoking combination of the specificity of those developed with Google with the more semantically conceptual fragments provoked by Reframe (Figure 32).

Reviewing the data mapped against the design space dimensions individually reveals some larger trends about how the levels of contextuality and interpretability affect creative output. Figures 5 and 6 show the ratings for each of the tools for the metrics described above mapped along the design space dimensions. (As both of the themes tested provided similar responses—most ratings were within one Likert point—the data has been combined into a single average.) Lines have been added between the discrete data points to indicate trends in how the creativity metrics might vary as a design tool includes more or less contextuality and interpretability. Quantity of ideas is not included as all tools generated similar results (1-2 ideas), probably due to the short time allowed for the task.

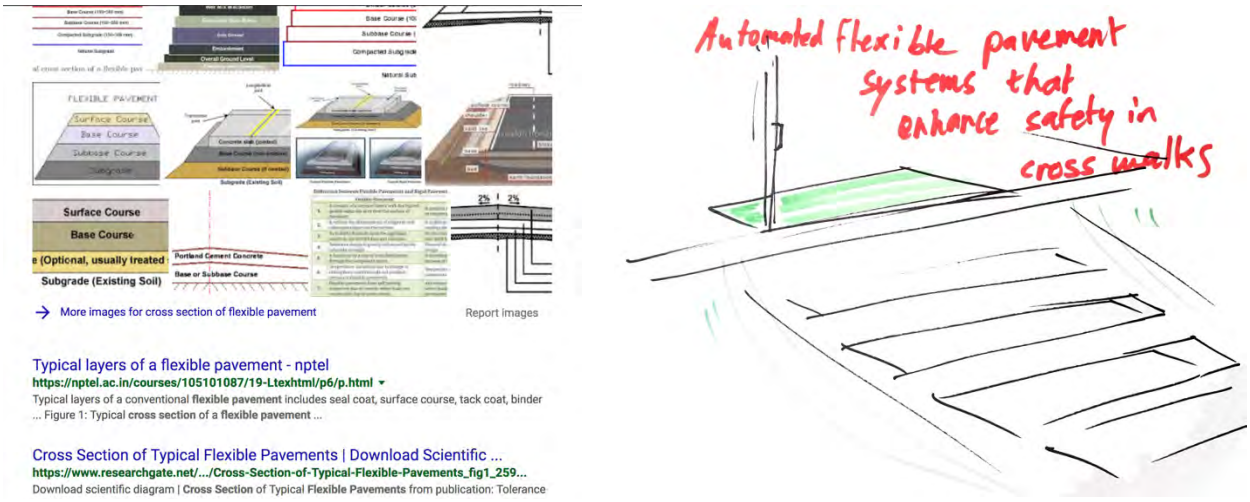


Figure 30. Example of inspiration found on Google and resulting idea for "automated systems that we trust"

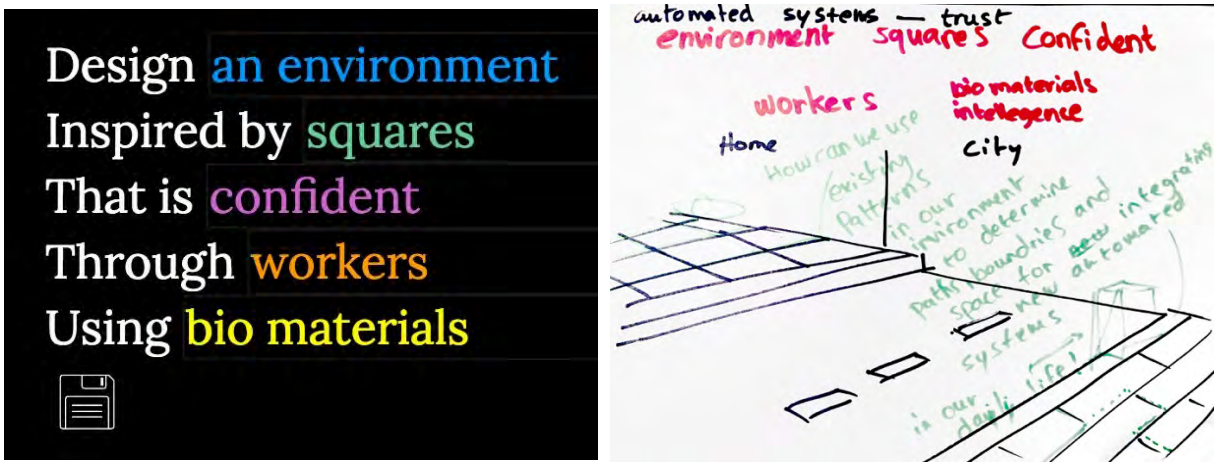


Figure 31. Example of inspiration found on Reframe and resulting idea for "automated systems that we trust"

Figure 32. Example of inspiration found on Looking Sideways and resulting idea for "automated systems that we trust"

High contextuality is good for exploring a narrow subject but low contextuality can provide tangentially associated responses that provoke new interpretations

Figure 33 shows that Google—the tool with the highest rated contextuality—had the lowest ratings for most of the metrics (between 2.33 and 3.83). Despite participants' familiarity with using Google to gather a large quantity of information on a theme, its high contextuality meant this knowledge was situated in terms of what other people have done and thought before; the *"generally accepted 'norm' answers"*. While this helped some participants identify common features or trends, it led others to feel there was *"too much priming in the wrong direction."* The high contextuality of Google was considered beneficial when the participant has already *"honed in on something narrow"* and is *"thinking about framing their enquiry"*, but was *"not useful for deeply assessing where [their] ideas were situated"* and therefore not the right tool for coming up with new ideas.

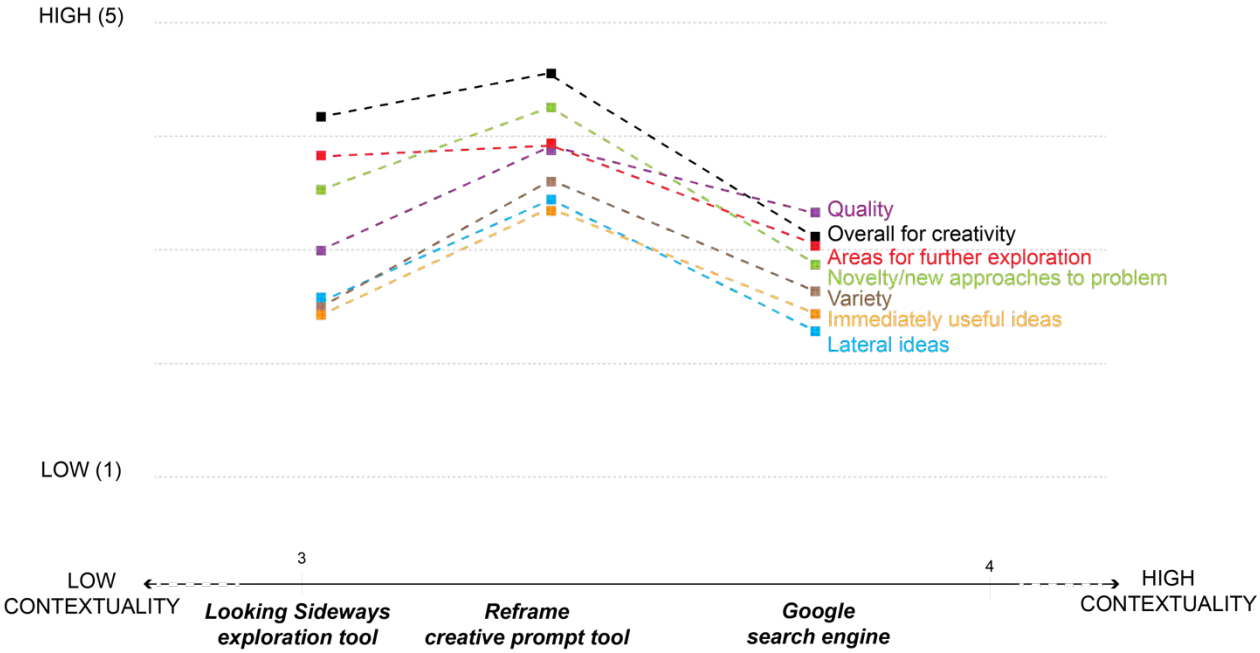


Figure 33. Map of creativity metrics against the level of contextuality in each of the tools studied

In contrast, the Reframe tool (medium contextuality) was rated highest for all metrics (between 3.17 and 4.67). The lower level of contextuality was found helpful in liberating the participants from their own preconceptions. Being primed with text related to the two themes allowed the tool to easily provide many simple but different *"relatively stable starting points"* from which ideas could be constructed. However, due to the format of the tool, some participants felt that the prompts often fell into more project-based tasks rather than general inspiring concepts, limiting their boundaries of thought. Another participant also commented that while *"arbitrariness can be very powerful for lateral thinking...sometimes it can feel forced or difficult to draw connections"* and that *"knowing when to skip and when to ponder"* a seemingly irrelevant connection requires consideration, and potentially guidance.

Helping to see links between ideas was one of the features that participants liked in the Looking Sideways exploration tool; adding a level of contextuality to seemingly unconnected concepts. This ability to visually map how random concepts intersect *"provided nice tangents"* to open up their existing idea domain. As participants controlled the context of the exploration by entering their own search terms *"some connection to the goal is there"* which guided one participant *"into a headspace that is comfortable and that I feel authoritative in, but is new territory."* Despite this feedback, participants still rated the tool as fairly low contextuality and it did not score as highly as the Reframe tool in terms of creativity (between 2.56 and 4.11). In general, participants liked that the search results were not defined by popularity such as on Google, but due to limitations in the number of content sources in the current prototype, there wasn't a large enough amount of information available to explore a concept deeply—as Google provides—or consider many new perspectives—as the Reframe tool provides.

Overall, it appears that tools which provide more highly contextual responses, i.e. Google, are good for exploring a narrow subject once design parameters (or search terms) are known but the focused range of similar information limits the ability to generate new ideas or connections. Tools that have a lower contextuality—Reframe and Looking Sideways—can provide tangentially associated responses that prompt participants to reconsider how concepts could be interpreted and connected, providing them with interesting *"starting points"* for new ideas to explore further.

High interpretability encouraged various interpretations and a greater opportunity for new connections and ideas to be made

Mapping the same results onto the interpretability axis, Figure 34 shows a clear trend towards greater creativity with higher levels of interpretability. For Google (low interpretability), participants are relied upon to come up with interesting search terms, hence the responses can only be *"as creative as your own mind essentially allows you to be."* This improved with higher levels of interpretability in the Looking Sideways tool as its ability to connect random user-defined concepts provided fresh, unexpected input that *"encouraged momentum and outgrowth"* and *"a way to riff out from where I already am"*. Presenting the responses in a more visual, disorganised manner also allowed for the participants to *"make a mess"*, inspiring less literal connections and more varied interpretations because they can find their own sense in the content.

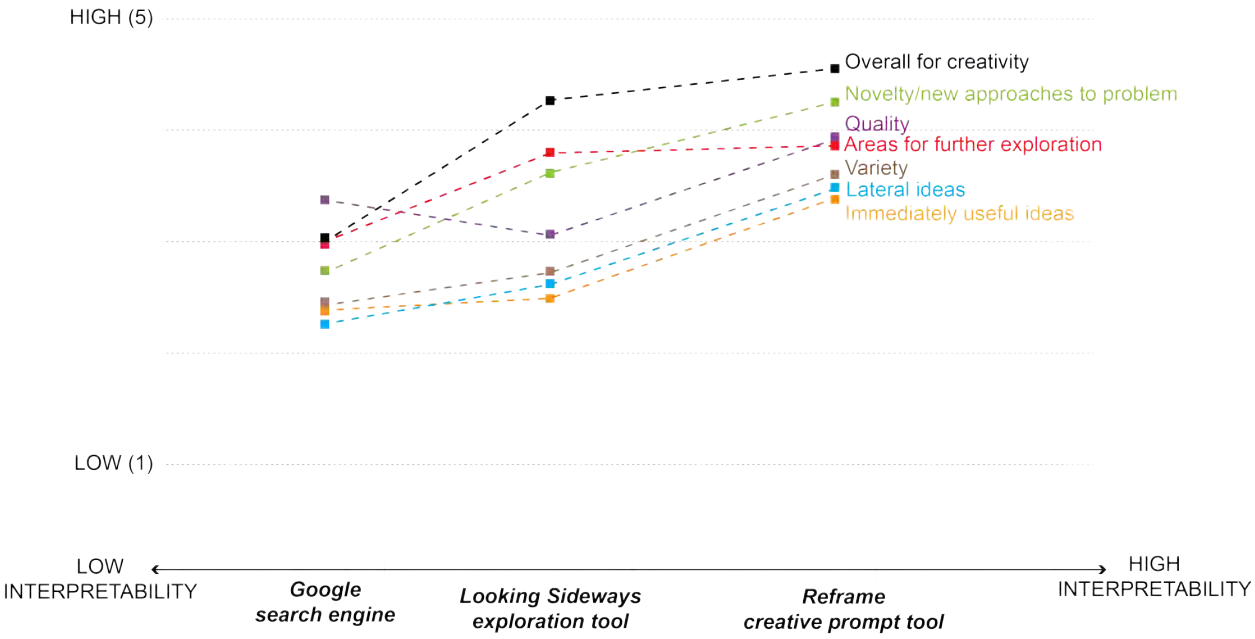


Figure 34. Map of creativity metrics against the level of interpretability in each of the tools studied

The tool that provided the most varied and new connections was the Reframe tool (high interpretability). Participants found that when they allowed themselves to let go of controlling the tool and consider the often ambiguous responses in a more flexible way, the random juxtapositions of concepts challenged them to take on *"a more non-structural thinking"* that prompted *"new and very different points of views on my ideas";* a feeling that several participants described as being rare in comparison to other computational design tools today. However, while many participants enjoyed the possibility to quickly iterate through a high number of ambiguous prompts as it helped them get into a different mindset, a few considered the juxtaposition of even two of the often very broad concepts required a lot of time to think deeply about the potential connections between them.

Overall, there seems to be a clear trend that higher levels of ambiguity in the responses provided by the tools—something we could also describe as a higher level of creative agency on the machine's part—allowed for more variety of interpretations within the information presented and therefore a greater possibility for new connections and ideas to be made.

5.1.3. Intervention insights: tools with a medium level of contextuality and a medium-to-high level of interpretability are best for provoking new ideas, especially when incorporated into a suite of tools that cycle between high contextuality and high interpretability

From the results discussed above, it appears that computational tools with a medium level of contextuality and a medium-to-high level of interpretability can positively influence creativity in the early phases of the design process. The lateral responses to search queries and somewhat random provocations enabled by higher levels of interpretability allow participants to have some

agency over the direction of explorations but also be provoked to rethink how something seemingly irrelevant could be contextual; responses that make 'just enough' sense and provide a high *potential* contextuality for participants to generate relevant but novel ideas.

This upper right quadrant of the design space dimensions (high interpretability and high contextuality) was also rated the most desirable for inspiring new ideas. However, one participant commented that desiring tools in this quadrant of the design space seemed like a paradox. This relates to how participants felt Google—and the general trend for efficient search tools—had conditioned them to think in a logical way and using the Beyond Average tools helped them embrace more ambiguous, non-deterministic approaches.

The effect of these different approaches was noticeable through the order effects that emerged. When the Beyond Average tools were tested first, participants started to consider how they could use Google more creatively, with mixed success due to its more efficiency-oriented search approach. The fact that these tools can influence each other is an exciting finding. While some participants did distinguish the tools for separate design activities, e.g. Reframe for brainstorming and Looking Sideways as a mapping tool to document their creative process, most thought they would be useful as a suite. Using a mediumly contextualised version of the Reframe tool was considered a useful creative 'ice breaker' for seeding interesting new directions for further exploration, followed by the Looking Sideways tool to suggest lateral connections between concepts and Google to gather more focused information to further frame their ideas. Integrating information related to key concepts explored in Google and the Looking Sideways tool back into a more contextualised version of the Reframe tool was suggested as a way to further generate novel but more focused ideas related to the participant's emerging themes and design parameters.

This imagined role of the tools in the design process indicates a somewhat cyclical need for high levels of contextuality and interpretability in exploration and ideation activities. When using computational tools with very high levels of contextuality, e.g. Google, the creative agency is determined by the human; the search terms are determined by the designer, often through some non-computational means such as brainstorming. When the computational tool can have creative agency as well, e.g. through providing unexpected but relevant provocations as the Reframe and Looking Sideways tools do, the computer can become more of a natural partner to guide—and more importantly, creatively disrupt—the designer as they search for new ideas.

5.2. Intervention B: Beyond Average tools as creative disruptors

However, exciting the findings from this first intervention were, the nature of the observed, structured 'lab' study somewhat limited the insights about the applicability of these tools when used by real designers in real companies in real world projects. The tools needed to be let loose in the wild! Building on these insights that the purposeful creative disruption that these tools can bring is useful to the idea generation process, I aimed to repeat these findings in longer, unstructured, unobserved, real world interventions.

5.2.1. Methodology

In-depth interventions were carried out with several designers in companies including IDEO design consultancy, IDEO CoLab innovation studio and BBMG brand consultancy amongst others. After short demonstrations of the tools, initial interviews were carried out to understand the designer's/organisation's own creative process and how best the tools might be situated within existing projects. The designers were then given access to the tools through customised website links (with instructional videos for further guidance) and asked to use them at least once in their project over a two-week period. As this intervention took place in various design studios in Boston and New York, it wasn't practical to include the Design Daydreams ideation table or post-it note; as a result, participants accessed the Beyond Average tools on their laptops. I didn't want to overly distract the participants from their normal process other than through the use of the tools, therefore only carried out a post-use interview and survey to receive feedback on how the tools were used, what interesting outputs they generated and any limitations they encountered.

5.2.2. Intervention findings

Initial interviews with designers and design researchers at IDEO identified several moments in the arc of a project's development where they thought the creative disruption that the Beyond Average tools provide could be useful. Confirming my earlier research, they suggested that these tools would be most useful in the initial idea generation and research activities where they are actively looking for new ways of thinking about a concept and lateral insights. In particular, they could imagine using the Reframe creative prompt tool in brainstorms to collaboratively ideate on extreme concepts, and the Looking Sideways tool to explore these concepts further and identify analogous research opportunities. These tools were not only imagined to be useful in the studio; the design researchers were also excited about using Reframe in their user interviews as a tool to contribute to a creative co-design activity with their subjects.

