Dynamic Problem Solving for Breakthrough Innovation: The Case of a Social Robot

Dynamic Problem Solving for Breakthrough Innovation: The Case of a Social Robot

A dissertation presented

by

Johnathan R. Cromwell

to

The Harvard Business School

in partial fulfillment of the requirements

for the degree of

Doctorate in Business Administration

in the subject of

Management

Harvard University

Cambridge, Massachusetts

April 2018

Dissertation Advisors: Johnathan R. Cromwell
Professor Teresa M. Amabile
Professor Heidi K. Gardner

Dynamic Problem Solving for Breakthrough Innovation: The Case of a Social Robot

Abstract

This dissertation consists of four chapters that propose a novel theoretical framework for understanding organizational creativity and innovation that I call *dynamic problem solving*. Previous scholars have proposed extensive theory to explain how people can develop novel and useful solutions to well-defined problems, but this overlooks many situations in which people must work on creativity and innovation projects before they have constructed a well-defined problem. One such situation is developing a breakthrough innovation, which is characterized by extreme levels of uncertainty and ambiguity throughout the development process. Most scholars argue that people should approach these situations by first defining a problem and then developing a solution—a process that I call *deliberate problem solving*. However, a small body of research suggests that people can take the opposite approach, in which they develop a solution first and then define a problem—a process that I call *emergent problem solving*. These processes seem to fundamentally conflict with each other, leaving open the question of how people engage in problem solving to develop a breakthrough innovation. I addressed this overarching research question by conducting a two-year ethnography of an organization that built one of the world's first social robots for the home. I found that developers did not use one type of problem solving at the exclusion of the other, but instead dynamically shifted between them over time, thus engaging in dynamic problem solving. I develop theory for this process at both the individual and group levels of analysis.

Contents

For my Grandpa Les,

the Dr. Cromwell I humbly follow.

Acknowledgements

Passion. Persistence. Grit. Without them, this dissertation would not be possible. Without them, I would have succumbed to the one feeling that could have single-handedly derailed my journey through the intellectual wilderness: doubt. When I began this journey six years ago, I had little reason to doubt myself. I had just been accepted to my top choice doctoral program, a milestone I set out to accomplish four years earlier when I decided I wanted to study the social dynamics *around* innovation rather than the science and engineering principles that give rise to innovation itself. Six years ago, my future was bright. There was nothing I could imagine that would get in my way of hitting the next major milestones: completing classes, passing a field exam, finding a dissertation topic, writing research papers, and finally defending a dissertation. Although I knew there would be challenges and setbacks along the way, it all felt so doable to me at the time. However, that is only because I had never experienced *true doubt* before—the type of doubt that makes you question your core abilities, that makes you second-guess your motivations, that makes you ask the question, "what if I *can't* actually do this?"

One of the most humbling experiences you can go through is that of pursuing a doctorate. The goal is to introduce a new idea—a new piece of knowledge—to the world that has never been thought by anyone else before, but can still be understood by everyone. Suffice it to say that I experienced my fair share of obstacles that gave me plenty of reasons to doubt myself in pursuit of this goal. And several times, I nearly gave in. The only reason why I was able to overcome these moments of doubt—these moments of true doubt—is because relationships with my family, friends, colleagues, and mentors gave me the passion, persistence, and grit necessary to succeed. For that, I owe them a great deal of gratitude.

To my mom and dad—Sandra and Russ—it was a long time ago that I stopped asking you for help on my homework, and only recently have I realized that this was by design. Thank you for allowing me to pour my own milk as a toddler, to choose my own soccer teams as a child, and to stay out late as a teenager. Also, thank you for forcing me to do chores around the house, to do homework over the summer, to pull weeds in the front yard, and to shovel rocks in the back yard. Finally, thank you for encouraging me to explore the world, make mistakes, and above all else pursue my interests with 100% of my effort. It was only because of your deliberate effort to raise me as an independent and self-sufficient child that I was able to succeed as an independent and self-sufficient scholar as an adult. This dissertation is as much a product of your hard work as it is mine.

To my sister Leah, my dear twin sister, who has made it her mission in life to frustrate me (and constantly outshine me with all those chores around the house), I don't tell you this enough, but I am constantly inspired by the integrity of your actions and thoughtfulness of your decisions as you've lived your adult life on the West Coast. There were many times when I faced a difficult decision or troubling setback here, and it always seemed that you were one step ahead of me, as you had just overcome a similar obstacle there. Learning how you navigated those issues provided a guiding light for me to navigate through my own issues here. You have influenced me in more ways than you know. Although we've been separated by more than 3,000 miles for the past 13 years, I feel closer to you now than I ever did growing up, and I'm excited to return back to California as we both take an important step in the next chapter of our lives. Also, to my pseudo-sisters—Shannon and Bahar—two powerful women who astound me with your balanced perspective and professional drive; it is from you where I learned the true meaning of grit and persistence. Your accomplishments and unconditional support continue to inspire me to do great things.

To my close friends from high school and college—Adam, CJ, Reid, Christine, Armen, Jared, Nicole, Emily, Kelsey, Kristi, Sue, Jenn, Sally, Trevor, Matt, Tim, KPan, Benson, Sun, EBJ, Yuta, Owen, Payday, KWang, RVL, Liu-kachoo, JLee, The Zhu, Big Twigg, Fogg, Krack, JTan, and JV—who fondly knew me as the "party animal," the "dumb pledge," or the "captain of the leader-ship," you might be as surprised as I am to find that I decided to pursue such an intense intellectual endeavor rather than, say, keep rolling with the good times. Although I've gone into social hibernation in my ivory tower these past few years, I've cherished staying in touch with you as I've gone through this roller coaster of an experience. Thank you for keeping me grounded, never letting me forget where I came from, and always encouraging me to go the distance.

To my friends and colleagues from HBS who have embarked on their own journey through the intellectual wilderness, it has been an honor to ride by your side. To those who came before me—Clarence, Luciana, Pat, Lisa, Liz, Hila, Michele, Pam, Everett, Matt, Andrew, Rachel, Lizzie, Curtis, Ryann, Frank, Anil, Anoop, Tiona, Maarten, and Jean-François—thank you for providing a light during nightfall and leaving a trail of bread-crumbs to help me navigate my way. To those who rode shotgun with me—Hise, Tami, Cheng, Vitaly, Maria, Jasmina, Chris, Catarina, Allie, Erin, Ovül, Karthik, Sam, Paul, Michaela, Jee-Eun, Mariam, and Matty J—it's been a bumpy ride for us all. At times it may have felt like the blind were leading the blind, but together we harnessed the wisdom of the crowd to overcome and succeed. Thank you for providing your thoughtful guidance and direction whenever I needed it. And to those who are coming after me—Dan, Mike, Peter, Michael, Yusaku, Jonathan, Lumumba, Hayley, Alicia, Stefan, Jeff L., Jeff S., Ohchan, James, Sourobh, Yo-Jud, Do Yoon, and Daniella—thank you for your continued interest and support for me and my work. Your confidence in me often gave me the courage to continue persisting. Your day will come.

To my mentors and advisors: I have learned an invaluable skill from each of you that will allow me to overcome any doubt that creeps into my path as I encounter new obstacles and continue on this intellectual journey long into my future. From Teresa, I learned about the power of precision and detail in my writing, theorizing, and logical conceptualizing. Your training has been akin to taking a dull knife to a whetstone; you have helped grind, sand, and polish my mind into a much sharper intellectual tool. From Heidi, I learned how to view the world through a kaleidoscope—one full of puzzles, tensions, contradictions, and paradoxes—which has given me the power to sift through vast swathes of ambiguous knowledge frontiers and identify the most fruitful opportunities for impactful research. From Mike, I learned how to become a "complete" researcher, one who studies social phenomena with his mind as much as his gut. I've learned to stay grounded in the phenomenon, combine rigor with relevance, and constantly take a step back from abstract theorizing to ask simple but important questions: "does this *really* make sense? Is this *really* that important?" And from Spencer, I learned to embrace the power of analogy and visualization, allowing me to chase down wild hunches, tackle fuzzy concepts, and cultivate clear and compelling ideas. Your ability to transform wildly complex ideas into simple and powerful insights feels akin to a master painter changing worldviews with a simple stroke of his brush; I hope to emulate it as I continue with my career.

To my other mentors, advisors, and guides who came before them, thank you for taking the time and effort to coach a young mind and shepherd me through various phases of my development. To Greg Tilson, my soccer coach as a boy, who taught me the difference between simply liking an activity and being passionate about it. To Karl Reid, the first person who ever suggested that I pursue a doctorate; I laughed at the time, but here I am now, 10 years later, ready to receive one. To Steve Immerman, who played a vital role in helping me transition from my life as an engineer to my life as a social scientist. I'll never forget the hardest and most important question that anyone ever asked me: “Why?” To Blade Kotelly, who recognized that some people are *indeed* meant to pursue a doctorate; our years of discussing life, art, design, style, and innovation all while cooking up pasta e fagioli will have an ever-lasting impact. To Tony Mayo, Ranjay Gulati, and Nitin Nohria: thank you for taking a chance on a bright-eyed engineer from MIT to help you write a textbook on management. That was the tipping point that set this entire trajectory in motion. And to Jen Mucciarone, who was quite possibly the MVP of getting me over the rivers and through the woods to complete the doctoral program. Your success is fully deserved and I wish you the best of luck as you continue shepherding hundreds more doctoral students throughout your career. The world will truly be better and more knowledgeable for it.

Finally, to my participants—the designers, product managers, software engineers, and executives at Roboto—who welcomed me on their own journey of creation with open arms, thank you for your kind and generous support. Allowing an ethnographer such as myself to study the inner depths and details of your daily activities not only took incredible courage, but also required a great deal of trust—trust that I in no way deserved when I first started my research, but hopefully earned over the course of two years. You took an unnecessary risk by letting me into your company, and for that I am eternally grateful. Perhaps my deepest gratitude is reserved for my friends on the design team—and in particular the design research team—who felt the strongest brunt of my ethnographic methods and yet graciously accepted me as one of their own. I hope the ideas expressed in this dissertation will be in some way helpful to you in your careers, but I’m sure that—even collectively—it will never match the magnitude by which you helped me with mine. I wish I could thank each of you by name, but to protect your identity, I must resort to a generic (but heartfelt) “thank you” to you all.

Sincerely,

Dr. Johnathan R. Cromwell

List of Tables

List of Figures

Introduction

Creativity and innovation are vital processes within organizations that lead to the introduction of new products and services to the world. Creativity refers to the production of novel and useful ideas for these products and services, and it includes several activities such as generating, evaluating, and selecting ideas that occur near the beginning of the development process. Innovation refers to the successful implementation of selected ideas, which occurs later in the process to yield a final outcome. The outcomes of such endeavors help secure new streams of revenue for organizations and can deliver many positive benefits to society such as helping people live more comfortable, healthy, and prosperous lives. Scholars have been inspired to dedicate their time, attention, and expertise for nearly 100 years to understanding the complex dynamics that support these delicate processes among individuals and groups. In this dissertation, I contribute to this cumulative body of knowledge by focusing on how people develop breakthrough innovations in organizational settings.

Breakthrough innovations are highly novel and useful products or services that have the potential to create entirely new markets and spur new industries. However, the people trying to develop such innovations must overcome unique challenges during the development process. Primarily, breakthrough innovations are characterized by unstable customer preferences and divergent designs, resulting in extreme levels of uncertainty and ambiguity. Under these conditions, it is not always clear how people should define a problem for an innovation, and it is even less clear how they can develop a solution to the problem. Although prior research has developed extensive theory explaining how people can develop novel and useful solutions to well-defined problems, little theory exists to explain how people can overcome uncertainty and ambiguity for both problems and solutions while developing an innovation. Therefore, studying how people develop a breakthrough innovation can lead to new insights that expand our view of creativity and innovation processes more generally.

To date, scholars have proposed two competing processes of creativity and innovation that can potentially explain how people develop a breakthrough innovation. These processes are not unique to breakthrough innovations, as they reflect processes that most people use to accomplish simple tasks in their everyday lives. For example, the first process would be familiar to anybody who has cooked a new dish by doing the following: searched through existing recipes, combined elements across recipes to create a new recipe, gathered the necessary ingredients, and finally cooked the dish. By contrast, the second process would be familiar to anybody who has done the following to cook a new dish: searched through the refrigerator or pantry, gathered a random set of available ingredients, combined the ingredients in an unexpected way, and finally developed a new recipe while cooking the dish. While the first process begins with developing a new recipe and is followed by gathering ingredients, the second process begins with gathering ingredients and is followed by developing a new recipe.

These processes have been formally described in prior literature, but on their surface, they appear to be quite different from each other. The first process reflects *deliberate problem solving*, which begins with defining a problem and is followed by developing a solution to address that problem. The second process reflects *emergent problem solving*, which begins with developing a solution and is followed by defining a problem that the solution addresses. Prior research shows that each process can lead people to produce highly novel and useful outcomes—and in some cases even develop breakthrough innovations. However, these processes seem to conflict with each other regarding the order in which people tackle problems and solutions. Therefore, it is unclear how people engage in problem solving to develop a breakthrough innovation.

In this dissertation, I addressed this overarching research question by conducting a two-year ethnography of an organization that developed one of the world's first social robots for the home. Throughout my time collecting and analyzing data from the field, I focused on how people defined and solved problems while developing this breakthrough innovation. I found that people engaged in both deliberate problem solving and emergent problem solving throughout the development process; furthermore, they dynamically shifted between these two seemingly different processes over time. My dissertation explores these two processes of creativity and innovation, as well as the conditions that foster them, for both individuals and groups. Ultimately, I show that they are not actually two separate processes that compete with each other, but instead are two extreme versions of the same underlying process that I call *dynamic problem solving*.

I describe the insights from my research in four chapters of this dissertation. Chapters One and Two consist of theoretical papers that focus on how *individuals* can produce highly *creative ideas*, which may or may not be implemented through innovation. These chapters theorize how deliberate problem solving and emergent problem solving differ in fundamental ways, yet can still be integrated into a coherent model of dynamic problem solving. These chapters also lay the theoretical groundwork to further investigate how people engage in problem solving to develop a breakthrough innovation, which requires *groups* of people to collaborate to produce highly *innovative outcomes*, which are implemented ideas that introduce new products and services to the world. Importantly, groups confront many coordination, communication, and conflict issues throughout the development process that individuals do not face. Therefore, Chapters Three and Four consist of qualitative empirical papers that explore how groups can overcome these challenges while developing a highly uncertain and ambiguous innovation such as a social robot. These chapters build on the theoretical framework described in the first two chapters to reveal how *groups* can engage in a process of dynamic problem solving to develop a breakthrough innovation.

Each chapter of this dissertation also makes unique theoretical contributions to prior literature. In Chapter One, which is titled *Further Unpacking Creativity with a Problem-Space Theory of Creativity and Constraint*, I describe how individuals operating under completely different confluences of constraints are able to produce similar levels of creative outcomes. One confluence of constraints corresponds to deliberate problem solving, in which people are working on a highly constrained problem and have relatively unconstrained resources to develop a solution. The other confluence of constraints corresponds to emergent problem solving, in which people are working with highly constrained resources—and thus can only generate a small number of ideas—but they can explore those ideas in a relatively unconstrained problem domain until a more specific problem and solution emerge together. I argue that each set of conditions can lead individuals to develop highly creative outcomes because they promote high levels of both intrinsic motivation and cognitive flexibility.

In Chapter Two, which is titled *An Integrated Model of Dynamic Problem Solving Within Organizational Constraints*, I describe how deliberate problem solving and emergent problem solving can be integrated into a coherent model of dynamic problem solving for individuals. Building on my argument from Chapter One, I trace the theoretical origins of each problem-solving process to reveal that they descend from the same cognitive model of problem solving, but they differ based on the time at which constraints (generally speaking) are applied to this model. However, prior theorists do not differentiate between resources constraints and problem constraints; therefore, I build a typology of constraints that differentiates between two types of constraint (resource constraints and problem constraints). Then, I integrate all activities that have been associated with each process into a coherent model of dynamic problem solving, and I reveal how the two confluences of constraint from Chapter One can reproduce the two different problem-solving processes that have been described in prior literature.

In Chapter Three, which is titled *The Emergent Innovation Process in Groups: Ethnographic Insights on Developers of a Social Robot*, I begin to address the unique challenges that groups face when engaging in problem solving to develop a breakthrough innovation. My aim was to understand how developers of a social robot defined and solved a problem for the overall product. To this end, I studied how more than 50 developers (i.e., designers, product managers, software engineers, and executives) collaborated with each other in different permutations to develop several features of the product (e.g., Messaging, Photography, Utilities, Character, Interaction Rules, and Visual Style) over the course of two years. By focusing on the feature as an embedded unit of analysis within a single-site case study, I generate new theory on the emergent innovation process in groups. This process demonstrates how groups can develop a solution for a product (i.e., develop a product's features) by engaging in a cyclical iteration of activities that includes generating ideas, implementing ideas, and interpreting ideas—*before* defining a problem for the overall product to solve. This process contrasts with the deliberate innovation process, whereby groups develop a solution for a product by engaging in a cyclical iteration of activities that includes generating ideas, evaluating ideas, and implementing ideas—*after* defining a problem.

Finally, in Chapter Four, which is titled *The Social Process of Developing a Social Robot: A Model of Dynamic Problem Solving in Groups for Breakthrough Innovation*, I transition to focus on how developers collaborated to define and solve problems for dozens of sub-features of the social robot, allowing me to investigate a broader range of group dynamics related to problem solving for breakthrough innovation. Prior theory would lead to the expectation that groups will use a deliberate innovation process for each sub-feature, which involves defining a problem *before* developing a solution; but theory developed in chapter three suggests that groups can also use an emergent innovation process for each sub-feature, which involves defining a problem *after* developing a solution. In this paper, I generate new theory that describes a model of dynamic problem solving in groups, which consists of an iteration between three stages of collaboration over time that systematically differ based on the extent to which problems are open (i.e., ill-defined). This model describes how groups can use a deliberate innovation process, an emergent innovation process, or a dynamic shift between these two processes as they develop various sub-features for a breakthrough innovation over time.

Altogether, this dissertation proposes a novel theoretical framework for understanding creativity and innovation in organizational settings. By developing theory on the process of dynamic problem solving for both individuals and groups, I lay the groundwork for future research to further investigate various ways by which people develop new products and services in organizational settings. In particular, I show that two seemingly different types of problem solving (i.e., deliberate problem solving and emergent problem solving) actually descend from the same underlying model of dynamic problem solving, and I specify the environmental conditions that give rise to one type of problem solving versus the other. In so doing, I provide theoretical guidance for future scholars to better understand when, why, and how people engage in different types of problem solving, and I provide practical guidance to managers who wish to foster greater success among their employees who are working on creativity and innovation projects in their organizations.

CHAPTER 1

Further Unpacking Creativity with a Problem-Space Theory of Creativity and Constraint

Johnathan R. Cromwell

Abstract

Over the last several decades, a dominant paradigm for creativity and innovation has emerged, in which people work on a well-defined problem and search broadly across resources to develop novel and useful solutions to the problem. However, several scholars have proposed alternative models for creativity that challenge some of the underlying assumptions of this paradigm. For instance, Unsworth (2001) "unpacked creativity" to argue that people may be more creative when working on more open-ended problems, and others have argued that people can be more creative when working with a more constrained set of resources. In this paper, I synthesize these disparate views on creativity into a coherent model by examining the way that various constraints structure the problem space for creativity. I identify conditions under which there is a healthy balance of constraint, which results in two active zones of creativity that I call *deliberate problem solving* and *emergent problem solving*, and conditions under which there is an unhealthy imbalance of constraint, which results in two dead zones of creativity that I call *ambiguous opportunity* and *futile effort*. I also develop propositions that summarize how movement across these zones can result in increased, decreased, sustained, or curvilinear effects on creativity.

1.1 Introduction

Creativity in organizations often comes from people drawing on resources to produce novel and useful solutions to a problem (Amabile, Conti, Coon, Lazenby, & Herron, 1996; Shalley & Zhou, 2008; Sonenshein, 2014). However, it is not always clear what conditions lead to success, and there may be different psychological processes that facilitate more creative outcomes under various conditions (Unsworth, 2001). Take for example two recent breakthroughs—one in the field of autonomous vehicles and the other in archaeology—that both used LIDAR technology to achieve feats that had never before been accomplished. LIDAR is an acronym that stands for "light detection and ranging." Similar to the way that bats use echo-location, LIDAR emits pulses of light to illuminate a target and measures how long it takes for the reflection to return to a sensor, using differences in return times to render high-resolution digital maps of real physical environments.

The first breakthrough came in 2004, when DARPA announced a Grand Challenge that promised to give $1 million to anybody who could develop an autonomous vehicle that finished a 142-mile race through the Mojave Desert in the fastest time (Davies, 2017). Dozens of teams entered the competition using a wide range of technologies, but in the first year, no team actually completed the race. The team that made it the farthest, however—approximately 7.4 miles—used LIDAR technology. A year later, several teams developed more robust LIDAR systems and successfully completed the race for the first time. The second breakthrough came in 2009, when two archaeologists learned about LIDAR technology from biologists and decided to use the technology to study ancient ruins in the jungles of Belize (Hopkins, 2014). Within one week, they collected more data by flying over the jungle in an airplane than they had from 25 years of hacking through the jungle on the ground, and they also discovered new details about the ancient ruins that went overlooked from their traditional excavation techniques.

In each example, one particular resource (LIDAR) was used to develop a highly creative solution to a problem, but the conditions that led to success were entirely different. The autonomous-vehicle example represents conditions that many scholars argue to be optimal for creativity: people were working on a well-defined problem and developed ideas by drawing upon a broad set of resources (Amabile, 1983; Amabile & Pratt, 2016; Mumford, Mobley, Reiter-Palmon, Uhlman, & Doares, 1991; Wallas, 1926). This model has become the dominant paradigm for creativity and innovation in organizations (Anderson, Potocnik, & Zhou, 2014; Shalley & Zhou, 2008), as scholars have found support for it across many contexts such as product design (Hargadon & Sutton, 1997), research and development (Perry-Smith, 2006), patent production (Fleming, Mingo, & Chen, 2007), and scientific inquiry (Simonton, 2004). Therefore, it is not surprising that people were able to produce a highly creative (i.e., highly novel and useful) outcome under these conditions.

However, the archaeology example represents a seemingly opposite set of conditions: people worked on an open-ended problem and developed ideas by drawing upon a single technology material, which was a highly constrained resource. Yet, they still managed to produce a highly creative outcome. Some scholars have investigated these effects, but they have proposed competing explanations for why people can be highly creative under these conditions. For example, Unsworth (2001) suggests that people working on more open-ended problems have the potential to be more creative (e.g., Getzels & Csikszentmihalyi, 1976), because they are confronted with less extrinsic constraint and therefore experience greater intrinsic motivation (Amabile, 1996). By contrast, Ward (1994) argues that people working on more open-ended problems tend to be less creative because they suffer from lower levels of cognitive flexibility. To counter these effects, Ward and other scholars argue that people can work with a more constrained set of resources (Finke, 1990; Hoegl, Gibbert, & Mazursky, 2008; Moreau & Dahl, 2005; Stokes, 2001; van Burg, Podoynitsyna, Beck, & Lommelen, 2012).

These examples illustrate that the existing literature presents contradictory theoretical positions that limit our understanding of creativity in organizations. Some scholars argue that broader and more abundant resources can enhance creativity by increasing intrinsic motivation (e.g., Amabile et al., 1996; Hunter, Bedell, & Mumford, 2007), while others argue that more constrained resources can enhance creativity by increasing cognitive flexibility (e.g, Finke, Ward, & Smith, 1992; Moreau & Dahl, 2005). Similar contradictions can be found in discussions of problem definitions, with some scholars arguing for more well-defined problems (e.g, Amabile, 1983; Mumford et al., 1991), and others arguing for more open-ended problems (e.g, Getzels & Csikszentmihalyi, 1976; Unsworth, 2001). Thus, it appears that there may, indeed, be different types of creativity in organizational settings—as suggested by Unsworth (2001)—but it is still unclear *when* different types are likely to flourish, and more importantly *why* people can be highly creative under various conditions.

In this paper, I attempt to resolve these contradictions by proposing a problem-space theory of creativity and constraint, which explores how the confluence of resource constraints, problem constraints, and external constraints work together to structure the problem space for creativity and influence people's perception of that problem space. I argue that creativity is highest when people perceive a healthy balance of constraint, and that there are multiple ways in which such a balance can be achieved. I identify conditions in which people are over-constrained or under-constrained, in which low levels of intrinsic motivation and cognitive flexibility engender low levels of creativity; and conditions of balanced constraint, in which people experience high levels of each mechanism to facilitate a high level of creativity.

This paper builds upon prior theoretical work and contributes to creativity literature in several ways. First, Unsworth (2001) developed a typology of creativity by identifying two dimensions of creativity that influence intrinsic motivation: driver for engagement (internal versus external) and problem type (open versus closed). However, she does not account for how these dimensions affect cognitive flexibility, and she does not explain what conditions give rise to different levels of creative outcomes. In this paper, I introduce a third dimension—resource constraints—and explore how it interacts with the two dimensions identified by Unsworth to influence creativity through both intrinsic motivation and cognitive flexibility. By doing so, I further unpack creativity to develop a new typology that explains how competing models of creativity can operate under entirely different conditions, and yet still facilitate equivalent levels of creative success.

Second, this paper resolves a theoretical tension between intrinsic motivation and cognitive flexibility with respect to constraints. Some scholars have argued that constraints have a negative effect on intrinsic motivation (e.g., Amabile et al., 1996; Deci & Ryan, 1985; Hunter et al., 2007), while others have argued that constraints have a positive effect on cognitive flexibility (e.g, Finke, 1990; Hoegl et al., 2008; Moreau & Dahl, 2005). Because both intrinsic motivation and cognitive flexibility are supposed to enhance creativity, it is unclear how they might interact to influence creative outcomes. I argue that, rather than having monotonic relationships with constraint that conflict with each other, intrinsic motivation and cognitive flexibility have curvilinear relationships with constraint that mutually reinforce each other. Few studies consider how constraints affect both mechanisms simultaneously (Caniëls & Rietzschel, 2015). Thus, in this paper, I integrate these mechanisms into a coherent model, which provides a stronger foundation for future research to build upon.

