Mining the Role of Design Reflection and Associated Brain Dynamics in Creativity

Neeraj Sonalkar, Sahar Jahanikia, Hua Xie, Caleb Geniesse, Rafi Ayub, Roger Beaty and Manish Saggar

Abstract Reflection—the activity of reasoning through an action that has occurred—has been shown to be of importance to the development of design expertise. Although design reflection has been widely studied previously, several gaps in the knowledge still exist. First, previous work in design reflection has been mostly limited to *descriptive* and *prescriptive* research, while very few researchers investigated the effect of design reflection on performance of individuals and teams. Second, previous researchers limited the study of reflection to the language used and its reference to the design problem or solution space. Third, previous work on design reflection has not taken into account the antagonist of reflection—i.e., *rumination*. Rumination is characterized as repetitive and persistent evaluation of the meaning, causes, and consequences of one's affective state and personal concerns, and has been shown to negatively affect creativity and problem solving. In this project, we planned to address these limitations by (1) assessing the effects of different types of reflection on creative performance; (2) going beyond the frontier of language (or speech) and

N. Sonalkar (✉)
Center for Design Research, Stanford University, Building 560,
424 Panama Mall, Stanford, CA 94305-2232, USA
e-mail: sonalkar@stanford.edu

S. Jahanikia · C. Geniesse · R. Ayub · M. Saggar
Stanford University School of Medicine, St 1356, 401 Quarry Road, Stanford, CA 94305, USA
e-mail: saharjkobfuscate@stanford.edu

C. Geniesse
e-mail: geniesseobfuscate@stanford.edu

M. Saggar
e-mail: saggar@stanford.edu

H. Xie
OHSU Center for Regenerative Medicine, 3181 SW Sam Jackson Park Road,
Portland, OR 97239, USA
e-mail: xieh@ohsu.edu

R. Beaty
Department of Psychology, The Pennsylvania State University,
140 Moore Building, University Park, PA 16802, USA
e-mail: rub736@psu.edu

C. Meinel and L. Leifer (eds.), *Design Thinking Research*,
Understanding Innovation, https://doi.org/10.1007/978-3-030-28960-7_10

additionally investigating the role of brain and interaction dynamics during design reflection; and (3) including psychological construct of rumination in addition to reflection. We hypothesized that given the critical importance of reflection in design thinking, our approach will provide a comprehensive understanding of the *interplay* between brain dynamics, design reflection, and creativity.

1 Introduction

Reflection—the activity of reasoning through an action that has occurred—has been shown to be of importance to the development of design expertise. Schön (1983) put forward the theory of reflective practice to explain what designers do, beyond what is captured in the technical rationality of process models and flow diagrams. Dorst and Reymen (2004) put forward seven different levels of design expertise—beginner, advanced beginner, competent, proficient, expert, master and visionary—and posit that *reflection is critical to the development of higher levels of design expertise*. In this project, we are employing dynamical information from three different domains—i.e., brain, design interaction and speech—*to quantify the reflection process and link it to individual differences in creativity and design thinking.*

Despite being widely studied previously, our understanding of design reflection is still limited by several gaps. First, there is a lack of investigation of the effect of design reflection on performance of individuals and teams. Second, previous researchers have mainly focused on the language used and its reference to the design problem or solution space. Third, previous work on design reflection has largely ignored the nemesis of reflection—*rumination*. Rumination is characterized as repetitive and persistent evaluation of the meaning, causes, and consequences of one's affective state and personal concerns (Whiteman and Mangels 2016), which has been shown to negatively affect creativity and problem solving (Verhaeghen et al. 2005).

In this project, we aimed at addressing these limitations by (1) assessing the effects of different types of reflection on creative performance; (2) going beyond the frontier of language (or speech) to study the role of brain and team-interaction dynamics during reflection; and (3) including psychological construct of rumination. We hypothesized that given the critical importance of reflection in design thinking, our approach may shed light on the *interplay* between brain dynamics, design reflection, and creativity.