These insights of particular moments within a real project structure where the Beyond Average tools might be useful were integrated into interventions in two IDEO CoLab innovation projects: one two-day 'sprint' project and another week long workshop where 6 teams worked on various project briefs resulting in a prototype for a new technology design and accompanying business model. During these projects, teams carried out the following activities: research and discussions

around the project topic, journey mapping to identify overarching themes, brainstorming 10-20 How Might We ideas (a guiding prompt that encourages the participants to find ideas that are not too big to focus on and not too small as to constrain), synthesising them into 2-3 ideas to research further in user interviews/design research, developing their insights into technology prototypes and business model designs to demonstrate, synthesising feedback of their demos into overall insights and key themes related to their original brief and learnings about the design process to take further in future iterations. Reframe was introduced just before the brainstorm activity as a tool that could broaden the participants' ideas by contributing unexpected prompts, and Looking Sideways was introduced after the brainstorm as a tool that could be useful for deeper research and framing of their selected concepts as they develop them further.

Participants acknowledged that the provocations provided by the Beyond Average tools could help open up their creativity

Feedback from the participants in this intervention was generally positive. They all agreed that the potential for these tools impacting their creative process was huge as they acknowledged that they are all pre-primed with certain assumptions when starting a project and these tools introduced new variables that opened up their creativity. In particular, the high level of interpretability in the Reframe creative prompt tool was appreciated in the brainstorming session as *"those out of the box ideas sometimes help us get to more interesting and thoughtful places."* Participants then used the unexpected but relevant content from Looking Sideways to challenge and deepen the ideas that came out of the brainstorming session: *"By making non-traditional associations between key words and strands of thought, we were able to invite new and interesting questions to the mix."*

The impact of the creative disruptions was limited by a perceived incongruence of how the tools integrated into the studio environment and existing project structures

Despite this positive feedback, this intervention highlighted several limitations to the creative impact of the Beyond Average tools in these early phase activities. One limitation related to the interface to the tools. I noticed early in the interventions that accessing the tools on a laptop disrupted the natural flow of conversation that the teams were having around the table and whiteboards they were using to visualise their discussions (Figure 35); the participants either stopped talking to each other to use the tools individually, or they just focused on conversation and didn't use the tools! As one participant mentioned, the tools *"need to feel [they] work well around a table."*

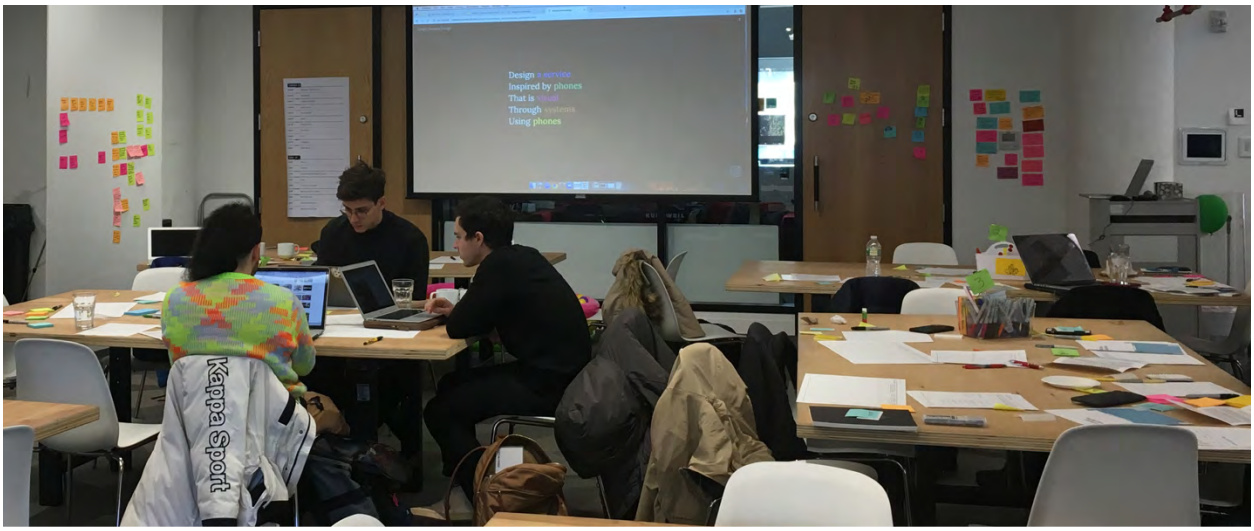


Figure 35. Participants using the Reframe and Looking Sideways tools as part of their brainstorming activity

Another limitation points to a larger issue with this intervention: while participants liked the idea of the disruption these tools could bring to their creative process, they struggled to seamlessly integrate them into the existing structure of their projects. The artists and designers who participated in the projects had a more intuitive understanding of the tools and how they could be useful due to their acceptance that the creative process is an ambiguous journey in which you *"don't always know where to go [and you have to] accept that the tool will guide you"*. The non-designers in the projects did not have this expertise and comfort in the more unstructured creative process in which the tools thrive, preferring the comfort and seeming efficiency that a more structured process can bring; comments such as *"they don't make enough sense"*, *"I don't have time to learn this new tool"* and "*how can I use it to work under pressure?"* were common among these participants.

Unfortunately, this resistance for the tools to fit into the existing structures and attitudes of designers and researchers working on real projects in large organisations was so common that, despite many initial conversations, no other substantial interventions of this format were carried out.

5.2.3. Intervention insights: creative provocations are desired but these disruptions need to be designed into a larger process

While initial discussions with designers confirmed my expectations that the Beyond Average tools could be useful in provocative brainstorming sessions and divergent exploration activities, overall this intervention was not as successful as I had hoped.

A simple solution to one of the limitations identified was to take the Beyond Average tools off the laptop screen. The environment and other tools that the participants used during their ideation processes were often non-digital, e.g. pen/paper/post-it notes, and situated around a table to facilitate conversation and fluid transitions between different visual and tactile media; as one

IDEO designer said, *"research activities are horizontal"*. As I had intended to try to situate the Beyond Average tools into the participants projects as naturally as possible, I did not integrate the Design Daydreams ideation table; this was evidently an error and therefore needed to be included in future interventions.

A more challenging limitation was the resistance to retroactively fit these new tools into a designer's and organisation's existing structures and creative processes. The overarching impression was that these tools—and the creative disruption they provide—are not always considered a useful activity in the creative process, at least for projects within a more corporate innovation setting. The irony in this insight, as one interviewee commented on, is that I *"need to get people to want to ask questions before [they] even get to tools"*.

A crucial insight from this intervention is the need to design the Beyond Average tools into a larger process, one in which participants embrace the creative disruptions the tools can provide. In hindsight, I was naive to ignore that, as with all tools, these systems have a learning curve. In future interventions, I needed to purposefully teach users why, when and how these tools and the ambiguity and seeming 'chaos' they provide can be useful in their creative process.

5.3. Situating the Beyond Average tools within the art of creative thought

> "The purpose of thought is not organic harmony but truth, and the seeker for truth must always be prepared to sacrifice harmony." (Wallas, 1926)

The findings from the above intervention show that "sacrificing harmony" is easier said than done. Design approaches such as 'divergent thinking' and 'disruptive innovation' are commonplace among many people working in the creative industries. However, when presented with tools that help users do exactly those things, they were not quickly embraced; aiming to explore the positive creative benefits of serendipitous disruptions, the Beyond Average tools ended up interrupting—and therefore revealing—the dominant efficiency mindset prevalent in corporate design cultures. A new methodological approach was needed for the final intervention.

The double diamond design process model discussed earlier represents the four phases of the design process as two symmetric diamonds representing the divergent and convergent activities within the four phases. Confirmed by the findings from Intervention B and additional interviews, designers often feel limited in the time and energy they can spend in this first area of divergent exploration; a more accurate representation of this model would probably show the first diamond being a quarter of the size of the second diamond! Moving through this first diamond requires us to move from concrete, unambiguous information to ambiguous abstractions and back to concrete information (Dubberly et al., 2008), i.e. moving from the left side of the design dimensions diagram to the right and back again. However, it seems that, if left to our own inclinations, we would prefer to stay in the left hand side of the design dimensions diagram; the side of clear, unambiguous, seemingly 'efficient' activities and specific answers. In this side of the spectrum we

are bound to the deep-reasoning questions that are characteristic of convergent thinking (Eris, 2003). As one design researcher commented on, with this attitude we ask *"does [this inspiration] fit, rather than how can it grow?"*

However, as Leski (2015) writes "a creative process comes from displacing, disturbing, and destabilizing what you know." In order to ask the more generative design questions (Eris, 2003) that help disrupt and diverge our thinking, we need to move into the right side of the Beyond Average design dimensions. This is the side of more abstract, ambiguous activities and vague provocations; the space of liminal thinking where old assumptions are jettisoned in order to transition to new ones. While artists and designers are disposed and trained to patiently navigate our way through this liminal space, the destabilizing nature of this more creative thought process is uncomfortable to many and therefore shied away from. It is not just individuals that fear the unpredictability of the liminal space; serendipity as a whole resists the Taylorist formalization that is encoded in today's efficiency-driven technologies, a way of working that is seen by organisations as more manageable. As one creative technologist succinctly noted: *"We give up creativity for increased predictability."* The Beyond Average tools and the disruptive benefits they can bring, situated in the more liminal side of the design space dimensions, are evidently too unfamiliar to many users and not naturally embraced within more efficiency-driven organisational productivity structures. A framework that situates and guides people to use the Beyond Average tools within this liminal space is required.

Discussions with other creative facilitators and tool developers highlighted several techniques that help people feel freer to wander in this discomforting liminal space. One powerful technique that many found useful was to treat the liminal space where expectations are confounded and new ideas generated as a sort of 'magic circle'; a liminoid experience that is a playful break outside of their 'normal' workaday world (Turner, 1974). In this magic circle, normal rules don't apply; thinking can change; risks can be taken. But the user needs an invitation into the magic circle and an off-ramp to get out of it. Therefore, in order for the Beyond Average tools to be more impactful, they need a structure to guide users into the liminal space and expose all of the possibilities they didn't realise were available, then help them see how these disruptive ideas can be relevant in the real world and successfully implemented in their projects.

If, as Robinson (2011) says, "[creativity] is not a specific type of activity but a quality of intelligence," what is a model of the process of creative thought that helps one arrive at an idea? A question that has been considered by many philosophers, intellectuals, scientists, and artists over the centuries, it was first synthesised into a succinct model in the early 20th century. Wallas's (1926) model consists of four stages: preparation, incubation, illumination and verification. In the preparation stage, the problem and any success criteria for the solution are defined and deconstructed and any information or early hunches about solutions gathered from many different places. The incubation stage is a moment to step back from the problem to let the subconscious process it; this can be achieved through temporarily working on another activity or turning to

something completely different to stimulate the imagination and emotions, such as listening to music, reading a book or going for a contemplative walk." This incubation prepares the mind for illumination; the 'Aha!' moment where the information gathered from the preparation stage will come together in a rush of new insights in a short space of time. While the ruminations of the incubation stage and flashes of abductive insight in the illumination stages are ruled by the intuition (Rand, 2017), the final verification stage is a more intellectual endeavour. Here, activities are carried out to determine whether or not the ideas that emerged in the illumination stage have enough potential to lead into the next phase of research and development.

The role that the Beyond Average tools play in this process is that of illumination; helping users find those unexpected 'Aha!' moments where new associations and ideas are made. Building on the insight that these tools—and the area where unexpected ideas can be found—are situated in the top left corner of the design dimensions (high contextuality and interpretability), I propose that the four stages of Wallas's model can be mapped to the Beyond Average design dimensions as shown in Figure 36. The final intervention used this liminal ideation framework to guide participants to more successfully use the Beyond Average tools in their real world projects.

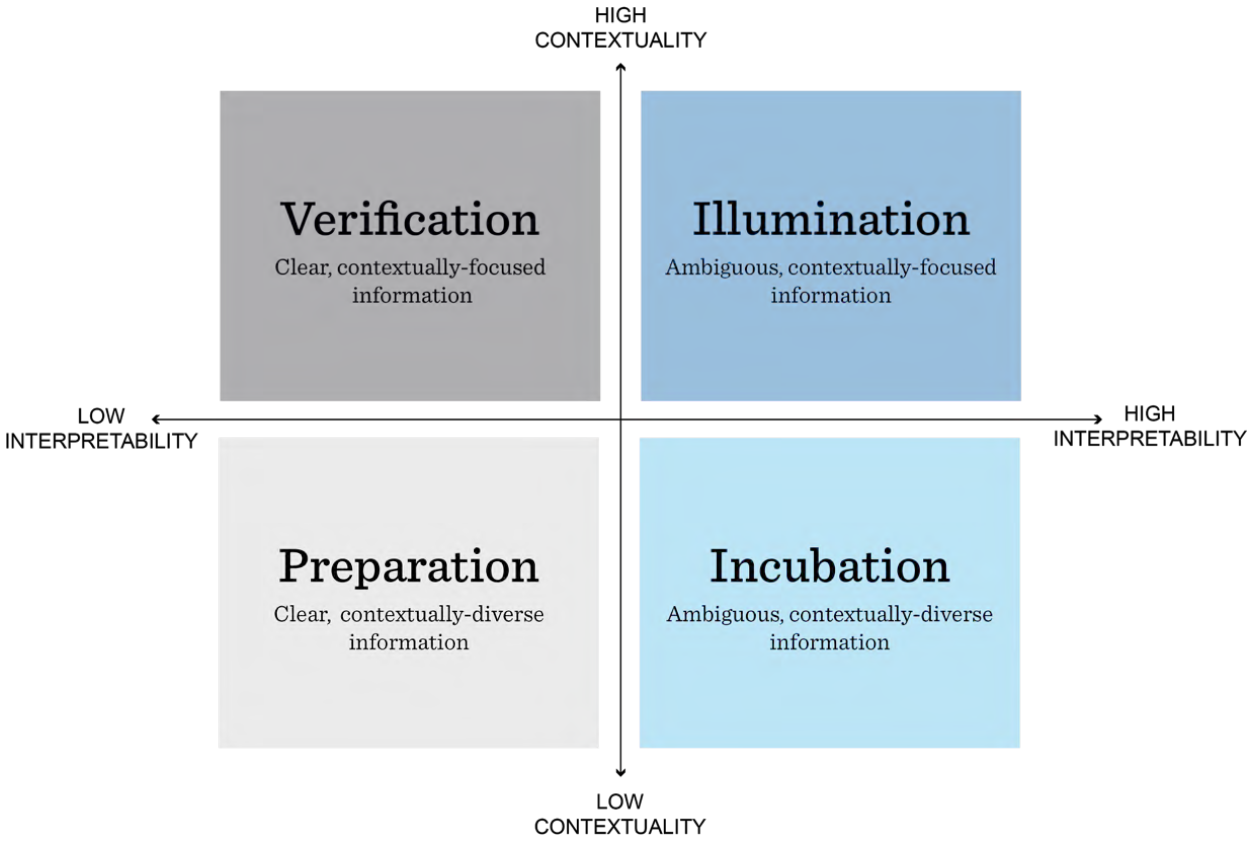


Figure 36. The liminal ideation framework: Wallas's (1926) four stages of creative thought mapped onto the Beyond Average design dimensions

5.4. Intervention C: Beyond Average tools as part of a digitally liminal process

The final intervention in this research situated the Beyond Average tools within this liminal ideation framework as part of a 60-90 minute creative workshop. The aim was to understand if framing the Reframe and Looking Sideways tools within activities that guide participants through the four stages of creative thought and introducing more seamless physical-digital interfaces for the tools—the Design Daydreams ideation table and post-it note—could improve their creative impact. 18 professional participants—10 creative practitioners, i.e. artists and designers, 5 entrepreneurs, 4 technologists, i.e. scientists and engineers (10 men and 8 women)—from both large and very small organisations generated ideas for an early phase project they were working on. Five of these participants—4 artists and designers, 1 entrepreneur (3 men and 2 women)—returned for a second follow-up session where they used the tools to continue to work on their projects in a more unguided process.

5.4.1. Methodology

After a short pilot study where 10 participants were guided through a semi-structured creative ideation session with the tools, the following activities were designed to guide participants through the four phases of the liminal framework:

Preparation activity (low contextuality, low interpretability)

This 10-15 minute activity guided the participants to define, deconstruct and gather a diverse set of information relating to the area of their project they wanted to work on. After a short discussion of the project they wanted to work on, participants were asked to use a laptop and pen and paper to write some text about their project and the problem within it that they wanted to ideate around; this could be full sentences or just a 'brain dump' of words related to what they're thinking about their project. Participants were also encouraged to find links to relevant or inspiring websites (either through memory or Google search engine). To guide this activity, the following prompts were provided: What is your project about? Who is it for? What are the technologies used? What are the measures and success criteria for your project? What are the challenges you are having at the moment? After 10 minutes, participants were asked to verbally summarise the text that they had written and write down a few concepts they considered important to their project. This content was then uploaded to the Reframe tool to customise the prompts to the participant's project.

Incubation activity (low contextuality, high interpretability)

As it would have been impractical in this workshop to do a long incubation activity such as 'go for a walk' to provide divergent, ambiguous stimulus, participants carried out a ~10-minute creative exercise to distract them from their project. As well as engaging their bodies by drawing with pen and paper while standing at the Design Daydreams ideation table, this activity also aimed to prime participants to start thinking more metaphorically; an important factor in abductive and liminal

thinking (Andel, 1994). As Geary (2011) writes, a metaphor "systematically disorganises the common sense of things—jumbling together the abstract with the concrete, the physical with the psychological, the like with the unlike—and reorganises it into uncommon combinations"; it therefore requires an openness of thought to imagine alternative relationships and "postulate similarities between apparently unlike things" (Gordon, 1961).

