Introduction

Larry Leifer and Christoph Meinel

Abstract The Hasso Plattner Design Thinking Research Program (HPDTRP) has always put emphasis on investigating the design team in various ways. As our experience with newly emerged instruments like fMRI (functional magnetic resonance imaging) or fNIR (functional Near-Infra-Red) expands and we build on evidence from neuro-economics, neuro-marketing, neuro-engineering, and neuro-science we see a field of neuro-design evolving—a development that complements the broad Design Research landscape. This chapter invites readers to imagine how neuroscience instruments might be brought to bear on measuring and understanding design team performance better.

1 Investigation of Design Team Performance

Design Research has always sought to put the design team in the petri dish; whereas virtually all other design programs put the customer-client there. In 2011, Malte Jung delivered the thermometer (a physics metaphor) for teams in that petri dish (Jung 2011). Then, in 2012, Neeraj Sonalkar delivered an oscilloscope (an electronics metaphor) for team dynamics in the petri dish (Sonalkar 2012).

During the DTRP 2012–2013 academic year we supported our first major applications of neuroscience instrumentation, fMRI (functional magnetic resonance imaging) studies of brain structure changes brought about through creativity training (Reiss et al. 2013). We now see fMRI and its subsequent technology, fNIR (functional Near-Infra-Red) imaging of the brain during design activities, as being the physics equivalent of a microscope we can use to measure the microstructure of

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what's going on in that petri dish. Given the thermometer, oscilloscope, and microscope we can image an age in which the design of human intelligence can keep pace with the evolution of artificial intelligence.

As our experience with these instruments expands and we build on evidence from neuro-economics, neuro-marketing, neuro-engineering, and neuro-science we see the field as evolving towards neuro-design—a development that complements the broad Design Research landscape. This evolutionary path has been visualized in Fig. 1 and we can understand it as a deep part of the evolution of "western culture".

Of course, the story we tell here is only one thread leading to neuro design. Many more stories could be told—and hopefully many more will be told, as people recognize how their own works contribute to neuro design, or endeavor to carry out novel studies to advance this emerging field.

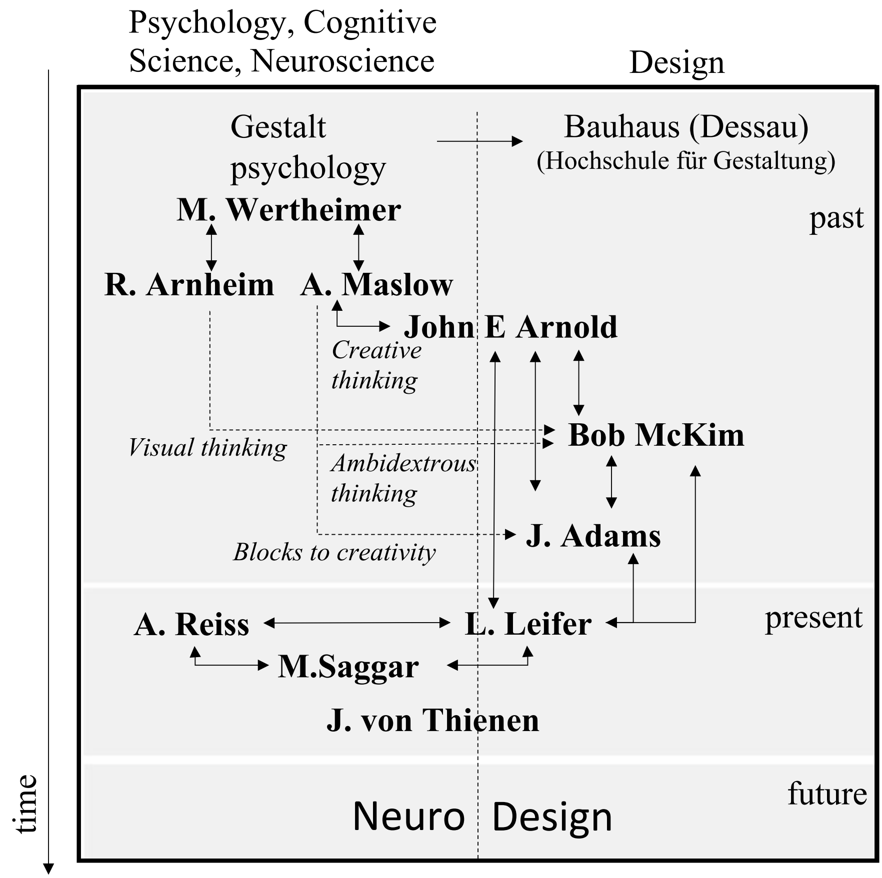

Fig. 1 The evolution of psychology, cognitive science, neuroscience, and design towards neuro design

Our story begins with Gestalt theory and the Bauhaus. This story covers a century with 2019 marking the 100th anniversary of the founding of the Bauhaus. The 2nd Bauhaus in Dessau is named "Hochschule für Gestaltung". At the same time, there is little evidence people from Gestalt theory and Bauhaus had deeper interaction with each other. So, initially, we see rather independent roots of design on the one hand and predecessors of cognitive neuroscience on the other.