1.2 Further Unpacking Creativity

Unsworth's (2001) typology is based on two dimensions that influence the creative process in organizations. First, she argues that the driver to engage in creativity can be either "internal," in which people are motivated to solve problems through self-determined choice (e.g., Deci & Ryan, 1987), or "external," in which people are compelled to solve problems due to external demands (e.g., Amabile, 1979). She also argues that problems can be either "closed," in which problems are clearly formulated before developing a solution (e.g., Amabile et al., 1996), or "open," in which problems are discovered by people while developing a solution (e.g., Getzels & Csikszentmihalyi, 1976).

However, an issue arises when applying these two dimensions to the examples above. The autonomous-vehicle example represents an *externally* driven process to solve a *closed* problem, and the archaeology example represents an *internally* driven process to solve an *open* problem. Prior research shows that people are less intrinsically motivated when driven to engage in creativity by external forces rather than self-determined choice (Deci & Ryan, 1985; Ryan & Deci, 2000), and thus are less creative (Liu, Jiang, Shalley, Keem, & Zhou, 2016). Also, that people have more cognitive flexibility when working on a closed problem compared to an open problem (Ward, 1994), and thus are more creative (Rietzschel, Nijstad, & Stroebe, 2014a). Therefore, these two dimensions create conditions in which existing theory would predict opposing effects between intrinsic motivation and cognitive flexibility, resulting in an overall ambiguous effect on creativity.

It is possible that the examples above reflect empirical anomalies, in which people produced highly creative outcomes in spite of the opposing effects between important psychological mechanisms of creativity. However, I propose an alternative explanation—that there is a third dimension of creativity that, once accounted for, resolves the theoretical puzzle just described and leads to a new typology that better explains the differences (and similarities) between the examples above. This dimension is based on the degree to which resources used for developing a solution—such as time, finances, materials, and knowledge (Amabile et al., 1996; Baer & Oldham, 2006; Hunter et al., 2007)—are constrained during the creative process.

To develop theory on how these three dimensions work together to influence creativity, I recast them in terms of constraint, which I define quite broadly (e.g., Rosso, 2014) as *any factor that places limits or boundaries on creative problem solving*. Accordingly, Unsworth's first dimension of creativity—internal versus external engagement—can be described as a form of *external constraint* on creative problem solving (e.g., Amabile, 1983; Ryan & Deci, 2000; Shalley & Perry-Smith, 2001); and her second dimension of creativity—open versus closed problems—can be described as a form of *problem constraint* (e.g., Finke et al., 1992; Getzels & Csikszentmihalyi, 1976; Rietzschel et al., 2014a). To these dimensions I add *resource constraint*, allowing me to explore generally how these constraints work together to influence creativity.

1.2.1 How External Constraints Can Affect Creativity

To illustrate the effects that external constraints have on creativity, I compare two experiments that had very similar designs but dramatically different results, leading the experimenters to draw different conclusions on the mechanisms that facilitate creativity. The first experiment was conducted by Amabile and Gitomer (1984), who recruited children to create collages by using materials that were presented in ten closed boxes. To manipulate external constraint, they divided subjects into a "choice" condition, in which subjects were told to choose any five boxes of the ten to use in making a collage, and a "no-choice" condition, in which five boxes were chosen for them by the experimenter. A yoked design was used, so that subjects in the no-choice condition were given the same five boxes as subjects in the choice condition, ensuring that all materials were identical across the two conditions. Afterwards, the experimenters removed the other five boxes and subjects were given ten minutes to complete their work. Results showed that subjects in the choice condition produced more creative collages than subjects in the no-choice condition, despite spending an equal amount of time on the task.

These results are consistent with a long line of research that contributes to the *intrinsic motivation principle of creativity* (Amabile, 1996). This principle holds that people working under perceived external constraint are less intrinsically motivated to work on a task and, as a result, exhibit lower levels of creativity. In the intrinsically motivated state, people become deeply engaged in the activity itself and are more likely to explore divergent cognitive pathways, take risks, and search for new, interesting, and useful outcomes (Amabile, 1979; Csikszentmihalyi, 1996). In the extrinsically motivated state, people are more concerned with achieving extraneous goals or satisfying external demands, and thus, tend to view the activity as a job to be finished rather than a satisfying endeavor in itself. They are more likely to search for solutions that can solve a problem quickly and definitively and are less likely to take risks on more novel ideas (Amabile, 1993; McGraw, 1978).

The second experiment was conducted by Finke (1990), which was part of a series of experiments that were designed to understand the cognitive processes underlying creative thought. In this experiment, students were recruited to use a subset of three out of 15 materials (e.g., hook, sphere, spring, etc.) to create new inventions in one of eight problem domains (e.g., furniture, toys, appliances, etc.). The experimenter manipulated external constraint by dividing subjects into two conditions: In the first, subjects were told to choose their own subset of materials, and the experimenter gave them a problem domain; in the second, the experimenter gave subjects both the subset of materials and the problem domain. Subjects then had two minutes to visualize an invention and draw it, and their ideas were rated for creativity by an independent set of judges. Results showed that subjects in the second—more externally constrained—condition produced more creative ideas than those in the first condition.

When comparing these results with those of the first experiment, the findings can—at first blush—seem paradoxical. Amabile and Gitomer found that external constraint reduced creativity, while Finke found that external constraint enhanced creativity. I reconcile these findings by exploring the differences between the two experiments. Amabile and Gitomer told subjects to choose five of ten boxes of materials to use for creating a collage, and Finke told subjects to choose three of 15 materials to use for creating an invention. The core difference is that materials in each box from the first experiment were quite similar to each other, so that any one set of five boxes of materials were nearly identical to any other set of five. This was done to eliminate the possibility that cognitive factors related to choosing materials influenced the creative process. By contrast, subjects in the second experiment were told to choose three specific materials for the task, which was done to allow cognitive factors to influence the creative process.

This is consequential because theories of cognition argue that cues inherent in a task will trigger particular ideas in the minds of individuals who are engaged in the task, which are constructed from prior experience (Walsh, 1995). In the context of the second experiment above, subjects were more likely to choose materials that they were more familiar with, making it easier for them to generate ideas that were similar to cognitive templates that already existed based on prior experience. Consequently, their ideas were less creative. Ward (1994) describes this process as “following the path of least resistance” and argues that it is more likely to occur when people have more cognitive freedom during a task rather than less. Many studies find similar results (e.g., Goldenberg, Mazursky, & Solomon, 1999; Hoegl et al., 2008; Moreau & Dahl, 2005), which together support the *creative cognition theory of creativity* (Finke et al., 1992).

According to this model, constraints place limitations on the categories, features, functions, components, or resources used during the creative process, and they can push people off the path of least resistance. As constraints are added to a task, problems become more challenging to solve, and people must search for more distant ideas in their semantic network or create more unique combinations of ideas to satisfy all the constraints. In other words, their cognitive flexibility is enhanced.

Together, these two experiments represent theoretical frameworks that propose contradicting views on the relationship between external constraint and creativity. In this paper, I resolve this contradiction by showing how external constraint can be applied independently to the other two dimensions of constraint (problem constraints and resource constraints), so that the overall confluence of constraints promotes high levels of both intrinsic motivation and cognitive flexibility. But first, I consider how these other two dimensions influence creative outcomes.

1.2.2 How Problem Constraints and Resource Constraints Can Affect Creativity

I illustrate these effects by comparing another set of experiments, this time showing how problem constraints and resource constraints work interdependently to influence creative outcomes. The first experiment was conducted by Rietzschel and colleagues (2014a), who were interested in understanding the cognitive processes that lead to higher quality—as opposed to higher quantity—ideas. In this experiment, students were recruited to generate ideas on ways to improve education within their university. The experimenters manipulated problem constraint by separating subjects into two conditions: In the first, subjects were told to generate ideas about "possible improvements in the education at the department of psychology;" and in the second, they were told to generate ideas on "possible improvements in the lectures at the department of psychology." Note that the problem in the second condition is a sub-problem of that in the first condition; therefore, it is more constrained. Subjects were then given 20 minutes to generate as many ideas as possible, which were rated for originality and feasibility. Results showed that subjects in the second condition produced more creative ideas than those in the first, despite generating an equal number of ideas.

The authors argue that they found these results because the more constrained problem forced subjects to think more deeply within a smaller domain, which pushed them off the path of least resistance and helped them produce more creative ideas. Similar results have been found in other studies (e.g., Coskun, Paulus, Brown, & Sherwood, 2000; Dennis, Valacich, Connolly, & Wynne, 1996; Rietzschel, Nijstad, & Stroebe, 2007), lending further support to the creative cognition theory of creativity. However, another experiment conducted by Finke (1990) reveals that there may be limits to such effects. In a follow-up experiment to the one described above, in which subjects were given three out of 15 materials to create an invention in one of eight problem domains, the experimenter manipulated problem constraint by telling subjects in one condition to develop a new invention for "furniture" and subjects in another condition to develop a new invention for a "chair." This time, results showed that subjects in the second—more constrained—condition produced less creative ideas than those in the first, which is the opposite of what Rietzschel and colleagues (2014a) found.

I reconcile these seemingly paradoxical findings—again—by exploring the differences between the two experiments. In the first, subjects were told to generate ideas to improve either the "education" or "lectures" of the psychology department, and they were unconstrained when generating ideas. By contrast, subjects in the second experiment were told to invent either new "furniture" or "chairs," but were constrained to use a particular subset of three materials when generating ideas. As a result, subjects in the second experiment experienced relatively higher resource constraint than subjects in the first experiment, which bounded their ability to produce distant and unexpected combinations of ideas. In other words, their cognitive flexibility was limited, which subsequently inhibited creativity.

Together, these two experiments illustrate an important point that has yet to be theorized in the creativity literature: that cognitive flexibility is affected by the combination of problem constraints and resource constraints working simultaneously together to influence creative thinking. In the next section, I elaborate on these effects and explain how these conditions also influence intrinsic motivation. Furthermore, I integrate the third dimension of creativity—external constraint—to add further nuance to the overall effects of constraints on creativity.

1.3 A Problem-Space Theory of Creativity and Constraint

I develop this theory by outlining the effects that three dimensions of constraint—external constraints, problem constraints, and resource constraints—together have on the psychological mechanisms of intrinsic motivation and cognitive flexibility. I use as a cornerstone a key assumption in the creativity literature—that creativity is fundamentally a problem-solving process—and view prior research through the lens of a cognitive problem-solving model (Newell & Simon, 1972). I argue that the level of creativity for a final outcome depends on the way that constraints structure an individual's problem space for creativity. By this, I mean that constraints determine the size of the pool of potential ideas and pool of potential solutions that an individual can generate. Moreover, that different combinations of these pools determine an individual's psychological experience during the problem-solving process, which in turn forms the basis for a new typology of creativity. I summarize these arguments in a set of formal propositions that describe when movement between each type of creativity has positive, negative, sustained, or curvilinear effects on creativity.

1.3.1 How Constraints Structure the Problem Space for Creativity

According to Newell and Simon (1972), all creative problem solving takes place within a *problem space*, which comprises an initial state, a desired goal state, and all possible intermediate states. A problem exists when individuals have goals or objectives that they want to obtain, but do not know what steps can be taken to achieve them. To solve the problem, people engage in an iterative process of interpreting the problem statement, generating an internal representation of the problem, choosing a set of knowledge and conceptual tools that may be relevant to solving the problem, and using the knowledge and tools to generate one or more ideas that could become a potential solution. An idea becomes a "solution" once it satisfies all the objectives that are specified in the goal state; the ideas that precede the solution and the order in which they are generated define the intermediate states of the problem space.

As I defined it, constraint is any factor that places limits or boundaries on creative problem solving. Resource constraints place limits or boundaries on the time, finances, materials, and knowledge that are used to generate ideas that make up the intermediate states of the problem space. Lower resource constraint means that people have a broader set of resources to use, resulting in a larger number of potential ideas that can be generated. New ideas come from the combination of existing ideas (Guilford, 1950; Koestler, 1964); therefore, each additional resource exponentially increases the number of potential ideas that can be generated. For example, when subjects from the Finke (1990) study chose three materials for their invention, they had the capacity to create 455 unique combinations of materials, which could then be used as starting points for thousands of new ideas. If they had been allowed to choose just one additional material (four total), they could have created 1,365 unique combinations—three times as many potential starting points.

Problem constraints place limits or boundaries on the requirements, needs, objectives, or demands that define the goal state. Lower problem constraint means that people are working within a broader problem domain and have fewer requirements to meet. For example, in the archaeology example, people explored how LIDAR could solve problems within a particular domain, but they did not know in advance what specific problems could be solved. Under these conditions, more ideas have the potential to solve a problem because there are fewer pre-defined requirements to meet. By contrast, higher problem constraint means that people are working within a narrower problem domain and have more requirements to meet. Under these conditions, fewer ideas can satisfy all the requirements, and therefore people must generate a larger number of ideas before developing a viable solution. For example, in the autonomous-vehicle example, many people competed in the race using a wide range of technologies, and it took multiple attempts before developing a LIDAR system that could navigate the course successfully.

Together, the level of resource constraint and problem constraint work together to structure the problem space for creativity, which is stylistically depicted in Figure 1.1. People facing a low level of resource constraint and a low level of problem constraint (the lower-left quadrant of Figure 1.1) can generate a large pool of potential ideas—a high proportion of which can potentially become a solution to a problem. People facing low resource constraint and high problem constraint (lower-right quadrant of Figure 1.1) can generate a large pool of ideas, but only a small proportion can become a solution to a problem. High resource constraint and low problem constraint (the upper-left quadrant of Figure 1.1) results in a small pool of ideas, of which a high proportion can become a solution to a problem. And finally, under high levels of both resource and problem constraint (upper-right quadrant of Figure 1.1), people can generate only a small pool of ideas, and a small proportion—if any—can become a solution to a problem.

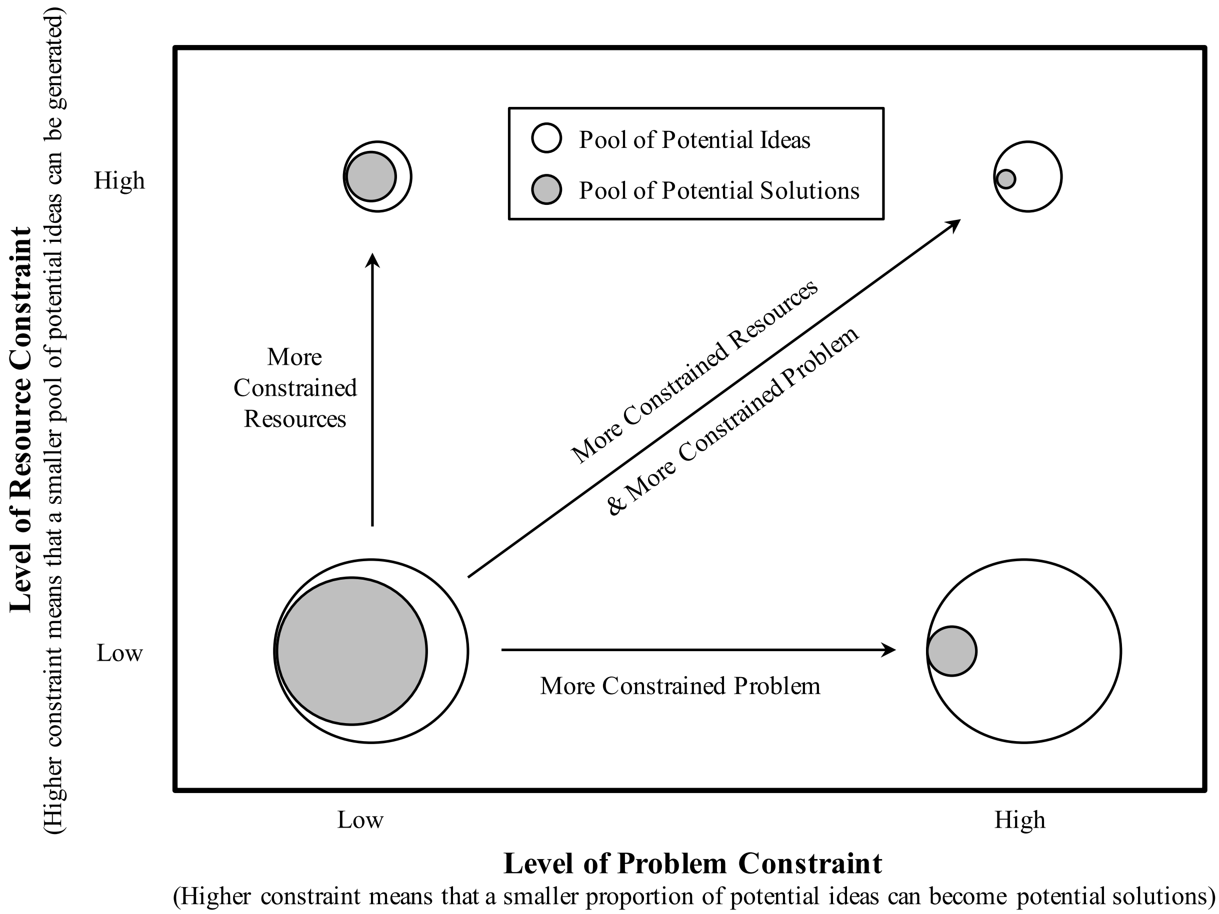


Figure 1.1: How Resource Constraints and Problem Constraints Structure the Problem Space for Creativity

1.3.2 How Constraints Shape the Perceived Problem Space for Creativity

The problem space is always filtered through the problem solver's individual perceptions (Cronin & Weingart, 2007; Newell & Simon, 1972); therefore, the degree to which constraints influence creativity is determined by *perceived* levels of constraint. With this view in mind, external constraints do not change the underlying structure of the problem space—as resource and problem constraints do—but instead change the *perceived* level of constraint for each of these other dimensions. When external constraint is lower, people have more control over the resources or problems that structure the problem space, and thus feel less constrained; when external constraint is higher, people have less control over resources or problems, and thus feel more constrained. External constraints are often imposed on the problem-solving process by other people, but they can also arise naturally from the problem-solving task itself. For example, when an explosion on the *Apollo 13* spaceship damaged the air filtration system, NASA engineers had only a few hours to fix the problem (King, 1997). Under these conditions of high external constraint, the engineers successfully diagnosed the problem and developed a solution that saved the astronauts' lives.

When the problem space depicted in Figure 1.1 is viewed through the lens of individual perceptions, a perceived problem space emerges where each zone in Figure 1.1 corresponds to a different psychological experience of creativity, which is summarized in Figure 1.2. When people perceive low levels of both resource and problem constraint (lower-left quadrant of Figure 1.2), they believe they have ample resources to generate many ideas and ample opportunity to solve many problems. While this condition may seem favorable to creativity because it offers the most freedom, people may instead feel overwhelmed by choice and suffer from a lack of direction on which ideas to pursue, resulting in a "dead zone" of creativity that I call *ambiguous opportunity*. By contrast, people experiencing high levels of resource and problem constraint (upper-right quadrant of Figure 1.2) may feel that the problem is so challenging that no matter how many resources they use, they will fail to generate an idea that satisfies all the problem requirements. This represents another dead zone of creativity that I call *futile effort*.

However, some confluences of constraint can foster high levels of creativity, which is represented by the shaded area in Figure 1.2 that I call the *zone of creativity*. When people perceive a high level of problem constraint and a low level of resource constraint (lower-right quadrant of Figure 1.2), they feel that they are working on a challenging problem and have enough resources to generate ideas that will eventually solve it. I call this zone *deliberate*

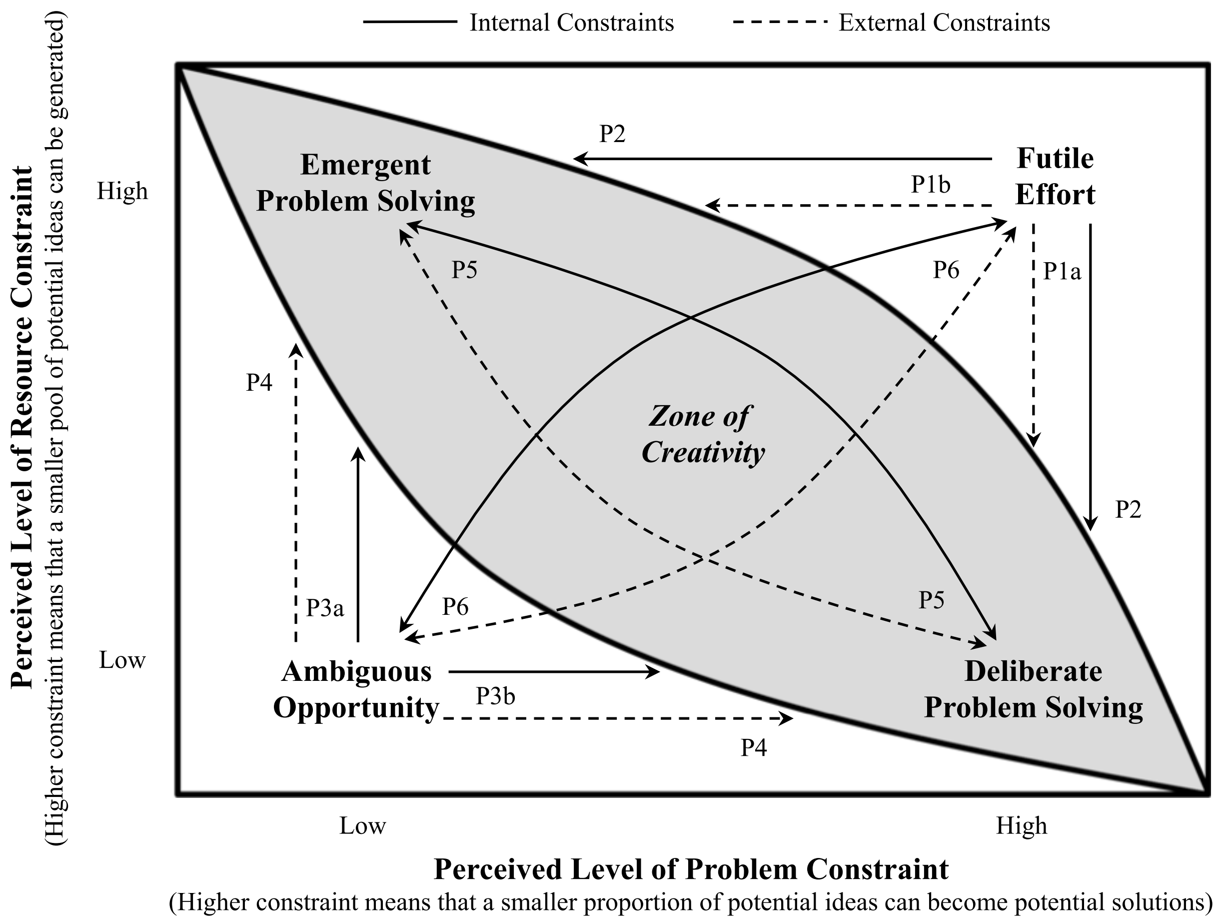


Figure 1.2: A Typology of Creative Problem Solving as Emergent from Different Confluences of Constraint

problem solving, because it reflects the process of deliberately engaging in the creative process with the intent of solving a clearly defined problem (e.g., Amabile, 1983)—such as what occurred in the autonomous-vehicle example. By contrast, when people perceive a high level of resource constraint and a low level of problem constraint (upper-left quadrant of Figure 1.2), they feel that they have the flexibility to discover a problem to solve with a particular set of resources. I call this zone *emergent problem solving*, because it reflects the process of using a constrained set of resources to generate ideas, which are then explored in the context of a problem domain until a problem and solution emerge together (e.g., Finke et al., 1992)—such as what occurred in the archaeology example.

Viewed as a whole, Figure 1.2 summarizes the conditions in which people can be highly creative or uncreative, revealing various ways in which constraints can be manipulated to increase, decrease, or sustain overall levels of creativity. In the dead zone of futile effort, *decreasing* the perceived level of resource or problem constraint can enhance creativity—up to a point. In the dead zone of ambiguous opportunity, *increasing* the perceived level of resource or problem constraint can enhance creativity—up to a point. By contrast, in the zone of creativity, increasing one type of constraint must be accompanied by a decrease in the other, so as to maintain an overall balance of constraint. If constraints are adjusted too much, so that they take people out of the zone of creativity, creativity will suffer. In the following sections, I describe how changes to resource constraints, problem constraints, and external constraints affect intrinsic motivation and cognitive flexibility to yield these effects.

1.3.3 The Zone of Futile Effort: When and Why Decreasing Constraint Enhances Creativity

When people are working under conditions of futile effort, they suffer from low levels of both intrinsic motivation and cognitive flexibility. Prior research shows extensive evidence that constraints can negatively affect intrinsic motivation (Byron, Khazanchi, & Nazarian, 2010; Hunter et al., 2007), but the reason why people experience low intrinsic motivation in the over-constrained condition of futile effort differs from what has been previously theorized in the creativity literature. In Deci and Ryan's (1985) seminal paper on self-determination, they identify three causality orientations that describe how people can experience their environments, which in turn influence their cognitions, behaviors, and emotions. They differentiate between an *autonomy orientation*, in which people experience a high degree of choice over the factors that initiate and regulate their behaviors, a *control orientation*, in which people feel that their behaviors are controlled primarily by external factors, and an *impersonal orientation*, in which people believe that they are unable to regulate their behavior in a way that will reliably lead to desired outcomes.