This chapter is organized as follows: in Sect. 2, we provide the background information and literature review, followed by the challenges faced and our experimental design in Sect. 3. In Sect. 4, we provide preliminary results and discussion, followed by a brief on future work and impact in Sect. 5.

2 Background

2.1 Defining Reflection

The term reflection when referring to a mental process is commonly understood as the action or process of thinking carefully or deeply about a particular subject, typically involving influence from one's past life and experiences.[1] More specifically in field of learning and philosophy, it was John Dewey who developed the concept of reflection as a key component of experiential learning. Dewey defined reflection as

> Active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and further conclusions to which it leads… it includes a conscious and voluntary effort to establish belief upon a firm basis of evidence and rationality (Dewey 1933, p. 9)

A key component of reflection in Dewey's writings is that reflective activity involves the perception of relationships and the connections between the parts of an experience and relating it to other experiences or beliefs from one's past life. Kolb elaborated on Dewey's work to develop a model of experiential learning cycle in which a person learns by going from concrete experience to reflective observation to abstract conceptualization and then to active experimentation to test the new concepts again into a concrete experience. According to Kolb, reflection refers to the act of associating an incoming idea with one already in the mind of the observer (Kolb and Fry 1975).

Summarizing past literature on reflection in learning, Boud et al. (2013) have defined reflection as a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations.

Based on these definitions and writings, we can identify the phenomenon of reflection as having the following necessary and sufficient characteristics.

1. The first step towards reflection is *awareness* of a past experience.
2. Awareness of the experience is followed by *evaluation* of the experience in relation to other experiences and beliefs from a person's past.
3. The activity of reflection leads to a *new learning outcome*—an understanding or appreciation which wasn't accessible before reflection.

[1] Oxford English Dictionary, http://www.oed.com.stanford.idm.oclc.org/.

2.2 The Role of Reflection in Design Thinking

Schön (1983) took Dewey's concept of experience as interaction including the role of reflection in experiential learning and applied it to the discipline of design. Before Schön, design researchers mainly from the fields of architecture and engineering were engaged in developing prescriptive models of design activity that could guide practitioners (Bayazit 2004). Schön argued that models of technical rationality do not capture the full extent of the practice of designers. He put forward a model of reflective conversation that uses reflection-in-action as a key phenomenon to describe designers' artistry of dealing with the real-world issues that are beyond technical models. According to this model, designers engage in a conversation with the situation they are designing using activities such as sketching, prototyping etc. They develop on-the-spot hypotheses, modify the materials to represent them, and then reflect on how the modifications fit in with the situation. This could lead to new learning that helps in re-framing the situation which involves changing the perceptual meaning the situation holds for them. See Schön (1992) for a detailed description. Schön's frame of describing design struck a chord with design practitioners and researchers who had an experience of doing design work. Building on Schön's description, a number of researchers conducted studies and wrote articles describing *design reflection*.

Valkenberg and Dorst (1998) extended the study of reflection to design team interactions. Dorst and Reymen (2004) put forward seven different levels of design expertise—beginner, advanced beginner, competent, proficient, expert, master and visionary—and posit that reflection is critical to the development of higher levels of design expertise. Others such as Roozenburg and Dorst (1998) appreciated that Schön's model of reflective conversation went beyond the simplistic view of professionals applying scientific knowledge to real world problems, but at the same time criticized it for being weak and fuzzy in its definition of reflection.

Not surprisingly, design educators have incorporated reflection in their research and have developed activities and conducted studies to examine the effectiveness of reflection in learning design process (Turns et al. 1997) and design teamwork (Hirsch and McKenna 2008).

We summarize our literature review on reflection in design as follows.