In the realm of cognition research, the legacy of Max Wertheimer is specifically noteworthy, because it has strongly impacted design thinking and recent neurodesign studies in this tradition. Wertheimer supervised both Rudolf Arnheim and Abraham Maslow, who had an influence on J. E. Arnold and his future colleagues at Stanford University. Arnold had a B.A. in Psychology before studying Engineering at MIT. Together with Robert McKim and James Adams, he started the Design Division in Stanford's Mechanical Engineering Department. Highly integrative approaches to theorizing, research and practice in design began to take shape. In this context, cognition and design studies merged into a fruitful synthesis.

To name a few of the milestones in this story, we can appreciate how John Arnold advanced a human-centered framework of comprehensive design based on creative thinking and innovation theories (Arnold and Clancey 2016; von Thienen et al. 2017). Thus, he merged design and cognition studies, without yet including neuroscientific analyses. Robert McKim furthered the human-centric design perspective and elaborated bodily aspects in design, such as the importance of visual thinking and "ambidextrous" engagement in design activities (McKim 1972; von Thienen et al. 2018). This new synthesis included a great array of physical ("bodily") aspects, though brain research was barely mentioned at this stage. An important question pursued over decades was how to overcome creativity blocks (Adams 1974; Arnold and Clancey 2016). Here, a lasting concern was how to help designers/creative teams use their full range of abilities, beyond rational-symbolic processing (Faste 1994; von Thienen et al. 2016). In these debates, brain research was beginning to be referenced, though not discussed in detail.

A substantial bridge between psychology/cognitive science/neuroscience on the one hand and design on the other hand was attempted by Larry Leifer, who had "insider knowledge" in both fields. After earning a master's degree in art (industrial design), he wrote his dissertation in the Neurology department at Stanford. This was even prior to the evolution of the term "neuroscience". Leifer's (1969) Ph.D. research used single cell electromyography in humans performing a controlled tracking task, like driving or flying, to reveal how the nervous system was modulating force. In 1984, Leifer founded the Center for Design Research at Stanford University. A number of projects that emerged in this academic culture came to explore sweet spots between design, neuroscience and medicine (e.g., Aldaz et al. 2015; Aquino Shluzas et al. 2011; Johnson et al. 2001).

In recent years, front-end neuroscience has become an integral part of design (thinking) studies. A number of technically sophisticated research endeavours have added new details and precision to our understanding of design, creativity and innovation. At present we witness technical progress permitting the investigation of questions that were out of reach just a few years ago. Here, we can highlight the pioneering works in the laboratories of Allan Reiss, Director of the Center for Interdisciplinary Brain Sciences Research (CIBSR), and Manish Saggar, head of the Brain Dynamics Lab, at Stanford University. Their research elucidates brain dynamics, not only of individuals in laboratory settings, but of design teams working in their natural environment (Mayseless et al. 2018; Reiss 2018) using state-of-the-art technology such as Functional Near-Infrared Spectroscopy (fNIRS). Importantly, these works include the design of novel study setups and metrics that allow comprehensive investigations of creativity and design (Hawthorne et al. 2016; Saggar et al. 2015, 2017). These metrics elucidate visual processing, spontaneity, emotions and many other aspects of design performance from a neuroscientific perspective, moving far beyond more traditional studies on cognitive rational processing abilities. The historical concepts of creative, visual and ambidextrous thinking have evolved to include precise neuroscientific descriptions (measures), explanations and predictions.

Moreover, technical advancements now permit the analysis of brain dynamics of single designers on a moment-to-moment scale (Saggar et al. 2018). That is great progress compared to standard neuroimaging approaches, which average findings across several study participants and/or various study trials. Thus, it is now possible to explore patterns of individual design actions and the person's moment-to-moment neuroimaging results, opening up a vast range of new research opportunities.

Studies with this potential can be especially fruitful when they are discussed within various expert communities. Again, it is collaboration across boundaries and the union of knowledge domains (which all too often act in isolation from each other) that permit the greatest rate of learning for everyone involved. Neuroscientific research on design, creativity and innovation thrives in a network of expertise that spans diverse perspectives on these topics.