Prior research on creativity has drawn on differences between the autonomy and control orientations to develop theory that explains why people suffer from lower levels of intrinsic motivation when confronted with greater *external* constraint (e.g., Amabile, 1996). However, people operating in the dead zone of futile effort are faced with high perceived levels of resource and problem constraint, which are independent of external constraints, and instead are induced to experience an impersonal orientation rather than an autonomy or control orientation. Deci and Ryan argue that people who experience an impersonal orientation "see themselves as incompetent and unable to master situations. They experience tasks as being too difficult and/or outcomes as being independent of behavior" (p. 112). People experience depressive feelings and strong anxiety about their situation, resulting in negative effects on their intrinsic motivation that go beyond the negative effects that occur under a control orientation (further elaborated in Ryan & Deci, 2000).

People also suffer from low levels of cognitive flexibility. As described earlier, people working on a highly constrained problem feel like they are trying to solve a problem that has difficult objectives to obtain. While this has the potential to increase cognitive flexibility by pushing people off the path of least resistance (Ward, 1994), a constrained set of resources bounds their ability to combine ideas in novel ways, resulting in a smaller pool of potential ideas that can be generated. People are unable to draw upon the most relevant resources that can help them navigate through the problem space effectively, and consequently, their capacity to produce potential solutions to the problem at hand is limited. As people continue generating ideas while navigating through the problem space under futile effort, they will eventually run out of ideas as they confront the boundaries of their cognitive flexibility. This can add further fuel to the impersonal orientation, thereby exacerbating the negative effects on intrinsic motivation and contributing to increasingly lower levels of creativity over time.

However, there are two ways in which decreasing constraint can reverse these effects to increase intrinsic motivation and cognitive flexibility—and in turn—enhance creativity. First, decreasing the perceived level of resource constraint can move people from the dead zone of futile effort to the active zone of deliberate problem solving. As people gain access to more time, materials, resources, or knowledge to use during the problem-solving process, they can expand the boundaries of their cognitive flexibility and generate a larger pool of potential ideas. They can search more broadly within their semantic network for more relevant ideas or create more unique combinations of ideas that will satisfy all the problem requirements. They will also feel like they have greater choice in the way that problems are solved, which will shift their causality orientation from an impersonal orientation to an autonomy orientation. This will increase intrinsic motivation and activate additional cognitive, behavioral, and emotional processes that enhance creativity. Problem solvers will be more likely to explore divergent cognitive pathways and take risks on more novel ideas while navigating through the problem space.

Alternatively, decreasing the perceived level of problem constraint can move people from the dead zone of futile effort to the active zone of emergent problem solving, which also has positive effects on cognitive flexibility and intrinsic motivation. Decreasing problem constraint increases cognitive flexibility, not by increasing the size of the pool of potential ideas, but instead by increasing the size of the pool of potential solutions. People can take the small pool of ideas that are generated from limited resources and explore how they can solve new or different problems—a process that some scholars call *bricolage* (e.g., Baker & Nelson, 2005; Sanchez-Burks, Karlesky, & Lee, 2015; Sonenshein, 2014). Decreasing problem constraint can also improve intrinsic motivation by (a) helping people regain the feeling that they have control over their outcomes, which reduces their impersonal orientation; and (b) giving people more choice over the factors that regulate their behavior, which increases their autonomy orientation.

Therefore, I propose that decreasing resource constraints, problem constraints, or both can improve creativity if it is enough to move people from the dead zone of futile effort to the active zone of creativity, but not so much that it moves them past the zone of creativity and into the dead zone of ambiguous opportunity. These possibilities are illustrated in Figure 1.2 with the lines labeled P1a and P1b.

Proposition 1: When people are working under conditions of futile effort, their creativity can be enhanced by (a) decreasing the perceived level of resource constraint or (b) decreasing the perceived level of problem constraint, or both.

The degree to which decreasing resource and problem constraints improves creativity is also moderated by the extent to which they are external constraints. To understand these effects, consider two situations: one in which resource and problem constraints are completely externally controlled, for instance by a manager in an organization, and another in which resource and problem constraints are completely internally controlled by the person who is engaged in creative problem solving. In the first situation, decreasing constraint can lower the impersonal orientation, but there will still be the perception that the problem solver's behaviors are at least partially regulated by an external source; consequently, some of their causality orientation will shift from an impersonal orientation to a control orientation, which limits positive effects on intrinsic motivation. In the second situation, decreasing constraints will fully shift the problem solver's orientation from an impersonal orientation to an autonomy orientation, leading to greater positive effects on intrinsic motivation.

However, there is also a possibility that the second situation may have a lower positive effect on cognitive flexibility than the first. When people choose their own resources or problems to focus on, they are more likely to follow the path of least resistance and produce less creative ideas (e.g., Finke, 1990). However, this is unlikely to be the case under conditions of futile effort, because low levels of cognitive flexibility are not caused by people following the path of least resistance, but instead by people confronting boundaries when searching for distant and unique combinations of ideas. As a result, people in the first situation may be forced to work with a particular set of resources that cannot solve the problem at hand, and people in the second situation may have the flexibility to draw upon more relevant resources that can help them generate ideas that successfully solve the problem.

Therefore, when individuals are working under conditions of futile effort, decreasing constraints will have a greater positive effect on both intrinsic motivation and cognitive flexibility when constraints are internally controlled versus externally controlled. In other words, decreasing resource or problem constraints will be negatively moderated by the extent to which they are external constraints, which is reflected in Figure 1.2 with the lines labels P2.

Proposition 2: When people are working under conditions of futile effort, the effects of decreasing perceived resource constraints or perceived problem constraints will be negatively moderated by external constraint, such that decreasing externally controlled constraints will have a lower positive effect on creativity than decreasing internally controlled constraints.

1.3.4 The Zone of Ambiguous Opportunity: When and Why Increasing Constraint Enhances Creativity

When people are working under conditions of ambiguous opportunity, they also suffer from low levels of intrinsic motivation and cognitive flexibility, but for different reasons than the zone of futile effort. Under these conditions, people believe that they can generate a large number of ideas and have the opportunity to solve a large number of problems, which should promote intrinsic motivation because people experience a strong autonomy orientation. However, these are conditions in which people may have so much autonomy during problem solving that they suffer from the "tyranny of freedom" (Schwartz, 2000). According to Schwartz, "unconstrained freedom leads to paralysis and becomes a kind of self-defeating tyranny. It is self-determination within significant constraints—within rules of some sort—that leads to well-being, to optimal functioning" (p. 81). People are most likely to suffer from this tyranny when they have ambiguous preferences or cannot make valid comparisons between several desired outcomes.

These are precisely the conditions that people face when working in the zone of ambiguous opportunity. When people perceive a low level of problem constraint, they have the opportunity to solve numerous problems across several domains, and it becomes difficult for them to compare the value of solving problems in one domain versus another. For example, if it was the year 2002, it would be nearly impossible to determine whether LIDAR technology would have a greater impact in the field of autonomous vehicles or the field of archaeology. This issue gets compounded when people also perceive a low level of resource constraint, because people can generate a large number of potential ideas for each problem that is being considered. Because creative problems are ill-structured (Reitman, 1965; Simon, 1973)—meaning that it is unclear which ideas will lead to desired outcomes—people suffer from excessive choice when evaluating ideas as potential solutions to problems, which can lead to negative emotions that undermine intrinsic motivation (Iyengar & Lepper, 2000) and subsequently inhibit creativity (Chua & Iyengar, 2008).

A high degree of cognitive freedom also makes people more susceptible to following the path of least resistance, resulting in low levels of cognitive flexibility, as described earlier. Therefore, although people can generate a large number of potential ideas and a large number of potential solutions to problems, the actual creativity of their ideas is low. This may seem counterintuitive—especially when compared to literature arguing that higher creativity comes from people generating a larger number of ideas (e.g., Campbell, 1960; Simonton, 1999, 2004); however, it is consistent with a broad range of research examining the cognitive processes underlying creative problem solving (e.g., Finke, 1990; Rietzschel et al., 2014a; Ward, 1994). I build a bridge between these competing theories by considering the different ways that increasing constraint can improve creativity under conditions of ambiguous opportunity.

First, increasing the perceived level of problem constraint can move people from the dead zone of ambiguous opportunity to the active zone of deliberate problem solving. As the problem gets more constrained, it becomes more difficult for an idea to satisfy all the problem requirements, making it easier for people to eliminate ideas from consideration during the problem-solving process. As a result, people can transition from a state of excessive choice when evaluating ideas as potential solutions to a problem, to a state of optimal choice, which can foster higher levels of intrinsic motivation. Additionally, more constrained problems can force people off the path of least resistance to increase cognitive flexibility. Therefore, people can be highly creative when they have the capacity to generate a large number of ideas while simultaneously focusing their efforts toward solving a highly constrained problem, which may explain why scientists are more creative when they produce a larger number of ideas (Simonton, 2004).

Alternatively, increasing the perceived level of resource constraint can move people from the dead zone of ambiguous opportunity to the active zone of emergent problem solving. Such a move reduces the feeling of excessive choice, not by decreasing the pool of potential solutions, but by decreasing the pool of potential ideas that can be generated altogether. When people are forced to work with a smaller set of resources, their capacity to generate ideas becomes limited, which makes it easier for them to evaluate potential contributions of each idea within a particular domain. During this process, people do not eliminate potential solutions from consideration for a particular problem—which occurs in the zone of deliberate problem solving—but instead eliminate potential problems from consideration for a particular set of resources. In both cases, the number of potential solutions that need to be evaluated during problem solving decreases, which lowers the anxiety of excessive choice. Indeed, such constraints may enable choice rather than limit it (Schwartz, 2000), helping people feel like they have more control over the factors that regulate their behavior, thereby enhancing intrinsic motivation.

Furthermore, increasing resource constraint moves people closer to conditions that scholars argue lead to optimal cognitive flexibility—in which people first generate an idea in the absence of problem constraint, and then explore how that idea might solve problems within a problem domain (Finke et al., 1992). To demonstrate this point, Finke (1990) conducted yet another experiment in which subjects used three out of 15 materials to create an invention in one of eight problem domains. In the first condition, the experimenter gave subjects both the materials and problem domain at the beginning of the task, followed by two minutes for subjects to generate ideas for an invention. In the second condition, the experimenter gave subjects the materials at the beginning of the task, followed by one minute to generate a "potentially useful" idea for an invention; then gave the problem domain, followed by an additional minute for subjects to explore their idea within that domain. Results showed that subjects in the second condition produced more creative ideas than those in the first, suggesting that cognitive flexibility is highest when a randomly generated idea is explored in the context of a randomly chosen problem domain.

Therefore, when people are working under conditions of ambiguous opportunity, increasing their perceived level of problem constraint, resource constraint, or both can have positive effects on creativity if it moves them from the dead zone of ambiguous opportunity to the active zone of creativity, but not so much that it moves them into the dead zone of futile effort. These effects are illustrated in Figure 1.2 with the lines labeled P3a and P3b:

Proposition 3: When people are working under conditions of ambiguous opportunity, their creativity can be enhanced by (a) increasing the perceived level of resource constraint or (b) increasing the perceived level of problem constraint, or both.

Similar to the zone of futile effort, the degree to which increasing resource or problem constraints enhances creativity is moderated by external constraint, but this time the direction is reversed, such that increasing constraint is positively moderated—rather than negatively moderated—by external constraint. To understand these effects, consider again the two situations that I described earlier, in which resource and problem constraints are either completely internally controlled or completely externally controlled. When the problem solver has full control over constraints, they have to make all decisions about which problems to focus on and which ideas to develop as potential solutions during the problem-solving process; but when constraints are externally controlled, some choices about problem solving are made for the individual problem solver. Either some problems will be eliminated from consideration due to external demands, or some ideas will no longer be potential solutions because of restricted resources; in both cases, the feeling of excessive choice can be reduced, which increases intrinsic motivation.

External constraints also have a stronger positive effect on cognitive flexibility than internal constraints, as shown in several experiments described earlier (e.g., Finke, 1990; Rietzschel et al., 2014a). However, an important addendum I make to existing theory is that these effects only occur in the zone of ambiguous opportunity, because these are the conditions in which people experience enough cognitive freedom that make them prone to following the path of least resistance. When people have less cognitive freedom—such as when they are operating in the zone of futile effort—external constraints will be more likely to force people to confront the cognitive boundaries that inhibit creative thinking than internal constraints, and thus will not have the same positive effect on cognitive flexibility.

Therefore, when individuals are working under conditions of ambiguous opportunity, increasing problem constraints or resource constraints will have a greater positive effect on both intrinsic motivation and cognitive flexibility when they are externally controlled versus internally controlled. I capture these effects in Figure 1.2 with the lines labels P4.

Proposition 4: When people are working under conditions of ambiguous opportunity, the effects of increasing perceived resource constraints or perceived problem constraints will be positively moderated by external constraint, such that increasing externally controlled constraints will have a greater positive effect on creativity than increasing internally controlled constraints.

1.3.5 The Zone of Creativity: Maintaining a Balance of Constraint to Sustain High Levels of Creativity

When people are operating in the zone of creativity, they experience a balance of constraint that facilitates high levels of both intrinsic motivation and cognitive flexibility. However, the primary source of each mechanism differs depending on where people are operating within the problem space. In the zone of deliberate problem solving, people perceive a high level of problem constraint coupled with a low level of resource constraint. Intrinsic motivation is facilitated by an autonomy orientation, and therefore people will derive most of their intrinsic motivation from being able to choose resources for generating ideas and choosing solutions to a problem. By contrast, cognitive flexibility is facilitated by being pushed off the path of least resistance, and therefore people will derive most of their cognitive flexibility by working on a highly constrained problem that is difficult to solve. This explains why people can be highly creative when resources are internally constrained and the problem is externally constrained—such as in the autonomous vehicle example.

In the zone of emergent problem solving, people perceive opposite conditions, and therefore derive intrinsic motivation and cognitive flexibility from opposite sources. A low level of problem constraint gives people a high degree of choice over the problem they are trying to solve, which becomes the primary source for intrinsic motivation; and a high level of resource constraint forces people to develop solutions to problems with a small set of resources, which becomes the primary source for cognitive flexibility. This explains why people can also be highly creative when resources are externally constrained and the problem is internally constrained—such as in the archaeology example.

Maintaining a balance of constraint can help people sustain high levels of creativity as they transition between different types of creativity. When starting from the zone of deliberate problem solving, there are two ways in which changing constraints can threaten to undermine creativity. The first is when the perceived level of resource constraint is increased, which reduces intrinsic motivation by shifting an individual's causality orientation from an autonomy orientation to an impersonal orientation; and reduces cognitive flexibility by creating boundaries that prevent people from using relevant resources to solve the problem at hand. To counteract these forces, problem constraint can be decreased, allowing people to apply existing resources to new problems, thereby preventing them from feeling an impersonal orientation and helping them avoid the boundaries that limit cognitive flexibility. This process can continue in an incremental fashion until eventually people are operating in the zone of emergent problem solving.

During this transition, the boundary between the zone of creativity and dead zone of futile effort is defined based on the problem solver's belief that they have enough resources to develop a solution to a problem. At the extreme end of deliberate problem solving, people are working on a challenging problem and therefore need many resources to believe that they can develop a solution to the problem. At some point—represented by the tip of the zone of creativity—the problem becomes so challenging that it seems impossible to solve, regardless of how many resources are available. At the extreme end of emergent problem solving, people are working with a small set of resources, but believe that they can generate at least one idea that can solve a problem in some domain—once it is discovered. But at some point—represented by the other tip of the zone of creativity—resources become so deficient that people will believe they cannot generate even a single idea that can solve a problem in any domain.

Second, decreasing the perceived level of problem constraint can also threaten creativity. It can reduce intrinsic motivation by giving people the opportunity to solve multiple problems, which may create choice anxiety if the problem solver does not have clear preferences for solving one problem over another. It can also reduce cognitive flexibility by allowing people to choose an easier problem to solve. To counteract these forces, resource constraint can be increased, which reduces the number of ideas that can be generated. This can make it easier to evaluate the potential value of solving each problem, helping people eliminate problems from consideration, and makes it more difficult to generate potential solutions to problems, which prevents people from following the path of least resistance. This process can also continue incrementally until people are operating in the zone of emergent problem solving.

During this transition, the boundary between the zone of creativity and dead zone of ambiguous opportunity is defined based on the level of anxiety that people experience when evaluating potential solutions to a problem. When people are operating near the zone of deliberate problem solving, there will be more potential solutions to evaluate than problems, and anxiety comes from trying to eliminate potential solutions from consideration for each problem. When operating near the zone of emergent problem solving, there will be more problems to consider than ideas that can be generated, and anxiety comes from trying to eliminate problems from consideration for a given set of resources.

When transitioning from emergent problem solving to deliberate problem solving, people can sustain creativity by adjusting constraints in the opposite directions. This can be done by (a) increasing problem constraint and subsequently decreasing resource constraint to prevent people from drifting into the zone of futile effort; or (b) decreasing resource constraint and subsequently increasing problem constraint to prevent people from drifting into the zone of ambiguous opportunity. Altogether, generalizing from these paths, I propose that whenever people are operating within the zone of creativity, high levels of creativity can be sustained by maintaining an overall balance of constraint, such that an increase in the perceived level of one type of constraint is accompanied by a similar decrease in the perceived level of the other type of constraint, and vice versa. These paths are reflected by the curved lines in Figure 1.2 labeled P5.

Unlike previous sections, I do not propose moderating effects for external constraint, because they are likely to differ depending on where people are operating within the zone of creativity.

Proposition 5: When people are working within the zone of creativity, high levels of creativity can be sustained by maintaining an overall balance of constraint, such that an increase in the perceived level of resource constraint is accompanied by a similar decrease in the perceived level of problem constraint, and vice versa. This balance only needs to be maintained if changing the perceived level of resource or problem constraint takes individuals outside the zone of creativity.

When people fail to maintain an overall balance of constraint, such that decreasing or increasing constraint takes individuals outside the zone of creativity, they will suffer from lower levels of intrinsic motivation and cognitive flexibility. However, the direction in which people move across the perceived problem space changes the reasons why they experience low intrinsic motivation and cognitive flexibility at different points in time. When starting in the dead zone of ambiguous opportunity, intrinsic motivation is low because of choice anxiety, and cognitive flexibility is low because of the path of least resistance; when moving into the dead zone of futile effort, intrinsic motivation becomes low because of a lack of choice, and cognitive flexibility becomes low because people are bounded to using a particular set of resources that are irrelevant to solving a particular set of problems. By contrast, when beginning in the zone of futile effort and ending in the zone of ambiguous opportunity, people experience low intrinsic motivation—first because of insufficient choice and then because of excessive choice; and they experience low cognitive flexibility—first because they are bounded to a particular set of resources and problems and then because they are unbounded.

It is likely that moving across the problem space in different directions results in qualitatively different experiences for individuals during the problem-solving process, which may have different effects on creativity over time. There are also likely to be nuances in the way that problem constraints, resource constraints, and external constraints work together to influence creativity throughout this process. However, theorizing about these dynamics can be done more comprehensively in a separate paper or through empirical research. For now, I end with a general proposition that any constraint can have a curvilinear effect on creativity if it moves people from one dead zone of creativity to the active zone of creativity, and then to the other dead zone of creativity. These possibilities are shown in Figure 1.2 with the lines labeled P6.

Proposition 6: Increasing or decreasing any constraint (resource constraints, problem constraints, or external constraints) can have a curvilinear effect on creativity if it moves people from one dead zone of creativity to the active zone of creativity, and then to the other dead zone of creativity.

1.4 Discussion and Conclusion

This paper presents a theory that aims to change the way that scholars think about and study creativity and innovation in organizations. The dominant paradigm in organizational creativity research is based on a model in which people work on a well-defined problem and adopt a variety of creative behaviors so that they can produce novel and useful solutions to the problem (Amabile, 1983; Amabile & Pratt, 2016; Mumford et al., 1991; Wallas, 1926). This approach benefits greatly from factors such as access to broad knowledge (e.g., Hargadon & Sutton, 1997; Taylor & Greve, 2006), broad networks (e.g., Fleming et al., 2007; Perry-Smith &

Shalley, 2003), and broad cultural perspectives (e.g., Chua, Roth, & Lemoine, 2014; Jang, 2017). A key theme underlying this research is that people are more creative when they have access to broader resources, because it gives them a greater capacity to engage in divergent thinking and produce more distant and unique combinations of ideas.

However, a number of scholars have proposed alternative models that challenge some of the underlying assumptions of this paradigm. Most notably, Unsworth (2001) points out that this model takes for granted the fact that problems are constrained at the beginning of the creative process, and that there are many types of creativity that exist in organizations that creativity research has largely overlooked (e.g., Getzels & Csikszentmihalyi, 1976). To address this gap, she develops a typology of creativity that is based on the degree to which (a) people are driven to engage in the creative process by internal or external forces, and (b) problems are open or closed. However, there are two issues with this typology that—once addressed—provide opportunities for me to make theoretical contributions to the creativity literature.

First, while this typology accounts for the degree to which problems are constrained during the creative process, it fails to account for the degree to which resources are constrained, raising questions about the dimension of “driver for engagement.” Unsworth claims that internal engagement is based on the extent to which people determine their own behaviors during the creative process (Deci & Ryan, 1987), and thus associates internal engagement with the process of choosing to develop solutions to a problem. However, this conflates driver for engagement with developing solutions, because theories of problem solving argue that the problem definition is the primary driver for creative behavior when developing solutions (Mumford et al., 1991; Newell & Simon, 1972). Therefore, the process of choosing the problem itself should have an equally strong effect on internal engagement as the process of choosing solutions. Consequently, my first contribution is that I further unpack creativity by introducing a third dimension (resource constraint), and I argue that people can be internally engaged in creativity either when they choose the problem that is being solved or when they choose the solution to a given problem.

Second, Unsworth was concerned "primarily with *types* of creativity rather than levels" (p. 2001, emphasis added), and thus did not seek to explain why different types of creativity are associated with different outcomes. As a consequence, she only considers the role that intrinsic motivation plays in affecting creativity, and concludes that a majority of creativity research is based on situations in which people are likely to be least creative—when they are *externally* engaged to solve *closed* problems (e.g., Amabile et al., 1996). She also suggests that the field should develop a more thorough understanding of creativity under the opposite conditions—in which people are *internally* engaged to solve *open* problems—because it may be more conducive to creativity and can reveal new insights that may help scholars develop a more "universal theory" of creativity.

However, her argument is inconsistent with research showing that people can indeed be intrinsically motivated when working on closed problems (e.g., Amabile, Hill, Hennessey, & Tighe, 1994; Liu et al., 2016). And when considering research that does investigate situations in which people are more internally engaged to solve open problems (e.g., Finke, 1990; Goldenberg et al., 1999; Moreau & Dahl, 2005; Rietzschel et al., 2014a), we learn that people are actually less creative under these conditions because they suffer from low levels of cognitive flexibility (Finke et al., 1992; Ward, 1994). Consequently, when accounting for the effects of both intrinsic motivation and cognitive flexibility on creativity, the typology proposed by Unsworth is limited because it cannot meaningfully explain differences in creative outcomes. Therefore, my second contribution is that I synthesize a broader range of theoretical and empirical work to develop a typology that explains *when* people are likely to be more or less creative, and I identify mechanisms that explain *why* people are more or less creative under these various conditions.

The creative cognition scholars have also proposed an alternative model—the "Geneplore" model of creativity (Finke et al., 1992)—that challenges some of the assumptions of the dominant paradigm. Geneplore is a word that reflects a cognitive process in which people *first* generate an idea and *then* explore how the idea can solve problems in a particular domain. According to this model, people arrive at creative solutions to problems by discovering the problem and solution together—in an emergent fashion—as described earlier. Other scholars have described a similar process in which people discover "need-solution pairs" without formulating a problem (von Hippel & von Krogh, 2016). This approach stands in stark contrast to the dominant paradigm of creativity, which is built on a cognitive model in which people *first* define the problem and *then* generate ideas in an attempt to solve the problem (Mumford et al., 1991; Newell, Shaw, & Simon, 1962; Wallas, 1926). In chapter two of this dissertation, I more deeply explore how these two models yield different *creative processes* (Cromwell, Amabile, & Harvey, in press), but in this paper, I develop theory that explains how they yield similar effects on *creative outcomes*.

I do this by considering how different confluences of constraint work together to influence the psychological mechanisms of intrinsic motivation and cognitive flexibility, which goes beyond prior research in several ways. In the original description of the Geneplore model, Finke and colleagues (1992) argue that constraints are fundamental to shaping the process of generating and exploring ideas, but they do not recognize that different types of constraints can have different effects on each part of the process. Since then, some scholars have identified a fundamental difference between resource constraints and problems constraints (e.g., Rosso, 2014), and others have explored how both of these constraints can affect creativity (e.g., Caniëls & Rietzschel, 2015; Chua & Iyengar, 2008; Finke, 1990; Moreau & Dahl, 2005). However, most of these studies theorize how constraints affect only one psychological mechanism of creativity—either intrinsic motivation or cognitive flexibility—and none theorize how external constraints can be combined with resource and problem constraints to influence creativity.

Therefore, my final contribution is that I draw upon a broad range of theoretical and empirical research to develop a coherent theory that explains how three different dimensions of constraint work together to structure the perceived problem space for creativity, which in turn influences both intrinsic motivation and cognitive flexibility to affect levels of creativity. This provides a clearer picture on the different ways that people can engage in creativity in organizational settings, as it integrates fundamentally different models of creativity into a single model (Amabile, 1983; Finke et al., 1992). By doing so, I identify the conditions in which one type of creativity arises over another, and I explain why each model can be equally powerful in producing highly creative outcomes. Furthermore, I specify a variety of ways in which people can manipulate constraints—including managers and problem solvers—to enhance creativity, which offers both theoretical and practical guidance to those who are interested in understanding and facilitating creativity in organizations. Altogether, this model provides a foundation for future research to build upon regarding the factors that predict more creative outcomes.