1. The concept of reflection is a popular concept both in the research on understanding design activity, as well as in design education.
2. However, reflection is not well-defined as a phenomenon in design discipline.
3. The studies on reflection in design either use post-activity writings, sketches or speech recordings to collect and evaluate reflection phenomenon, or they use video for characterizing reflection-in-action. In both cases, the boundary between reflection and other forms of cognitive reasoning such as goal-oriented thinking, critical evaluation or judgment is not drawn sharply.
4. In spite of the lack of clear definition, reflection in design learning is considered a key component of developing design expertise.

2.3 Defining Rumination

In Psychology, rumination has been defined as

> a class of conscious thoughts that revolve around a common instrumental theme that recur in the absence of immediate environmental demands requiring the thought (Martin and Tesser 1996).

Thus, rumination is characterized by persistence of a thought even after the immediate stimuli is removed. When the persistent thought pertains to one's self such as feelings or memories, then the rumination is called self-reflective rumination (Nolen-Hoeksema et al. 1993). While rumination is not necessarily defined by the persistence of negative thought, prior studies have implication ruminative thinking style with increased vulnerability to depression and negative mental affect (Mor and Winquist 2002; Treynor et al. 2003).

2.4 The Role of Rumination in Design Thinking

Rumination has not directly been studied in design research. However, rumination has been shown to negatively affect creativity and problem solving. Verhaeghen et al. (2005) studied a sample of 99 undergraduate college students, using path analysis and found that self-reported past depressive symptomatology was linked to increased self-reflective rumination and rumination, in turn, was related to current symptomatology and to self-rated creative interests and objectively measured creative fluency, originality, and elaboration. The authors proposed that without a direct link between currently depressed mood and either creative interest or creative behavior, it was rumination that mediated the association between depression and creativity.

Creative problem solving is an essential characteristic of design activity. It is reasonable to hypothesize that ruminative thinking could be linked to design performance. However, the relationship between rumination and reflection and the roles that they play with respect to each other and with respect to design performance are not yet known. The experimental design we describe in the next section aims at shedding light on this relationship.

2.5 Relationship Between Reflection and Rumination

The literature review for a hypothesized or known relationship between reflection and rumination resulted in us finding the following framework by Christoff et al. (2016). The authors proposed a dynamical framework for how the mental states change over time depending on the cognitive control of deliberate constraints and non-cognitive control or automatic constraints. Christoff et al. suggested a relationship between different spontaneous mental states as shown in Fig. 1 [adapted from Christoff et al.

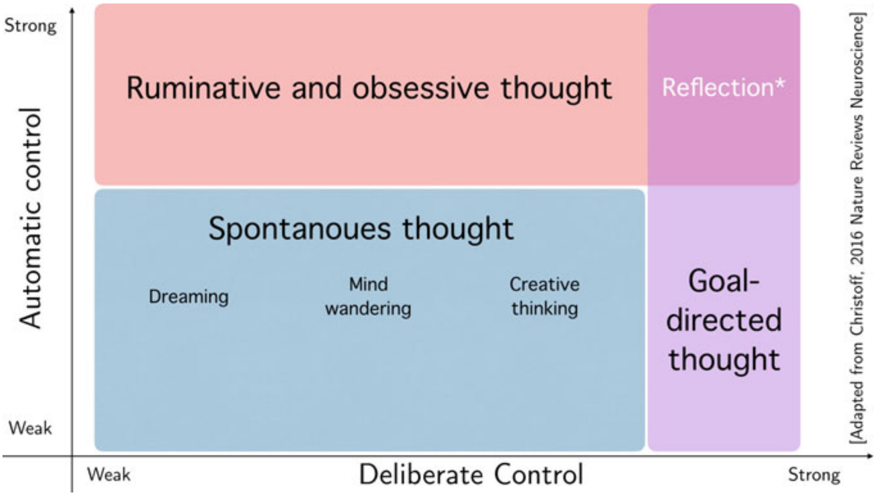

Fig. 1 Spontaneous mental states and their relationship to deliberate control and automatic constraints

(2016)].