Existing activities to test these divergent and convergent thinking skills include the Alternate Uses Test (Guilford, 1967)—where participants are asked to think of the different uses for a simple object like a paperclip or brick—and the Remote Associates Test (Mednick, 1971)—where the goal is to find a concept that connects three different concepts, e.g. 'cottage', 'swiss' and 'cake' are all connected by 'cheese'. For the incubation activity, I developed an exercise that combined these skills: after selecting two cards from a deck of 50 inspiration images (NSRF, n.d.), participants were asked to write or draw as many ideas that they could think of that connected the images with a paperclip. For example, if a participant had an image of a bunch of bananas and a light bulb, one idea that could link these to a paperclip could be a design for a new light fixture consisting of several paperclip-shaped filaments grouped together at one end to look like a bunch of bananas. The participants were given clues to help break down the concepts e.g. think about the shape, materials, uses etc, and encouraged to think wildly and embrace seemingly nonsensical ideas.

Illumination activity (high contextuality, high interpretability)

My aim for the first two preparation and incubation activities was to prepare the participants to see relevant insights within the disruptive 'Aha!' moments provided by the Beyond Average tools in the illumination activity. In this next stage, participants used the full suite of Beyond Average tools to generate new ideas for their projects: while standing at the Design Daydreams ideation table, the Reframe tool—customised with the text from the preparation activity—is used for ~10 minutes to identify 5-10 prompts that they want to explore further in Looking Sideways for a further 10-15 minutes. The Design Daydreams post-it note is introduced here as an alternative interface through which to view the images that emerge from the Looking Sideways exploration.

Verification activity (high contextuality, low interpretability)

To help guide the participants out of the liminal space and make sense of the ideas that had emerged while using the Beyond Average tools, this final 10-minute verification activity asked them to write down a few key inspirations and new directions. These were compared to notes from the preparation activity to help participants identify some practicable next steps for their projects.

Following these guided activities, the participants carried out a survey that asked for feedback on the different parts of the workshop and rate them for contextuality and interpretability. Ratings for the creativity and lateral thinking metrics used in Intervention A were also collected as well as overall comments about how the workshop activities influenced the participants' generation of new ideas, how it could integrate into their creative practice and suggestions for modifications.

Participants were invited back for a follow up session where they could use the Beyond Average tools and other workshop activities to continue developing their project ideas. Unlike the relatively large amount of facilitation and teaching I provided in the workshops, these follow up sessions were completely unguided (other than the occasional user interaction question) so that I could not bias their creative explorations. Participants were presented with all of the tools that were available in the workshop—the incubation activity image cards and paperclip, their customised Beyond Average tools and Google search engine projected on the Ideation table display, the Design Daydreams viewers, pen and paper—to use as and when they wanted throughout the 60 minute ideation session. During a brief interview after the session, participants were asked to rate the tools that they used on the Beyond Average design dimensions and discuss the differences in how they engaged with the tools between the initial workshop and this follow up session.

5.4.2. Intervention findings

Interventions A and B demonstrated that the Beyond Average tools could help generate novel ideas but that the participants needed more guidance to understand the contextual relevance of these provocations within the existing structures of their projects and processes. Overall feedback from this final intervention indicates that setting the tools within the liminal ideation framework described above provided this guidance and therefore improved their creative impact. Rather than experiencing the creative disruptions as irrelevant, participants could more readily embrace the provocations provided by the tools and identify unexpected 'sparks' of ideas and new horizons to explore. This was shown in the ratings for the creativity and lateral thinking metrics (Figure 37).

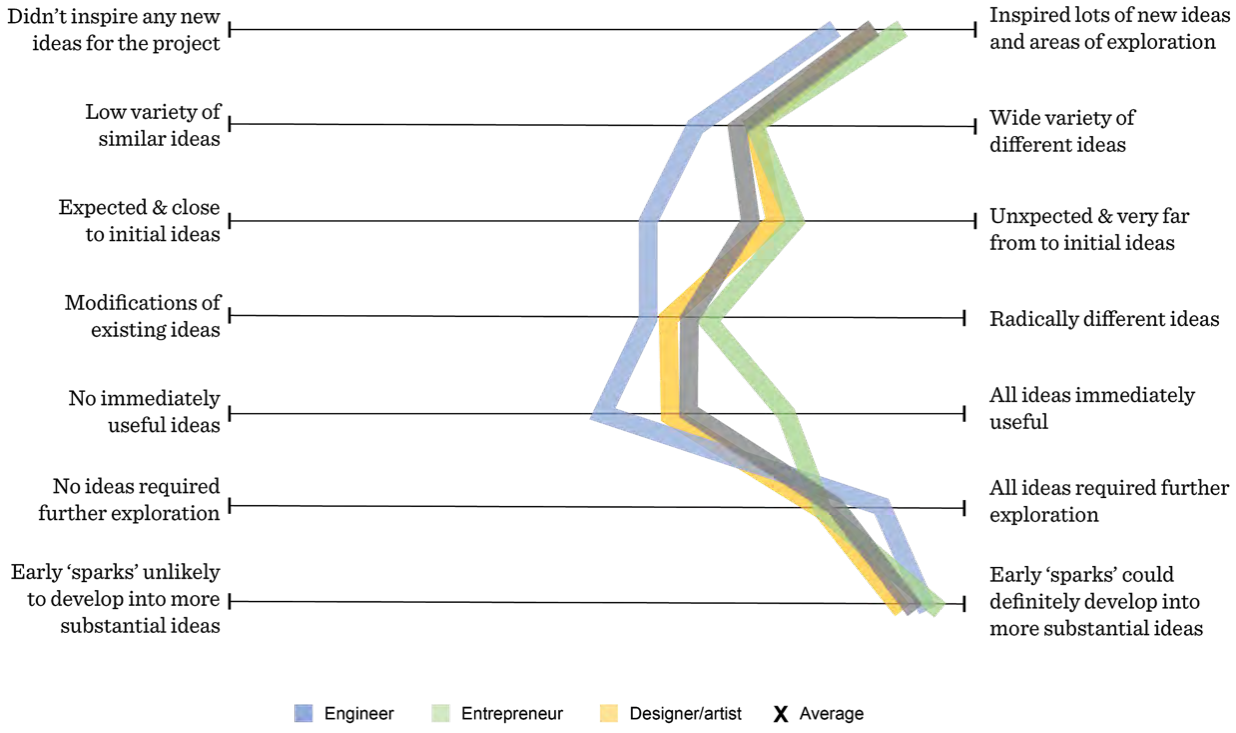


Figure 37. Overall creativity and lateral thinking ratings

Participants found the overall creativity of the workshop and tools to be relatively high (average 4.45 on a 5 point Liekert scale) as it inspired several novel ideas (av. 3.4) that incorporated lateral thinking, i.e. ideas that were not immediately useful (av. 3.45) but required further exploration (av. 4.25). In comparison to Intervention A, the variety and lateral thinking of these ideas was rated far higher (av. 3.75 and 3.8 respectively), and most importantly, there was a significant increase in the perceived quality of these ideas (av. 4.7); the tools actually helped people generate ideas that they would continue to develop in their projects!

The liminal thinking framework was effective at helping participants apply the ambiguous, creative disruptions provided by the Beyond Average tools. Average ratings gathered on the contextuality and interpretability of each of the activities show that participants mainly agreed with my hypothesis for how the four stages of creative thought could be mapped to the design dimensions (Figure 38). Detailed feedback for each of the four stages of the workshop is discussed below.

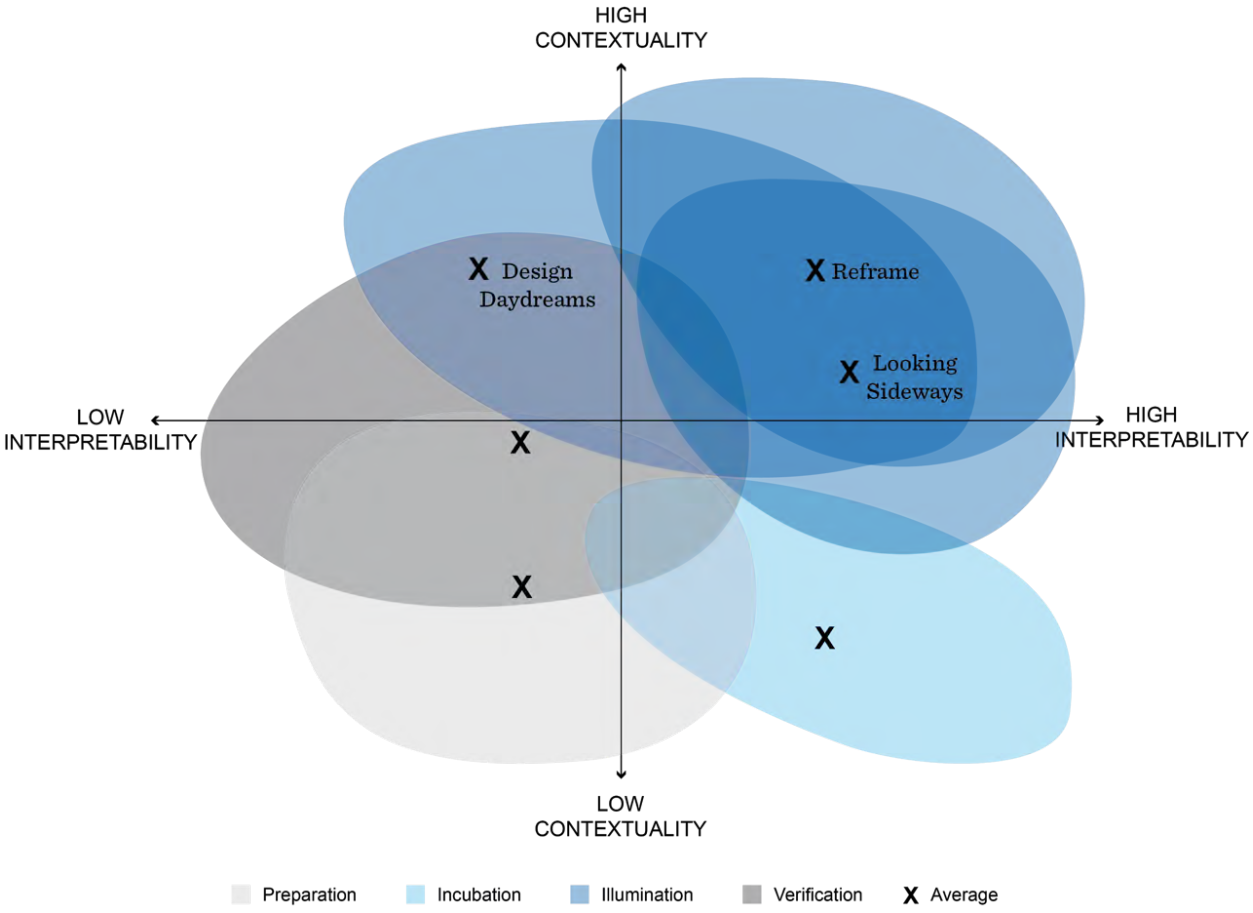


Figure 38. Participant's contextuality and interpretability ratings of the four activities

The preparation activity initiated a clarification and widening of the participants' initial ideas

The average rating for the preparation activity was in the low contextuality-low interpretability quadrant, as expected (contextuality = 2.0, interpretability = 2.55). For most participants, their notes about their project and ideas were limited in scope; as one participant said *"it took a little while to expand my thinking in this part"* and I often had to prompt them with questions more than originally intended. The designers and artists—who had a more open ended research process and natural affinity for organising diverse information—were more readily able to expand their thinking and refer to a wider range of more ambiguous inspiration and research sources (yellow area on Figure 39). As well as contributing to the customisation of the tools, this act of thinking and writing (and sometimes talking) about the text and websites related to their project was considered a useful exercise in itself; it clarified the problem around which to ideate and helped participants *"come to a clearer framework for what I wanted to do and realise that it included a variety of possibilities"*.

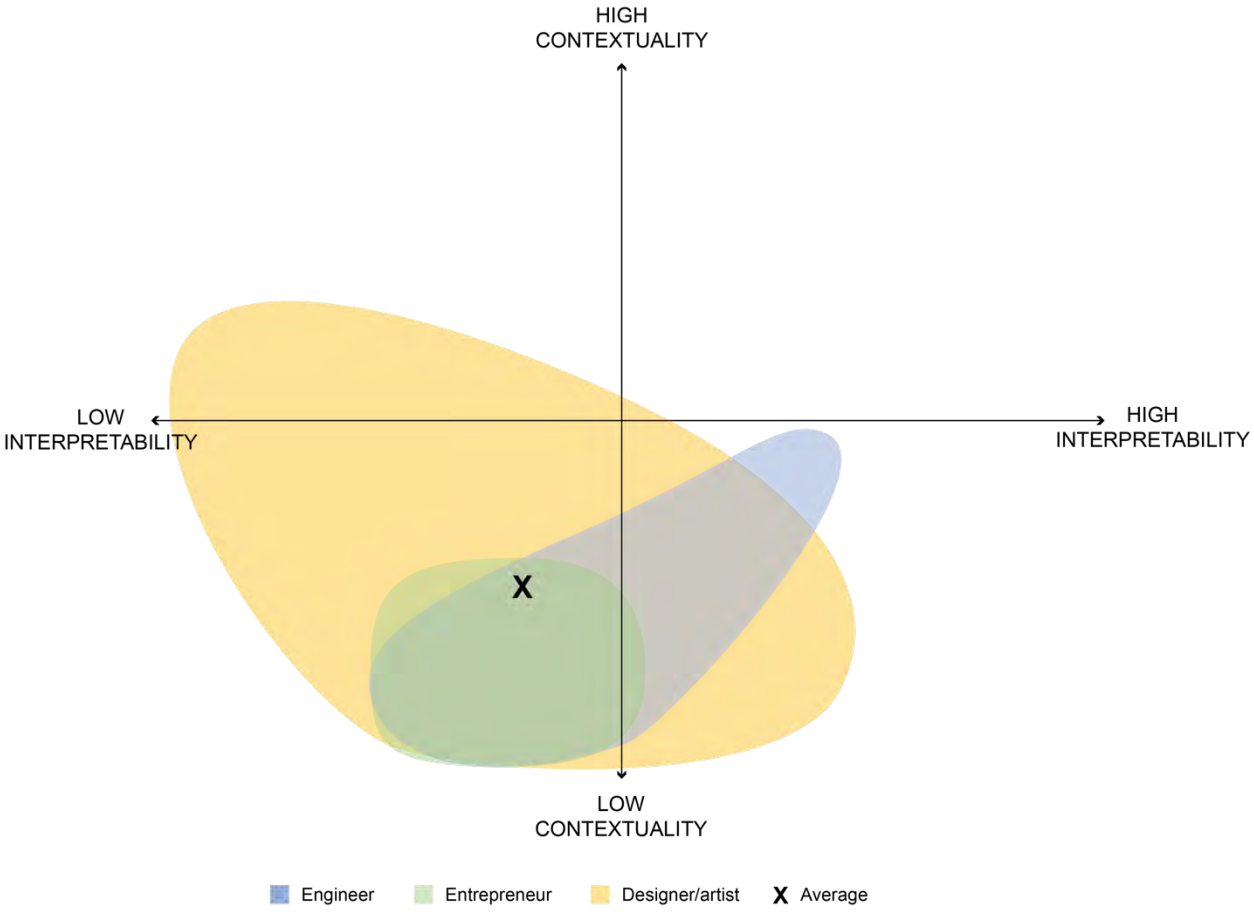


Figure 39. Participants' responses to the preparation exercise

The incubation activity stimulated the participants' ability to think metaphorically

Moving onto the incubation activity (contextuality = 1.7, interpretability = 3.9, details shown in Figure 40), participants consistently considered the low contextuality-high ambiguity associative thinking exercise to be a useful warmup in combined divergent-convergent thinking to *"activate the creativity in my brain in a limitless way"*. The playful, unrelated nature of the activity that engaged more visual and physical modalities, i.e. drawing on pen and paper while standing at the ideation table (Figure 41), evoked similar attributes to experiences that the participants sought out to jolt their creativity: *"Do something easy, without predefined outcomes. Get back to play, even if it's in a totally different area."* While the creative practitioners were more used to this type of metaphorical thinking, the entrepreneurs and technologists found it challenging at first: *"like a cold shower of creativity"*. However, once these participants relaxed into the exercise, it opened their eyes to how *"you could draw some connections between such vastly different elements"* and were often *"surprised by the happy convergences"* that could emerge. This feedback was very encouraging as it demonstrated that this activity primed the participants to be open to the types of creative disruptions that the Beyond Average tools would provide in the next illumination activity.