1.4.1 Opportunities for Future Research

There are a variety of ways in which scholars can build upon this model, but I believe that the most promising avenue for future research will come from combining this theory with yet another model that challenges one of the underlying assumptions of the dominant paradigm—the dual pathway to creativity model (De Dreu, Baas, & Nijstad, 2008; Nijstad, De Dreu, Rietzschel, & Baas, 2010). According to this model, people can achieve creative insights by following two distinct cognitive pathways: either a “flexibility pathway,” in which they flexibly switch between broad categories or perspectives to make distant combinations of ideas (e.g., Amabile, 1983); or a "persistence pathway," in which they engage in systematic and in-depth exploration of ideas within narrow categories or perspectives (e.g., Ward, 1994). Similar distinctions have been made by other scholars, for instance, by showing that people can be creative either through "broad search" or "local search" (Kaplan & Vakili, 2015; Taylor & Greve, 2006).

Upon immediate inspection, it seems that the dual pathway to creativity model is in direct conflict with the present theory, because I argue that people who are working on a more constrained problem (i.e., are pursuing the persistence pathway) are actually using the flexibility pathway to develop solutions because they are being pushed off the path of least resistance. However, upon deeper examination, I propose that the two models are not inconsistent with each other, and that they can be integrated together to yield new insights that advance each perspective.

Most importantly, my model suggests that flexibility and persistence can vary along two dimensions—for both resources and problems—so that people can follow both pathways simultaneously. For instance, it is possible for people to persistently work on a highly constrained problem while also flexibly searching across broad knowledge resources when generating ideas to solve the problem. Alternatively, it is also possible for people to persistently work with constrained resources while also flexibly searching across numerous problem domains to discover problems that could be solved with those resources. Further understanding how flexibility and persistence operate in harmony with each other—rather than in competition—can unlock a rich stream of research that may fundamentally alter our views on the underlying dichotomies of creativity and innovation. For example, rather than differentiating between flexibility and persistence (or broad search versus local search), my theory suggests that a more fruitful line of research may come from understanding the differences between deliberate and emergent problem solving.

To this end, scholars can build upon the already impressive body of knowledge that Nijstad and colleagues have accumulated from developing the dual pathway to creativity model (see Nijstad et al., 2010 for a review). For example, they have investigated how numerous factors about individuals—such as personal need for structure (Rietzschel, Slijkhuis, & Van Yperen, 2014b), personal fear of invalidity (Rietzschel, De Dreu, & Nijstad, 2007), and positive or negative moods (De Dreu et al., 2008)—can moderate the effects of flexibility or persistence on creativity. However, most of these studies have been conducted under conditions that reflect the zone of deliberate problem solving, in which subjects are asked to solve problems within a single problem domain. Thus, several new insights could be discovered by conducting experiments that reflect the zone of emergent problem solving, in which subjects are allowed to address problems across numerous problem domains. This research could be further elaborated by varying the level of problem constraint in combination with the level of resource constraint. Understanding these dynamics could help us develop a sort of topographic map for the zone of creativity, which may have peaks and valleys that vary according to the characteristics, personalities, thinking styles, or moods of individuals who are engaged in the problem-solving process.

Another option would be to elaborate upon my model by continuing to investigate the relationship between creativity and constraint. For example, I propose that constraints can have a curvilinear effect on creativity because of curvilinear effects on both intrinsic motivation and cognitive flexibility, but other scholars have proposed that these effects come from a curvilinear effect on activation levels (Baer & Oldham, 2006; Byron et al., 2010). This raises an important question about the mechanisms that explain the effects of constraints on creativity. When considering the fact that prior research on creativity and constraint has not actually measured activation levels (e.g., Gardner, 1990), an opportunity arises to make a significant contribution by disentangling these effects and revising existing theory. This could be done by manipulating constraints and subsequently measuring each mechanism to determine the extent to which each mechanism mediates the relationship between constraint and creativity.

It also raises the question of whether different types of constraint influence creativity through different mechanisms. For example, Byron and colleagues (2010) differentiate between "social evaluative threats," which come from people feeling like they can be negatively judged by others, and "uncontrollability," which comes from people believing that their behaviors will not affect their outcomes. Note that in the context of my theory, social evaluative threats come from high external constraints, and uncontrollability comes from operating in the zone of futile effort, which comes from a combination of high resource and problem constraints. They find that social evaluative threats have a curvilinear effect on creativity, which they argue shows evidence for a curvilinear effect on activation levels, and uncontrollability has a negative effect on creativity, which they argue shows evidence for a negative effect on intrinsic motivation. I suggest that these results also show evidence for my theory, and they raise an important question about the generalizability of my propositions. In chapter two of this dissertation, I develop a detailed taxonomy for the wide variety of constraints that occur in organizations (Cromwell et al., in press), and future research could draw from this taxonomy to more deeply explore how different constraints might influence creative outcomes through different mechanisms.

1.4.2 Conclusion

Organizations rely on people to produce new products, processes, services, or ideas in order to gain a competitive advantage against rivals and to flourish, but creativity is a challenging endeavor because people must work within a complex confluence of constraints that are constantly in flux. Prior research has described various ways by which people can navigate through these complex environments to deliver highly creative outcomes. However, many of these approaches provide contradicting views on various aspects of the creative process, particularly with regards to constraint. This paper reconciles these contradictions by integrating these approaches into a single model—a problem-space theory of creativity and constraint—revealing that people are most creative when they experience a balance between different types of constraint. This model introduces a new typology of creativity that explains when and why people are likely to be highly creative or uncreative, laying the foundation for a new stream of research that can further our understanding of creativity and innovation in organizations.

CHAPTER 2

An Integrated Model of Dynamic Problem Solving within Organizational Constraints

Johnathan R. Cromwell, Teresa M. Amabile, and Jean-François Harvey

Abstract

Prior theory on creativity argues that people can be highly creative when they begin with a well-defined problem and then engage in a range of creative activities as they develop novel and useful solutions to the problem. However, there is a growing body of research supporting an alternative model to creativity, in which people can also be highly creative by first generating ideas without a clear problem in mind, and then evaluating those ideas across numerous problem domains in an effort to discover a problem that can be solved by the ideas. In this paper, we resolve the apparent contradiction between these problem-first and idea-first models of the creative process by examining the role that constraints play in shaping the creative process. We begin by developing a typology of constraints that differentiates between two types of constraint and two sources of constraint. Then, we integrate the two disparate models of the creative process into a new dynamic problem-solving model. Finally, we show how particular confluences of constraint systematically shape the activities that people engage in during the dynamic problem-solving process, thereby facilitating two effective modes of problem solving, which we call *deliberate problem solving* and *emergent problem solving*.

2.1 Introduction

The journey that people take to produce creative ideas is often a winding path that involves several twists, turns, detours, and reversals of direction. At many points throughout the process, people are confronted with questions of whether they should keep investing resources into an existing idea, start searching for a new idea, or change the problem they're working on altogether. The result is that creative projects often take seemingly unique paths to success, making it difficult to predict the circumstances of creative success. Consider, for example, the creation of the commercial light bulb and the Nintendo Wii, two technological inventions that took quite different paths to development.

In 1878, more than 75 years after the electric light bulb was invented, Thomas Edison began a research program with the goal of developing a commercially viable light bulb, which needed to satisfy the criteria of being long-lasting, cheap to produce, and energy efficient (Israel, 1998). Throughout the course of development, Edison and his team conducted thousands of experiments using different combinations of designs and materials. After more than a year of experimentation, in October 1879, they developed a viable solution that went on to revolutionize the energy industry. By contrast, the Nintendo Wii was created in 2006 based on a technology that was developed nearly 30 years earlier by people working in a completely different industry (Verganti, 2009). In the late 1970's, a company called STMicroelectronics developed a new semiconductor that could detect three-dimensional movement. After creating the technology, engineers searched for commercial applications across a broad range of industries, but found limited success with applications in computers, home appliances, and automobiles. It was not until 2005, after meeting with game developers at Nintendo, that they learned how their technology could be used to create a highly novel gaming experience. Shortly thereafter, the Nintendo Wii debuted on the market and went on to transform the gaming industry.

Both of these stories illustrate creative invention, but they differ in two important ways. First, the creative process seemed to take two different paths to success. In the case of the light bulb, Edison and his team began with a well-defined problem and then searched broadly for materials and technology that could solve the problem, generating thousands of different idea combinations until they finally developed a viable solution. This creative process resembles the "problem-solving" model of creativity that is commonly described in the organizational creativity literature. According to this model, an inventor first finds, defines, or formulates a problem (e.g., Getzels & Csikszentmihalyi, 1976; Mumford, Reiter-Palmon, & Redmond, 1994), and then engages in a dynamic process of gathering information, generating ideas, elaborating ideas, evaluating ideas, and selecting ideas until a solution has been created (Amabile, 1983; Amabile & Pratt, 2016; Mumford et al., 1991).

In the case of the Nintendo Wii, however, engineers started with a well-defined technology and then searched broadly for commercial applications across different industries, eventually discovering a problem in the gaming industry that could be solved with their technology. This process resembles the "Geneplore" model of creativity (Finke et al., 1992), in which an inventor first generates a potentially useful idea—what is known as a "preinventive structure"—and then explores how it may solve problems across a wide variety of problem domains until a problem and solution emerge together. While the problem-solving model begins with the definition of a problem and is followed by a search for solutions, the Geneplore model begins with the creation of a preinventive idea and is followed by a search for problems. At first blush, these *problem-first* and *idea-first* models seem to describe entirely different creative processes.

The second way in which these two examples differ is that the conditions of constraint for each group of inventors appear to have been quite different. Edison and his team were heavily constrained by the problem they were trying to solve, but they had great flexibility when searching for a solution to that problem. The semiconductor engineers, on the other hand, were heavily constrained by the technology they were working with, but had great flexibility when searching for a problem that could be solved with that particular preinventive idea.

In each case, inventors experienced a different confluence of constraints and engaged in a different creative process. We argue that this is no mere coincidence. Indeed, these examples suggest that constraints might systematically influence the creative process—an idea that has received little attention in the creativity literature (see Caniëls & Rietzschel, 2015 for a review). While prior literature has developed extensive theory on how constraints can influence *creative outcomes* (e.g., Amabile et al., 1996; Baer & Oldham, 2006; Byron et al., 2010; Finke et al., 1992; Hunter et al., 2007), it has developed little theory on how they might shape the *creative process*.

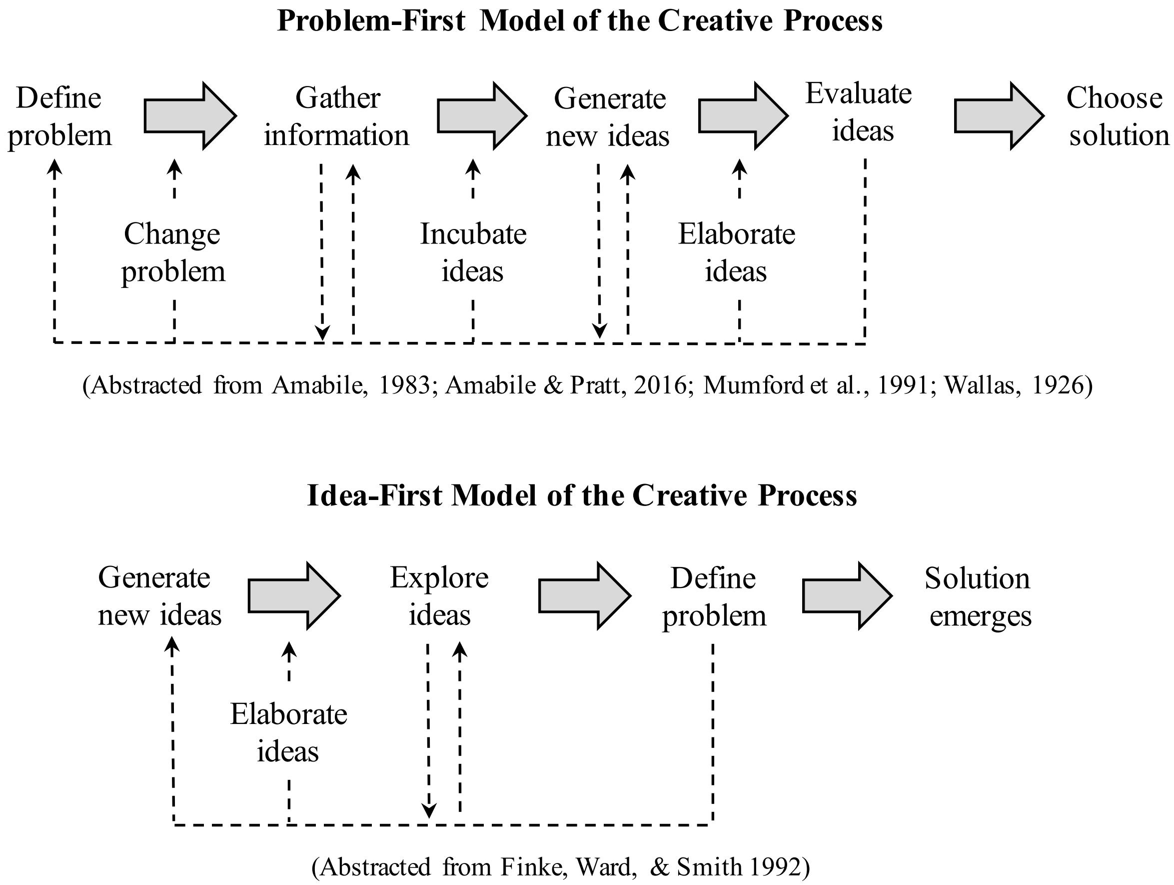
Taken as a whole, prior literature presents two competing models of the creative process, each of which is compelling. But it is unclear when and why people are likely to engage in one process over the other. In this paper, we address this puzzle by first reviewing the theoretical foundations of each model, showing that they originate from the same underlying cognitive framework of problem solving. However, we find that a clear differentiator between the two models is based on the level and type of constraint that people face at different times during the creative process. We use this observation—that constraints can shape the creative process—as the underlying premise for our own model, and we expand upon these arguments to account for more recent findings on creativity and constraint.

We build our model by first developing a typology of constraints that is based on two fundamental dimensions of constraint—types of constraint (*resource constraints* versus *problem constraints*) and sources of constraint (*internal constraints* versus *external constraints*). We then synthesize the problem-first and idea-first models of the creative process into a new *dynamic problem-solving* model. The result is an integrated model in which different creative processes unfold depending on the confluence of constraints that people face on a creative project. The model is dynamic, in that it allows for dynamic iteration between these two models, so that as constraints shift over time, inventors may shift from one creative process to the other.

2.2 The Creative Process: Two Paths or One?

Creativity in organizations is the creation of novel and useful (or appropriate) products, processes, services, or ideas (Amabile, 1983, 1988; Oldham & Cummings, 1996; Shalley & Zhou, 2008; Woodman, Sawyer, & Griffin, 1993). To produce these outcomes, people engage in a messy and unpredictable process that includes a wide range of activities such as defining problems, generating ideas, and evaluating ideas against criteria—amongst others. While many of these activities are often necessary for creativity, the order and sequence by which they produce creative outcomes can vary widely. Scholars have broadly codified these activities into one of two general models, which we refer to as the *problem-first* and *idea-first* models of the creative process. We summarize these models in Figure 2.1, showing how each model theorizes the set of activities and sequence of activities that characterize the creative process.

A majority of organizational creativity research has adopted the problem-first model of the creative process (Amabile, 1983, 1988; Amabile & Pratt, 2016; Mumford et al., 1991; Wallas, 1926). According to this model, organizational creativity begins when a problem is defined, which is often considered the most important step of the process. As Einstein described it, “The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in



Notes: Dotted lines refer to feedback loops in which individuals can return to earlier activities of the creative process. According to the theorists cited, the activities in each creative process need not occur in the exact sequence shown.

Figure 2.1: Summary of Two General Models of the Creative Process

science" (Einstein & Infeld, 1938). In organizations, problems are usually defined when a higher-level manager presents a problem to an employee, but it can also occur when employees define their own problem to solve (Getzels & Csikszentmihalyi, 1976; Unsworth, 2001). Once a problem has been defined, people engage in a sequence of activities—such as gathering information, generating ideas, and evaluating ideas against criteria—until a viable solution has been reached. Gathering information involves the collection of data and materials that will help individuals solve a problem. Generating ideas involves drawing on resources to develop a set of ideas that can potentially solve the problem. And evaluating ideas involves taking a subset of promising ideas and evaluating them against the problem criteria.

When an idea satisfies all the criteria, it becomes a viable solution to the problem and can be selected for implementation, thereby ending the creative process. But if an idea fails to satisfy all the criteria, people must revert back to earlier stages of the process. For instance, they may need to generate a new set of ideas or elaborate upon existing ideas (Perry-Smith & Mannucci, 2017). They may need to gather additional information about the problem, or they can set the problem aside and not consciously work on it for a time—a process known as incubation that can sometimes result in a breakthrough idea (Guilford, 1950; Kounios & Beeman, 2015; Wallas, 1926). They may also need to change the problem they are working on by applying existing resources to new problems (e.g., Baker & Nelson, 2005; Sonenshein, 2014). In most versions of the problem-first model (e.g., Amabile & Pratt, 2016), people can return to an earlier point from any later point in the process, resulting in a cyclical process until (ideally) a viable solution is created that satisfies all the problem criteria.

By contrast, a growing body of literature draws from an idea-first model of the creative process (Finke et al., 1992). According to this model, the creative process begins when people generate a new idea that has the potential to be useful, but the problem has not yet been defined. These ideas are called "preinventive structures" because they do not reflect fully formed solutions, but rather, reflect ideas that are precursors to solutions that will eventually emerge from the creative process. For example, the STM engineers began their creative process by developing a semiconductor that could detect movement in three-dimensional space. While this initial technology represented a potentially useful idea, they did not know specifically what problems could be solved with it (Verganti, 2009), and thus, it was only a preinventive idea.

Once a preinventive idea has been created, people can explore whether it can solve a specific problem within a problem domain. If a problem cannot be defined, then people must return to an earlier activity in the process, either generating a new preinventive idea, elaborating an idea that they already generated, or exploring their idea in the context of a different problem domain. If a problem can be defined, a viable solution emerges to become a creative outcome. For example, the STM engineers explored whether their new semiconductor could solve a problem within a broad range of industries, but they struggled to develop creative solutions in many of them. Once they came across the gaming industry, however, they discovered a specific problem that could be solved with their technology, and a solution emerged in the form of a new videogame system.

2.2.1 Theoretical Origins of the Problem-First and Idea-First Models of the Creative Process

An initial comparison of these two models suggests that they reflect entirely different creative processes. However, both models are actually built on a cognitive framework of problem solving (Newell et al., 1962; Newell & Simon, 1972), and they differ in their assumptions about individuals who are engaged in this problem-solving process. According to the cognitive framework, problem solving occurs within a problem space, which consists of (a) an initial state, (b) a desired goal state, and (c) all intermediate states in between. The process begins when an individual reads a problem statement, which triggers a variety of memories, concepts, or other cognitive elements that are relevant to the problem at hand. Then, drawing from these cognitive elements, the individual generates ideas that could solve the problem. For example, imagine a movie producer who is presented with the problem of creating her tenth film. When presented with this problem, she will draw on all her prior expertise and knowledge from developing her previous nine films (as well as her formal and informal training), which could then be applied to developing her tenth film.

After generating a potential pool of ideas, the individual evaluates these ideas against the criteria of the goal state. If an idea satisfies all the criteria, it is considered a viable solution to the problem and the process can end. But if it fails to satisfy the criteria, the individual must revert back to earlier stages of the process. She can generate new ideas based on cognitive elements she already possesses, or gather new information from the environment to build a larger base of cognitive elements to use for generating ideas. The particular set of ideas and the sequence in which they are produced define the intermediate states of the problem space.

A key feature of this process is that problems exist along a continuum, ranging from being "well-structured," in which all three parts of the problem space are well known, to being "ill-structured," in which at least one part of the problem space is unknown (Reitman, 1965; Simon, 1973). When a problem is well-structured, it can be solved algorithmically: That is, an individual can apply her existing knowledge to the new problem, and problem solving will be fairly linear. For example, a movie producer who has extensive experience creating *Spider-Man* movies will be able to develop much of a new *Spider-Man* movie by relying on her existing knowledge. Although audience tastes may change and resources or equipment can evolve, developing the film will follow a fairly linear and predictable sequence of steps.

Problems become ill-structured when aspects of the problem space are unknown. The simplest form of ill-structured problems occurs when the goal state is known and the initial state and intermediate states are unknown. Under these conditions, a problem must be solved heuristically: That is, an individual must use their intuition to develop ideas that might solve the problem, but there is more uncertainty because they are operating with incomplete information. For example, if the movie producer who specializes in *Spider-Man* movies tries to develop a movie for a different superhero—such as Superman—much of her knowledge might still be relevant, but she may need to spend more time gathering new information, elaborating ideas, and evaluating ideas against criteria throughout the process. If she were creating a film in an entirely different genre—such as a comedy—she would need to spend even more time engaging in these activities, resulting in an even more cyclical creative process. Generally speaking, the degree to which problems are ill-structured determines the degree to which the creative process is cyclical.

The most complex form of ill-structured problems occurs when all three aspects of the problem space are unknown, including the initial state, intermediate states, and final goal state. These problems have been described as "open problems," whereas situations in which the goal state is known are called "closed problems" (Unsworth, 2001). When problems are open, problem statements are vague and poorly defined, and they fail to trigger specific cognitive elements that can be used to solve the problem at hand. For example, a movie producer may be given the problem statement, "develop a new breakthrough movie," but this can be so vague—even for an experienced movie producer—that it does not trigger any specific cognitive elements that can be used to produce a viable solution. This was the situation that movie producers at Pixar found themselves in when they were developing the world's first feature-length computer-generated film in the late 1990s (Catmull, 2014). Aided with new computer technology that gave them the ability to create any plotline, character, or setting they could imagine, they experienced extreme levels of ambiguity and struggled to develop ideas that could solve their problem. It was not until they focused their efforts on developing a compelling storyline that their idea for *Toy Story* began to take shape.

It is under these open-problem conditions that the two models of the creative process begin to diverge. According to problem-solving scholars, people can approach open problems by engaging in a multi-tiered version of the problem-first model (Simon, 1973). First, they read the vague problem statement, which triggers several vague cognitive elements that are relevant to the problem. For example, the movie producer who is asked to "develop a new breakthrough movie" will think of several vague cognitive elements such as “genre, plotline, cast, characters, and breakthrough movies.” Each of these vague cognitive elements then becomes a new sub-problem to solve, which triggers a new set of cognitive elements. For example, addressing the “genre” sub-problem might trigger cognitive elements such as “action, adventure, comedy, etc.,” which in turn could trigger a new set of cognitive elements that become new sub-problems. With each tier of the process, problem statements and cognitive elements become more specific; eventually, the open problem is adapted into a network of smaller, more specific, and closed sub-problems.

An important consequence of this process is that the various sub-problems become interdependent, meaning that solving one sub-problem changes the problem space for other sub-problems. For example, the movie producer may develop a solution to the “character” sub-problem, which in turn may change the initial state of the “genre” sub-problem; and developing a solution to the “genre” sub-problem may change the initial state of the “plotline” sub-problem—and so on. Each time the problem space for one sub-problem changes as a result of progress made on other sub-problems, the problem solver has to re-assess whether the goal-states across all sub-problems are aligned. If there is any misalignment, she must modify some of the goal-states of the sub-problems. Therefore, when people are working on open problems, a new activity emerges that does not exist for closed problems: They must constantly re-define problems during the problem-solving process. Eventually, open problems become closed problems, and people can then adopt the problem-first model to developing solutions.

By contrast, the idea-first model proposes an alternative set of activities when working on open problems (Finke et al., 1992). Rather than adapting open problems into a network of smaller, closed sub-problems, the opposite can be done—that is, the problem statement can be removed altogether, allowing people to generate ideas in the absence of thinking about a specific problem at all. To demonstrate this point, Finke (1990) conducted an experiment in which subjects were given a subset of three out of 15 materials (e.g., hook, ball, and spring, etc.) to develop inventions in one out of eight problem domains (e.g., furniture, toys, or appliances, etc.). In the first condition, subjects received both the materials and problem domain at the beginning of the task, and they were given two minutes to develop an idea for an invention. In the second condition, subjects received the materials at the beginning of the task, and they were given one minute to generate a "potentially useful" idea; then, they received the problem domain and were given an additional minute to explore their ideas within that problem domain. Results showed that subjects in the second condition produced more creative ideas than those in the first condition, revealing that people can be highly creative when they first generate an idea and then explore that idea in the context of a problem domain.

2.2.2 Two Paths or One? The Role of Constraint

Finke and colleagues argue that while the problem-first model is a useful tool to understand the creative process for closed problems, it is ultimately limited, because in the real world, few meaningful problems are truly closed: "[Problem-solving] approaches detail specific processes, but they apply to highly restricted domains rather than to creative functioning in general. We believe that in order to understand the true nature of creativity, cognitive processes must be considered in a much broader perspective, where the *problems and solutions are not necessarily restricted or known*" (Finke et al., 1992, p.5; emphasis added). They go on to argue that the key difference between their framework and the problem-first model comes down to a difference in when constraint appears in the problem-solving process: "[Our] approach can complement the more usual [problem-solving] approach… whether one approach or the other should be used depends on how early in the creative process product constraints would need to be imposed" (Finke et al., 1992, p. 191). Therefore, according to these scholars, when constraints are applied early in the process, the problem-first model unfolds, and when constraints are applied late in the process, the idea-first model unfolds.