In Fig. 1, rumination is shown as a mental state with strong automatic constraint, which means that once the state occurs it captures the attention and retains it on the ruminative thought strongly, and with weak deliberate constraint, which means that it is difficult to deliberately control ruminative thought. Our understanding of reflection is that it would fit in the upper right-hand corner where the ruminative thought overlaps with the goal directed thought. Thus, it is a mental state that has strong automatic constraint, as well as strong deliberate constraint. So, one could presume that a participant could control reflective thought much more readily than ruminative thought.

3 Our Approach

Based on the framework by Christoff et al., which highlights cognitive processes other than reflection and rumination, like goal-directed thought, creative thinking, mind wandering and dreaming, could play an important role in the study of design thinking (Fig. 2). Hence, we adapted the framework for designing current experimental study (see Fig. 2) that included mind wandering, creative thinking, goal-directed thinking and reflection/ruminative thinking. We left out dreaming since it is difficult to induce willful dreaming within the planned fMRI setup.

We developed the following experimental design to study reflection and associated thinking styles in designers participating in a team design activity. Here, we present our approach in the following three phases:

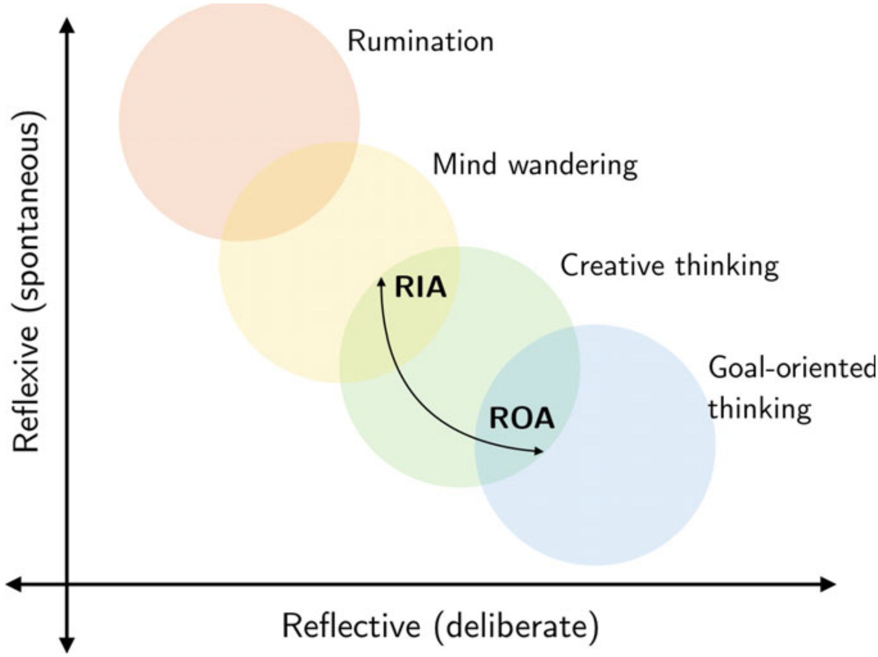

Fig. 2 Expanded conceptual framework for experiment design

3.1 The Design Team Activity Phase

In this phase, we invited participants in a triad to participate together as a team in a series of three rapid design activities. Each activity is divided in three stages—team brainstorming stage in which individuals interact and generate solution concepts together; individual prototyping stage in which individuals work on their own to prototype concepts using a box of provided materials; and team prototyping stage in which the individuals interact to synthesize their prototypes and build a common solution prototype. The following figures describes the process schematic for design team activity phase (Fig. 3).

The three design activities are video recorded in the Design Observatory setup at the Center for Design Research. Figure 4 shows the Design Observatory setup with four cameras capturing the design activity from four different perspectives.