To help integrate neuroscientific perspectives and other design, creativity or innovation expertise, Julia von Thienen initiated platforms of exchange for neuroscientists and further design or creativity scholars as well as practitioners (von Thienen 2017; Reiss 2018). Her work is underpinned by cross-disciplinary reviews of study outcomes to help members of neuroscientific and other communities explore pieces of work that merge to yield the larger picture(s) of one or more overall puzzle(s) (von Thienen 2013, 2018). It was in this context that Larry Leifer came to coin the term "neuro design" to describe the happy synthesis of neuroscience and design.

Once this new field of work was discovered, many new research avenues could be explored. From a computer science perspective, Christoph Meinel noted the additional avenues of progress, besides the new study designs and formats of exchange. Obviously, a large corpus of neuroscientific data already exists. Without a doubt, many more study outcomes will emerge in the near future. What opportunities exist to learn the most from this wealth of data? Might there be opportunities for big data analyses or other technically-supported means to benefit from current research?

On the whole, we see promising examples of ground-breaking neuroscientific and design studies to further broaden our existing corpus of design research and gain new insights. Collaboration across boundaries is gaining momentum. We believe the time is ripe for even broader, orchestrated efforts to merge physiological perspectives and design research. Neuro design opens up a wide perspective for many new research questions and practical projects. It invites new unions of insight and the joining of resources for work in various directions.

As a sample topic in the broad realm of neuro design, we will briefly address the issue of creativity blocks—an important theme in design thinking traditions ever since the 1950s. Dealing with creativity blocks show us how the integration of neuroscientific perspectives can bring about the next leaps of understanding and practical implementation.

1.1 Identifying and Overcoming of Creativity Blocks

The topic of creativity blocks has been discussed in recent times by Cross (2007) in his treatise *Designerly Ways of Knowing.* Specifically, Cross points out the phenomenon of *fixation.* This concept applies when designers "may be too ready to re-use features of known existing designs, rather than to explore the problem and generate new design features" (p. 104). Typically, designers are designers of something. They own and are identified with that thing, or style of thing. To avoid the block, we prompt the designer within each of us to pause and question the problem as stated.

Does this familiar problem really deserve to be re-solved? The posing of this question stems from observations in both professional and academic environments. The constraints that define problem spaces are either shaped internally or impacted by forces extrinsic to the problem itself. In most cases these constraints prompt a quickness in the execution of design action that is perceived to be optimal, yet rarely proves to be. The quickness introduced by *solution-fixation* is for the most part not helpful, as it precludes the questioning or interrogation of problems stated by others. As a result, it prematurely freezes the problem space before it fully forms. The evolution towards neurodesign promises to afford quantitative research into the cognitive foundations of high performance design-teams and thereby to gain insight on a physical basis of how those teams overcome or even avoid creativity blocks (see Sect. 1.2). At the same time, teams or individuals might get a chance to shield themselves against those effects in situation where solution-fixation is undesirable. Thanks to the current neuroscientific studies, we are now able to identify those no longer invisible mechanisms and actively avoid practices such as creativity blocks by developing measures to guard against them.

The liabilities of *solution-fixation* are numerous; therefore our challenge is to be mindful of its causes. These causes are invariably tied to how problems themselves are first identified and managed. Design researcher Dorst (2015) names five causal syndromes of conventional problem-solving practices:

- *Lone Warrior*: A particular entity owns the problem-solution space
- *Freeze the World*: Stop the world, prevent change, and utilize static thinking
- *Self-Made Box*: Solve the problem with solutions from our past
- *Rational High Ground*: Believe in and assert our own rationality

- *Identification*: The problem and its solution are identified through organizational autopoiesis

Proceed with extreme caution when you detect these in your respective environment or culture.

Such blocks can arise both in practice and research. For instance, theories and measures of design, creativity and innovation can be primarily concerned with a person's rational abilities. This is expressed as falling victim to the "Rational High Ground" block. Neuroscientific studies recommend themselves as helpful antidotes to free us from such biases. They permit the scanning of the entire brain beyond the rather narrow bodily substrates associated with a person's rational thinking abilities. It becomes possible to elucidate how further human capacities fuel creativity, innovation and design, beyond rational processing. In this regard, notably, Saggar et al. (2017) found high creative performance associated with activity in the cerebellum (the motion coordination center in the brain) and reduced activity in the brain's pre-frontal cortex (known for rational planning).