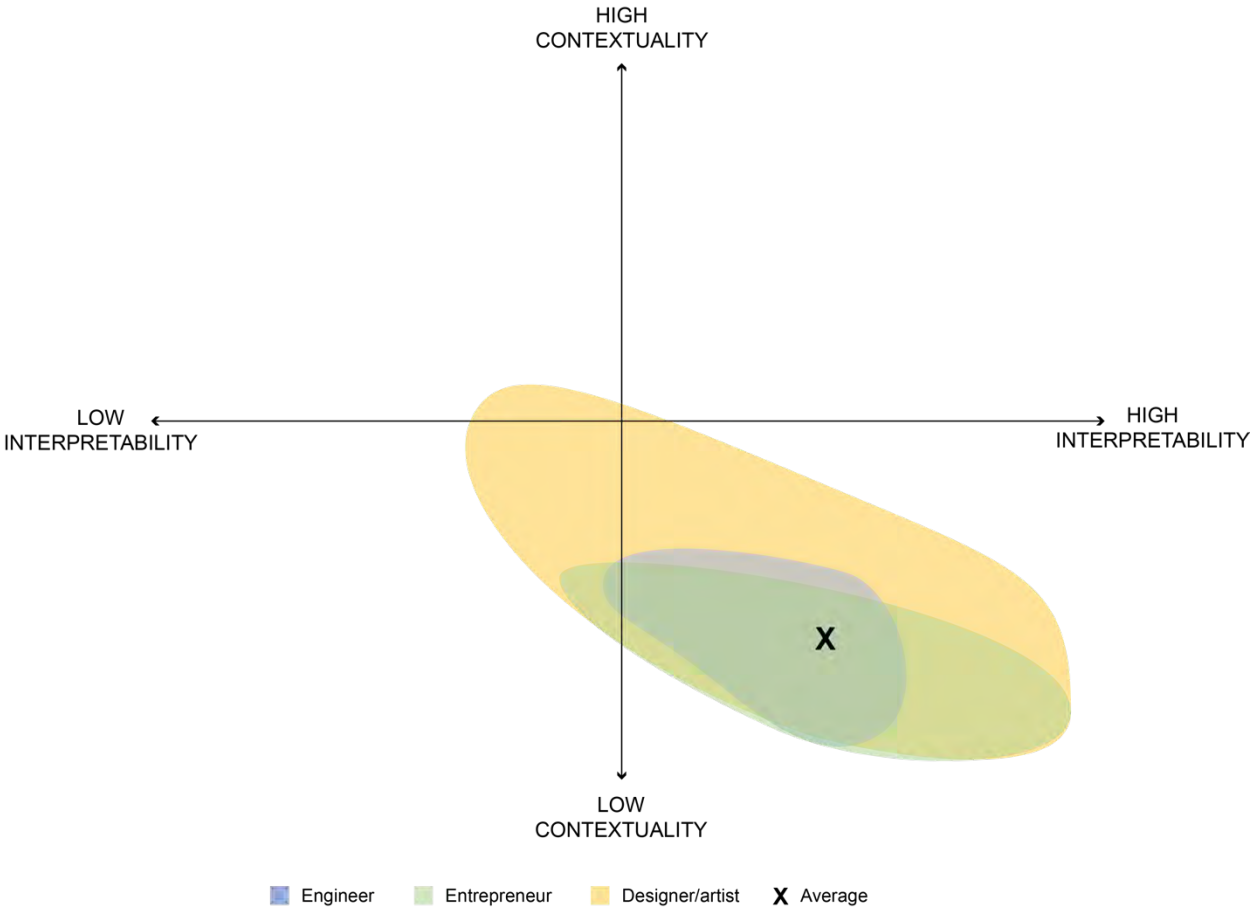


Figure 40. Participants' responses to the incubation exercise

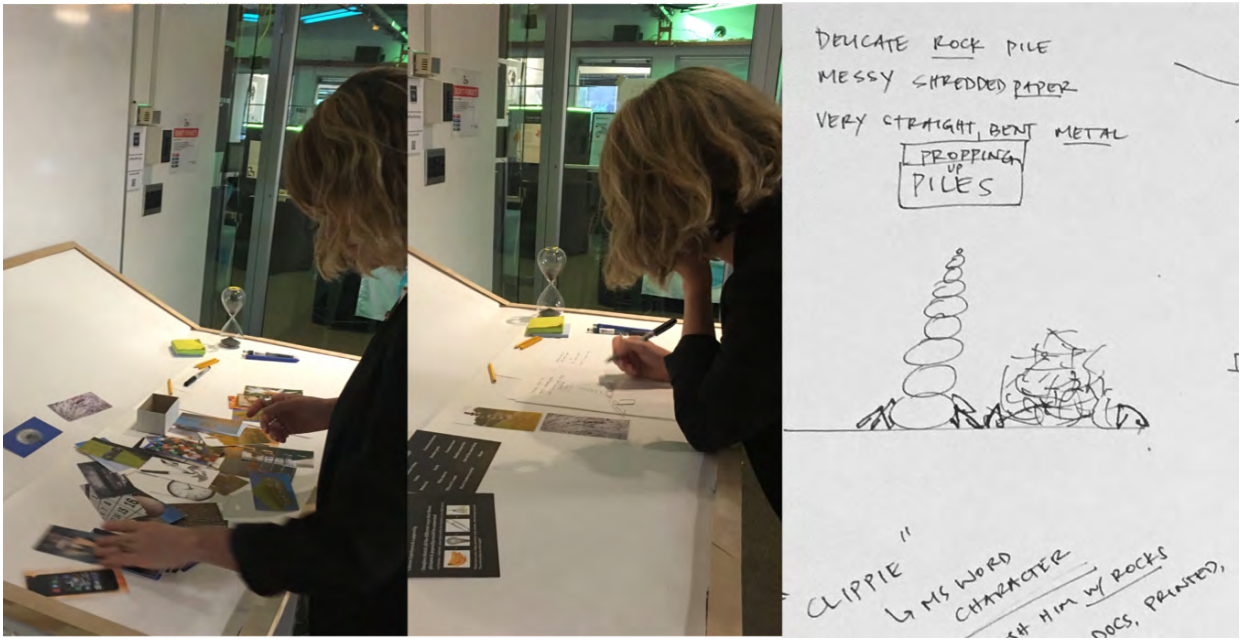


Figure 41. Participant sketching ideas inspired by two cards selected in the metaphorical thinking exercise

Using the Reframe tool in the illumination activity quickly provoked many new ideas to explore further, but only for the more creative participants in the early phase of their projects

In the illumination activity, participants used all of the Beyond Average tools to explore new ideas for their projects. Both the Reframe and Looking Sideways tools were rated by most participants as high contextuality-high interpretability (contextuality = 3.9, interpretability = 3.85; contextuality = 3.3, interpretability = 4, respectively; details shown in Figure 42 and Figure 43). The Design Daydreams tool was rated with slightly lower interpretability; this difference to the expected value will be discussed later.

Similar to the incubation activity, many participants were pleasantly surprised at the power of the Reframe creative prompts to provoke new perspectives and *"bring new ideas into old concepts"*. The ability to quickly click through many randomly juxtaposed prompts allowed participants to consider unexpected, divergent concepts that they wouldn't have found in their normal creative processes or tools. The customisation of the prompts also meant that they could converge on a few ideas that were still relevant to their project: *"it makes me understand a new word that I wouldn't have related to the project"*.

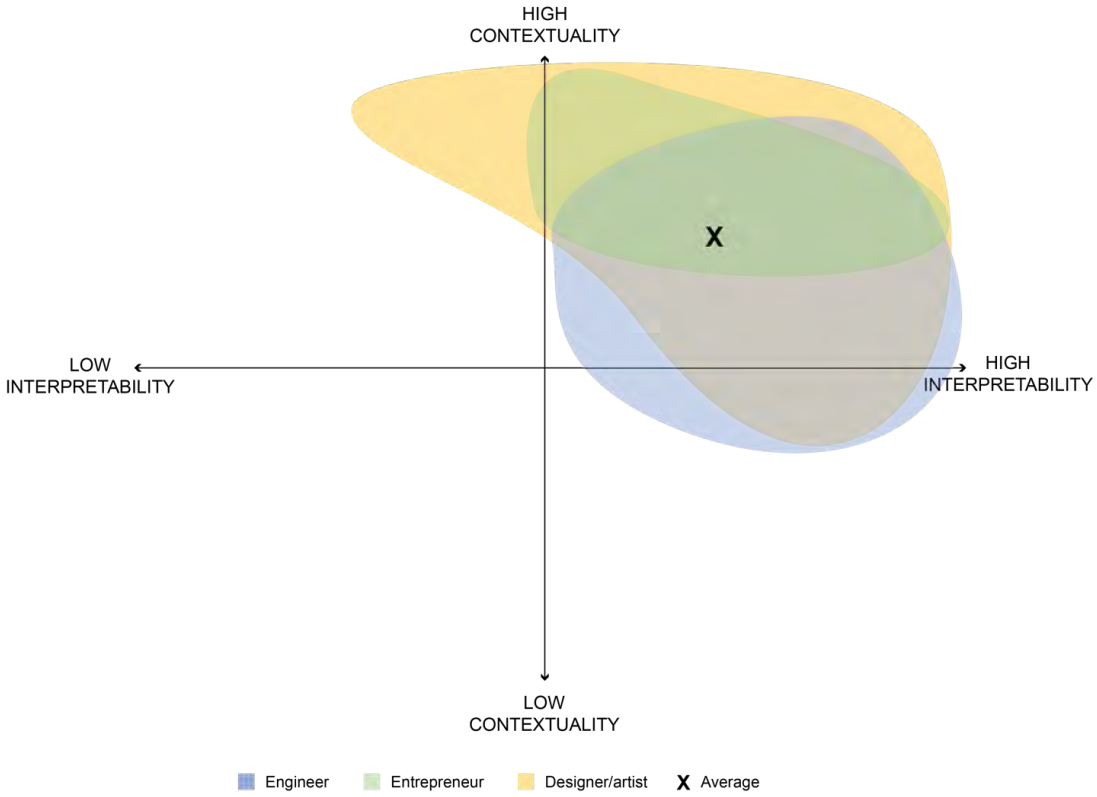


Figure 42. Participants' responses to the Reframe tool in the illumination exercise

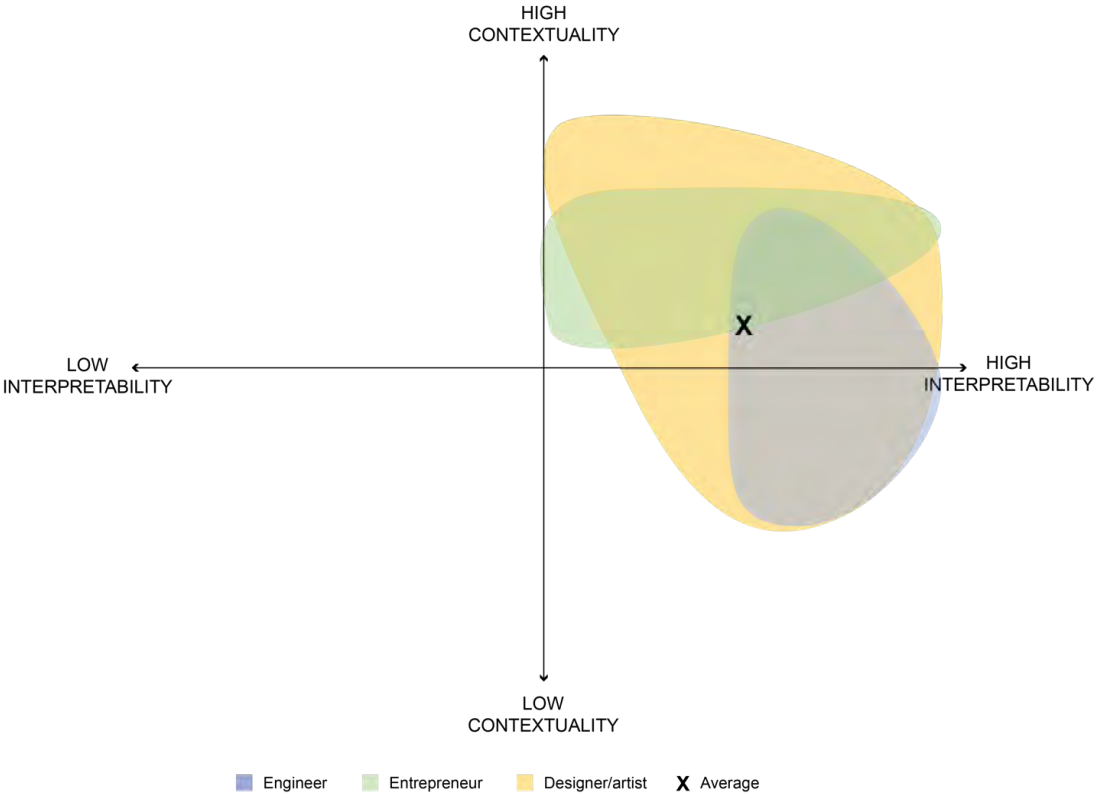


Figure 43. Participants' responses to the Looking Sideways tool in the illumination exercise

The prompts offered by the Reframe tool were not equally effective for all participants, however; some participants clicked through many different prompts before finding one that was inspiring, while others more patiently considered how each prompt might be relevant before noting it down on paper (Figure 44). The ConceptNet commonsense semantic knowledge graph (Speer et al., 2017) was used to further understand why certain prompts were chosen over others by calculating the relatedness between the words in the prompts generated (relatedness values range from -1 to 1, where higher is more related). Figure 45 shows examples of these calculations, e.g. a prompt where the words are more obviously conceptually connected has several relatively high relatedness values, whereas a prompt that is not obviously connected has several negative relatedness values resulting in a lower average relatedness.

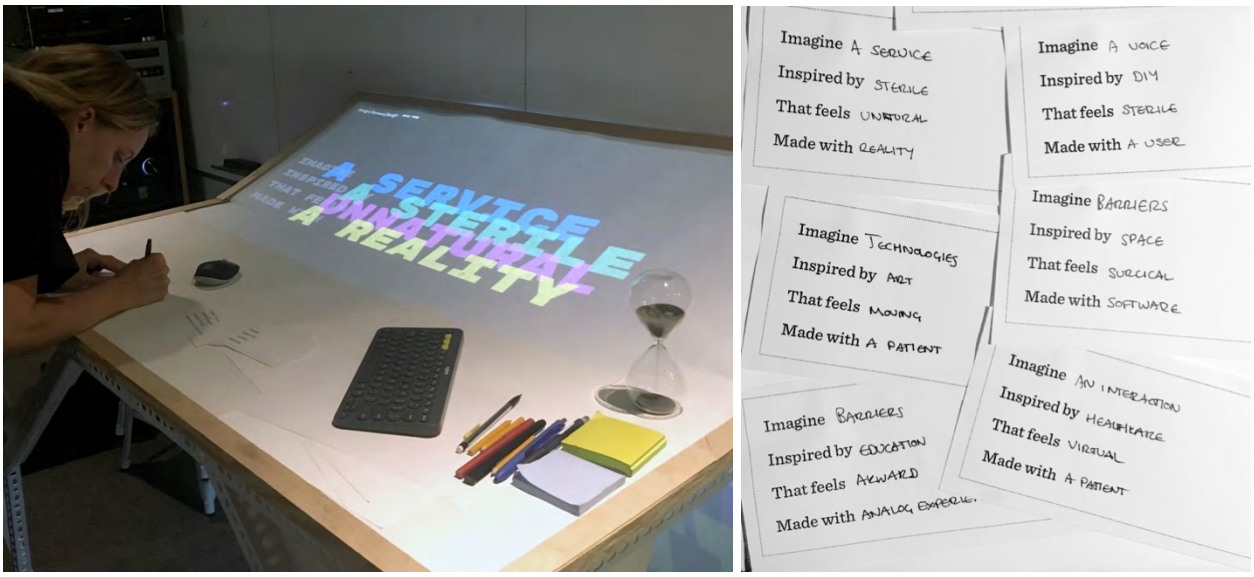


Figure 44. Participant recording Reframe prompts that they were inspired by

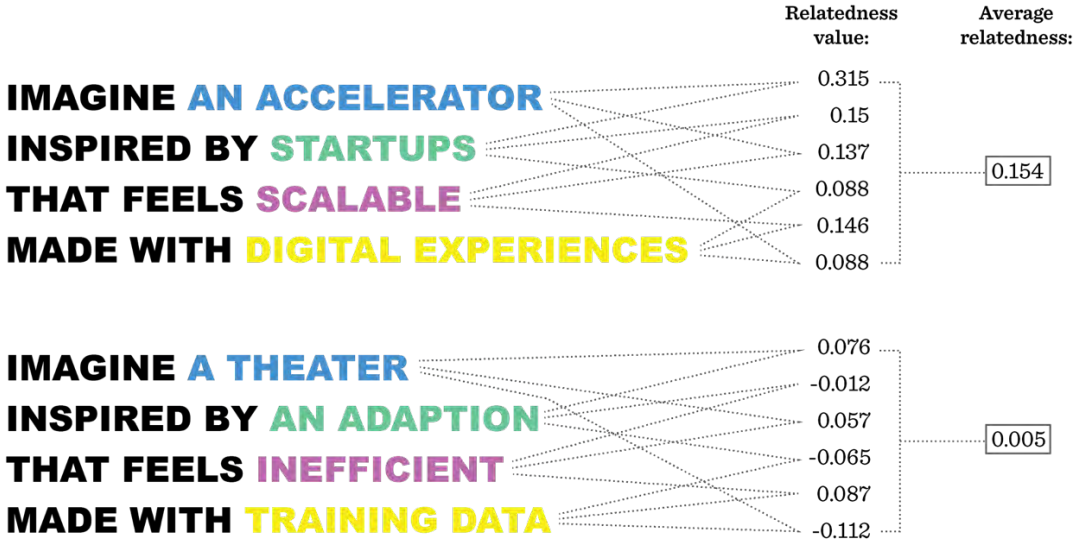


Figure 45. Examples of high and low relatedness values of Reframe prompts calculated using ConceptNet

While this analysis did not reveal any significantly generalisable findings, it did reveal some insightful trends. The average relatedness of the chosen prompts ranged between -0.04 and 0.181, i.e. prompts where the words were moderately related were ideal for this type of disruptive inspiration, while prompts that had lower relatedness scores were often rejected. Predominantly, the technologists and participants with very specific projects choose prompts with higher relatedness values (above 0.045), i.e. prompts with more immediately obvious connection to their existing ideas. This also correlated with these participants clicking through many more of the prompts that the tool presented (greater than 100) and recording fewer to continue developing (less than 5). In comparison, the creative practitioners and participants with early phase projects often rejected prompts with words that were too related, preferring to slowly consider fewer prompts (less than 50) and record more prompts (greater than 7) with lower average relatedness values (less than 0.03). Several of the participants commented on how the interaction design of the Reframe tool—a slowly animated swelling and overlapping of the prompt words—helped in this reflective process and encouraged new interpretations of seemingly conflicting concepts.