Once the videos of design team activity are recorded, there are synced with independently recorded audio files, and are further analyzed using the Interaction Dynamics Notation (Sonalkar et al. 2013). Only five minutes of team brainstorming for each design challenge are used for IDN analysis. We conducted pilot studies (n = 6 participants) with showing the entire 15 min of video or sections of all three stages but decided to focus on brainstorming videos since they contain more interactive episodes for which IDN could be used meaningfully.

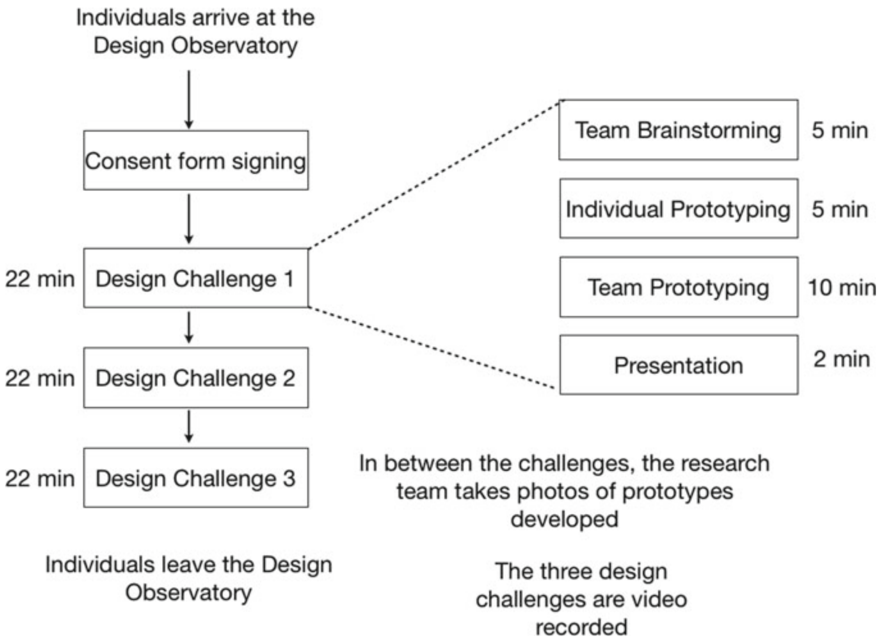

Fig. 3 Process schematic for design team activity phase

Fig. 4 Video recording setup in the Design Observatory

After conducting the IDN analysis, each brainstorming section is broken into smaller clips of various durations (10–100 s) in such a way that each clip highlights a particular aspect of team interaction—questions, humor, agreement or disagreement. These clips are shown to the subjects during the fMRI scan session.

3.2 Behavioral Assessment Phase

In the behavioral assessment phase, the participants were invited to participate individually in a series of behavioral tests. These include the following: intelligence, creativity assessments (divergent and convergent thinking, and creativity achievement), neuropsychological testing for cognitive flexibility and personality, and mind-wandering scales. Besides these tests, each participant's demographic data were also be collected in this phase.

These assessments would allow us to gain information about each participant that could be further associated with the fMRI data and/or the reflection speech data recorded as part of the scan phase.

3.3 fMRI Scan Phase

The fMRI scan phase is divided into three runs. In the first run, two video clips of his or her own team brainstorming activity or one video clip of team brainstorming activity from our pilot study were shown to each participant, during which a series of prompts showed up asking the participant to comment on the interaction type (i.e., questions, humor, agreement or disagreement). At the end of watching videos of a brainstorming activity from a design challenge, the participants were prompted to reflect on the videos they had just seen to come up with ways to improve his or her interaction with others based on it. After the scanning is over, the participants were then asked to speak out and describe what they just thought about. This speech is recorded via a mic. The speech is further analyzed using sentiment analysis for understanding the quality of reflection for each participant.

In the second run, we collected data on a number of different cognitive and affective responses to cover the expanded conceptual framework (as shown in Fig. 2). The following tasks were covered in this run—emotion, guessing, convergent thinking, theory of mind, divergent thinking, working memory, mind wandering, and visuomotor tasks.