While we agree with this general notion, we also believe that these scholars have defined constraints too narrowly—as they focus on constraints related to the problem definition. When considering more recent research on creativity and constraint, a much broader range of constraints have been shown to influence the creative process. For instance, constraints on resources such as time, finances, materials, or knowledge can limit creativity by undermining a person's engagement in the creative process (e.g., Amabile et al., 1996; Byron et al., 2010; Hunter et al., 2007). Therefore, we believe the picture is more complex than what has been previously theorized.

In the following sections, we aim to develop a more complete theoretical model that presents a more complex view of constraint and encompasses both the problem-first and idea-first models of the creative process. First, we draw on research in organizational creativity to derive two dimensions of constraint that we use to build a typology of constraints that affect creative problem solving in organizational settings. Then, we synthesize the creative activities that make up the problem-first and idea-first models into a new model that we call the *dynamic problem-solving* process. Finally, building on Finke's assertion about the timing of constraint, we develop a set of propositions that describe when particular confluences of constraint influence the dynamic problem-solving process to result in different creative processes.

2.3 Dynamic Problem Solving Within Organizational Constraints

Prior researchers have defined constraint in one of two ways: as any element that influences problem solving (e.g., Finke et al., 1992; Reitman, 1965), or as any external factor that in some way limits—or could be perceived as limiting—the way that a problem solver completes a task (e.g., Amabile, 1979; Amabile & Gitomer, 1984; Deci & Ryan, 1985). To encompass these somewhat different views, we define constraint quite broadly as *any factor that places limits or boundaries on creative problem solving*. With this definition in mind, we derive two dimensions of constraint that we believe to be important in all problem-solving situations.

The first dimension is *type of constraint*, which is based on Rosso's finding that there are two fundamentally different types of constraint that influence the creative process (Rosso, 2014). First, he identified "process constraints," which include limitations on time, materials, finances, and equipment that restrict people's ability to engage in the creative process. Second, he identified "product constraints," which include product requirements, customer preferences, and organizational needs that structure the goals that people pursue during the creative process. He argued that while process constraints usually place detrimental limits on creative problem solving, product constraints can provide structure to problems that improve the creative process.

Viewing process constraints and product constraints through the lens of the cognitive framework on problem solving (Newell & Simon, 1972), we reason that these two types of constraint are related to different factors that structure the problem space. Process constraints place limits on the resources that people use when generating ideas as they navigate through the problem space; and product constraints establish how the problem is defined by the goal state. Therefore, we differentiate between *resource constraints* (what Rosso calls "process constraints") and *problem constraints* (what Rosso calls "product constraints") to reflect the qualitatively different effects that constraints can have on problem solving.

The second dimension of constraint is the *source of constraint* (Deci & Ryan, 1985; Ryan & Deci, 2000), which influences the degree to which people perceive themselves to be constrained during the problem-solving process. According to Deci and Ryan, an individual's autonomy is determined by the extent to which they feel like they have control over the factors that influence their behavior. When an individual feels like they have a high degree of self-determination of their own behavior, they perceive higher levels of autonomy; when they feel like external factors determine their behaviors, they perceive lower levels of autonomy.

In the context of creative problem solving, resource constraints and problem constraints determine the behaviors that people can engage in during the problem-solving process. Therefore, the degree to which people feel like they have control over the resources and problems that structure their problem space determines how constrained they feel during the creative process. For the sake of simplicity, we dichotomize this dimension, differentiating between internal constraints and external constraints, but we acknowledge that this dimension can be more accurately depicted as a bipolar continuum, such that constraints can range from being completely internally controlled to completely externally controlled (e.g., Ryan & Deci, 2000). *Internal constraints* refer to resource or problem constraints that are self-imposed on creative problem solving; *external constraints* refer to resource or problem constraints that are imposed by an external source—for instance, by a higher-level manager or supervisor.

2.3.1 Typology of Constraints

Together, these two dimensions of constraint form a typology of constraints that serves as the foundation of our model. In the typology, each dimension has two categories, creating four quadrants of constraint: (a) *internal resource constraints*; (b) *external resource constraints*; (c) *internal problem constraints*; and (d) *external problem constraints*. Before describing the specific list of constraints that occupy each quadrant in more detail, we note two caveats. First, we tried to include constraints that we believe to be relevant in organizational settings, but we recognize that our list may not be entirely exhaustive. We expect that the four quadrants of constraint will generalize across all problem-solving situations, but specific constraints may differ according to the particular setting. Second, we categorized constraints based on what we believe to be typical in most organizational settings—that is, when an individual employee is working on a creative project under a manager in an organization. However, we understand that constraints can also be categorized differently, depending on the situation.

Internal Resource Constraints. This quadrant includes resource constraints that are implicitly "imposed" on the creative process by the individual who is engaged in creative problem solving. These resources include the individual's *creativity skills*, which reflect the person's ability to combine ideas in novel ways, and *domain-relevant skills*, which include knowledge and technical expertise that is necessary for navigating the problem space and generating ideas (Amabile, 1983). People who have more diverse sets of knowledge and greater skills can represent a problem in multiple ways, giving them a greater capacity to generate ideas through conceptual combination and analogic thinking (Finke et al., 1992; Newell & Simon, 1972). Such knowledge and skills are also valuable for defining or formulating problems (Mumford et al., 1994; Runco, 1994), which can also result in more creative outcomes (Getzels & Csikszentmihalyi, 1976; Reiter-Palmon, Mumford, O'Connor Boes, & Runco, 1997). These resources are constrained based on the extent to which the individual lacks creativity and domain-relevant skills; therefore, it can be difficult and time-consuming for people to decrease these constraints over time. Although an individual can acquire new knowledge or learn how to think more creatively, each of these resources can take a long time to develop and may not be readily applied to solving an immediate problem.

External Resource Constraints. This quadrant includes resource constraints that are imposed on the creative process by external forces such as managers or supervisors. These constraints include limitations on resources such as *time*, *materials*, or *finances*, all of which help people generate ideas (e.g. Amabile et al., 1996; Baer & Oldham, 2006; Weiss, Hoegl, &

Gibbert, 2011). We also include a resource that we call *extrinsic knowledge*, which is different from domain-relevant knowledge in that it exists in the external world and can be acquired by the individual problem-solver through search activities (Fleming, 2001; Taylor & Greve, 2006). For example, designers at IDEO regularly solved problems by taking ideas from one industry and applying them as solutions to problems in another industry (Hargadon & Sutton, 1997). Similarly, individuals may communicate with people inside or outside their organization to search for ideas that can help them solve a problem they are working on (Hargadon & Bechky, 2006; Lingo & O'Mahony, 2010; Perry-Smith & Shalley, 2003).

Internal Problem Constraints. All creative problems are defined by at least two primary criteria: *novelty* and *usefulness* (or appropriateness) (Amabile, 1982, 1983; Shalley & Zhou, 2008; Woodman et al., 1993). Novelty is based on the extent to which an idea is original or different from previous ideas that solve a problem; and usefulness is based on the extent to which an idea provides some objective or useful value to a designated audience, which in organizational settings, is typically a customer. Prior research shows that managers have a fairly strong bias against novelty and a preference for usefulness (Berg, 2016; Ford & Gioia, 2000; Mueller, Melwani, & Goncalo, 2012; Rietzschel, Nijstad, & Stroebe, 2006, 2010). Therefore, we reason that in most organizational settings, novelty is determined primarily by an individual's desire to generate novel ideas (i.e., is an internal constraint), and usefulness is determined primarily by a manager's preferences or customer demands (i.e., is an external constraint). Other internal problem constraints include *domain-relevant goals*, which are goals that are motivated by an person's desire to have an impact in a particular domain of expertise, but may seem superfluous in the eyes of other stakeholders. For example, circus performers who are creating new performances may be motivated to create new acts that showcase their particular talent or skill (and thus, impress other circus professionals), but managers primarily care about how much a paying audience likes the act, and may therefore discount ideas that do not appeal to a mass audience (Berg, 2016).

External Problem Constraints. Finally, this quadrant includes constraints that place external limits or boundaries on the problem definition. In most organizational settings, problems are largely defined by other stakeholders such as managers, organizational leaders, teammates, customers, colleagues, or collaborators from other organizations. These various *stakeholder demands* represent criteria that an individual must satisfy that are beyond the scope of the problem that they would otherwise try to meet. For example, an engineer who developed the world's first digital camera at Kodak created a product that was novel and potentially useful for customers, but failed to meet the criterion of aligning with the organization's strategy, which was imposed by senior managers, and therefore the product was rejected (Lucas & Goh, 2009). Similarly, a problem may be constrained by *broader contextual factors* such as an organization's culture, societal values, or institutional norms coming from the environment. For example, when Edison developed the commercial light bulb, he was constrained by customers' expectations about gas-lighting technology, so he artificially reduced the power of his light bulbs to conform to external institutional pressures (Hargadon & Douglas, 2001). Finally, there are other *situational factors* that are viewed as inherent to the task itself that may also constrain the problem. For example, during the *Apollo 13* space mission to the moon, an unexpected explosion damaged the air filtration system within the space capsule. NASA engineers in Houston were confronted with the problem of needing to change the oxygen-to-carbon dioxide ratio to a certain level within a certain period of time, or else the astronauts would die.

2.3.2 The Dynamic Problem-Solving Process

The four types of constraint described above are always operating on people as they engage in the creative process, but they are not always operating in equal strength. It is possible for people to experience high levels of one type of constraint and low levels of another type of constraint, which can influence the overall creative process differently. For instance, Edison and his colleagues were operating under low levels of internal and external resource constraint, as they had ample amounts of time, materials, finances, and expertise to use for experimentation; but they also had a high level of external problem constraint, because the specific criteria that had to be satisfied to develop a commercially viable light bulb were determined primarily by factors outside of their control—such as customer expectations about the technology and scientific limitations inherent in the problem itself. Alternatively, the STM engineers experienced a different confluence of constraints, in which they experienced high levels of external resource constraints—in the form of a restricted technology—and low levels of internal and external problem constraints.

We visually depict how various constraints relate to the creative process in Figure 2.2. The horizontal dimension of constraint depicts the two types of constraint, with the left half representing resource constraints and the right half representing problem constraints. The vertical dimension depicts the two sources of constraint, with the lower half representing internal constraints and the upper half representing external constraints. In the center of Figure 2.2 lies the *dynamic problem-solving* process, which synthesizes all the activities from the problem-first and idea-first models of the creative process into a more unified, comprehensive model. We call it "dynamic" specifically because it accounts for both prior models while also allowing for dynamic iteration between them.

Creative activities such as generating ideas, elaborating ideas, and incubating ideas are represented together on the left side of the figure, because they are all directly influenced by the level of resources available during the creative process. By contrast, activities such as defining problems, evaluating ideas, and changing problems are represented together on the right side of the figure, because they are all directly influenced by the problem constraints that people face during the process. Gathering information and exploring ideas are represented near the top of the

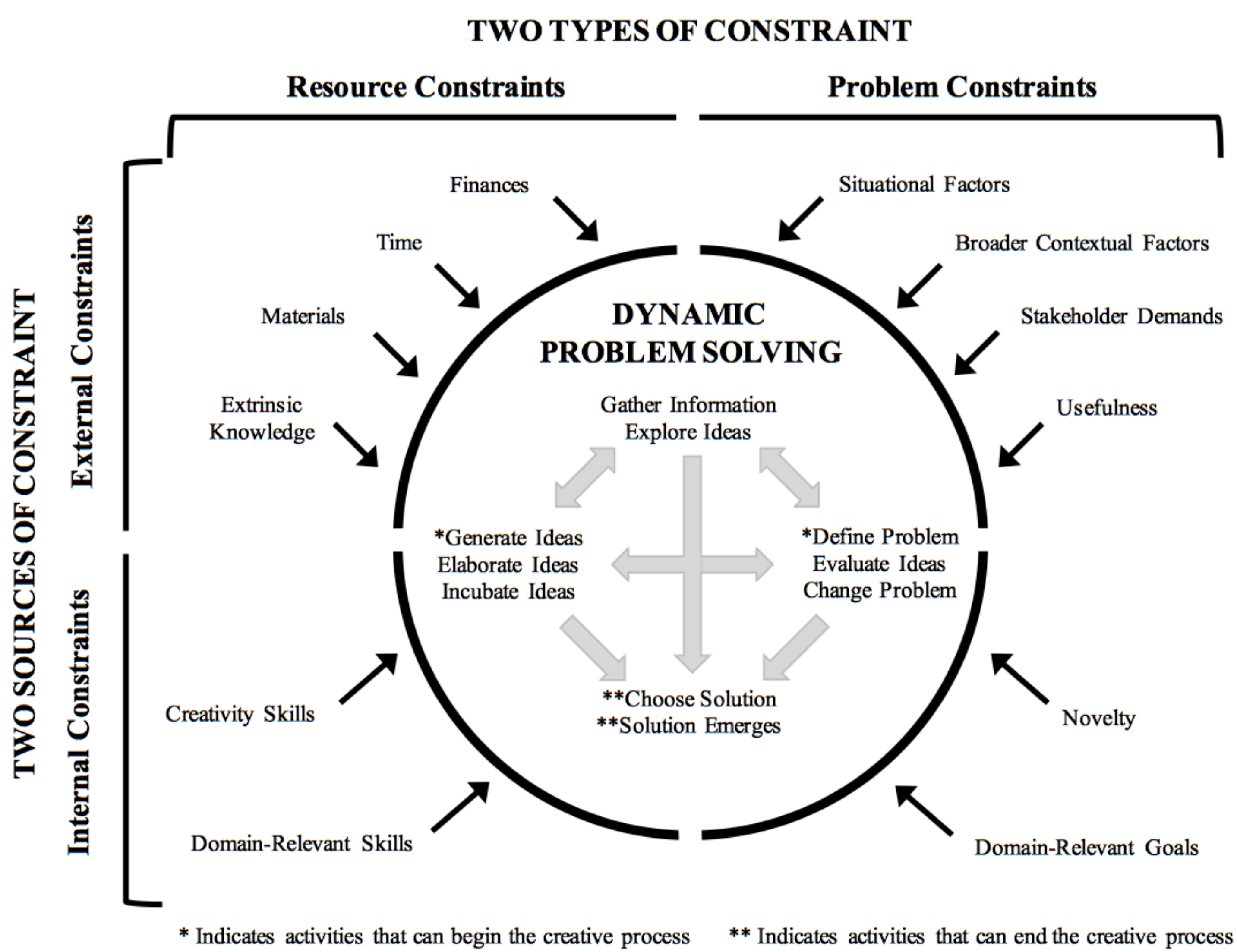


Figure 2.2: Typology of Constrain

figure because they are directly influenced by constraints that are external to the problem solver. Finally, the activities of choosing a solution or a solution emerging are represented near the bottom of the figure because they are directly influenced by constraints that are internal to the problem-solver.

One important difference between our model and prior models is that, rather than linking creative activities together through cyclical feedback loops, as shown in Figure 2.1, we connect different sets of activities with double-headed or single-headed arrows. This allows for a dynamic model that can account for both models that are depicted in Figure 2.1. On one hand, individuals can begin the dynamic process by defining the problem and then moving through an iterative process of gathering information, evaluating ideas against criteria, and elaborating ideas until a solution is chosen—as depicted by the problem-first model in Figure 2.1 (Amabile, 1983; Amabile & Pratt, 2016; Mumford et al., 1991). On the other hand, individuals can begin the dynamic process by generating new ideas and then exploring them in the context of different problem domains until a problem and solution emerge together—as depicted by the idea-first model in Figure 2.1 (Finke et al., 1992).

Our model also allows for alternative paths that involve a dynamic iteration between the problem-first and idea-first models. We believe that such flexibility is important to capture a broad range of creative processes that might occur in real organizational settings. For example, problem solvers may begin the creative process by trying to develop a solution to a well-defined problem, thereby following the problem-first model. But they may confront an obstacle that forces them to pivot their efforts to pursue a new problem (e.g., Baker & Nelson, 2005), at which point they may need to transition from a problem-first model to an idea-first model. Once they discover a new problem to solve, they can transition back to a problem-first model. Although there are many possible paths that individuals can take to produce creative outcomes, the dynamic problem-solving process begins either when people define a problem or generate ideas, and it ends either when people choose a viable solution to a problem or a solution emerges by discovering a problem that can be solved with a previously-created preinventive idea.

2.4 How Constraints Shape the Dynamic Problem-Solving Process

The degree to which constraints shape the problem-solving process is primarily a function of the *level* of each type of constraint. Prior research has focused on how levels of constraint influence creative outcomes, but it presents a confusing picture. For instance, research has shown that people can be more creative when they experience lower levels of resource constraint (e.g., Amabile et al., 1996; Hunter et al., 2007), higher levels of resource constraint (e.g., Hoegl et al., 2008; Moreau & Dahl, 2005), lower levels of problem constraint (e.g., Getzels & Csikszentmihalyi, 1976; Unsworth, 2001), and higher levels of problem constraint (e.g., Finke, 1990; Ward, 1994). In an effort to bring more clarity to this picture, we develop theory that explains how different confluences of constraint shape the creative process. For the sake of simplicity, we theorize about very high or very low levels of each type of constraint, while acknowledging that each type of constraint can be depicted as a continuum (similar to sources of constraint). By dichotomizing this dimension into extreme levels of constraint, we outline the boundary conditions for which our theory explains creative phenomena in organizations.

We also consider how the source of constraint can have a moderating influence on the relationship between the levels of each type of constraint and the dynamic problem-solving process. Many constraints are based on concrete limitations to problem solving such as the amount of time, finances, materials, or knowledge that are available for generating ideas. However, the source of these constraints can have a strong influence on the *perceived* level of constraint (e.g., Amabile & Gitomer, 1984; Byron et al., 2010; Deci & Ryan, 1985). Thus, we develop theory that also explains how the source of constraint interacts with the levels of each type of constraint to influence the creative process.

We summarize our theory in Figure 2.3, which shows how two particular confluences of constraint can shape the activities that people engage in during the dynamic problem-solving process, which yield two effective modes of problem solving. When people perceive a low level of resource constraint and a high level of problem constraint (depicted on the left side of Figure 2.3), they feel like they are working on a well-defined problem and have the flexibility to engage in a wide range of creative activities in the pursuit of developing a solution to the problem. We call the mode of problem solving under this particular confluence of constraints *deliberate problem solving*, because it reflects the experience of deliberately generating ideas with the intent of solving a well-defined problem (e.g., Amabile & Pratt, 2016).

Alternatively, when people perceive a high level of resource constraint and a low level of problem constraint (depicted on the right side of Figure 2.3), they might feel limited when generating ideas, but they have the flexibility to explore their ideas across several problem domains as they try to discover a problem that can be solved by one of their ideas. Sometimes, a solution never emerges, and other times—as in the case of the Nintendo Wii—a breakthrough solution emerges. Therefore, we call this mode of problem solving *emergent problem solving*, because it reflects the experience of generating an idea and then exploring that idea in the context of a problem domain until a problem and solution emerge together (e.g., Finke et al., 1992). Together, our model shows how two seemingly different creative processes—as shown in Figure 2.1—can transpire from the same underlying dynamic problem-solving process.

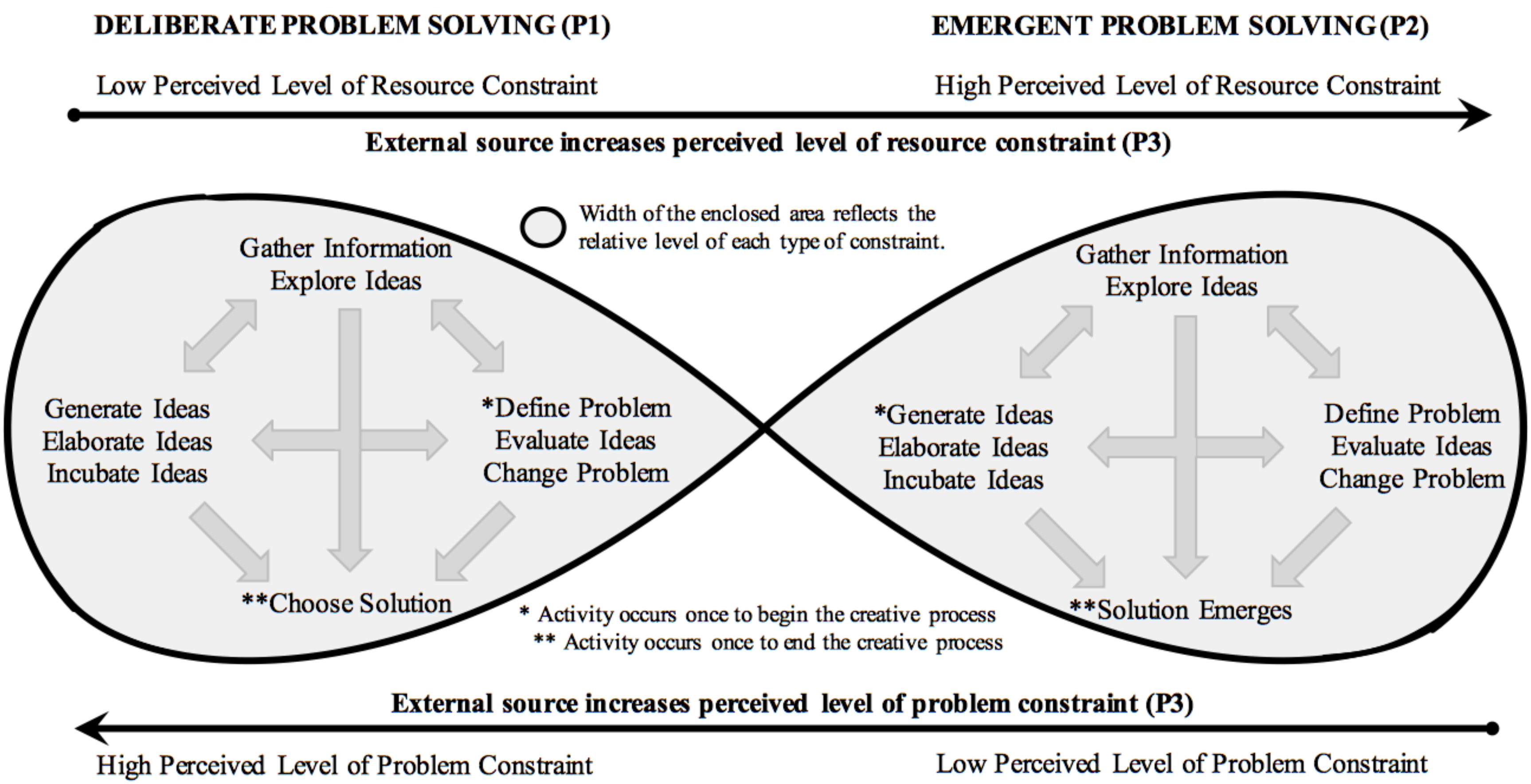


Figure 2.3: Two Types of Problem S

2.4.1 The Dynamic Problem-Solving Process as Shaped by Two Confluences of Constraint

As defined earlier, resource constraints place limits on the time, finances, materials, and knowledge that people use when generating ideas during the problem-solving process. Generating new ideas involves the conceptual combination of existing ideas (Guilford, 1950; Koestler, 1964), and consequently, increasing the amount of resources available (i.e., reducing the level of resource constraint) exponentially increases the number of ideas that can be generated during problem solving. For example, when participants in Finke's (1990) problem-solving experiment were given a subset of three out of 15 materials, they had the potential to create 455 unique material combinations, which could then be used to develop thousands of new conceptual ideas. If they were given just one additional material (for a total of four), they would have been able to create 1,365 unique material combinations—or three times as many.

Therefore, when people perceive low levels of resource constraint, they have a high degree of flexibility when generating ideas, elaborating ideas, and incubating ideas. For example, Edison and his colleagues had access to a large number of financial and material resources, in addition to great expertise, enabling them to generate and elaborate upon thousands of ideas in their quest to develop a commercially viable light bulb. As the level of resource constraint increases, flexibility decreases, and people suffer from a reduced capacity to engage in these activities. At the most extreme levels of resource constraint, they can only generate one initial idea, which can make it difficult to solve problems, but not impossible. For example, the STM engineers took a single new idea—the semiconductor technology that detected three-dimensional motion—and explored broadly for commercial applications across several industries.

Problem constraints, on the other hand, refer to the internal and external demands that define the goal state. When there are low levels of problem constraint, problem statements are vague or poorly defined, meaning that people have a high degree of flexibility when engaging in activities such as defining problems, evaluating ideas against criteria, and changing problems. For example, the STM engineers were not confined to using their technology within a particular industry, and each time they explored their technology in the context of a new industry, they defined new problems or changed problems in their quest to discover a commercial application of their technology. As the level of problem constraint increases, flexibility decreases, and people become more restricted when defining or changing problems. At the most extreme levels of problem constraint, problems are clearly defined and highly rigid, meaning that the problem is defined once during the problem-solving process and cannot be changed. For example, Edison and his colleagues identified several criteria that needed to be met in order to produce a commercially viable light bulb; once defined, the problem did not change over the course of the entire project.

Levels of these two types of constraint work together to produce two stylized versions of the dynamic problem-solving process. First, people may perceive a low level of resource constraint and a high level of problem constraint, which creates conditions for deliberate problem solving to unfold—as depicted on the left side of Figure 2.3. Under these conditions, the problem-solving process begins when an individual defines a problem (or is presented with a well-defined problem). It continues as the individual engages in a wide range of activities that include gathering information, generating ideas, elaborating ideas, incubating ideas, exploring ideas, and evaluating ideas against criteria. The process ends when an idea that fully satisfies all the problem criteria is selected as a viable solution. Note that this process closely resembles the problem-first model of the creative process (e.g., Amabile, 1983; Amabile & Pratt, 2016; Mumford et al., 1991; Wallas, 1926). Therefore, we propose the following:

Proposition 1: When people perceive a low level of resource constraint in combination with a high level of problem constraint, they are likely to engage in a deliberate problem-solving process that resembles the problem-first model: The problem will be defined once at the beginning of the process, and then people will engage in a variety of creative activities until they choose a solution to end the process.