Situating the Looking Sideways tool in the illumination activity primed participants to be open to the tangential exploration of seemingly disparate concepts that help reveal new insights about their projects

Participants used their collection of Reframe prompts as initial search queries in the Looking Sideways tool (Figure 46). Similar to feedback in Intervention A, the lateral nature of responses given by the tool was appreciated by many participants as *"the system's power is in its potential to resist against convergence and to leverage ambiguity to push the creator out of her/his comfort zone."*

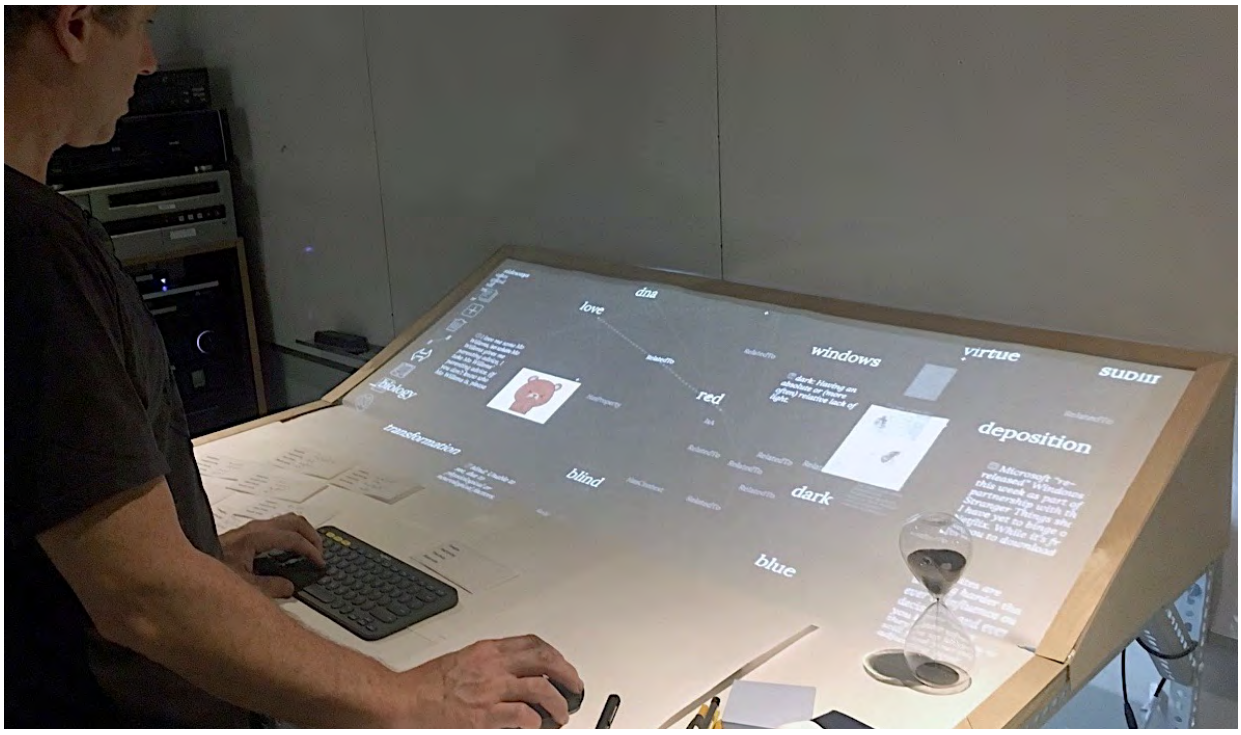


Figure 46. Participant using recorded Reframe prompts to explore content in Looking Sideways

Fairly often, the responses to a search word returned different and unexpected interpretations of the concept (resulting in the lower contextuality rating). For example, when exploring the word 'waves', one participant expected to see content related to ocean waves but was pleasantly surprised when information about the physics of waves was returned, a reinterpretation that helped widen her understanding of a founding concept in her project. Another participant's project was designing a radio-style app and so he was very focused on digital concepts about storytelling. Looking Sideways had other ideas, though; presenting images of mid-century radio sets and letters, the participant was prompted to think of how the physical artifacts that we used to gather around and communicate through could be metaphors for his app.

The images returned were often most powerful at provoking new conceptual interpretations; participants particularly noted that, while quite ambiguous and laterally connected to the main concept, including images from the museum APIs felt like a breath of fresh air to their thought process, especially the artists and designers for whom image collection is a large part of their normal process: *"I found the animated gifs also compelling in the way the animated words made the experience a little ephemeral."* This is encouraging feedback when compared to Interventions A and B where the content returned wasn't always considered creatively useful partly due to the jarring difference between the experience of using Looking Sideways when set against expectations of current more direct search engines. In this intervention, participants were better primed to be open to more ambiguous inspiration content and really liked the new search experience that provided a *"diversity of information with a directed path"*.

The feature that particularly helped guide participants through the open-ended liminal space of information and ideas presented by Looking Sideways was the association tool as it *"helped bridge concepts that are not necessarily (or evidently) related*". In particular, the ability to semantically connect disparate concepts enabled them to feel *"unafraid to go off on a tangent"* and explore further afield to identify new conceptual horizons (Figure 47). When participants used this feature in Intervention A, they appreciated this ability of Looking Sideways to take them off on a tangent but in Intervention B participants found this divergence to be distracting and not relevant to their project. The positive feedback in this intervention shows that framing Looking Sideways within a larger liminal-thinking framework enabled the participants to more readily see these opportunities for reinterpretation and lateral thinking as not only still relevant to their project, but as important 'Aha!' moments of illumination in their creative process.

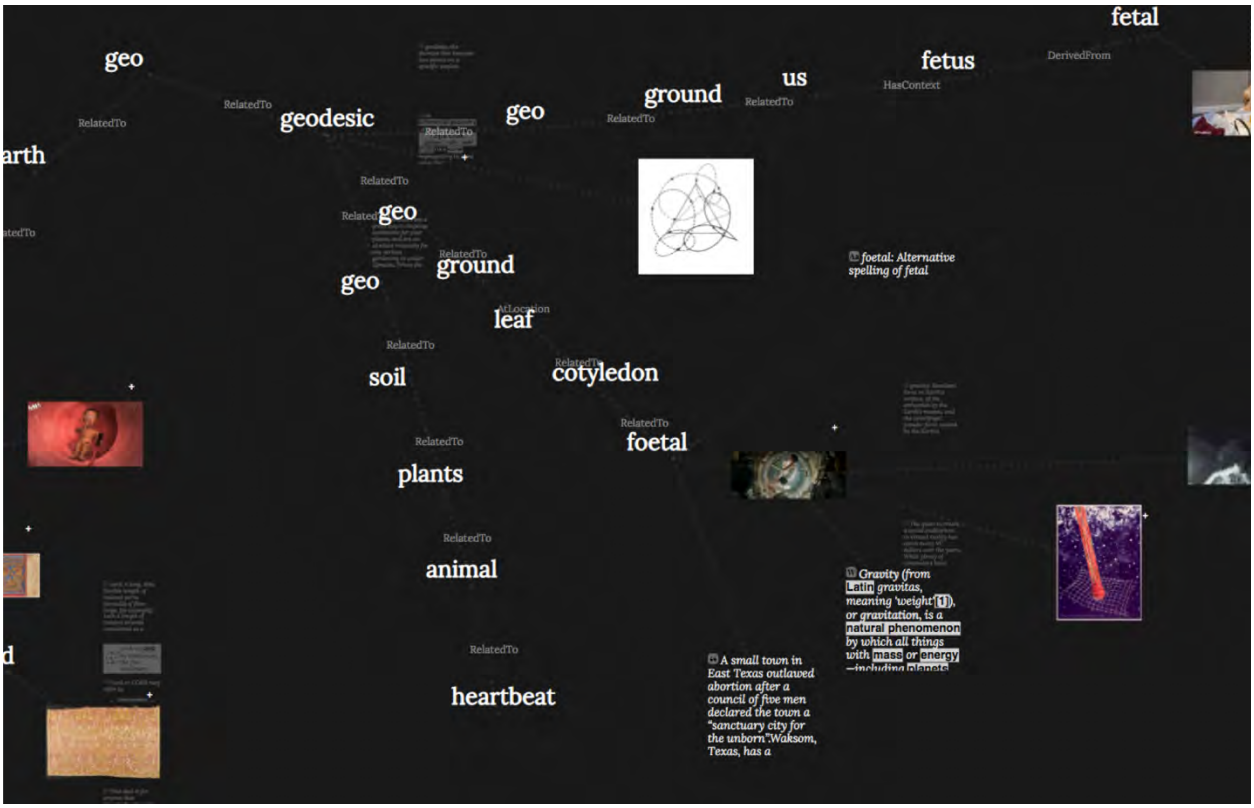


Figure 47. Example of a participant using the association feature to connect two very disparate concepts

The open-ended nature of the Looking Sideways tool also allowed a more varied range of uses by the participants, making it widely useful across designers, artists, entrepreneurs and engineers than the Reframe tool. As commented on in Intervention A, participants appreciated the ability to move and organise the nodes of information around more freely: *"I liked the agency I had in exploring them, mixing things up, making connections, adding new prompts."* Many of the entrepreneurs took the approach of exploring individual, often closely-connected words before using the association tool to explore further afield; experiencing how this feature could connect seemingly disparate concepts stimulated them to search for more diverse terms, knowing that the tool could guide them to understanding how they might be relevant to their project. The engineers often dove straight into making these semantic connections between many of the words collected from the Reframe prompts, sometimes only exploring content related to individual words later in the exploration process. This approach seemed very focused at first, but actually resulted in an overwhelming amount of content presented at once. In comparison, the creative practitioners took more considered approach; reflecting on each word and piece of content that the system presented before deciding whether to keep it, where to move it to and how to connect it to other information in the exploration. Figure 48 shows two different styles of exploration in Looking Sideways.

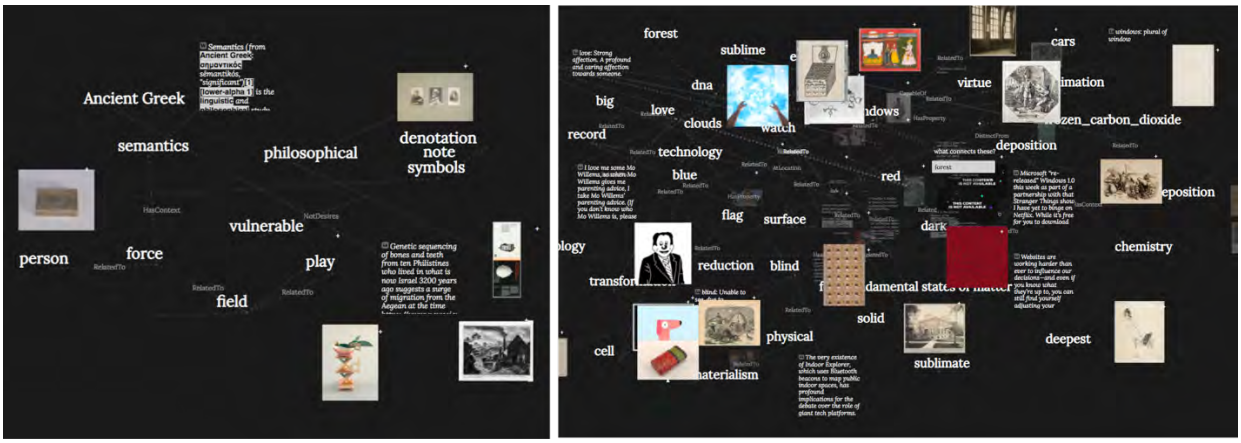


Figure 48. Two participants' very different end results from their explorations in Looking Sideways

This interaction flexibility allowed participants to somewhat direct the content of their exploration towards or away from their project focus, resulting in a wider range of ratings for contextuality (Figure 43): *"you can steer towards clarity or ambiguity or towards diverse or focus, it can move in different directions because you can control what you put on and take off."* It also encouraged a more internal reflection in several participants; having to decide how to direct the exploration helped some participants reveal deep personal motivations for why they are working on their projects, and reminded them to listen to their underlying experience and intuition throughout their projects. For example, one participant was trying to integrate more playfulness into her project and the Beyond Average tools inspired her to think about theatrical plays, which reminded her to use her training in acting as an approach to her project.

This openness still caused some challenges for the less creatively practiced participants and suggestions for improvements to the system included: adding more responsiveness to the node positioning to limit overlapping content; being able to view different types of content separately e.g. just see the words or images in the exploration; and better control the divergence of the exploration by adding more contextual curation, e.g. by using machine learning to present new content based on previous exploration terms. This, disappointingly, feels a little like the 'it would be better if it made more sense' feedback received in Intervention B, but, as will be discussed later, was likely due to the learning curve of this new way of working.

While the 'fuzziness' of the Design Daydreams post-it note provoked inspiration through contemplative sketching, the sequential nature of the image visualisation meant that the tool was best used as a more focused exploration on a specific idea

Initially, the Design Daydreams post-it note was to be introduced as part of the Looking Sideways exploration during the illumination activity as another way to explore the images discovered. However, very early on in the intervention it became clear that the function it provided jarred with the divergent exploration of Looking Sideways; the entrepreneurs and technologists especially found the addition of another tool to the illumination activity to be overwhelming. The

participants who did manage to engage with Design Daydreams (often creative technologists) used it once they had done some initial explorations in Looking Sideways and found some specific ideas and images that they wanted to do a more focused exploration around: *"I largely used the augmented post-it to realize a concept inspired or suggested by the prior tools"*. Additional feedback from a small group of expert designers agreed that the Design Daydreams post-it note was a great sketching interface for inspiration around a more focused idea, not a tool for broad exploration like Looking Sideways. Based on this feedback, this tool was introduced in between the illumination and verification activities for the second half of the studies in this intervention. Once participants had finished their explorations in Looking Sideways, they were prompted to summarise a few key ideas and use the Design Daydreams post-it note to make some sketches inspired by those concepts.

This change in protocol improved the engagement with the Design Daydreams post-it note dramatically: participants in the first half of the studies only rated it an average of 2.71 out of 5, which improved to an average of 3.83 after the change. Consequently, Figure 38 only uses data collected from the second half of participants and the expert designers who gave additional feedback (n=10). It shows that the tool was rated with lower average interpretability (2.33) and higher average contextuality (3.67) than I expected, moving it into the verification quadrant.

Observing how participants used the Design Daydreams post-it note revealed why this tool did not match my hypothesis. Many participants using the tool to directly 'trace' an image that they found on Looking Sideways onto a piece of paper by looking through the post-it viewer (Figure 49): *"it is focused in that it has only one image at a time and you can direct it"*. They then sketched on top of and around that tracing to build on the concept. Using the viewer to overlay different images (static or animated) on top of these existing, very focused sketches allowed the participants to diverge from their original concept by merging several visual concepts into new ideas (Figure 50): *"there's this parallax between allowing to draw what's here and draw what's on the overlay and it's really fun when you can merge the two."* This seamless blending of images discovered in Looking Sideways allowed the participants to start synthesising more focused ideas from their exploration: *"you take from the learning [on Looking Sideways] and select different things and put them down next to each other. [Design Daydreams] blurs into the Looking Sideways space and forces you to push towards clarity."* This advantage to overlay the images viewed on Design Daydreams did not extend to overlaying them onto objects in the surrounding environment, however, as the juxtaposition of too many random concepts was too overwhelming to provoke relevant inspiration: *"if it's any image against any shape then it's too much"*.

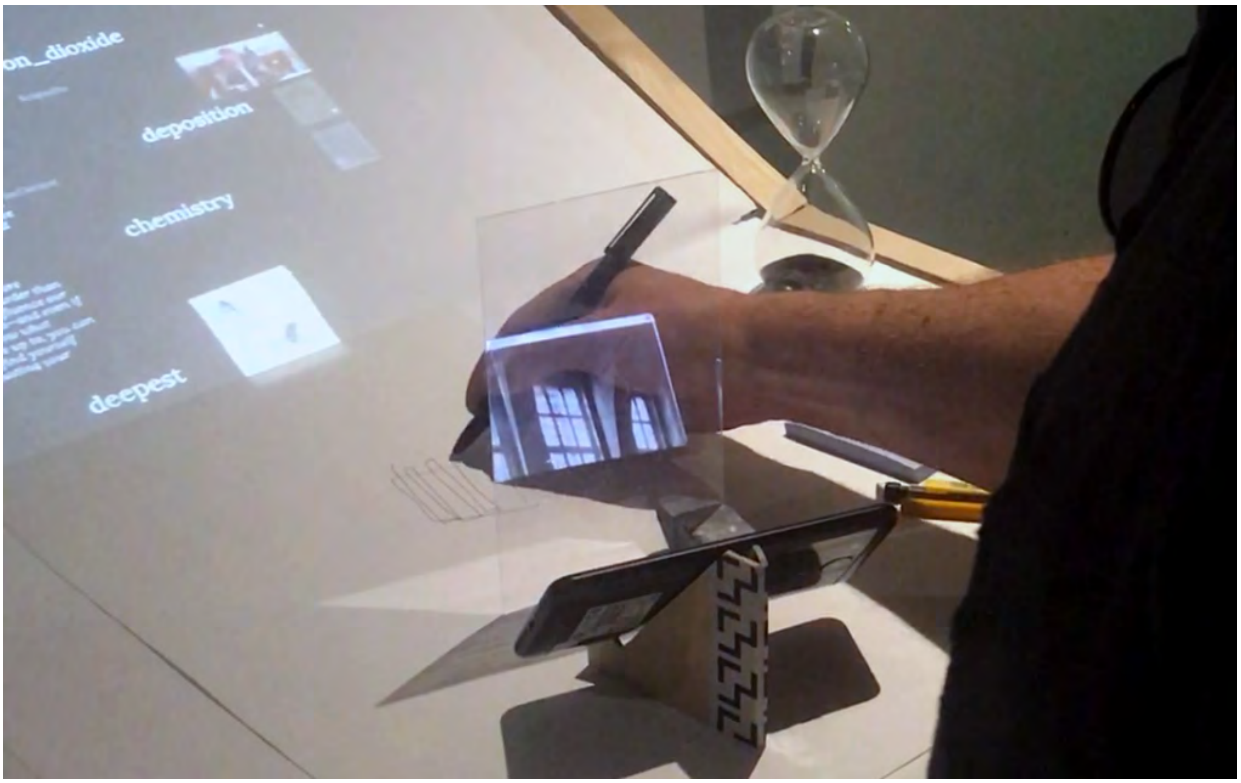


Figure 49. Participant using the Design Daydreams post-it note to trace an image

Figure 50. Participant using the Design Daydreams post-it note to overlay multiple images on a single sketch