In the third run, we collected data while participants performed the Creative Foraging task [see Hart et al. (2017)]. Here participants played a game to search for novel and valuable solutions in a large and well-defined space made of all possible shapes made of ten connected squares. Using just 10 connected squares, participants could discover categories such as digits, letters, and airplanes as well as more abstract categories. The exciting part of this game is that it allows (and measures) the amount of exploration and exploitation done by each participant and potentially tracks exploration-exploitation dynamics with the brain imaging data (Hart et al. 2018). It also allows for measuring an experimental proxy for "creative leaps" (e.g., when a new category is discovered by a participant in a non-prototypical way) (Hart et al. 2017). The Creative Foraging task has been included in the study design to be able to comment on reflection and rumination not just from the watching of videos, but also in the context of on-going exploration or exploitation phases of creative design work.

4 Challenges Faced and Discussion

The data collection for the study has been recently concluded. Here, we present some of the preliminary insights from the data. From the behavioral assessments, Figs. 5 and 6, show two teams participating in the study. The images have been modified to preserve the anonymity of the subjects.

Figures 5 and 6 show the view of all four cameras combined. For the video shown during scanning, we chose a single camera view from multiple cameras and switched one after another given by the size of the display screen inside the scanner.

Once the videos were recorded, we conducted multiple behavioral pilots for the scanner run. These consisted of prototyping the prompts that the participants would get in a scanner and then doing a test run outside the scanner in which the participants would respond to the prompts and also give feedback on what they were thinking when they saw each prompt. This helped us to refine the design of the study and develop an understanding of what might the participants be thinking when a video prompt is presented in the scanner.

> These iterative behavioral pilots for the scanner run were crucial to develop a sound experiment design that would capture the phenomenon of reflection that we aim to study, while conforming to the restrictions of the scanner environment.

Fig. 5 Team 1 Pilot performing a design challenge

Fig. 6 Team 2 Pilot performing a design challenge

These restrictions include noise, inability to move your head, small screen size and input through button-press (instead of real-time feedback). While doing these pilot runs, we realized that reflection was quite loosely defined in the design discipline and we needed to sharpen the definition as described in Sect. 2 of this chapter. The experiment design described in Sect. 3 resulted from the iterative exploration that involved behavioral pilots, literature view, and revising study frameworks.

We are currently in the process of analyzing data collected in all three phases—design team activity, behavioral assessment and fMRI scanner run—for close to 30 participants.

5 Future Work and Impact

The study we are currently implementing is oriented towards understanding the dynamics of mental states as designers reflect on their design activity. How does one enter into a reflective state? What neural patterns distinguish it from ruminative state, creative thinking, mind wandering, or goal directed thought? Is there any personality, creative, reflection, or ruminative tendency that could be identified on a behavioral assessment that correlate with the occurrence of different mental states? How are the mental state dynamics related to the actual team interaction quality or the outcome of the design task?

The investigation of these questions will help us develop a behavioral and neural model of design reflection. This when coupled with an understanding of exploration vs exploitation behavior of designers could be to develop a closed-loop behavioral and/or neural feedback system that allows designers to practice reflective thinking that could actually improve design team performance.

The first step towards creating a closed-loop reflection feedback system is to analyze the data collected in this study and develop reliable models for reflection brain dynamics. This analysis will include building brain dynamic models using a Quantified Brain Dynamics approach previously developed by our group (see Saggar et al. 2018 for details).

These brain models will be correlated with behavioral assessment data, team interaction data as measured by the Interaction Dynamics Notation, design outcomes generated in the brainstorming session recorded, the quality of reflection as noted through sentiment analysis of recorded reflection speech and exploration-exploitation dynamics during the Creativity Foraging task.