By contrast, people may perceive a high level of resource constraint and a low level of problem constraint, which creates conditions for emergent problem solving to unfold—as depicted on the right side of Figure 2.3. Under these conditions, problem solving begins when an individual generates an idea, which is followed by a series of activities such as exploring ideas in the context of numerous problem domains, defining problems that could be solved by that idea, and elaborating on the original idea until a solution emerges to a discovered problem. Note that this process resembles the idea-first model of the creative process (e.g., Finke et al., 1992), but our synthesized model also includes a broader range of activities. Many of these activities—such as gathering information, evaluating ideas, and changing criteria—were actually discussed by Finke and his colleagues in their original work, but were only implicitly included in the model. Therefore, our model provides a more complete, explicit version of activities that can take place during emergent problem solving.

One notable change that we make to the idea-first model is that we also include incubating ideas, which Finke and colleagues specifically rejected. They developed their model under the assumption that creative thinking is a purposeful cognitive activity rather than a passive, unconscious one. While we agree that much creativity occurs through purposeful cognitive thought, recent research has provided physiological evidence that people can indeed produce creative breakthroughs that arise into consciousness seemingly out of nowhere (Kounios & Beeman, 2015). Therefore, we include idea incubation to complement the purposeful creative activity that Finke and colleagues described. Therefore, we propose the following:

> *Proposition 2: When people perceive a high level of resource constraint in combination with a low level of problem constraint, they are likely to engage in an emergent problem-solving process that resembles the idea-first model: An idea will be generated once to begin the process, and then people will engage in a variety of creative activities until a solution emerges to end the process.*

The source of constraint can also shape dynamic problem solving—specifically by changing the individual's perception of the level of constraint during the process (Deci & Ryan, 1985). Amabile and Gitomer (1984) conducted an experiment to demonstrate this effect for resource constraints. In their experiment, they asked subjects to create a collage using various materials. In the first, "choice" condition, subjects were presented with ten closed boxes of materials and were told to choose five of the ten boxes to use for the task. In the second, "no choice" condition, the experimenter presented all ten boxes and then chose five boxes for the subjects to use. Results showed that subjects in the "choice" condition produced more creative outcomes than subjects in the "no choice" condition, despite using an identical set of materials and spending an equal amount of time on the task. These results are consistent with a broad range of research showing that externally controlled resource constraints can decrease the feeling of autonomy, which in turn can inhibit creativity by increasing the perceived level of constraint (Amabile et al., 1996; Deci & Ryan, 1985; Hunter et al., 2007).

These effects can also be applied to problem constraints. Ryan and Deci (2000) argue that any factor that reduces the feeling of having control over one's own behaviors can increase the perception of constraint. According to problem-solving scholars (Newell & Simon, 1972), the problem definition is the primary driver of behavior during the creative process. Therefore, when people have control over the problem, they should also feel like they have control over their behaviors during problem solving, and thus perceive a lower level of constraint. When external forces control the problem, people feel like they have less control over their behaviors, and thus perceive a higher level of constraint. Altogether, we reason that the extent to which resources or problems are external determines the degree to which people perceive themselves to be constrained. Internal constraints decrease the perceived level of constraint, whereas external constraints increase the perceived level of constraint. We summarize these possibilities in the following proposition:

Proposition 3: The source of constraint will moderate the perceived levels of resource or problem constraints, such that external constraints will be perceived as more constraining than internal constraints.

2.4.2 Ineffective Problem-Solving as Shaped by Two Other Confluences of Constraint

The two forms of problem-solving described in the previous section, each arising from a different confluence of constraint, can be highly effective in leading to creative outcomes. However, two other confluences of constraint are also possible, which result in ineffective modes of problem solving. First, when people perceive high levels of both resource and problem constraints, they feel like they are working on a well-defined and highly rigid problem, but they do not have the flexibility to generate, elaborate, or incubate ideas as they try developing a solution to the problem. When working on a well-defined problem, people need flexibility to generate a wide variety of ideas to increase their chances of developing a viable solution. Without that flexibility, people are likely to feel that their problem-solving efforts are futile, which will inhibit their capacity to produce viable solutions.

Second, when people perceive low levels of both resource and problem constraints, they feel like they can develop a large number of potential solutions to a large number of potential problems. While these conditions may seem favorable because they provide people with a high level of flexibility throughout the entire problem-solving process, research shows that people can actually struggle to think creatively under these conditions (Goldenberg et al., 1999; Moreau & Dahl, 2005; Ward, 1994). People may have little direction on which idea to pursue, resulting in a feeling of ambiguity that increases levels of stress, anxiety, and frustration (Schwartz, 2000). These negative feelings can reduce a person's engagement in the problem solving process (Iyengar & Lepper, 2000), which can subsequently inhibit creativity (Chua & Iyengar, 2006, 2008). In summary, then, our model describes the confluences of constraints that are most likely to result in successful creative problem-solving efforts, and it also points to confluences of constraints that are likely to undermine the problem-solving process.

2.5 Discussion and Conclusion

Creativity is a challenging endeavor in which people must navigate through a complex confluence of constraints on their journey to discovery and creation. Most research in organizational creativity has been conducted under the assumption that problems are closed (or clearly defined at the outset) (Unsworth, 2001), and that people can be creative when they have a high degree of flexibility to develop a wide range of ideas during the creative process. According to this view, the most important tools that organizations have at their disposal to foster a more creative workforce are to give people a well-defined problem and provide them with enough resources to solve it creatively (Amabile et al., 1996; Anderson et al., 2014; Shalley, Zhou, & Oldham, 2004). Within this paradigm, resources play an important role in facilitating the creative process, but perhaps the most important step is defining the right problem to solve in the first place (Amabile, 1983; Getzels & Csikszentmihalyi, 1976; Mumford et al., 1994).

However, these approaches overlook an alternative model of problem-solving that may be more appropriate when people are working on open, ill-defined problems. Under such circumstances, rather than focusing on adapting a vague, poorly defined problem into several well-defined sub-problems (Simon, 1973), it may be wiser to start the process by generating ideas in the absence of a clear problem definition altogether (Finke et al., 1992).

We believe that the main contribution of this paper is the synthesis of these two previously disparate views on the creative process. We show how they emerge from the same underlying dynamic problem-solving model, but differ as a function of the confluence of constraints that people perceive as operating on them during the process. Understanding these dynamics can be important for organizational creativity scholars, because creativity in the workplace is often subject to a shifting set of demands from numerous stakeholders (Drazin, Glynn, & Kazanjian, 1999; Kanter, 1988), resulting in an ever-evolving set of constraints. Problems in real organizations are also considerably more open than what prior theory on organizational creativity has assumed (Unsworth, 2001), and our theory provides guidance on how to better understand and explain creativity under these challenging conditions.

2.5.1 Implications for Theory and Research

In this paper, we developed an integrated model of dynamic problem solving, which makes theoretical contributions to both prior models. We contribute to literature citing the problem-first model by allowing for a more dynamic sequence of activities during the creative process, which helps account for a broader range of phenomena in organizations that the problem-first model could not previously explain. Most importantly, it could not explain creative processes that begin with generating ideas and end when a solution emerges to a discovered problem (e.g., Finke et al., 1992; von Hippel & von Krogh, 2016).

We also contribute to literature citing the idea-first model by expanding the scope of activities that take place during the creative process and providing a clearer structure to explain how various activities are affected by constraints. For example, Finke and colleagues built their model on the assumption that constraints play a fundamental role in shaping the generation and exploration of ideas, but they failed to recognize that different types of constraints can have a stronger effect on different parts of the process. Building on more recent research that studies creativity and constraint (e.g., Rosso, 2014; Ryan & Deci, 2000), we develop a more detailed model that explains how different types of constraint can systematically shape different parts of the creative process.

Our second contribution is that we develop theory that explains how seemingly different models of the creative process are derived from the same underlying problem-solving process. Previous researchers have described two unique paths in developing creative outcomes—summarized as the problem-first and idea-first models of the creative process—but for the most part, literature citing each model has remained isolated from each other. The majority of organizational creativity literature draws from the problem-first model to frame research (e.g., Amabile & Pratt, 2016; Anderson et al., 2014; Perry-Smith & Mannucci, 2017; Shalley & Zhou, 2008), overlooking the apparent contradiction with the idea-first model. By contrast, literature drawing from the idea-first model addresses the contradictory nature that constraints can have on creative outcomes (e.g., Caniëls & Rietzschel, 2015; Chua & Iyengar, 2008; Hoegl et al., 2008; Moreau & Dahl, 2005; Roskes, 2015), but has not explicitly addressed how constraints might influence the creative process. We take a broad view to show how various constraints work together to shape the problem-solving process, thereby providing a more comprehensive picture of the relationship between creative problem solving and constraint.

By integrating these two disparate views of the creative process into a coherent model, we also raise several new questions that can be investigated in future research. Primarily, we describe two modes of problem solving that are optimal under two confluences of extreme levels of constraint: deliberate problem solving (low resource constraint, high problem constraint) and emergent problem solving (high resource constraint, low problem constraint). Yet, in organizational settings, the process of creating new products, ideas, processes, or services is highly dynamic, and the levels of resource and problem constraints are constantly shifting over time. While recent research has provided glimpses into how people can engage in different creative processes to deal with different confluences of constraint (e.g., Frishammar, Dahlskog, Krumlinde, & Yazgan, 2016; Harrison & Rouse, 2014; Harvey & Kou, 2013; Sonenshein, 2014), it is still unclear how people might transition between deliberate and emergent modes of problem solving over time. How might people impose or relax constraints on themselves to facilitate the problem-solving process? How might they react to unexpected shifts in their constraint environment? What role do organizations and managers play in facilitating these dynamics? These reflect only a few of the numerous questions that can be addressed in future research.

Another possibility is to investigate the degree to which individuals with different characteristics thrive under different confluences of constraint. For example, one of the earliest streams of creativity research focused on explaining creative outcomes through individual traits and abilities (Guilford, 1950; Koestler, 1964; Nicholls, 1972; Rothenberg & Greenberg, 1976). One useful distinction that came from this research was that people have different problem-solving styles. For example, Kirton (1976) differentiated between *adaptors*, or people who excel at "doing things better"; and *innovators*, or people who excel at "doing things differently." Similarly, Jabri (1991) differentiated between *logical* problem solvers, or people who prefer to solve problems in a logical sequence of steps, and *intuitive* problem solvers, or people who prefer to solve problems by making unexpected connections between ideas and embracing the uncertainty associated with creative thinking.

In light of our theory, it may be possible that individuals with different problem-solving styles may be better suited to different modes of problem solving. For example, logical problem solvers (or adaptors) may thrive when they are engaged in deliberate problem solving, but struggle when they are engaged in emergent problem solving. Alternatively, intuitive problem solvers (or innovators) may thrive when they are engaged in emergent problem solving, but struggle when they are engaged in deliberate problem solving. This reflects only one of many opportunities to investigate how individual characteristics and traits may influence an individual's ability to engage in different modes of problem solving.

Similar research can also be developed at the team level of analysis, which may offer even more opportunities to develop novel insights given the relative lack of research on team creativity compared to individual creativity (Anderson et al., 2014; Shalley & Zhou, 2008). For instance, prior research shows that teams can benefit from both broad search and local search during creative problem solving (Perretti & Negro, 2006; Taylor & Greve, 2006). In the context of our theory, it is possible that broad or local search can apply to either searching for solutions or searching for problems, and teams may be most successful when engaging in a combined process of broad search for solutions and local search for problems—or vice versa. Rather than viewing search as a single continuum, different combinations of search may be optimal based on different confluences of constraint. Such distinctions have neither been theorized nor empirically tested, providing rich opportunities for future research.

2.5.2 Managerial Implications

Organizations are complex environments in which problems are often ill-structured and open, and our theory offers insights that could help managers better understand how to manage the creative process under these difficult conditions. One dilemma that managers face is how to give workers enough flexibility to solve problems creatively while also asserting enough control so that workers produce solutions that are aligned with the organization's goals. Perhaps the most powerful application of our model is that it provides managers with a tool to understand how they can manipulate constraints to strike this flexibility-control balance more effectively.

One approach is that managers can adopt a deliberate mode of problem solving, in which they give people a well-defined problem that aligns with the organization's goals, but also give people enough resources so that they can develop an optimal solution to the problem. The search for solutions can be done within the organization's boundaries, where workers draw on the available skills and resources to solve the problems themselves (for a review, see Shalley & Zhou, 2008), or it can be expanded beyond the organization's boundaries, allowing people to gather and evaluate solutions developed by a crowd of problem solvers (e.g., Lifshitz-Assaf, 2017). This mode of problem solving can help managers simultaneously maintain control over the outcomes of the problem-solving process while providing flexibility to workers so that they may determine the best way to solve the problem.

Another approach would be to adopt an emergent mode of problem solving, which might be particularly useful when organizations experience greater ambiguity in their mission and goals. For example, any organization that is trying to develop a breakthrough technology is operating under conditions of high ambiguity (Kaplan & Tripsas, 2008), and startup organizations are often trying to identify target market needs while simultaneously trying to develop the product (e.g., Navis & Glynn, 2010). In these conditions, organizations can maintain control by restricting the set of resources that they are committing to a new project, but also provide flexibility by allowing workers to search broadly for problems that could be solved with those resources. This approach could help organizations shorten product development cycles (Ries, 2011) or foster the creative use of resources (Sonenshein, 2014), which may be particularly valuable when organizations are operating in highly dynamic markets that are changing quickly (e.g., Brown & Eisenhardt, 1997; Eisenhardt & Tabrizi, 1995).

2.5.3 Conclusion

Creativity is an essential source of new ideas, products, processes, or services that help organizations gain a competitive advantage against rivals and flourish, but creativity is a challenging endeavor because people must work within a complex confluence of constraints that are constantly changing over time. Prior research has described two fundamentally different models of creativity, but each model provides contradicting views on the creative process, raising questions about how people can successfully navigate through these complex environments to achieve highly creative outcomes. This paper reconciles these contradictions by synthesizing these models into a coherent model, revealing that different modes of problem solving emerge from different confluences of constraints. In so doing, we advance a new integrated model of dynamic problem solving within organizational constraints, which offers guidance to both scholars and practitioners who are interested in understanding and facilitating creativity in organizational settings.

CHAPTER 3

The Emergent Innovation Process in Groups: Ethnographic Insights on Developers of a Social Robot

Johnathan R. Cromwell

Abstract

Prior research on group innovation has come to a consistent conclusion that groups operate most effectively when they have a shared set of goals or criteria for an innovation, because it helps them overcome several coordination, communication, and conflict issues that can arise when they are working under highly ambiguous conditions. Consequently, many scholars argue that the process of defining a problem and constructing a shared representation of an innovation is vital to success, because it reduces ambiguity and promotes positive group dynamics while developing a solution. However, there is scant research investigating how groups can overcome the initial state of ambiguity that exists for most innovation projects to accomplish these important milestones. In this study, I addressed this question by conducting a two-year ethnography of an organization that developed a new product called a social robot. My findings reveal an emergent innovation process that describes how groups can discover a coherent representation of an innovation at the end of the development process—and thus fully develop a solution—while never cultivating a shared set of goals for the innovation—and thus never defining a problem for the innovation to solve. These findings provide a strong counterpoint to existing theory.

3.1 Introduction

Innovations are novel and useful products or services that are an important source of revenue for organizations (Amabile, 1988; Kanter, 1988; Oldham & Cummings, 1996). A growing body of research shows that groups can play a fundamental role in developing innovations (Singh & Fleming, 2010; Wuchty, Jones, & Uzzi, 2007). Consequently, scholars have become increasingly interested in understanding the group dynamics that affect the development of innovations in organizational settings (Baer, Leenders, Oldham, & Vadera, 2010; Hargadon & Bechky, 2006; Harrison & Rouse, 2014, 2015; Harvey & Kou, 2013; Hulsheger, Anderson, & Salgado, 2009; Kurtzberg & Amabile, 2000; Paulus & Nijstad, 2003; Perry-Smith & Shalley, 2003; Taylor & Greve, 2006).

One of the key tensions highlighted by this research is that groups—on one hand—must comprise people with diverse cognitive perspectives in order to bring an innovation to market successfully (Brown & Eisenhardt, 1995; Dougherty, 1992; Drazin et al., 1999), but on the other hand, must avoid the coordination, communication, and conflict issues that can arise when people with diverse cognitive perspectives collaborate during the development process (Baer, Dirks, & Nickerson, 2013; Cronin & Weingart, 2007; Dougherty, 1992; Okhuysen & Bechky, 2009). Navigating this tension is particularly difficult for groups because the reason why diverse cognitive perspectives are valuable is that they allow groups to construct *diverse representations* of an innovation, meaning that they can interpret an innovation through the lens of different sets of knowledge (Reiter-Palmon, in press; Reiter-Palmon, Herman, & Yammarino, 2008). These representations can enable groups to generate more divergent ideas (Kavadias & Sommer, 2009; Osborn, 1953; Sutton & Hargadon, 1996), but they also introduce ambiguity that can lead to disagreements about which ideas should be developed (Kaplan & Tripsas, 2008; Leonardi, 2011;

Weick, 1990). Therefore, the very mechanism that enables innovative thinking in groups is the same mechanism that undermines group dynamics that are needed for developing an innovation.

Scholars argue that groups can bridge their cognitive differences and foster positive group dynamics by constructing a *shared representation* of an innovation (Carlile, 2004; Cronin & Weingart, 2007; Okhuysen & Bechky, 2009), meaning that all group members have the same interpretation of the goals, criteria, and ideas that must be developed for an innovation. Groups can use a variety of practices such as metaphors, narratives, and prototypes to help construct a shared representation (Bartel & Garud, 2009; Bechky, 2003a; Boje, 1991; Carlile, 2002; Dahl & Moreau, 2002; Stigliani & Ravasi, 2012), and researchers find that groups are most effective when they construct a *coherent representation* across all these practices, meaning that there is no conflict between the particular metaphors, narratives, and prototypes that are used during the development process (Seidel & O'Mahony, 2014). Failing to maintain coherence can allow ambiguity to seep into the process, which can undermine group dynamics for innovation.

However, prior research has been conducted largely under the assumption that groups are working on a "closed" problem (Shalley & Zhou, 2008; Unsworth, 2001), meaning that the problem is well-defined at the beginning of the innovation process and is followed by a cyclical iteration of activities such as generating ideas, evaluating ideas, and implementing ideas until a final solution is developed (Amabile & Pratt, 2016; Mumford et al., 1991; Perry-Smith & Mannucci, 2017; Wallas, 1926; West, 2002). This ignores the fact that the process often begins with an "open," ill-defined problem (Unsworth, 2001), meaning that groups must first define the problem before developing a solution. Although prior research shows how groups can *maintain* a shared representation after it has been constructed (Seidel & O'Mahony, 2014), it does not reveal how groups can overcome the initial state of ambiguity to construct a shared representation at the beginning of the innovation process. Trying to resolve this ambiguity can lead to intense debates that fracture group dynamics (Drazin et al., 1999; Kaplan, 2008), and in some cases the ambiguity may never be resolved (Leonardi, 2011). Therefore, it is still unclear how groups can construct a shared representation of an innovation *before* the problem has been defined.

I address this research question by conducting a two-year ethnography in a startup organization that developed one of the world's first social robots[1] for the home. When I began collecting data, groups used highly ambiguous representations to develop isolated features for the product. By the time I finished, they used a coherent representation to develop a product that integrated all features into a final outcome. By conducting a longitudinal study on the group dynamics that took place between these two end-points in time, I induce an *emergent innovation process* in groups that reveals an alternative pathway for developing an innovation that contrasts with prior theory.

Primarily, existing literature assumes that ambiguity is the primary reason why groups struggle to collaborate effectively when defining and solving problems (Baer et al., 2013; Cronin & Weingart, 2007; Leonardi, 2011; Okhuysen & Bechky, 2009; Seidel & O'Mahony, 2014). My findings challenge this underlying assumption by revealing an emergent innovation process that begins when groups experience high levels of ambiguity and ends when they have constructed a coherent representation that reduces ambiguity. My study suggests how group members can collaborate effectively while experiencing ambiguity throughout the entire innovation process, and it suggests how groups may be able to overcome the initial state of ambiguity to construct a

[1] The term "social robot" was coined by an academic sub-field of robotics in the early 1990s. These devices were designed to interact with humans through verbal communication while exhibiting some type of emotional or social intelligence. By the mid-2010s, several organizations were attempting to commercialize this technology as a consumer product, one of which became the empirical setting for this study.

shared representation of an innovation that involves less contentious debate (cf. Drazin et al., 1999; Kaplan, 2008; Leonardi, 2011).

Furthermore, I found that the emergent innovation process consisted of a cyclical iteration of activities including generating ideas, implementing ideas, and interpreting ideas, which gave developers the opportunity to discover a well-defined problem at the end of the innovation process. This stands in contrast to the deliberate innovation process (Cromwell et al., in press), which *begins* with a well-defined problem and is followed by a cyclical iteration of activities that include generating ideas, evaluating ideas, and implementing ideas to develop a solution (Amabile & Pratt, 2016; Mumford et al., 1991; Perry-Smith & Mannucci, 2017; Wallas, 1926). The primary difference between these two processes lies in the way that groups assess ideas, which depends on whether ideas have been implemented or not. In the deliberate innovation process, groups *evaluate ideas* to decide what will be implemented in a *future version* of the product, and in the emergent innovation process, groups *interpret ideas* to better understand what has already been implemented in an *existing version* of the product.

The difference between these two processes can have a significant impact on the way that groups develop an innovation. When groups use the deliberate innovation process, they must *eliminate* ambiguity and construct a shared representation *before* developing the solution (e.g., Seidel & O'Mahony, 2014); when they use the emergent innovation process, they can *embrace* ambiguity and discover a shared representation *after* developing the solution. In other words, groups using the deliberate process can thrive under coherence, and groups using the emergent process can thrive under ambiguity. Future research can further investigate how these two processes complement each other in organizational settings (Cromwell et al., in press), which may lead to new theory that describes how groups can navigate the various tensions between ambiguity and coherence that permeate throughout the innovation process over time.

3.2 Group Dynamics for the Innovation Process

The innovation process that is typically described in prior literature (Amabile, 1983; Amabile & Pratt, 2016; Mumford et al., 1991) is built on a cognitive model of individual problem solving (Newell et al., 1962; Newell & Simon, 1972). According to this model, the process begins when a developer receives a problem statement and constructs a *representation* of the problem, which triggers the recall of an implied set of knowledge, experiences, and methods that can be used to generate ideas in an attempt to solve the problem. For example, a developer attempting to build a social robot can represent this product as a "social companion," which may lead her to draw on knowledge related to friendships, relationships, or family members when generating ideas; or she can represent this product as an "assistant robot," which may lead her to draw on knowledge related to products such as Roomba, the automatic vacuum cleaner, from iRobot. Once the developer generates ideas, she can evaluate the ideas against the problem criteria; if the ideas fail to satisfy all the criteria, she can either generate new ideas, elaborate upon existing ideas, or change her representation of the problem, which can trigger her to recall a new set of cognitive resources that can be used for generating new ideas.

An important feature of this process is that people generate ideas based on the particular representation they use to interpret the problem (Kaplan & Tripsas, 2008). Consequently, a developer who can represent a problem from multiple perspectives has a greater capacity to generate more divergent ideas (Amabile, 1983, 1996; Mumford et al., 1991), which can often lead to more novel and useful solutions (Campbell, 1960; Guilford, 1950; Simonton, 1999, 2004; Staw, 1990). When this mechanism is extended to the group level of analysis, it means that groups with more diverse cognitive perspectives can use broader and more diverse representations of problems than groups with similar perspectives (Reiter-Palmon, in press; Reiter-Palmon et al., 2008), which can help them generate more innovative ideas during earlier stages of the innovation process (Nemeth & Kwan, 1987; Osborn, 1953; Paulus & Yang, 2000; Sutton & Hargadon, 1996), and converge upon more innovative ideas when evaluating and selecting ideas to be implemented later in the innovation process (Girotra, Terwiesch, & Ulrich, 2010; Putman & Paulus, 2009; Rietzschel et al., 2006; Runco & Smith, 1992).

However, the diverse representations that are essential for solving problems in groups can also be the source of ambiguity that can undermine several group dynamics that are essential for developing innovations. First, ambiguity can undermine *coordination* processes that are needed to integrate various tasks of an innovation project (Faraj & Sproull, 2000; Okhuysen & Bechky, 2009). Coordination is particularly important for larger groups developing more complex products such as a social robot, which consist of several layers of features and sub-features that are integrated into a single outcome (Clark, 1985; Griffith, 1999). Groups that fail to construct a shared representation of these innovations can face significant challenges when trying to align individual work done on each task with the group's collective goals for the fully integrated innovation (Clark & Fujimoto, 1991; Seidel & O'Mahony, 2014).

Second, ambiguity can disable *communication* processes that are needed for groups to share ideas and make decisions during the innovation process. In a seminal study investigating new product innovation, Dougherty (1992) finds that developers working in different departments of an organization such as marketing, sales, and manufacturing operate in different "thought worlds" that influence how they interpret the environment and make sense of ambiguous situations (Daft & Weick, 1984). Each thought world consists of an "intrinsic harmony" of knowledge that dictates which criteria are most important for an innovation and which ideas are most appropriate for satisfying those criteria. Consequently, developers working in the same department often construct a shared representation of an innovation, allowing them to freely communicate with each other and exchange information. By contrast, developers working in different departments often construct different representations, which can act as barriers to communication and information processing.

When differences between representations are particularly large, it can lead to *conflict* in groups that is difficult to reconcile. Cronin and Weingart (2007) argue that "gaps" between group members' representations can vary according to the goals, assumptions, elements, and operators that members use for solving problems. Goals refer to the hierarchy of preferences that each member has for the problem criteria, assumptions refer to the hidden preferences that each member has for different criteria, elements refer to the set of knowledge and experiences that members draw from to generate ideas, and operators refer to the methods that members use to transform ideas. When representational gaps are small, group members have different elements and operators to use when generating ideas, but they also have shared goals and partially shared assumptions, making it possible for them to resolve conflict when developing solutions. When representational gaps are large, goals and assumptions are not shared, and thus, groups are more likely to suffer from irreconcilable conflict.