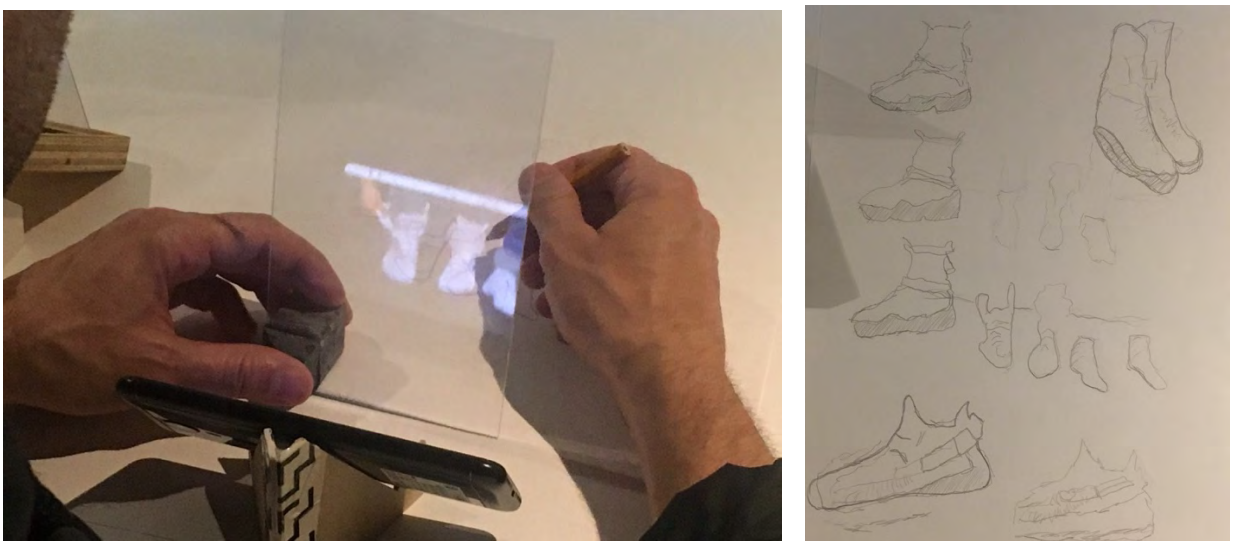


Figure 51. Example of a participant's slightly obscured view and 'fuzzy' sketches

This is not to say that the tool allowed precise representation of the participants' ideas; as well as physical design issues that made repositioning cumbersome, the nature of the AR viewer being in-between the eye and the sketching plane means that the user does not always have a crystal clear view of their sketch (Figure 51). The ambiguity this contributed to the sketching process was appreciated by many participants as *"when you draw precisely, you can't go anywhere else [but] when you're less precise, you can find new directions"*. This inherent low fidelity of the Design Daydreams post-it note and the resulting drawings allowed participants to be less precious about their sketches and quickly iterate through ideas: *"it does allow you to work quickly in a sort of sketch mode where's there's not a lot of weight or risk in making a bad sketch, you can move very quickly through things."*

The combination of this focused contextual application and inherently 'fuzzy' interface induced a contemplative experience that allowed many participants to feel unconstrained by the need to 'solve' something or produce hard outcomes: *"doing this for me is a non-think, it's just allowing your hand to do something and not think about it too much, and then allow a process to happen after."* Several participants mentioned that they liked to 'look through' the image on the viewer which stimulated a more liminal type of creative thinking: *"It really feels like to me like when you're daydreaming looking out of a window and when you're doodling and thinking about things while looking out of the window but you're also trying to concentrate. So you're looking through this [viewer], you're getting stimulation, but you're concentrated on the thing that you're trying to focus on."* This is welcome feedback considering the motivation behind using a low-fidelity AR technology was to encourage users to see images as inspiration 'cues' from which to build new ideas, not be distracted by perfect pixels.

Overall, the flexible format of both Design Daydreams and Looking Sideways allowed participants to balance how they used the tools and shape their own creative interactions and cycle between exploring random, ambiguous inspirations and directing the tools towards developing a more focused, specific idea: *"[Looking Sideways] is good for thinking about the idea and [Design Daydreams]*

is good for taking the idea into imagery, so sometimes I want to use [Design Daydreams] to get directly into the imagery and then take those ideas back into [Looking Sideways] to frame the idea." Extending the ability to shape the experience of the tools, participants suggested adding a feature to automate the casting of images *and* words found during their Looking Sideways exploration to the Design Daydreams viewers to further integrate the seamlessness of the digital and physical interfaces.

The Design Daydreams ideation table provided a multi-use workspace that seamlessly connected digital and physical inspiration content and allowed a bricolage approach to using the Beyond Average tools

Whereas the preparation and verification activities used only a laptop and pen and paper to record ideas, the incubation and illumination activities used the Design Daydreams ideation table to engage with the digital information. Compared to Interventions A and B, participants acknowledged many advantages of using the ideation table to interact with the Beyond Average tools. One simple benefit was the increased physical size and *"more real estate"* to more easily view a wider array of the digital content explored in Looking Sideways. This increased scale of not only the 'display' but also the writing area, joined together in one seamless surface, allowed participants to easily move back and forth between different tools and media throughout their creative explorations (Figure 52): *"seeing all [the Looking Sideways content] lets me go back to [my old notes and Reframe prompts] and these things inform [my sketches with Design Daydreams]. Being able to go back and forth is really important for me."* The seamless ability to switch between the digital and physical tools was considered very important as participants often assigned particular creative functions to each of them: *"[notes and drawings on paper] are for collating and summarising things because the act of physically writing something is a way of inspiration as well. But I can take that and very quickly go out [using Looking Sideways] and then come back in [using Design Daydreams and pen and paper]."*

Figure 52. Example of a participant's workspace using all of the Beyond Average tools

Figure 53. Participants ratings of the creativity of different media and environments

While not well designed for very tall users, most participants appreciated the physicality of the ideation table setup, noting that the projection on paper and black background of the tools helped create an ephemeral focus that they don't normally get when using digital tools on their normal computer screens or laptops. Almost all participants rated using pen and paper and standing to be better for creative and divergent thinking, while working on a laptop and sitting was better for productive, convergent activities (Figure 53); the natural ambiguity that tangible media brings enabled participants to more naturally embrace the liminal creative mode and escape the solutionist efficiency of the digital tools they use in their normal process.

Participants didn't identify clear ideas or next steps in the verification activity but it did help them collect a few new 'sparks' to continue researching after the workshop

The verification activity aimed to guide participants to synthesise a few clear ideas and practicable next steps from their explorations using the Beyond Average tools in the illumination activities. Comparing these new concepts to the initial project descriptions recorded in the preparation activity helped participants converge on a few new ideas that could be immediately impactful to pursue in their projects: *"I enjoyed comparing my thoughts to the first exercise which was much more practical and mapping my new found inspiration to the more concrete needs of the project."*

However, as is shown in Figure 54 participants didn't find this activity provided as clear resolutions from their explorations as I had hoped. While some participants rated the activity to be high contextuality-low interpretability, many—including most of the entrepreneurs—evaluated it as low contextuality-low interpretability i.e. the preparation quadrant (av 2.85 contextuality, 2.55 interpretability). Instead, the verification activity helped participants collect a few key insights and new 'sparks' to inspire the next phase of research in their project after the workshop; almost like a 'mood board' for conceptual inspiration. In fact, several participants mentioned that a good addition to the Beyond Average tools would be some sort of digital mood board to more seamlessly 'collect' key pieces of content that particularly inspired them.

This decreased level of contextuality could be related to the projects the participants were working on and the goals or types of output relevant at that particular moment in their creative process: *"The style used for summarizing ideas would depend on the type of goal. For highly speculative and creative projects, a wide range of info and ambiguity would be invaluable, whereas for projects that are focused on a well-defined problem would utilize focused and detailed information."* Customising the verification activity to help participants meld their new inspiration with a certain type of output that is most relevant to their projects, e.g. a storyboard or a reading list, could shape these 'sparks' into clearer ideas and more definite decisions for next steps in the development of their project.

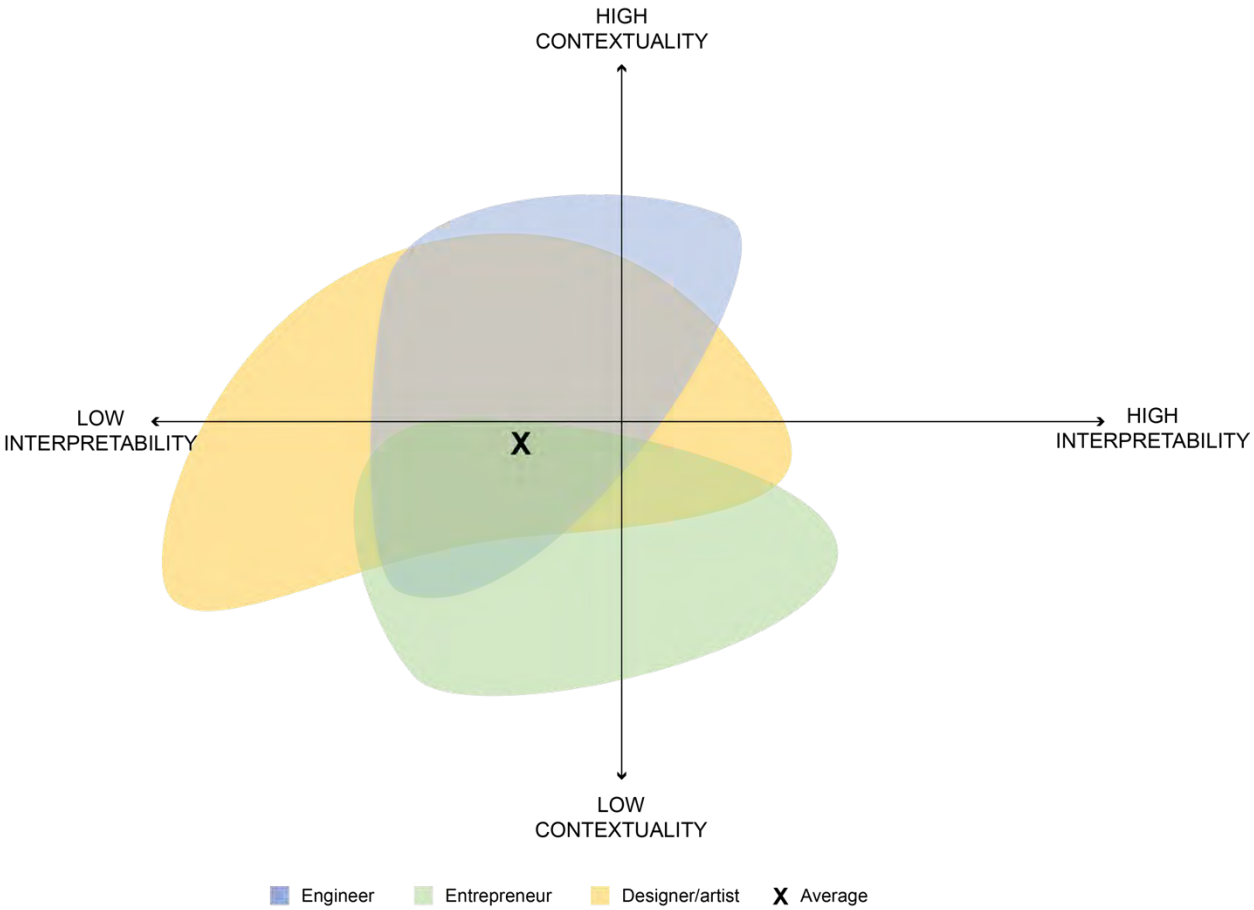


Figure 54. Creative practitioner, entrepreneur and technologist's responses to the preparation exercise

In follow up sessions, participants were confident to use the tools without guidance and more attuned to finding the 'right' disruptions they needed in order to continue with their project

Follow up sessions were offered to all of the participants and five returned (4 creative practitioners and 1 entrepreneur) within six weeks of their original session to continue developing their ideas using the Beyond Average tools. It was immediately evident that the bulk of the verification activity—where the participants determined which ideas to continue with in the next phase of research and development—was best completed outside of the workshop; participants had time to *"sit with the ideas for a while, try some things out...and iterate based on whether it is working"* as well as get feedback from others on which ideas have most potential. All of the participants came to the follow up session having reflected on the 'sparks' found in the initial workshop and synthesised them into much more focused ideas to explore further.

This self-guided management of their creative process was continued in the session, as the participants confidently dove into using the various tools on offer without any guidance from me (other than occasional interaction questions); the initial workshop had given them *"a sense of how*

the tool works and the types of connections and surprises it can give you", better framing their expectations for what they can achieve using the tools. Several of the participants came with a specific purpose for this session, aiming to explore a more focused concept within their project and come away with inspiration for a certain output: *"Before I was really just exploring and thanks to you I got a good take away from it, but this time I knew that I wanted to make a collection of [inspiration] that I wanted to take with me to keep exploring."* As one of the aims of this follow up session was to confirm that my facilitation wasn't required after the initial workshop session, this was reassuring feedback!

Due to this pre-prepared focus, all but one participant didn't carry out the incubation activity in the session; they just went straight into using the Beyond Average tools. The one participant who did use the metaphorical thinking cards as an incubation activity was the entrepreneur. In the initial workshop, she appreciated the guidance that helped her diverge and converge her ideas; the incubation activity in particular *"was very noticeable to me because it made my head go someplace weird...I wanted [the incubation activity] to kick me off because I think I needed that"* before using the Beyond Average tools.

This focus on a more specific idea also affected how useful the participants considered the Reframe tool in this follow up session; Figure 55 shows that opinion was divided as to whether it was too ambiguous or too focused to inspire relevant prompts for their projects. Some participants reflected that the ambiguity Reframe provides can help them consider new interpretations of their ideas before diving into exploring those concepts further: *"If I started with [Looking Sideways] I would just start typing the words that are in my head right now which probably would have been too focused on the project as I can see it, whereas [with Reframe] I get to explore words that are connected in new ways."* However, others only appreciated that openness in the initial workshop and didn't find Reframe as useful when working on a more focused idea: *"It's a little too general, a little too random, which I think is great in the beginning using this tool, but once you've chosen a path it would be nice if you could get a little more specific with it."*

This conflicted opinion is reflected in the analysis of the prompts chosen by the participants. Several participants only clicked through a few prompts before switching to using the Looking Sideways tool; those that did use the Reframe tool for longer, only noted down a few prompts (<5) out of the many they clicked through. These participants were waiting for prompts about more specific concepts related to their project, which is shown in the slightly higher average relatedness value of the chosen prompts compared to the ones they selected in the initial workshop (average relatedness values greater than 0.06, compared with less than 0.05 in the initial workshop). A suggested improvement to Reframe was to be able to slightly curate the prompts shown when they are using the tool on a more focused idea.

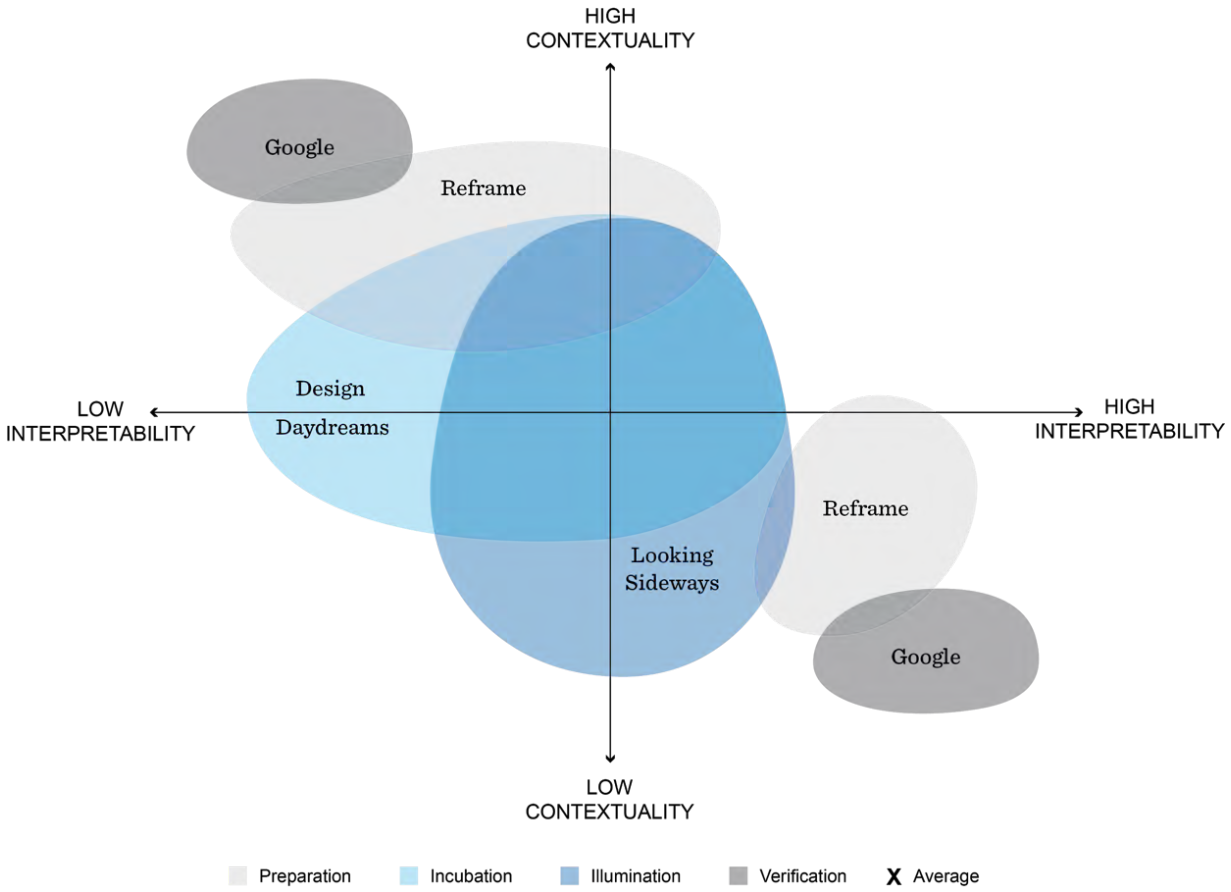


Figure 55. Participant's contextuality and interpretability ratings of Beyond Average tools in the follow up session

Participants appreciated the ability to direct the tool towards more or less focused content while using Looking Sideways. Participants used the tool similarly to the initial workshop—sometimes starting exploring individual concepts and then using the association feature to connect them, and other times connecting many words initially and then exploring a select few—albeit with a far greater sense of direction in their exploration. In comparison to the workshop where participants often embraced the ambiguity of the content presented by Looking Sideways to explore their early ideas more widely, they were more selective in the follow up session, carefully considering the content presented and regularly deleting unwanted content to converge on a more focused set of inspiration: *"Last time I felt like [Looking Sideways] helped me explore a bit more but now it's helping me frame it all together. I think it might depend on where you are in your brainstorming process."*

I was happy to see several participants switch between using the different tools throughout the session. The Design Daydreams post-it note was more actively partnered with Looking Sideways, often used after a short period of exploration where participants had identified an interesting image that they wanted to use as inspiration for a more focused sketching exploration. Some participants then used the ideas they generated from their sketches as new search nodes in Looking Sideways, or as text to further customise their Reframe prompts. The seamless flow between the different Beyond Average tools was also facilitated by Design Daydreams ideation table setup. Participants

used pen and paper to record the content that they were particularly inspired by, often creating diagrams that built on the concepts presented in Reframe or Looking Sideways or annotating sketches inspired by Design Daydreams (Figure 56). They also frequently reorganised the workspace as they moved between tools and recorded more ideas; the smooth transition between the digital projection and flat writing surfaces allowed the participants to lay out their physical notes next to the digital content they were exploring and consider them together (Figure 57).