Altogether, we believe our approach will further understanding of the *interplay* between brain dynamics, design reflection, and creativity.

References

Bayazit, N. (2004). Investigating design: A review of forty years of design research. *Design Issues, 20*(1), 16–29.

Boud, D., Keogh, R., & Walker, D. (Eds.). (2013). *Reflection: Turning experience into learning*. Routledge.

Christoff, K., Irving, Z. C., Fox, K. C., Spreng, R. N., & Andrews-Hanna, J. R. (2016). Mind-wandering as spontaneous thought: A dynamic framework. *Nature Reviews Neuroscience, 17*(11), 718.

Dewey, J. (1933) *How we think*. Prometheus Books. Original work published 1910. Buffalo, N.Y.

Dorst, K., & Reymen, I. M. M. J. (2004). Levels of expertise in design education. In *DS 33: Proceedings of E&PDE 2004, the 7th International Conference on Engineering and Product Design Education*, Delft, The Netherlands.

Hart, Y., Mayo, A. E., Mayo, R., Rozenkrantz, L., Tendler, A., & Alon, U., et al. (2017). Creative foraging: An experimental paradigm for studying exploration and discovery. *PLoS ONE, 12*(8), e0182133.

Hart, Y., et al. (2018). Creative exploration as a scale-invariant search on a meaning landscape. *Nature Communications, 9,* 5411.

Hirsch, P. L., & McKenna, A. F. (2008). Using reflection to promote teamwork understanding in engineering design education. *International Journal of Engineering Education, 24*(2), 377.

Kolb, D. F., & Fry, R. R.(1975).Towards an applied theory of experiential learning. *Theories of group processes*, 33–58.

Martin, L. L., & Tesser, A. (1996). Some ruminative thoughts. In R. Wyer Jr. (Ed.), *Ruminative thoughts* (Vol. 11, pp. 1–47)., Advances in social cognition Hillsdale, NJ: Erlbaum.

Mor, N., & Winquist, J. (2002). Self-focused attention and negative affect: A meta-analysis. *Psychological Bulletin, 128,* 638–662.

Nolen-Hoeksema, S., Morrow, J., & Fredrickson, B. L. (1993). Response styles and the duration of episodes of depressed mood. *Journal of Abnormal Psychology, 102,* 20–28.

Roozenburg, N. F., & Dorst, K. (1998). Describing design as a reflective practice: Observations on Schön's theory of practice. In *Designers* (pp. 29–41). London: Springer.

Saggar, M., et al. (2018). Towards a new approach to reveal dynamical organization of the brain using topological data analysis. *Nature Communications, 9,* 1399.

Schon, D. A. (1983). *The reflective practicioner: How professionals think in action* (Vol. 1). New York: Basic books.
Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Knowledge-Based Systems, 5*(1), 3–14.
Sonalkar, N., Mabogunje, A., & Leifer, L. (2013). Developing a visual representation to characterize moment-to-moment concept generation in design teams. *International Journal of Design Creativity and Innovation, 1*(2), 93–108.
Treynor, W., Gonzalez, R., & Nolen-Hoeksema, S. (2003). Rumination reconsidered: A psychometric analysis. *Cognitive Therapy and Research, 27,* 247–259.
Turns, J., Newstetter, W., Allen, J. K., & Mistree, F. (1997). Learning essays and the reflective learner: Supporting reflection in engineering design education. In *Proceedings of ASEE Annual Conference and Exposition*, Milwaukee, WI.
Valkenburg, R., & Dorst, K. (1998). The reflective practice of design teams. *Design Studies, 19*(3), 249–271.
Verhaeghen, P., Joorman, J., & Khan, R. (2005). Why we sing the blues: the relation between self-reflective rumination, mood, and creativity. *Emotion, 5*(2), 226.
Whiteman, R. C., & Mangels, J. A. (2016). Rumination and rebound from failure as a function of gender and time on task. *Brain Sciences, 6*(1), 7.