In summary, when group members use highly diverse representations during the innovation process, they can suffer from coordination, communication, and conflict issues that undermine their ability to define and solve problems effectively (Baer et al., 2013; Cronin & Weingart, 2007). For innovations such as a social robot, this can present many challenges, because developers from different organizational departments must collaborate with each during all stages of development (Dougherty, 1992; Drazin et al., 1999; Edmondson & Nembhard, 2009). To overcome these challenges, scholars argue that it is essential for diverse groups to construct a shared representation of an innovation (Carlile, 2004; Hargadon & Bechky, 2006; Okhuysen & Bechky, 2009).

3.2.1 Constructing a Shared Representation of an Innovation in Diverse Groups

Research shows that groups can reduce ambiguity and construct a shared representation by using a variety of practices throughout the innovation process such as prototypes, metaphors, and narratives (Edmondson & Harvey, 2017; Seidel & O'Mahony, 2014; Stigliani & Ravasi, 2012). *Prototypes* are physical objects such as drawings, sketches, or machines that allow people to express abstract ideas through concrete artifacts (Bechky, 2003a; Henderson, 1991). When diverse groups develop a prototype together, they can discuss different interpretations of a concrete object, which helps them translate ideas between different perspectives and build a common set of knowledge (Carlile, 2004; Star & Griesemer, 1989). Consequently, groups using prototypes have a greater capacity to share ideas, resolve ambiguity, and transform individual representations into a shared representation (Bechky, 2003b; Carlile, 2002; Carlile & Rebentisch, 2003). However, prototypes alone do not guarantee success, as developers can disagree on the ideas of an innovation before implementing them as prototypes (Leonardi, 2011).

Therefore, groups can also use linguistic practices such as metaphors and narratives to construct a shared representation (Seidel, 2007; Seidel & O'Mahony, 2014; Stigliani & Ravasi, 2012). *Metaphors* are conceptual tools that allow people to interpret new information in terms prior knowledge and experience (Cornelissen, 2005; Cornelissen, Oswick, Christensen, & Phillips, 2008). In the context of the innovation process, metaphors are particularly valuable when generating ideas, because developers can transfer knowledge from prior experience to a new project (Dahl & Moreau, 2002; Gentner, 1983; Schön, 1993), thereby helping them combine ideas to create innovative solutions to problems (Hargadon & Sutton, 1997; Koestler, 1964). But metaphors can also be effective tools for coordinating activity in groups. People often make sense of ambiguous situations through collective sensemaking (Walsh, 1995; Weick, Sutcliffe, & Obstfeld, 2005). Consequently, when people use metaphors to make sense of an ambiguous situation such as developing an innovation, they can develop a shared understanding of the criteria of the innovation (Hargadon & Douglas, 2001; Tripsas, 2009). For example, if developers of a social robot all think that the product is like a "social companion," they can develop a shared understanding that one of the criteria should be a "friendly personality."

Narratives are also conceptual tools that help developers communicate with each other, but they are longer and more structured than metaphors, allowing people to share more complex ideas (Martens, Jennings, & Jennings, 2007). Narratives typically include a storyline that describes a protagonist in pursuit of a goal, along with several factors that influence her ability to achieve that goal (Fiol, 1989; Lounsbury & Glynn, 2001). When people use narratives in day-to-day interactions, they rarely describe all elements of a narrative, but instead weave fragments of a narrative into conversation that reference ideas that are collectively held within the group (Boje, 1991). Consequently, group members can follow the conversation with a richer understanding of what the story-teller is trying to communicate.

Altogether, prototypes, metaphors, and narratives provide groups with three practices to help them construct a shared representation of an innovation. However, when each practice is used in isolation, conflicts can arise that lead to another form of ambiguity that undermines group dynamics for innovation (Seidel & O'Mahony, 2014). For example, developers of a social robot may collectively agree that an appropriate metaphor for the product is a "social companion," and they may also collectively agree that one of the prototypes reflects an "assistant robot;" the fact that there is conflict between these two practices creates ambiguity that can undermine the innovation process. To eliminate this ambiguity, groups must construct a "coherent" representation across all these practices and maintain it throughout all stages of development. During this process, the particular metaphor, narrative, and prototype that groups use can evolve (Seidel, 2007), but they must all stay coherent with each other over time.

3.2.2 Shortcomings of Existing Literature

Existing literature provides a consistent view that constructing a shared representation of an innovation is essential to fostering positive group dynamics during the development process. What makes a shared representation so powerful is that it provides groups with a shared set of goals and criteria that are clearly understood within the group. When groups are working on such a well-defined problem, members are more capable of coordinating their effort, communicating with each other, and resolving any conflict that arises when developing solutions to the problem (Cronin & Weingart, 2007; Kurtzberg & Amabile, 2000; Okhuysen & Bechky, 2009). However, many scholars argue that the first stage of the innovation process is to define the problem itself (Amabile & Pratt, 2016; Mumford et al., 1991). This stage can be fraught with extreme ambiguity as group members represent the problem according to their own knowledge, experiences, and expertise (Baer et al., 2013; Kaplan & Tripsas, 2008). Groups trying to resolve this ambiguity often engage in intense conflict that pit different factions against each other (Carlile, 2004; Kaplan, 2008), which can fracture group dynamics and prevent the group from constructing a shared representation of the innovation (Drazin et al., 1999; Leonardi, 2011).

Other scholars suggest that groups can avoid these debates by adopting practices that minimize differences between their perspectives (Bechky, 2003b; Majchrzak, More, & Faraj, 2012), and research suggests that practices such as metaphors, narratives, and prototypes can help groups construct a shared representation of an innovation before the problem is defined (Seidel & O'Mahony, 2014). However, there have been no studies investigating how groups use these practices to address an open problem (Unsworth, 2001), and theory on the process of defining problems in groups is still fairly sparse (Reiter-Palmon, in press; Reiter-Palmon & Robinson, 2009). Therefore, qualitative inductive research can be valuable for generating new theory on group dynamics for the innovation process (Edmondson & McManus, 2007).

3.3 Methods

I developed this research by conducting a two-year ethnography of a small startup organization called Roboto,[2] which developed one of the world's first social robots for the home. This product was a breakthrough innovation in consumer technology, making Roboto an extreme case study that was ideal for exploring how groups attempted to construct a shared representation of an innovation before the problem was defined (Yin, 2014). Breakthrough innovations are characterized by extreme levels of ambiguity, because there are no standard designs or concepts that dictate what features the innovation should have (Anderson & Tushman, 1990; Suarez, Grodal, & Gotsopoulos, 2015). Therefore, developers at Roboto used highly diverse representations when developing this product (Kaplan & Tripsas, 2008; Weick, 1990), and there were few external forces pressuring them to favor one representation over another (Grodal, Gotsopoulos, & Suarez, 2015). Consequently, many of the group dynamics that I observed reflected a collective sensemaking process in a highly ambiguous situation (Weick et al., 2005).

[2] All names of organizations, products, features, and individuals in this dissertation are pseudonyms.

This product was also a complex technology product that consisted of multiple features integrated into a single outcome (Clark, 1985; Griffith, 1999); consequently, people with diverse cognitive perspectives had to collaborate with each other throughout all stages of development (Dougherty, 1992; Drazin et al., 1999). In larger organizations, these collaborations often occur in different departments that are separated by hierarchical and geographic boundaries. But because Roboto was a small startup organization developing one product, all collaborations took place within a single office. This allowed me to gain unusually deep access across a broad range of activities related to the innovation process. I was able to collect in-depth data on groups as they confronted various coordination, communication, and conflict issues while developing the social robot, which was important for generating new theory on group dynamics for the innovation process (Langley, 1999).

3.3.1 Case Overview

Roboto was located in the Northeast region of the United States. When I started collecting data, Roboto had just raised their first round of venture capital funding and hired approximately 35 employees to begin developing a new consumer technology product that they called "Robo." Employees were distributed across several groups, some of which were responsible for developing technical components of the product such as cameras, motors, and a speech recognition system. Others were responsible for developing the conceptual features that customers interacted with—such as "Messaging," "Photography," "Utilities," "Character," "Interaction Behaviors," and "Visual Style" (described in more detail below). For this study, my primary *unit of analysis* was a conceptual feature, and my primary *level of analysis* was a group (Yin, 2014). Therefore, I tracked the development of several conceptual features over time, which included collaboration among different kinds of developers who got more or less involved depending on the stage of development. When defining and solving problems, groups typically consisted of designers, product managers, and executives; and when implementing solutions, groups also included software engineers. In total, I studied group dynamics among 55 developers that collaborated with each other in different permutations over the course of two years.

I was initially attracted to Roboto because I knew there had been relatively little research focusing on innovation under open-problem conditions (Unsworth, 2001); in particular, I was interested in understanding how developers defined problems for the product. I suspected that Roboto would offer fertile ground to observe these processes, which was encouraged by comments that participants made to me at the beginning of my research such as, "The picture is still fuzzy… it's distant, but we're making progress. It'll come into focus soon." I expected that within the first few months, developers would focus on defining the problem for the product and then develop its features, which would be consistent with prior literature (Amabile & Pratt, 2016; Mumford et al., 1991). What I found instead was that developers focused on developing features for the product, and the overarching problem remained stubbornly elusive. Even after 21 months of development, one participant confessed to me, "I think Robo is still a solution looking for a problem." Three months later, when I finished collecting data, Roboto had grown to more than 100 employees and were preparing to launch their product to market.

These comments are puzzling in the context of prior literature, because developers at Roboto developed a "solution" for the product without ever defining a "problem." Most prior theory would argue that the solution (i.e., the product) would be unsuccessful, because developers never constructed a shared representation of the innovation and therefore could not collaborate effectively throughout the development process (Cronin & Weingart, 2007; Dougherty, 1992; Kurtzberg & Amabile, 2000; Okhuysen & Bechky, 2009; Seidel & O'Mahony, 2014). However, others have suggested that the product could still be successful despite the fact that developers never constructed a shared representation (Leonardi, 2011).

What I aim to reveal in this study is that the events that unfolded at Roboto were somewhere in between these two extremes: Developers coordinated their effort effectively enough to arrive at a *coherent representation* of the product, meaning that they achieved consistency between different types of representations (i.e., metaphors and prototypes); but they did not construct a *shared representation* of the product, meaning that they did not agree on the specific goals and criteria that they were trying to satisfy with the product. Therefore, my study reveals how groups can overcome the initial state of ambiguity to arrive at a coherent representation of an innovation, but I also show that a coherent representation does not necessarily imply a shared representation (cf. Seidel & O'Mahony, 2014). By studying how groups navigated the highly ambiguous situation of developing a social robot, my findings disentangle these two cognitive states for groups, and I suggest that a coherent representation is an important precursor to constructing a shared representation in groups. I expand upon the implications of these findings later in the discussion section of this paper.

3.3.2 Data Collection

I collected data at Roboto by using participant-observation methods that are common to ethnographic field studies (Emerson, Fretz, & Shaw, 2011; Lofland, Snow, Anderson, & Lofland, 2006). I gained access to Roboto through a personal contact. After meeting with executive leaders and gaining approval for my research, I was given a desk on-site and a company email address, which allowed me to access the online company calendar and cloud-based storage system that was used for managing archival documents. From there, I had autonomy to attend any meetings that I believed were relevant for my research. As described earlier, I focused on meetings that included any group of developers working on any of the conceptual features for the product.

I also became an active participant at Roboto by working on the "design research team," which was a small group of designers responsible for developing usability tests to better understand how external users experienced their product. I provided expertise on how to design these tests to maximize the quality of the user research conducted at Roboto, but I tried to minimize my involvement in the analysis and interpretation of data, so that my opinions did not significantly influence decisions for the product. This role helped me become more "immersed" in the daily activities, routines, and experiences of my participants, allowing me to better understand what they found meaningful and how they made sense of ambiguous situations (Emerson et al., 2011). This internal perspective was particularly valuable when analyzing data for this study, which required me to have a deeper understanding of the diverse representations that groups used while developing the product.

One of the unique challenges that I faced at Roboto was that developers were under pressure to bring their product to market as quickly as possible, which influenced my methodological approach. For example, the CEO consistently repeated the mantra of "we're in a race" at all company-wide meetings; therefore, I could not ask participants to take time away from their busy schedules to conduct formal interviews for my research. To accommodate this constraint, I adjusted my research topic to focus specifically on *group dynamics* under open-problem conditions—as opposed to individual processes—because it required me to focus on communication and interaction patterns to generate new theory (Weick, 2000; Weick et al., 2005). Thus, I developed my findings primarily by analyzing data coming from direct observations and meeting transcriptions, and I triangulated my findings based on supplementary data coming from informal interviews and archival data.

Direct Observation and Field Notes. Over the course of two years, I spent time at Roboto on more than 320 days for an average of 25 hours per week, and I recorded more than 2,200 pages of field notes as I attended meetings, interacted with participants, and reflected on major events that were related to my research interests. During that time, the nature of my observations changed according to the progress that I made on my research and the progress that developers made on the product. During the first six months, developers were in the early stages of development, and my goal was to understand the processes, procedures, routines, and rhythms of collaboration between different developers. Therefore, I recorded meetings, conversations, and events in as much descriptive detail as possible without trying to interpret them through the lens of existing theory (Emerson et al., 2011; Lofland et al., 2006). I recorded most of my field notes in real time, but when this was not possible, I jotted down short phrases to outline high-level topics that I thought were important or interesting; then at a later time—usually within 36 hours—I returned to my field notes to elaborate on the details.

My initial insights for this study occurred after approximately four months, when I noticed a consistent pattern emerge in meetings: Developers would be working on one feature and made references to ideas on other features. This surfaced the notion that there could be conflicts or synergies between ideas across features. At the time, I was unaware of literature related to constructing a shared—or coherent—representation of an innovation (e.g., Seidel & O'Mahony, 2014), but I began steeping myself in the problem-solving literature to better understand the dynamics that were related to defining and solving problems (Cronin & Weingart, 2007; Getzels & Csikszentmihalyi, 1976; Newell & Simon, 1972; Unsworth, 2001). Over the following 16 months, I continued reading this literature and began interpreting my data through the lens of problem solving theory. During that time, my field notes transitioned from being purely descriptive to being both descriptive and interpretive. Toward the end of this process, I learned about Seidel and O'Mahony's piece on "coherence," which played an important role in the subsequent framing and analysis of this study.

Developers generally made steady progress on the product over 24 months, but they also underwent two watershed events that triggered intense periods of reflection, which led to significant changes that affected their representation of the overall product. The first occurred in month 11 and began when developers confronted unexpected resource constraints that forced them to re-assess their goals and priorities. The second event occurred in month 18 and began when developers received negative feedback from users during an early-stage usability test. Therefore, the overall development process consisted of three major phases of steady progress that were separated by two watershed events (Gersick, 1988, 1991), which I describe in more detail below. In the final four months of my study, developers completed their work for all conceptual features that were released in version one of the product. During this period, I spent less time collecting data at Roboto and more time cleaning data and preparing it for analysis.

Meeting Transcriptions. Early in the project, I gained permission to record meetings that were relevant to my research, and I attended more than 450 meetings as I tracked the development of several conceptual features over time. For this study, I theoretically sampled meetings based on Griffith's (1999) feature-based theory of sensemaking. According to this theory, features can be classified as either "core or tangential," which refers to the extent that features are related to the overall identity of the product. Features can also be classified as either "concrete or abstract," which refers to the extent that features can be described by objective facts. This theory explains how people make sense of new technologies (Weick, 1990); therefore, I used it to sample features that I believed would produce high variation in group dynamics related to constructing a shared representation of this innovation. In total, I sampled 110 meetings across six features, which resulted in 116 hours of transcribed audio; I summarize the distribution of these meetings across the six features in Table 3.1.

These features allowed me to collect enough depth of data to capture important developments for each feature while also capturing a broad range of group dynamics based on feature characteristics (Griffith, 1999). Messaging and Photography were *concrete* features that developers considered *core* to the product's identity; Character and Interaction Behaviors were *abstract* features that were *core* to the product's identity; and Utilities and Visual Style were *concrete* features that were *tangential* to the product's identity. I did not include features that were abstract and tangential, because I thought they would have a weaker influence on the process of constructing a shared representation for the overall innovation.

Table 3.1: Summary of Data Sampled for Analysis

Name of Feature	Description	Feature Characteristics	Period of Development	Meetings Sampled	Hours of Obervation
Messaging	Included any sub-features that allowed users to manage information within the household such as creating messages, reminders, or lists.	Core & Concrete	Months 1–18[a]	22	23
Photography	Included any sub-features that allowed users to use the robot's camera to record media such as creating pictures or video.	Core & Concrete	Months 1–21	22	24
Character	Included any sub-features that allowed users to interpret a "living" robot character such as personality, sound design, and body animations.	Core & Abstract	Months 4–21	23	26
Interaction Behaviors	Included any sub-features that allowed users to interact with the robot such as turn-taking error recovery, and the graphical user interface.	Core & Abstract	Months 4–21	23	24
Utilities	Included any sub-features that allowed users to manage basic robot functionality such as volume, alarms, timers, and wi-fi connection.	Tangential & Concrete	Months 4–21	12	9
Visual Style	Included any sub-features that affected the visual style of screen graphics such as color palette, font style, and visual animations.	Tangential & Concrete	Months 1–10	8	10
			Total	**110**	**116**

[a] Messaging was intentionally eliminated as a feature. All other features were implemented in the final version of the product.
Feature characteristics are based on two dimensions proposed by Griffith (1999): (1) core versus tangential; and (2) concrete versus abstract.

Supplementary Data. To complement my observations and meeting transcriptions, I regularly conducted informal interviews with participants and collected archival data such as online documents and pictures or videos of physical artifacts (Yin, 2014). I used informal interviews to better understand how participants defined and solved problems based on their internal representations; I also compared my interpretation of events to theirs so that I could better understand how they made sense of ambiguous situations while developing the product (Lofland et al., 2006). I used online documents—along with pictures and videos of artifacts—to capture the various prototypes that developers created throughout the process (e.g., Bechky, 2003a; Carlile, 2002). These ranged from sketches, spreadsheets, and simulations during earlier stages of development to a fully functioning robot during later stages of development.

3.3.3 Data Analysis

In this study, I develop a theory for an emergent innovation process by using an inductive approach that is informed by the grounded theory method (Corbin & Strauss, 2008; Langley, 1999; Locke, 2001). While in the field, I iterated between collecting data and reading literature to increase the clarity with which I interpreted events as they unfolded. However, I did not formally analyze data until Roboto completed developing their product and were preparing to release it to market. I did this for theoretical reasons, because I had to wait for a coherent representation of the product to emerge before I could determine which meetings were related to the process of constructing that representation. Furthermore, I could not withdraw from the field to analyze data while potentially important events that were related to process of constructing a coherent representation occurred. When I did conduct formal analysis, I iterated between analyzing data and reading literature with the aim of generating new theory that made novel contributions to literature on innovation while also being firmly grounded in the data.

Stage 0: Sampling Data for Analysis. I began analyzing data by reading my field notes in sequential order. My goal was to construct a descriptive narrative of events that unfolded at Roboto (Langley, 1999; Van Maanen, 1988) that were related to the process of constructing a shared representation of the product. I knew that the two watershed events in months 11 and 18 played an important role in shaping the way that developers conceptualized the product, but the details of how developers collaborated with each other during these events were still obscure. Therefore, I separated my data into three phases of development and focused on describing the details of each phase including the two watershed events. I defined the first phase as comprising an *ambiguous concept* that spanned between months 1–10, the second phase as comprising a *clarified concept* that spanned between months 11–17, and the third phase as comprising a *coherent concept* that spanned between months 18–24. I also identified important meetings that influenced the construction of the coherent representation over time, which allowed me to sample the 110 meetings that are summarized in Table 3.1 (Eisenhardt, 1989).

Stage 1: Identifying Modes of Collaboration. The grounded theory method relies on analyzing a large number of comparable "events" to detect patterns across events and aggregate patterns into phases of development over time (Langley, 1999). For this study, I defined an event as any *interaction* that included multiple people working together to develop a feature (e.g., Photography) or sub-feature (e.g., taking a photo) of the product. These interactions included a wide range of activities that have been associated with the innovation process in prior literature such as generating ideas, elaborating ideas, evaluating ideas, exploring ideas, gathering information, defining the problem, changing the problem, or choosing a solution (Cromwell et al., in press). I excluded interactions that were not related to developing features listed in Table 3.1, and I ignored all generic chatter about things like social lives, company matters, or topics that were unrelated to developing features for the product.

Beginning with the first meeting in my dataset, I conducted micro-analysis of the transcripts (Corbin & Strauss, 2008), using open line-by-line coding (Charmaz, 2006) to identify the communication patterns of how groups confronted and resolved ambiguity while developing features. As I coded data across all six features, I used constant comparative analysis to develop categories of collaboration (Miles & Huberman, 1994), which led me to notice a theme in my data, in which developers engaged in two distinct *modes of collaboration* to resolve ambiguity. One mode was *symbolic*, meaning that discussions were peppered with *metaphors* as developers communicated with each other; the other was *descriptive*, meaning that developers focused on describing concrete details of features or sub-features without metaphors; whenever they confronted ambiguity, they typically used short *vignettes* to communicate with each other. I describe these two modes of collaboration in more detail in the findings.

Stage 2: Identifying Collaboration Practices. Next, I conducted a focused coding of the data to develop axial codes for group dynamics that took place within each mode of collaboration (Charmaz, 2006; Locke, 2001). During this analysis, I noticed another theme emerge. Developers confronted two types of ambiguity, which led them to engage in two types of discussion: *interpreting existing ideas* and *generating new ideas*. The first type of ambiguity occurred when developers had diverse representations of an existing idea that had already been implemented in a past prototype. During these discussions, developers interpreted ideas with metaphors, vignettes, or a combination of the two to construct a shared representation of existing ideas. The second type of ambiguity occurred when developers had diverse representations of a new idea that they wanted to implement in a future prototype. During these discussions, developers generated ideas by—again—using metaphors, vignettes, or a combination of the two to construct a shared representation of new ideas.

Therefore, I found that both modes of collaboration (descriptive collaboration and symbolic collaboration) each included two types of discussion (interpreting existing ideas and generating new ideas). Therefore, I identified four collaboration practices that helped developers resolve ambiguity while developing features: (1) *interpretive metaphors*, (2) *interpretive vignettes*, (3) *generative metaphors,* and (4) *generative vignettes*. Interpretive practices helped developers resolve ambiguity when interpreting existing ideas from past prototypes, and generative practices helped developers resolve ambiguity when generating new ideas for future prototypes. Metaphors were references to concepts that came from developers' prior knowledge and experience, and vignettes were concrete and specific examples that helped developers illustrate abstract ideas to each other with more concrete language. In Table 3.2, I provide several examples from the data to illustrate each type of collaboration practice.

Stage 3: Constructing a Process Model. As I continued coding data from the second and third phases of development, I gained exposure to different types of meetings and noticed another theme emerge in my data: Interactions often began when developers reviewed existing ideas from past prototypes, and they ended when developers converged on new ideas that would be implemented in future prototypes. Sometimes interactions were brief, lasting only a few seconds as developers quickly resolved ambiguity and moved onto other ideas. Other times they lasted several hours or stretched across multiple meetings as developers confronted more ambiguous situations, which occurred when (a) developers needed to interpret ideas from more perspectives, (b) developers had stronger disagreements about ideas, and (c) developers needed to disentangle more interdependent ideas. Longer interactions included more iterations between the two types of discussion described above (interpreting existing ideas and generating new ideas); but overall, they still began when developers reviewed existing ideas in past prototypes and ended when developers converged on new ideas to be implemented in future prototypes.

Drawing from all the themes described above, I used chains of logic to begin building a preliminary process model (Miles & Huberman, 1994), which included a cyclical iteration of interpreting existing ideas, generating new ideas, and implementing new ideas through prototypes. I concluded my analysis by conducting focused coding of the data from the two watershed events, which allowed me to identify the specific factors that influenced the process of constructing a shared representation of the product during these intense periods of reflection.

During this analysis, I elaborated and refined the process model to create a generalized model of an emergent innovation process that was firmly grounded in the data that I collected from Roboto (Corbin & Strauss, 2008; Eisenhardt, 1989; Locke, 2001).

Table 3.2: Illustrative Quotes for Co

Collaboration Practice (Feature)	Illustrative Quotes[a]
Interpretive Metaphors	
(Interaction Behaviors)	NATALIA: I think that in general, a larger point that this touches upon is that, the only way this whole experience of [Robo] is going to work is if he can multi-task. It's going to be so limiting if you can only do one thing at a time. The whole way that you can have multiple apps open or multiple software. Like If he can only do one thing, that's lame. STUART: ***It would be like a really annoying person*** .
(Character)	LANCE: This sound here I think is very exciting [beep sounds]. The key to this whole thing where it's upper frequency but it's still in the zone where it could be "hey," "I love it," "look at that cool thing" ... or, "I haven't seen you for all day long." CHUCK: ***It sounds very R2-D2*** . NATALIA: They almost sound outdated ... ***they sound like fax machines or dial-up*** .
(Photography)	VICTOR: Alright, can I give you my rough high level diagnosis of this? So we started with a sharing model that's kind of awkward, right? You have this one loop thing, like multiple loops, you could be in different sets of loops. Every permutation of many to many loops is possible, right? TYSON: Right. VICTOR: I've seen this before. ***This is exactly pretty much the sharing model of Google Plus circles, more or less*** .
Interpretive Vignettes	
(Photography)	NATALIA: I had a question... So the thing was that [Robo] will center on the target before he takes a photo. ***So if I'm standing here, he'll turn until I'm centered***... But sometimes—rule of thirds—you don't want to be in the middle. ***What if I'm taking a picture with me and the base and I want to be like this, is he constantly gonna be moving to center me? And I'm like, "No no no, I want you to just look at me."***
(Messaging)	STUART: So this is [Mobile] App Reminders. MURPHY: So what does that mean. ***Is it like, "At 6:30 tomorrow, tell Stuart happy birthday" And then you don't see him 'til 6:30, whereas if I were to say, "Remind [Stuart] at 6:30 to take out the trash." Do you see it right away?*** STUART: I think you, I think you time delayed it for a reason, ***so if you say, "Tell [Stuart] to pick up trash." He says, "Great, I'll tell him next time I see him."... He would put it in the App, and then next time he sees me he says, "Oh, hey, Murphy said pick up the trash."***... Right?
(Visual Style)	MURPHY: Essentially the screen that we're looking at now is an ambiguous message screen ***like, "Hey, [Robo], send a message to Hugo." [Robo] will prompt, "Oh, what's the message?"*** This is sort of styled after the next few screens, which is the idea of word streaming... it's meant to be a dynamic font size. Essentially it will paint the words on scaled larger for the fewer words. As it fills up, it sort of shrinks down. It should be as fluid as possible. STUART: I think it's clear. Perfect.