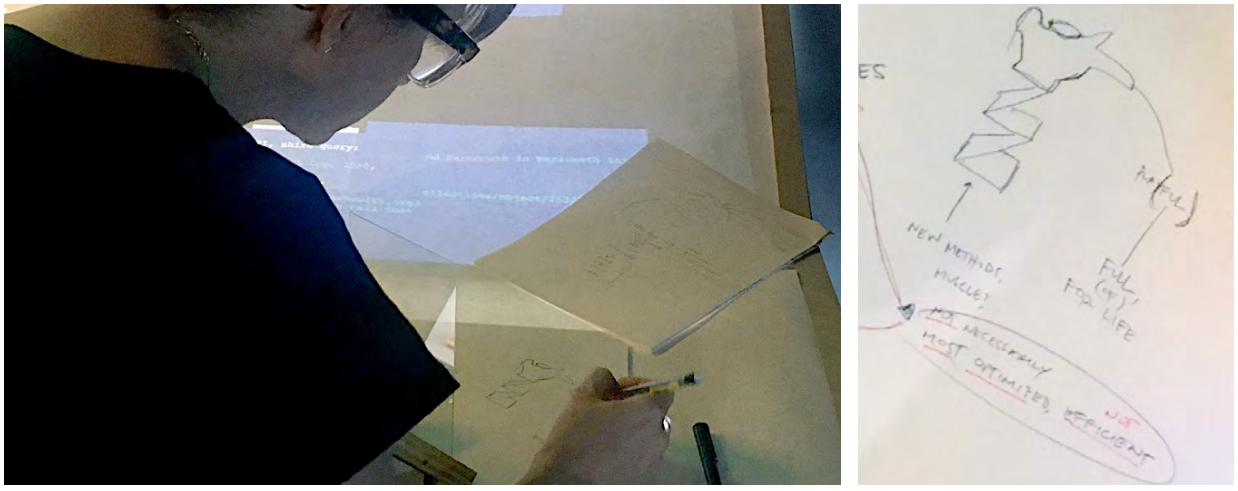


Figure 56. A participant using the Design Daydreams post-it note to trace an image which she then annotated

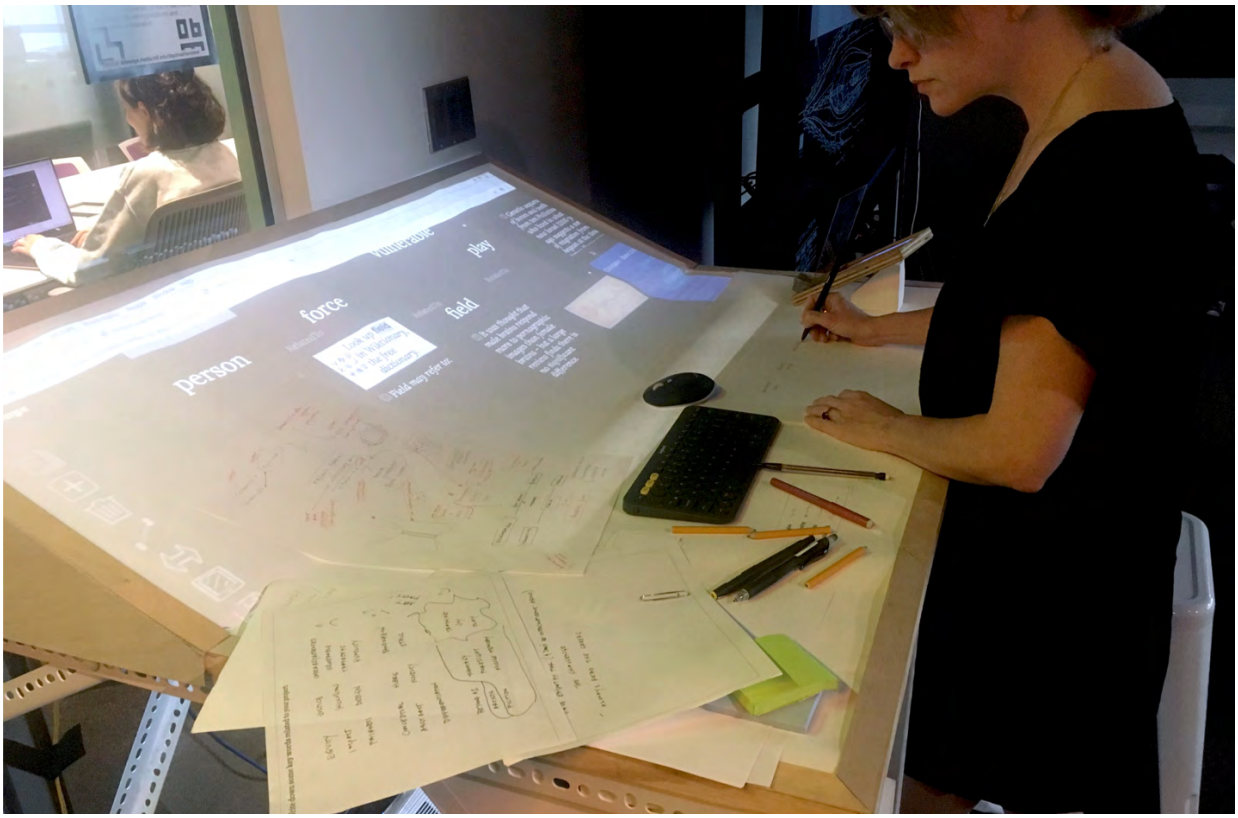


Figure 57. A participant rearranging the content on their workspace

5.4.3. Intervention insights: the liminal ideation framework helped shape expectations for when the Beyond Average tools are best used within a project and how to productively apply the creative disruptions they provide

After the disappointing feedback from Intervention B, this final intervention encouragingly demonstrated that the Beyond Average tools could indeed be an effective contribution to real world creative projects. The liminal ideation framework helped frame the use of the tools so that the provocative inspirations they provided could become a more familiar and continually productive part of a participant's creative process. The initial workshop helped to teach participants what the tools can do and how to use them, as well as how to scope the types of problems that the tools can best help with—early stage explorations or pivot moments later in a project—and confidently employ the serendipitous provocations generated.

Once participants understood how to use the more liminal explorations encouraged by Beyond Average tools, they realised that they tools provided a relatively fast and structured approach to integrating more divergent thinking and convergent illumination into their creative process: *"normally [my process] is Googling Googling Googling for days on end to try to find information to build a mood/inspiration board...This is a much more advanced and faster version of what I've done in the past."* The agency provided by the Looking Sideways tool especially afforded users some level of control in directing the serendipity towards a productive outcome, which, as one participant said, *"feels like the way a classically trained artist might approach a project or an idea."* The combination of these modes of creative and productive exploration was considered to be rare among the other tools available.

Reflecting on the benefits of more liminal tools in their creative process, participants recognised the power in 'unlearning' that these serendipitous approaches can provide. Like a good creative partner that builds on your ideas with new information or questions, these tools warmed up the participants' creativity and made them aware of how other tools might be shaping their ideas, reminding them to include more sources of inspiration in their process: *"[the workshop] made me realise how bad Google is when I used it after the other tools."* Once participants were familiar with and skilled in a more liminal approach, they pushed themselves to consider more diverse ideas, diving into the ambiguity of the low contextuality-high ambiguity quadrant and *"the fun part is to figure out how [those inspirations] can be relevant and focused*". Returning to the Beyond Average tools in the follow up sessions, participants approach the preparation activity from a broader perspective, including more of the divergent metaphorical thinking present in the incubation activity. Taking this more liminal approach to their preparation enabled the participants to be more open to seeing relevance in the provocations provided in the illumination activity, incorporating the convergent thinking relevant in the verification activity. Figure 58 proposes a new mapping of the stages of a digitally liminal creative process to the Beyond Average design space dimensions.

Figure 58. A digitally liminal creative process mapped onto theBeyond Average design space dimensions

Chapter 6.
Towards a Digitally Liminal Creative Process

The above interventions demonstrated that the creative disruptions that the Beyond Average tools provoke cannot exist alone; they must be situated in a larger design process that accommodates for serendipitous interjections and unanticipated ideas. The following chapter distills these findings as well as my own experiences developing and deploying the tools into a set of guidelines for designing tools to augment a digitally liminal creative process. I also consider how this research can be extended to explore the future of the digitally augmented creative process, detailing further studies for this research and proposing my vision for a Beyond Average creative workplace.

6.1. Designing Tools for Digital Liminality

Designing digital tools to augment the liminal period of the creative process requires integrating serendipity into the tools themselves but also embracing it in our expectations for how the tools can be of use in our creative processes. Discovery, therefore, consists of two elements: serendipity—exploring unexpected ideas—and sagacity—the ability to make use of these provocations (Halvorsen, 2016). Sagacity is often called the 'prepared mind'; an attitude characterised by curiosity, intuition, flexibility and "loose blinders" i.e. the ability to remove the blinders that keep us focused when a potentially inspiring tangent serendipitously presents itself (Andel, 1994). These serendipitous provocations are provided by the 'prepared system'; the environment or experiences that can optimise the opportunity to consider seemingly irrelevant but inspiring ideas.

Entering this liminal space of discovery can feel like a risky, uncomfortable endeavour to many. The answer to this challenge is not to make the experience less risky, thus limiting the great rewards that this ambiguity can offer, but to help people feel more confident as they wander

through the chaos of creative unknowns. Preparing users for this liminal experience creates a space within the design process for serendipitous inspirations to be embraced. Once confronted with these provocations, having the agency to direct them towards certain intuitive or tangible outcomes helps users apply these innovative ideas.

So, how do we leave space for serendipity in both the design process and the digital tools we use to explore new ideas? The following sections summarise guidelines for preparing for and provoking these digitally liminal serendipitous inspirations.

6.1.1. Preparing for serendipity

> "Getting lost is a concept that sounds romantic until you are actually lost and are either terrified, baffled or bored." —D'Ignazio (2014)

We are in the age of efficiency. The optimising approach adopted by many of the digital tools we use in our creative process have us running faster and faster towards 'answers'. But "you cannot run and be very aware of your inspirations" (Glimcher, 2012). The first step in preparing for serendipity is acknowledging that the seemingly inefficient tangents it provides are even worth the time to go down!

Planning occasional moments for serendipity

One way to do this is to reframe serendipity as a functional element within the creative process; an activity that helps to make the new connections through which novel ideas can emerge (Zuckerman, 2013). The tangents it provides may seem irrelevant initially but the divergent thinking it enables can reveal unknown paradigm-shifting ideas. Planning occasional moments in our busy efficiency-driven modern design process where we can remove our efficiency 'blinders' and wander in the liminal space of unexpected ideas can provide a comforting structure to this disruptive experience. The interventions demonstrated that the moments when the serendipity provided by the Beyond Average tools could be most valuable were very early in a user's project, i.e. the very beginning of the divergent discovery phase or at moments when the project needs to grow or pivot to a new approach.

Prepare the sagacity mindset to frame expectations

Once we are in this moment of liminality, we also need to feel confident that we will in fact learn something useful while wandering down the scenic route. In Intervention B, working in teams provided some of this support to explore concepts that the users wouldn't normally have done. But when individuals used the Beyond Average tools, they needed to learn how to make use of any serendipitous provocations that they were presented with. Part of this ability to draw insights from this liminal exploration process is skill and expertise; the creative practitioners (a range of designers and artists) naturally had this talent to systematically encourage the mind "to look at one thing and see another, and the ability to give meaning to those perceptions" (Hsu, 2011). The entrepreneurs

and technologists were often used to a more 'efficient' type of working and therefore needed additional guidance. Structuring the use of the Beyond Average tools within the liminal ideation framework helped to shape the user's expectations for the types of inputs, transformations and outputs that they can use in the exploration—and reminded the creative practitioners to utilise the liminal thinking skills they already had! The follow ups in Intervention C demonstrated that taking the participants through the initial workshop taught them this 'sagacity' as they knew what to come prepared with, e.g. distinct but conceptual ideas that they wanted to deconstruct and expand their understanding of, and what to aim to leave with, e.g. a collection of concepts that are new interpretations of their ideas to guide further research when they leave their liminal exploration.

Balance familiar and unknown tools in the experience

Incorporating the Beyond Average tools into an environment with a familiar creative setup and media, e.g. embedded into a table with liberal access to pens, paper, any other idiosyncratic detritus deemed to be useful in one's creative process, also contributed to making this liminal experience feel less daunting. Designing the interactions with this suite of digital and physical tools to be a bricolage experience allows the users to cycle between high interpretability and high contextuality, enabling them to direct their divergent, liminal explorations to a focused, relevant convergence.

6.1.2. Provoking serendipity

While sagacity is the prepared mind, serendipity is the prepared system; mechanisms through which we can discover unexpected and unknown ideas. The Beyond Average tools used the mechanisms of juxtaposition, randomness and customisation to shape the serendipity they provoked.

Design for 'somewhat relatedness'

The findings from Interventions A and C showed that computational tools with a medium level of contextuality and a medium-to-high level of interpretability can induce serendipitous provocations that make 'just enough' sense to inspire relevant but novel ideas. In the Reframe creative prompt tool, this is manifested through the prompts generated being somewhat related, i.e. having an average relatedness value ~0.05. Increasing the contextuality of the prompts by including words related to a user's project gives them one familiar stepping stone from which to explore new directions inspired by the unexpected juxtapositions.

This 'somewhat related' quality is also effective in the Looking Sideways exploration tool. The design of the relatively dumb search algorithm across the diverse selection of databases meant that the content presented for each search query chosen by the users was related but not too obvious; some responses were immediately understandable but not expected (unknown knowns) and others required a bit of digging and abductive thinking to consider how they were related (unknown unknowns). This quality was also enhanced by the association feature; it provided guidance for

how disparate concepts could be related, but these suggestions were not always the obvious answer, revealing unexpected conceptual reinterpretations for a user to explore further.

One guideline for engineering serendipity in this way is to resist the urge to over-design this relatedness quality—something I learned for myself while developing the Beyond Average tools. As I have described in Chapter 2, when designing digital tools, we have the powerful ability to 'optimise' the responses they give, thinking that these cognitive shortcuts will help our efficiency. However, when it comes to designing a digitally liminal tool that embraces serendipity, moderate inefficiency is optimal. Feedback from Interventions A and C showed that too much randomness at once is ineffective, e.g. the 5 word prompts in early Reframe prototypes were too confusing to take in all at once so were reduced to 4, improvements need to be made to Looking Sideways to prevent too much content overlapping, and it was too challenging to draw contextually relevant inspirations when overlaying images from the Design Daydreams post-it note onto other objects. However, once users are confident in the sagacity mindset required to make use of these serendipitous provocations, they are very able to 'fill in the gaps' left by some relatedness inefficiencies. In fact, this space leaves room for the intuitive interpretations that are so important in the incubation and illumination stages of creative thought.

Provide agency to direct the serendipity towards or away from ambiguity

Not over designing the interactions with these tools also gives users the agency to direct the serendipity they experience as they navigate their way through the liminal space and back out into the focused, efficient, 'real' world of their projects. This allows for a broader applicability of the Beyond Average tools across both project stages and user background. Designing the tools to provide opportunities to be divergent but give the users the choice to converge enables creative practitioners and those early in their projects to explore broadly, while also being useful to less-creatively minded users or those at more focused ideation phases.

The semi-random selection algorithms driving Reframe and Looking Sideways provide a relatively ambiguous and divergent baseline, but both tools also have features that give users the agency to direct these provocations towards a more contextually focused, convergent conclusion as and when they need. In Reframe, the two prompt generation features enable this direction of the serendipity; the user can change all the words when they want a very divergent provocation or just one at a time for more focused inspiration. Customising the prompts to have higher or lower average relatedness values depending on where they are in their project, i.e. exploratory phase or more focused brainstorming, can allow users to further direct this experience. The follow ups in Intervention C demonstrated that Looking Sideways is an inherently directable tool; due to the active engagement required for users to enter search terms, select content to explore further and connect, move and delete nodes throughout their exploration, users can easily diverge their thinking or converge it to a focused outcome.

This agency is also provided through a bricolage environment in which to interact with the tools. The Design Daydreams ideation table allows users to seamlessly cycle between the Beyond Average tools: using Reframe for jolts of provocative juxtapositions that they can use to inspire deeper explorations in Looking Sideways (or even other websites such as Google) before using pen and paper to annotate a more focused sketch made with the Design Daydreams post-it. A digitally liminal suite of tools optimally designed for serendipitous inefficiency!

6.2. An Alternative Future for the Digitally Augmented Creative Process

Ever since Engelbart (1962) wrote about how computers could "augment human intellect", we have been trying to integrate digital tools into our creative process. Above I have proposed some guidelines for how we can integrate more serendipity into both these tools and the experiences around using them. Here I outline future experiments to extend this idea of digitally liminal tools and propose a vision for how we could get to a more 'beyond average' creative workplace.