Another level at which the block of a "Rational High Ground" can afflict research practices pertains to the scientific procedure itself. Is this research rationally preplanned all along, or does it leave room for explorations and serendipity (cf. Eris 2003, 2004): To what extend do the scientists ask deep-reasoning questions ("rational approach"), which lead to ever-deeper expertise in a single direction? To what extent do the researchers ask generative design questions (apart from rigorous rationality), which facilitate divergent thinking in science and applied fields? We envision neurodesign as a field in which deep-reasoning and generative design questions can be balanced and intermix in a synergetic interplay.

1.2 Orientation

Overcoming creativity blocks may be more or less time-consuming across domains. For instance, while problems requiring software solutions can be reasonably updated in a short amount of time, problems of the built environment require solutions with physical configurations lasting years, decades or centuries. Problems with human cognition, perception, and cultural values might take even longer to address, although neurodesign could help to speed up change.

In terms of values, design thinking has long noted the importance of mindsets. Indeed, the pursuit of any problem-oriented design action requires a human-centered mindset. In turn, problem orientation is then an accurate indicator of whether the mindset guiding action is in fact human-centered, or instead if it is rooted within any number of other centrisms. Some examples of this include systems-centrism, type-centrism, or ego-centrism.

There are multiple strategies for pivoting towards problem-orientation. These include:

- *Identifying meaningful problems*. Does the problem identified have consequence, or is it inconsequential? Is it significant and relevant to stakeholders beyond the designers? Can the problem be reframed in multiple ways and still be of relevance to multiple stakeholder groups?
- *Phrasing effective questions*. Do the questions posed establish a larger context for the problem? Do the questions reveal details of the problem either invisible or previously unknown? Are the questions appropriately divergent and convergent for framing the design problem?
- *Developing "comprehensive propensities" for design action*. Is it possible to know the entirety of a problem within a single discipline, or is the scale of the problem so large that no single stakeholder can perceive it as a whole? Does this challenge of perception change as soon as one views the problem in a discipline agnostic way?

1.3 The Applicability of Neuro Design Research

With regard to how this emerging new branch of research might complement or deepen the existing broad approaches of Design research, a number of potential connection factors have been demonstrated. But how should these extension and elaborations look like? How might we instrument design teams to measure the fixations (biases) of design teams, their problem orientation versus solution fixation? Might these instruments help us re-orient our brains? What are the structural brain differences between individuals who prefer decision-making to question-asking? Even more profoundly, might these instruments help us quantify such behaviors in collaboration—versus cooperation-scenarios (Leifer and Meinel 2018)? Might we be able to implement these behaviors on an actionable basis, day-to-day and session-to-session? Does our culture's emphasis on solutions introduce observable brain rewards that overwhelm the rewards for problem discovery? We are on the threshold of being able to implement the human brain and other physiological structures during collaboration activities.

Design Research enables us to address these questions and others like them, with new metrics and a heightened awareness of unintended biases at the pursuit of breakthrough innovations in business, government, and academia. Design Research also promises great rewards while navigating new creative possibilities by prioritizing human-centered problem formulation. For design operations to find greater resonant meaning and impact, they must feature human users and we can now instrument those humans in ways that have previously only been possible with machines. We have a profound need to better understand human designers, as artificial intelligence and robotics play an increasingly central role in the creation and delivery of new products, services, processes, and business systems. We need human intelligence evolution to keep pace with technical evolution. This is the designer's workspace of the future.

In each of the subsequent chapters we invite the reader to imagine how neuroscience instruments might be brought to bear on measuring and understanding design-team performance better.

2 The HPI-Stanford Design Thinking Research Program

Design thinking as a user-centric innovation method has become widespread in recent years in practice, education, and academia. A growing number of people and organizations have experienced its innovative power. At the same time, the demand to understand this method has also increased. In 2008 the joint HPI Stanford Design Thinking Research Program was established, funded by the Hasso Plattner Foundation. Within this program, scientists, designers, and humanists from the Hasso Plattner Institute for Digital Engineering in Potsdam, Germany, and from Stanford University, USA, gain a deeper research-enabled understanding of the underlying principles of design thinking and, consequently, how and why this innovation paradigm succeeds or fails.

2.1 Program Vision and Goals

Multidisciplinary research teams from HPI and Stanford with backgrounds in disciplines such as engineering, design, humanities, social sciences, or more recently neuroscience, investigate innovation and design thinking in a holistic way. These areas of investigation center on technical, economic, and human factors. Applying rigorous academic methods, researchers examine how the design thinking paradigm can be improved and further developed.