6.2.1. Further Research

Like the inspiration they provide, the Beyond Average tools are just the beginning of this exploration. The insights described in the interventions and design guidelines above suggested improvements to the tools themselves as well as hinted at future opportunities for research.

Modifications to the Beyond Average tools

The interventions described above identified several limitations with the Beyond Average tools as they are currently designed. One immediate modification is to improve the physical design of the Design Daydreams post-it note so that it is less cumbersome to reposition when sketching. A larger challenge is how to improve the inclusivity of the tools. The main mode of interaction with the tools is semantic, i.e. the text based prompts in Reframe and the mainly text-based inputs and content in Looking Sideways. This proved a challenge to users whose first language was not English as they could not as intuitively engage with the content presented. It also presents a larger limitation in terms of including the metaphors that other cultures use; while the WordNet and ConceptNet databases that shape the content presented in both Reframe and Looking Sideways have multilingual capabilities, they are likely limited when it comes to including knowledge about multicultural idioms.

Improving the situated serendipity of our digital tools

The different interventions demonstrated the advantages of different 'levels' of serendipity. The immediate next step to research this phenomenon is to gather more quantitative data on how users engage with the content presented by the Reframe and Looking Sideways tools; diving deeper into what, when, why and how participants use the content presented by the tools as inspiring analogies in their projects (Goel, 1997). As the tools are based online, this can be achieved relatively simply

through logging the users' interactions while they are using them. I could then use this data to develop a deeper understanding case-based understanding of the relatedness values of Reframe prompts that are 'selected', i.e. prompts that users spend longer looking at or save images of, and of the types of content presented in Looking Sideways searches that are most engaged with. The analysis of this data could help to improve the liminal algorithms that determine the content presented and allow users to direct the serendipity these tools provide even further, e.g. present more curated content for a focused exploration.

This data could be collected through larger online studies similar to Intervention A where remote participants, e.g. on Amazon MechanicalTurk, use the Beyond Average tools to generate ideas around a certain problem. However, what Intervention C demonstrated was that the functionality of these tools changed at second use and at a slightly more developed state of the project, prompting questions such as: How effective could these tools be after the novelty factor has worn off? How long throughout the whole life cycle of a design project can the serendipitous inspirations these tools provide be impactful? Did the ideas that the tools inspired at the beginning of the project have a noticeable impact on the final designs? Longitudinal studies with several individuals and organisations over multiple design projects could begin to tackle these questions.

Exploring the sagacity mindset, both in and outside the creative process

The insight that has inspired me most throughout this research came after my most disappointing finding; the failure of the Beyond Average tools to be effective 'in the wild' during Intervention B. The success that the liminal ideation framework demonstrated at framing the participants expectations for how to effectively use the serendipitous provocations provided by the tools presents many exciting opportunities for further research. How long does this sagacity mindset last? Do participants need to occasionally experience the Beyond Average tools in further liminal ideation workshops throughout their design project? How does learning a sagacity mindset through the Beyond Average tools workshop affect the user's creativity outside of the design process? These questions could be investigated as part of the longitudinal studies mentioned above. Situating a Design Daydreams ideation table in the workplaces of the participants in this study, they could access the Beyond Average tools at any time they want, with additional workshops being carried out in the user's everyday environments surrounded by their collections of creative curiosities.

6.2.2. Imagining a Digitally Liminal Creative Workplace

When Engelbart (1962) imagined his vision for augmenting human intellect and the tools that could contribute to that experience, he wrote: "We do not speak of isolated clever tricks that help in particular situations. We refer to a way of life in an integrated domain where hunches, cut-and-try, intangibles, and the human 'feel for a situation' usefully co-exist with powerful concepts, streamlined terminology and notation, sophisticated methods, and high-powered electronic aids."

Despite this being written almost sixty years ago, we are almost further away from this concept than we were back then. Shaped by the driving force of industrialisation and automation, creativity has become synonymous with productivity which we have been conditioned to believe means efficiency. This belief has shaped the digital tools that we currently use throughout our design process. This dissertation aimed to demonstrate the limitations with that approach and present alternatives; tools and experiences that can seamlessly integrate a more liminal exploration into our digitally augmented creative processes.

How can we redefine what creative productivity looks like in this post-industrial, automation-lite, digitally liminal world? "Less haste, more speed" is an idiom that comes to mind.

When it comes to digital tools, we expect them to be fast. But what does this speed take away from the things we can learn while using the tools? Digitally liminal tools are certainly less direct than their efficient counterparts, but we can actually end up at more interesting and useful ideas. In a digitally liminal creative workplace, our tools are not just there to speed up our tasks through frictionless automation. The new philosophy for this alternative future of digital augmentation requires us to redefine our expectations for tools; they are not efficiency machines to do our bidding, they are slower, more conscientious computational partners that can challenge us to explore unknown horizons and extend the boundaries of our creativity.

However, as discussed earlier, all of the serendipitous prompts in the world won't inspire anything if there is not the time, space and attitudes to embrace a more liminal approach. In our rush to find comforting, predictable 'answers' to our creative problems, we often forget to think if we are in fact tackling the right question. The adoption of digitally-liminal tools is not only a matter of the learning curves required to use these new tools, but also of reflecting on and changing the existing cultural, organisational and managerial approaches that value efficiency overly truly disruptive creativity. A digitally liminal creative workplace begins with reorganising our project priorities and growing cultures of work that embrace the unexpected disruptions and friction that serendipity generates. What are new structures of projects or affordances of environments that could enable the conceptual wandering so vital to the divergent thinking that can lead to novel ideas? And could understanding the value these unexpected disruptions can bring to this new definition of creative productivity even contribute to organisations increasing the gender, cultural and intellectual diversity of their project teams, facilitating serendipity through organic means as well as through technological systems?

Creativity often requires patience, something that can be in short supply in today's efficient world. We need to be patient with our projects, leaving room in the early stages for divergent thinking and liminal explorations. We also need to be patient in our environments. In the age of remote working, co-working spaces and hot-desking, no desktop is our own other than our laptop. How can we collect the curious clutter and unexpected interactions that engage our liminal serendipitous thinking? What are the physical and digital aesthetics that can create more seamless serendipity

and reflective interactions? Coming of professional-age in the era of the hyper-ergonomic Aeron chair where product design meant designing physical objects, witnessing the trend towards workspaces filled with beautifully Instagrammable faux mid-century furniture where people hunch over their laptops is slightly jarring! A digitally-liminal creative workplace breaks down these barriers between the digital and physical worlds and allows us to seamlessly move between different tools throughout our creative process. Moving our digital content off the screens into which we constantly peer and onto material environment around us can not only offer opportunities for more seamless digital-physical interaction, but also elicit the social interactions that are another vital source of serendipity in the creative process. Interacting with screens should require us to interact with pen and paper; like Sutherland's original Sketchpad, recently recreated by Cardoso Llach (2018). Interacting with physical objects to engage with digital images, instead of using single fingers to swipe a screen or gesture through the air, could engage our natural intuitions and encourage us into a more liminal creative process.

Preparing our attitudes and our workplaces for serendipity can both encourage and give us the confidence to navigate our way through the seeming chaos of the liminal space. And once we have this sagacity mindset, what new things can we 'see'? Can a digitally liminal creative culture help us design solutions for the increasingly interconnected and complex systems we now live in? Can embracing serendipity help us explore and more curiously critique the mass of digital media we are bombarded with daily? Can learning to wander in the liminal space help us to continually grow our creative capabilities?

6.3. Conclusion

> "In all affairs it's a healthy thing now and then to hang a question mark on the things you have long taken for granted." –Bertrand Russell

This is a fundamental tenet of the early phases of the creative process. Unfortunately, the design of the digital tools that we are increasingly using to guide us to inspiration for new ideas don't always take this same approach. This dissertation explored how we could develop digital tools that could augment this questioning, liminal period of the creative process and help designers discover unexpected ideas.

The enthusiastic motivation that drove my research was to prevent the further homogenisation of our creativity perpetuated by certain 'optimising', average-driven technologies such as genetic algorithms and machine learning programs. Evaluating different models for the design process and how computational tools may be suited to the activities within them, I identified the activities in the early phases of the design process that offered opportunities for more digitally liminal tools: those in which we explore new information and generate new ideas from it.

If liminality is the space where unknowns are discovered, serendipity is the mechanism through which we might stumble upon these unexpected insights. By purposefully embedding ambiguity

into these traditionally predictable digital tools, we can be presented with provocations that help us to reconsider what we think we know. This was the intention behind the three 'Beyond Average' digitally-enabled tools that I developed as probes to investigate a more digitally liminal creative process: (1) the Reframe creative prompt tool that juxtaposes language from a designer's notes in surprising ways to provoke new associations between concepts in their project; (2) the Looking Sideways inspiration exploration tool that presents a diverse range of content for each search query and suggests connections for the concepts discovered; and (3) the digitally-augmented Design Daydreams ideation table and post-it note that seamlessly connects the physical and digital content that designers use in their creative processes.

These tools attempted to encourage us into the liminal space, an expanse of unpredictable, paradigm-shifting possibilities in between the thresholds of known worlds. If "to see is to forget the name of the thing one sees," (Valéry, 1938) this amnesia can be very disorienting. Even designing systems that provoke serendipitous inspiration by providing content that is 'somewhat related' to the user's expectations is not enough on its own; we need a sagacity mindset to prepare us to make use of these stimuli. This is where the landscape of design process models falls short; while they minutely guide us through detailed activities throughout the life of a design project, they often cannot help us understand the elements of creative thought that they are trying to evoke. Using, instead, the four stage model of creative thought, I developed a liminal ideation framework to shape the experience of using the Beyond Average tools.

Those who tested the Beyond Average tools within this liminal ideation framework were frequently surprised at the power that seemingly irrelevant provocations could be so inspiring; they were experiencing serendipity at its most potent. When we are open to this liminal approach, the guiding principles behind the Beyond Average tools—those of juxtaposition, randomness and flexibility—have the potential to create a space within the design process for unknown unknowns to be transformed into revolutionarily innovative ideas. Ideas that I hope will also, at some point, be unexpectedly turned on their heads to provide serendipitous inspiration as we wander through the liminal world of possibilities that is the future of the digitally augmented creative process.

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Appendices

Appendix 1. Literature review of the activities in the discovery and reframe/define phases (tasks in italics)

Author *** in Dubberly, 2004**	**Discovery phase design activities**	**Reframe/define phase design activities**
Alexander (1961)*	Understand context from actual world *Create mental model of context*	Connect mental models to visual stimuli *Create and connect visualisations of contextual mental models to visual stimuli*
Banathy (1996)*	Create divergence of information and ideas from an initial genesis *Create alternative images*	Converge information by envisioning possible futures *Create alternative images* *Synthesize and hypothesise future system*
Bernal (2015)	Frame the focus of interest Rapidly identify relevant aspects of a problem *Forming analogies* *Looking for emergence*	Shift direction of design development *Analogy* *Trigger unpredictable inferences* *Reformulation* Frame the design situation
Cross (1990)*	Decompose the existing situation *Break existing information into constituent parts*	Recompose into a new situation *Reassemble the parts in a new way*
Darke (1978)*	Collect and generate information	Conjecture new ideas from information
Doblin (1987)*	Gather information *Carry out interviews, data searches, field research* Structure the information *Create lists and matrices of data*	
Dubberly & Evenson (2008)		Devise stories about what could happen *Create hypotheses* Model alternatives *Create imagined speculative alternatives*

Author *** in Dubberly, 2004**	**Discovery phase design activities**	**Reframe/define phase design activities**
Finke (1992)	Generate diverse & novel info *Find associations* *Find attributes and infer functions* *Reduce information into categories and exemplars* Find novel interpretations *Shift contexts to reframe info* *Find incongruous info to inspire new understanding* *Find what won't work by finding limitations*	Allow new and unexpected features to emerge *Use analogical transfer, contextual shifting and conceptual interpretation to find new meanings* *Keep ambiguity in the information to allow for reinterpretation* Synthesise and transform information into new ideas *Create conceptual or verbal recombinations*
Fulton Suri (2008)	Collect information from many interpretations *Consider information from empathic, speculative, and interpretive views as well as descriptive and factual.* *Reference analogous situations* *Find extremes and boundaries* Learn from subjective experiences and interactions *Integrate personal perspectives from yourself as well as externally* *Challenge interpretations* *Build on information responsively*	
Gero & Maher (1993)	Consider idea first principles Reframe ideas *Consider information analogies several levels of abstraction away from the original context*	Reinterpreting the existing design *Mutating the features of the original information* Recombine ideas in surprising new ways
IDEO (2004)*	Gather info through observation *Use shadowing, behavioural mapping, consumer journey, extreme user interviews, story telling to gather and represent info about the project*	Use brainstorming to generate and reframe ideas *Create a large quantity of ideas* *Build on ideas and make them wild* *Represent the ideas in a visual way*

Author *** in Dubberly, 2004**	**Discovery phase design activities**	**Reframe/define phase design activities**
Jones (1970)*	Explore the design situation	Perceive or transform the problem structure *Consider alternatives (combine elements, new concepts, substitutions, reduction)*
Lawson (1980)*	Identify the first insight Prepare for new ideas by exploring that initial insight	Allow for incubation of that information Provide tools to provoke and highlight the moment of illumination
Mendel (2012)	Gather disparate sets of data *Collect information in a semiotic framework/database (labeling and tagging, etc)* *Create structural schemes and frameworks for organising and juxtaposing (bi-polar axes, dimensions, grids, persona models)* Create questions about the data	Understand relationships and gaps Consider data from multiple perspectives *Deconstruct data and relationships and recombine* *Compare data to similar and dissimilar aspects* *Visually map information in ways to reveal new salience, relationships, and meanings*
Polya (1945)*	Find and sort the unknown data *Introduce suitable notation* *Separate the various parts of the information*	Find the connection between data and the unknown *Find related problems* *Restate the problem differently*
Schneiderman (2007)	Gather information *Search previous and related work* *Create mechanisms for organizing search results* *Use tools for annotation & tagging* *Find distributions, gaps, & outliers* Use knowledge from others Generate multiple alternatives	Explore implications Generate hypotheses Produce some initial ideas Draw on opinions from other designers

Appendix 2. IDEO project maps


Inputs
Outputs
Knowledge & Tools
'Hunches'
Exploration
Reframing
Synthesis
Envisioning
Evaluating
Creating
Initial research questions:
'Hunches' for themes, users, early concepts inspired by project brief/topic to guide design research
Design research guide:
Profiles of interview participants, discussion themes and sacrificial concepts match/contrast to hunches
- Situational & procedural knowledge on archetypical design themes and design research methodologies
- Analysis of assumptions/trends related to project context
Consumer prototyping:
Selecting existing objects with similar/contrasting elements to possible final artefacts to provoke discussion of designs in interviews, e.g. same size, posture, ergonomics
- Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'
- Strategic knowledge of the design logic and vocabulary of existing design artifacts
Metaphorical inspiration:
Studio-based and real-world immersion research into designs and experiences analogous to the project context and design archetypes
Conceptually similar alternatives and design elements:
Semantic, visual and tactile descriptions of analogous experiences, artifacts and interactions
- Declarative and situational knowledge on general design outcomes and on relationship of design attributes to contextual experiences
- Declarative knowledge on general ergonomics
- Internet search for metaphors that reframe verbal & visual design elements
- Observation & photography
- Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'
- Strategic knowledge of the design logic and vocabulary of existing design artifacts
Interviews and observations:
Interviews with users and observing them interacting with consumer prototypes
Key insights and tensions:
Semantic descriptions from metaphorical experiences and interviews referring to general design areas of experience, artifact and interaction
- Analysis of research to identify extreme words related to contextual experience for general design themes and areas (strategic knowledge)
- Synonym/antonym finder
Extreme design elements:
Adjectives associated to design elements inspired by the insights and tensions
Extreme design element moodboards:
Words and images of existing artifacts, experiences and technologies related to the insights and tensions, grouping by general design element
- Declarative knowledge on general design elements - form, colour, patterning, material
- Strategic knowledge of the design logic and vocabulary of existing design artifacts
- Declarative & strategic knowledge on design elements relationship to experiential meaning
- Pinterest and Google image search
Technology constraints:
Design limitations based on ergonomic, cost, manufacturing issues etc
Engineering design principles:
Approaches for technology, material, manufacturing, modeling to enhance design experiences based on limitations
- Declarative & situational knowledge on design engineering elements based on product context
- Strategic & procedural knowledge on how to apply design elements within limitations
- Breakdown and reinterpret existing experiences and artifacts i.e. a 'teardown'
Opportunity areas & extreme themes:
Title and adjectives of ~3 design themes, e.g. Protection, Orientation
Extreme concept moodboards:
Words and images of existing artifacts, experiences and technologies related to the words associated to the extreme themes
- Semantic analysis to break-down and reframe theme into metaphors (procedural knowledge)
- Pinterest and Google image search
- Situational knowledge of design elements relevant to context to refine image search
Design principles:
Adjectives associated to design elements inspired by the extreme themes and relative importance to each design discipline
Design discipline moodboards:
Words and images of existing artifacts, experiences and technologies related to the extreme themes and design elements, considered from each design discipline e.g. ID, interaction, etc
- Declarative knowledge on general design elements - form, colour, patterning, material
- Strategic knowledge of the design logic and vocabulary of existing design artifacts
- Declarative & strategic knowledge on design elements relationship to experiential meaning
- Pinterest and Google image search
Feedback
Preferred design principles selected
- Discussion & visual/verbal coherence analysis
Extreme designs:
Application of chosen design themes and elements to product
Extreme design moodboards:
Words and images of new design experiments
- Procedural knowledge to apply design principles to general forms for the new artefacts
- Ballpark dimensions of final artefacts
- 3D models (CAD software, e.g. Rhino)
- Form studies (foam, card, 3D printed)
- Colour & pattern experiments (physical/digital)
Feedback
Preferred design principles selected
- Discussion and technical evaluation
Refined designs:
Detailed designs created
Final design principles:
Verbal, formal, visual, tactile design principles defined to guide creation
- Procedural knowledge to define form logic
- Technical requirements & layout
- 3D models (CAD software, e.g. Rhino)
- Colour & pattern palattes (Adobe software)