The program pursues the goal of advancing design thinking theory and knowledge within the research community. It ultimately improves design practice and education by funding original research to support design activities. The Design Thinking Research Program seeks to yield deep insights into the nature of human needs and the protocols that design thinking researchers might apply to achieve “insights” versus “data.” Beyond a descriptive understanding of the subject matter, this program assists the development of metrics that allow an assessment and prediction of team performance to facilitate real-time management of how teams work. Researchers study the complex interaction between members of multi-disciplinary teams, with special regard to the necessity of creative collaboration across spatial, temporal, and cultural boundaries. They design, develop, and evaluate innovative tools and methods that support teams in their creative work. The research projects address questions of why structures of successful design thinking teams differ substantially from traditional corporate structures and how design thinking methods mesh with traditional engineering and management approaches.

Researchers are especially encouraged to develop ambitious, long-term explorative projects that integrate technical, economical, as well as psychological points of view using design thinking tools and methods. Field studies in real business environments are useful to assess the impact of design thinking in organizations and if any transformations of the approach may be warranted.

Special interest is found in the following questions:

- What are people really thinking and doing when they are engaged in creative design innovation?
- How can new frameworks, tools, systems, and methods augment, capture, and reuse successful practices?
- What is the impact of design thinking on human, business, and technology performance?
- How do the tools, systems, and methods work together to create the right innovation at the right time? How do they fail?

Since the start of the program in 2008 more than 100 research projects have been conducted, and our understanding of this field has advanced with the authoring of new tools and yielding of new insights. This Design Thinking Research series shares scholarly insights with a public audience, whether in a multi-national corporation or a garage-based start-up.

2.2 Road Map Through This Book

In the tenth program year of the Hasso Plattner Design Thinking research program, researchers from HPI and Stanford University have conducted a wide range of research projects on design thinking. This annual publication is a compilation of their findings, sharing outcomes arranged into four parts that illustrate the programs comprehensive approach to design thinking research.

The first part of the book is dedicated to “New Approaches to Design Thinking Education,” including both analog and digitally mediated endeavors to teaching design thinking. Research-based training packages that bridge the existing gap between research and practice are proposed, as well as a tool for improving design driven creative practice in educational environments. Moreover, two ways are presented that leverage capabilities of new technologies for design thinking education: One chapter explores the use of Massive Open Online Courses (MOOCs) in design thinking learning scenarios, another chapter experiments with immersive virtual reality.

The studies clustered in part II “Exploring Effective Team Interaction” examine effective team interaction in a broad variety of ways. This interaction encompasses communication aspects, such as styles of design conversations and communication mediums for programmers and non-programmers. The examination ranges from showcasing the strength of network rotation in collective design and leveraging neuroscience to exploring team collaboration and mining the role of design reflection and associated brain dynamics.

The third part of this book introduces "Tools to Support Design Thinking Practices"—all of them leveraging digital technologies. Prototyper is a web browser-based collaborative virtual environment that supports the joint real-time creation of three-dimensional low-fidelity prototypes. Scenarios to combine AR and actuated tangibles with the potential to improve remote collaboration are proposed in the second chapter. The DT@IT Toolbox is a collection of design thinking methods targeted at design thinking novices that aims to support everyday software development activities. The last new tool presented in this edition of the DTR series is Poirot, a web inspection tool for designers that enables them to make style edits to websites using a familiar graphical interface.

The final part of this book is dedicated to "Applying Design Thinking Practices." A variety of application scenarios are showcased. First, design thinking is applied in developing the software system Tele-Board MED. The chapter captures the hands-on experience of psychotherapists when using TBM for the first time in consultation sessions with patients. In the second chapter, the design thinking methodology is applied to re-design the remote collab-spaces on the online learning platform openHPI to improve user-centeredness. The closing chapter focuses on overcoming common pitfalls of workspace (re-)design, using a theoretical perspective to reflect and shape practice.

2.3 Outlook

Many years of research conducted by the Hasso Plattner Design Thinking Research Program has yielded valuable insights on why and how design thinking works. Researchers have identified metrics, developed models and conducted studies that are featured in this book as well as in the previous volumes of this series.

We welcome engagement with scholars of design thinking research for further discussion and an exchange of ideas. At www.hpi.de/dtrp you will find the latest information on all research conducted within our HPDTRP program, and learn more about its contributors.

Moreover, the website thisisdesignthinking.net offers an easily accessible overview of current developments in design thinking. This pool of examples and interviews, enriched with detailed explanations, helps to localize all existing expressions of design thinking, including their advantages and disadvantages. For educators, the website serves as a resource for clarifying explanatory models, and offering perspectives on current problems in design thinking practice. Experiences, stories and inquiries can be sent to thisisdesignthinking@hpi.de.

Through the dissemination of graduate-level research on design thinking, we aspire to produce a book series that becomes a preferred resource for informing future design thinking action.

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