Table 3.2 (Continued): Illustrative

Collaboration Practices (Feature)	Illustrative Quotes[a]
Generative Metaphors	
(Utilities)	MURPHY: How many timers can [Robo] run concurrently? One. ***It's sort of like the microwave above the oven***. We okay with that? LANCE: Yup.
(Character)	MURPHY: Everything he does is improving the relationship you have with him. We can also take that to mean he's teaching you how to use him. But I would also want things like, he gets you the information you want. He teaches you to think. ***He's a teacher, maybe***. STUART: Yeah.
(Visual Style)	NICOLE: We talked about how we can use four colors ***for this mid-century modern graphic design type thing*** that's just sort of not blatant, but hinted at … That sort of look which felt really fitting because … It was kind of winking to a period that was very- STUART: Futuristic NICOLE: Yeah, referencing futuristic, but a very positive view, which is kinda right for a robot, right? ***It's not this sort of new humanoid creepy future robot. It's more like cute, Tomorrowland robot.***
Generative Vignettes	
(Messaging)	STUART: I thought the idea was fun where ***as you speak, [Robo] was filling up the screen with text. So if you say, "Tell Lance to call me," right? Like it's just big, boom boom, boom. If I'd say, "Tell Lance to call me because I'm going to be running late next week, and that Murphy is going to be blah blah blah," and it fills up until there's so much text that it just starts showing little squiggles.*** LANCE: Or scrolling. STUART: But it's like cramming, cramming, cramming. And I always thought that concept was cool.
(Interaction Behaviors)	LUKE: It's like you're in the middle of a question, and ***you ask for help: "Yes, play it." If there's no help there, go up a level. Is there any help for this task within a [feature]? Yes, great, play it. Go to the top of the [feature] and say, "Do we have help for this?" Yes, great play it. And then, let's say you go all the way to the top of the [feature] and [Robo] plays a help. It's like, "Well you're in Messaging. You can leave messages. You can set reminders for yourself."*** There's currently no way to go back down where you were when you requested for help. So maintaining state is yet another technical problem we have.
(Utilities)	MURPHY: So, what happens when the timer goes off while [Robo] is doing something? There are some instances where it makes sense to interrupt, ***you know, "D-d-do, d-d-d-do, d-d-do." So the timer trumps other things.*** LANCE: I think it's annoying but the timer has to interrupt, because I can come up with a very specific reason why I want that timer to let me know… It may not have to stop anything… ***It could be the timer starts ringing and you're like "Oh, hey [Robo] stop the timer."*** STUART: You don't want a situation where ***you set a cooking timer, and a kid comes over, wants to hear a story from [Robo] and you have to tell the kid "No, you can't because I have a timer going right now." It could be cool if he's telling a story, and he's like "Oh, hold on a second. Hey Lance, your timer's up."***

[a] Text highlighted in ***bold italics*** reflects the collaboration practice listed in the left-hand column.

3.4 Findings

In the following sections, I present the findings that emerged from my analysis. First, I describe how two modes of collaboration—*descriptive collaboration* and *symbolic collaboration*—yielded two qualitatively different ways that developers engaged in the cyclical process of interpreting existing ideas, generating new ideas, and implementing new ideas through prototypes. Second, I show how the overall product concept for the social robot emerged through three phases of development, which included (1) interpreting *illustrative prototypes* to develop an *ambiguous concept*, (2) interpreting *isolated prototypes* to develop a *clarified concept*, and (3) interpreting *integrated prototypes* to develop a *coherent concept*. Lastly, I synthesize these findings to theorize an *emergent innovation process* that allows groups to discover a coherent representation of an innovation near the end of the development process.

3.4.1 Two Modes of Collaboration

Prior theory suggests that developers should construct a shared representation of the innovation at the beginning of the development process (Cronin & Weingart, 2007; Kurtzberg & Amabile, 2000; Okhuysen & Bechky, 2009; Reiter-Palmon, in press; Seidel & O'Mahony, 2014). At Roboto, this would have been equivalent to developing a shared understanding of the overall product concept of the "social robot" first, and then developing a set of features that exemplified this concept. Although developers at Roboto did consider this approach, they believed it would be too complicated and thus adopted an entirely different approach. The following discussion, in which a group of two designers and a software engineer are discussing how to develop one of the product's core features—Interaction Behaviors (month 3)—reveals this decision.

> LUKE (designer): I was thinking about this last night and was wondering if focusing on the core Interaction Behaviors first might be useful, because everything else flows from those.

LANCE (designer): No. Those are too complicated. They're the most complicated things that we could possibly do. These behaviors are so complicated that I want them to be an emergent quality. First, we get all these features [i.e., Messaging and Photography] working and say, "Okay, the features work, they make sense, they're compelling, they're directionally right." Then [Interaction Behaviors] like error conditions, turn-taking, speaking, and recognition; all that stuff needs to be emergent from the features… I think putting them all together and making it all sing is kind of the last level of things that we need to conquer. Luke, do you think that's directionally appropriate?

LUKE: I think that's correct. I think we just—again—need to be very disciplined about identifying when we start seeing those emerging qualities.

LANCE: I definitely agree with that. I definitely agree with that.

RAPHAEL (software engineer): This is kind of the core of the core, in a way, right, because to some extent all features at their core will have some of these Interaction Behaviors, right?

LANCE: Exactly… This is right. I agree, it's emergent.

It seems that the developers at Roboto recognized that developing the product's core concept at the beginning of the process could have been valuable. As Raphael describes it, Interaction Behaviors are "core of the core" to the product's identity (Griffith, 1999), and Luke suggests that "focusing on the core Interaction Behaviors first might be useful, because everything else flows from those." Therefore, developing Interaction Behaviors may have helped the group develop a shared understanding of the product concept early in the process, which could have guided development on other features later in the process. However, the developers also seemed to recognize that Interaction Behaviors were so ambiguous that it would have been challenging to develop them. According to Lance, Interaction Behaviors are "too complicated… the most complicated things that we could possibly do." Instead, he suggests that they take an emergent approach to developing the product: "First, we get all these features working… Then interaction behaviors… need to be emergent from the features." By "features," Lance is referring specifically to the more concrete features such as Messaging and Photography.

The decision to develop the product's features (i.e., developing the solution) *before* developing the product's overall concept (i.e., defining the problem) may seem sensible; indeed, some scholars argue that such an emergent approach is an important and even necessary part of the innovation process (Finke et al., 1992; von Hippel & von Krogh, 2016). However, this approach presents a fundamental puzzle that prior literature has yet to address, which is that groups had to develop the product's features without understanding the goals and criteria that the features were supposed to satisfy. I found that groups at Roboto overcame this challenge by engaging in two different modes of collaboration—descriptive collaboration and symbolic collaboration—that allowed them to make progress on individual features without having a shared understanding of the overall product concept.

Descriptive Collaboration. When developers engaged in descriptive collaboration, they focused on describing features with concrete and specific language. These interactions typically began when developers reviewed existing ideas from a past prototype, and they often experienced ambiguity that required them to first construct a shared representation of existing ideas. The following discussion, in which a designer and product manager are reviewing an idea on a spreadsheet that describes how users can search for photos and videos on the robot (month 9), illustrates this dynamic.

MURPHY (designer): So, for the requirement RP02, which is the photo album. So, the requirement says that you can search by time. Should we also be able to search by type [i.e., photos or videos]? And I ask this because the design right now is that there's a combined album and it's just sort of like: photo, photo, video, video, photo, video. It's just sort of a chronology of everything you create in Photography. And working on the wire frames, it feels like I should be able to say it like, "Hey, show me *photos* from this weekend. Show me *videos* from Christmas."

SANJAY (product manager): So, I would bundle those into time. Because those reference a time.

MURPHY: Sure. But you could just say, "Show me my *photos*," and it's just like photos.

SANJAY: Yeah, that's right.

MURPHY: Okay…

SANJAY: But if I say, "Show me my photos from last year," it will show last year. "Show me my photos from last week, from December, Christmas, Thanksgiving." It should understand all that time-related stuff.

MURPHY: Yeah, so the question was, as far as I could tell, the requirement itself didn't reference specific search *by type*, like to search by photos only or videos only.

SANJAY: Oh correct. I think that's right… Yeah, I think we ought to err on the side of photos and videos are the same. So, if you ask for photos or videos, it should show you both. Because otherwise I think it gets too confusing for people

MURPHY: Okay.

In this discussion, Murphy poses a question to Sanjay to understand whether or not users can search for media *by type* (i.e., photos or videos) instead of by time. At first, it seems that Sanjay does not understand Murphy, because in line 7 he emphasizes that he would "bundle those into time," and he ignores the distinction that Murphy makes between photos and videos. This reflects ambiguity, because each developer has a different representation of the idea about how users can search for media on the robot (Cronin & Weingart, 2007; Newell & Simon, 1972). Sanjay believes that users should only search by time, and Murphy believes that users should also be able to search by type. However, by the end of the interaction, they resolve this ambiguity and construct a shared representation of the idea—which is that users can only search for photos and videos by time because searching by type would be too confusing.

A key collaboration practice that helps them construct this shared representation is that they use the same vignette to communicate with each other throughout the discussion. When Murphy poses his original question, he uses a vignette to illustrate his representation of the idea: "I should be able to say it like, 'Hey, show me *photos* from this weekend. Show me *videos* from Christmas.'" This concrete and specific example allows other members of the group to better understand what he means by the abstract and more ambiguous idea of "searching by type." But at first, Sanjay does not fully understand Murphy, so he uses the same vignette to illustrate his own representation of the idea: "But if I say… 'Show me my photos from last week, from December, Christmas, Thanksgiving.' It should understand all that time-related stuff." This allows Murphy to recognize that there is a misunderstanding between them, which leads him to restate the question and subsequently bridge his cognitive difference with Sanjay.

This discussion demonstrates how interpretive vignettes helped developers at Roboto communicate with each other to overcome the ambiguity that came from having diverse representations of existing ideas. It also reveals how vignettes are fundamentally different than narratives. Vignettes are brief examples that developers use to create imagery in the minds of other developers so that they can better communicate a vague or ambiguous idea. However, they do not reference a broader or more complex story that is collectively understood by the group (cf. Boje, 1991); thus, they lack the broader meaning and significance that can exist for narratives (Bartel & Garud, 2009; Lounsbury & Glynn, 2001). As the interaction continues, other developers in the group start contributing, and they use the same vignette as before to illustrate their representations to the group. For example, a product manager named Natalia voices her concern about the idea that Murphy and Sanjay agreed to, spurring additional debate.

NATALIA (product manager): So, if I said, "Show me *photos* from last month," there would also be videos in the list?

SANJAY: It'll show me everything that was either a photo or a video, anything that was done with Photography, or sent to me.

NATALIA: But do you think it's weird that I specifically said photos and it's also showing me videos?

SANJAY: Well, if I said, "Show me my photos from last Christmas," I think I'd want to see the videos if there were some videos that I took.

MURPHY: That feels easier, because it is weird to be like–

SANJAY: "Show me photos *and videos* from last year."

MURPHY: Yeah, exactly, that's awkward… I agree that it feels like we should just return both types. Although part of me is like, I asked you for photos and you returned videos. That's weird. It seems like you didn't understand me. That's like saying, "Show me the weather," and you get: "How 'bout some sports?"

Natalia begins by posing multiple questions to the group. First, she tries to understand the representation that Murphy and Sanjay agreed to: “So if I said, ‘Show me *photos* from last month,’ there would also be videos in the list?” Then, she raises a concern that challenges this representation of the idea: “But do you think it's weird that I specifically said photos and it's also showing me videos?” At this point, the group reverts back to having ambiguity about the idea, because Natalia re-introduces the competing representation that users should be able to search for media by type. To resolve this ambiguity, they begin interpreting the potential value that each representation brings to the user experience. In line 8, Murphy says that searching by time “feels easier," but in line 11, he also notes that it can make the robot seem like it "didn't understand me;" and in line 10, he says that searching by type feels "awkward."

Also note that the group continues using the same vignette from the previous discussion to communicate with each other. Sanjay illustrates one representation by saying, "Well, if I said, 'Show me my photos from last Christmas,' I think I'd want to see the videos if there were some videos that I took." Then he illustrates the other representation by saying: "Show me photos *and videos* from last year?" After each comment, Murphy describes the pros and cons of each representation without being confused. Therefore, vignettes served as vehicles of communication that helped groups discuss diverse representations of an idea without necessarily having shared goals (cf. Cronin & Weingart, 2007). This also extended to the process of generating new ideas, as revealed in the following discussion when another group member—a software engineer named Sebastian—uses the same vignette as before to generate a new idea, which resolves the ambiguity in the group and concludes the interaction.

1 SEBASTIAN (software engineer): You could be like, "Here's your photos, and I included the videos too."
2 MURPHY: Yeah. No, I mean seriously, he could say, "Here's everything from Christmas."
3 SEBASTIAN: Right.
4 MURPHY: That might be fine.
5 SANJAY: That sounds okay to me. I'm gonna defer to you guys on this one.

This entire interaction begins when developers interpret an existing idea from a past prototype (i.e., searching for photos and videos by time), and it ends when they generate a new idea that will be implemented in a future prototype (i.e., changing the phrase that the robot uses when delivering photos and videos to users). By using interpretive vignettes and generative vignettes throughout the interaction, developers can clearly communicate with each other as they discuss diverse representations of an idea and resolve ambiguity that arises from them. Thus, descriptive collaboration is one way that groups can construct a shared representation of an individual idea—thereby making progress on a feature—without having a shared understanding of the overall product concept.

Symbolic Collaboration. Another way that developers made progress on features was that they engaged in symbolic collaboration, which had many similarities with descriptive collaboration. Specifically, these interactions also began when developers interpreted an existing idea from a past prototype and ended when they generated a new idea to be implemented in a future prototype. Developers also used vignettes throughout the process to communicate with each other as they discussed diverse representations of an idea. For example, the following interaction between two designers and a product manager begins when they interpret an idea on a spreadsheet about how users will "read messages" on the robot, which quickly leads to a discussion about diverse representations of the idea (month 6).

> STUART (designer): Okay. So, this requirement is for reading messages.
>
> MURPHY: Okay, so this is like, if you come downstairs and you're like, "Hey Robo, do I have any messages?" He would be like, "Yeah, you've got a couple in there, a couple new messages, one's from Stuart, it says...." I think of it like we were talking about in Photography, like our messages are not stored on the robot [i.e., are stored on the cloud], but Robo can retrieve them via search and filters.
>
> STUART: Maybe, but I guess in some ways the question is, should this act the same way—where everything's stored in the cloud, you browse it, and it automatically retrieves? Is it weird to say that all the *photos* are not stored on robot but they're still accessible, and *messages* stay on robot? Does that just seem like a random distinction, or do we just say, "Well, messages are different?"
>
> CRYSTAL (product manager): So, what about the same concept we had in Photography—where one person deletes a shared photo, and it gets deleted for all accounts. So, if we're saying that Robo delivers a message to a family, and we're the family: on the robot it gets delivered to Stuart, and then Murphy comes up to Robo, Robo delivers the same message to Murphy, because Murphy hasn't read it yet. So, on the app, if one of you deletes it, does it get deleted everywhere, or is it just deleted from your app?
>
> STUART: Yeah. I think Robo's deleting it from the shared cloud account.

In this discussion, developers are experiencing more ambiguity than developers in the previous interaction because they are considering three alternative representations of the idea instead of two. Murphy thinks that messages could mimic the Photography feature so that they are stored on the cloud and "Robo can retrieve them via search and filters;" Stuart thinks that messages could be stored locally on the robot, but acknowledges that it may "seem like a random distinction" when juxtaposed with the Photography feature; and Crystal thinks that messages could be similar to shared photos, such that "if one of you deletes [a message]… it gets deleted everywhere." They also use vignettes throughout the discussion to illustrate their diverse representations of the idea to each other.

However, what made symbolic collaboration at Roboto different from descriptive collaboration was that developers also used *metaphors* throughout the process, which provided them with another channel of communication to better understand each other and resolve ambiguity. For example, as the developers continue discussing the Messaging feature, they converge onto one of the three representations from above, which triggers the use of several metaphors to help them make sense of the representation.

> CRYSTAL: So, the concept that we're gonna move forward with is, regardless of the feature, everything is shared. So, if things are sent to the robot, it doesn't actually matter who it's sent to… If one person in the group deletes anything—photo, video, or message—then it gets deleted for everyone.
>
> STUART: Right… So, if it's all in the cloud, you don't have your own local copy. It's just like you're editing on Google docs… Think of web-based Google docs versus like a locally synced folder, right? The rules are cleaner when you're talking about a centrally shared thing. There's only one instance of it as opposed to all these little instances, which I think can get messy.
>
> CRYSTAL: So, then what happens if you delete a message from the inbox before Murphy has seen it?
>
> STUART: Yeah, then I gotta delete it in the shared message.
>
> MURPHY: I kinda think that Robo is like the helper. If I said, "Hey, send everyone this note: Happy Halloween." And Robo is like, "I will tell everyone I know Happy Halloween." So, I tell Stuart, and if Stuart deletes it, then does Robo go out and still deliver this message to everyone else? Maybe that's weird.
>
> STUART: I shouldn't be able to prevent Crystal from seeing a message that you wanted to go to her… so I get the Happy Halloween message, and I'm like, "Ah, delete that, I hate Halloween," and then she doesn't get it? That is weird, I agree with you on that.

Like the previous interaction about searching for photos and videos, this group constructs a shared representation of the idea, only to revert back to having ambiguity about the idea once someone asks a question that challenges their shared representation. In lines 1–7, Crystal and Stuart agree that reading messages should mean that, "If one person in the group deletes anything—photo, video, or message—then it gets deleted for everyone." Then in line 8, Crystal raises a concern with this representation: "So, then what happens if you delete a message from the inbox before Murphy has seen it?" Also similar to the previous interaction, the group responds to the ambiguity by interpreting the value of each representation, using vignettes to communicate with each other. In line 10, Murphy describes sending a "Happy Halloween" note to illustrate a new idea that "Maybe [is] weird." Stuart then relays this vignette back to the group using his own words, subsequently agreeing with Murphy: "That is weird."

Metaphors are also peppered throughout the discussion to help improve communication. For example, in lines 4–5, Stuart uses an interpretive metaphor to say that their shared representation of the idea is "just like you're editing on Google docs… versus like a locally synced folder," which helps him communicate his point that "the rules are cleaner when you're talking about a centrally shared [message]." Similarly, in line 10, Murphy uses a generative metaphor—"I kinda think that Robo is like the helper"—to illustrate a new idea to the group. In each case, the metaphor not only transfers prior knowledge and experience to the social robot (Dahl & Moreau, 2002; Gentner, 1983; Hargadon & Sutton, 1997; Schön, 1993), but it also helps developers understand each other and construct a shared representation of ideas while developing the feature. Metaphors were particularly effective when all group members understood them, as revealed in the following discussion that concludes the interaction.

CRYSTAL: What if a message is delivered to one person, then that person can delete it at any time after they've read it; if a message goes to multiple people, it can't be deleted until Robo has delivered it to all recipients?

MURPHY: Maybe. If we're moving to this model of nothing on robot and all messages on the cloud, there is no real concept of a shared inbox. If I say, "Send this message to these two people," I'm essentially duplicating the message. Stuart gets it, Crystal gets it, and they're just separate discrete units that you can ignore, delete, whatever. They don't have a relationship to each other anymore.

STUART: It's almost like more of an event log than a message anyway. When you think about it, it's a very subtle distinction between your Gmail inbox and your Twitter feed, but the effect is hugely different, which is that you feel like you should empty your inbox, but you don't feel like you should empty your Twitter feed. So, it's an event log, right?... Like if Murphy said, "Happy Halloween to the family." That's it.

MURPHY: Yeah, right, yeah, yeah.… I'm 100% clear.

CRYSTAL: Yeah, okay, so I think I have it.

Throughout the development process, groups at Roboto often used diverse representations to interpret existing idea and generate new ideas while developing features. The interactions above reveal that vignettes and metaphors were valuable practices that helped groups clearly communicate with each other as they discussed these diverse representations. Furthermore, that when these practices were used together, they facilitated a symbolic mode of collaboration that was a powerful tool to help groups construct a shared representation of ideas—thereby helping them make progress on individual features—without having a shared understanding of the overall product concept.

3.4.2 Three Phases of Development

Groups engaged in both descriptive collaboration and symbolic collaboration throughout the development process, and I distinguish between these two modes of collaboration because they influenced the emerging product concept differently. Descriptive collaboration helped groups stay focused on developing *one feature*, whereas symbolic collaboration included metaphors that could be used to guide collective thinking across *multiple features*. For example, in the interaction above, developers used metaphors such as “Google docs,” “helper,” “Gmail inbox,” and “Twitter feed” to develop a shared representation of the idea about “reading messages.” One of these metaphors—the “helper” metaphor—was also used in an earlier discussion when the same developers were working on the Character feature (month 4).

STUART: So, here's a thought experiment. We could say that Robo has this personality. He is who he is. He has his own personality. The role he has in the house is to be like the family butler kind of thing. So, his role in his mind is to be helpful. That's why he's like, "I can share messages" and, "You can ask me to do stuff, and I'll do it for you. I can take pictures of you guys."

MURPHY: And that's broad enough where you and your family can be like, "Wow, he's like a butler!" Whereas I could be like, "Oh, he's like a dog!"... So you don't have to come out and say, "He is a butler."

STUART: No, definitely not. But the point is, we can have a good answer for why he has these features... I think he has these features in order to be helpful for his family.

Therefore, symbolic collaboration played an important role in helping groups construct a coherent concept across multiple features, which could potentially—over time—aggregate into a coherent concept for the *overall product*. Recall that developers at Roboto began the development process with an ambiguous understanding of the product. For example, Murphy emphasizes in lines 5–6 that the personality could make the robot seem both "like a butler" and "like a dog." In the following sections, I reveal how an ambiguous concept for the overall product evolved into a coherent concept through three distinct phases of development.

Phase 1: Developing an Ambiguous Product Concept. The first phase of development spanned between months 1–10, and it was characterized by high levels of ambiguity as groups struggled to develop a coherent concept—even for individual features. For example, in the following discussion, three designers are considering various concepts that could have been used to represent the Messaging feature, which would have influenced the way that they developed an idea about creating checklists on the robot (month 3).

> MURPHY: We came to the conclusion that… we can do what we want with checklists through messages, because we have this sort of open platform for communicating with the family… I think the idea of messages would be: you can communicate with members of your family, and if you want to say, "Pick up bananas and peppers from the store," that's one way to do checklists.
>
> LANCE: I think that's a different model. When I say, "Add paper towels to the list, add lemons," and then I go out and take a look at my list and check things off. There's a difference there that's not captured.
>
> STUART: I think we're saying that managing checklists is out, and I think there's a humble assumption behind this, which is that we have no idea what Messaging should be… So, we're saying let's create a blank-slate platform that allows people to use this thing in a way that meets their own expectations or meets the metaphor that they associate with it. So, if they want to think of Messaging as a robot's version of notes on a counter, then cool, they can do that. If they want to think of Messaging as voice enabled text messages, then they can do that. Or timed away emails. They can do that.

These developers begin with diverse representations of the idea for checklists. Murphy believes that checklists could be handled "through messages, because we have this sort of open platform for communicating with the family," whereas Lance believes that checklists should allow him to "take a look at my list and check things off." This ambiguity is difficult to resolve because they still have not developed a coherent concept for the Messaging feature. As Stuart describes in line 8: “we have no idea what Messaging should be.” However, rather than trying to converge onto one concept at this point, Stuart seems to embrace ambiguity and suggests that they develop a “blank-slate platform that allows people to use this thing in a way that meets their own expectations or meets the metaphor they associate with it.” This would enable them to use many diverse concepts to represent the Messaging feature such as “notes on a counter,” “voice enabled text messages,” or “timed away emails.”

When developers repeated this dynamic across all features of the product—including Photography, Utilities, Character, Interaction Behaviors, and Visual Style—it resulted in a large pool of potential concepts that could be used to represent the overall product. Some concepts had greater potential than others—such as “the helper” metaphor from above that groups used to develop the Character and Messaging features. However, Roboto was developing a breakthrough innovation that had never existed before. Therefore, although developers had many potential concepts to choose from—some of which were helpful for a particular subset of features—it was difficult for them to choose one concept that could be applied to all features of the product. The following discussion between designers trying to conceptualize the product highlights this challenge (month 3).

STUART: We're not building [Apple] Siri or that [IBM] Watson thing where you just say, "Ask me anything because I'm connected to the world's knowledge." We say, "No, Robo’s like a child with an open mind."… But then he also has this data feed? That doesn't seem right.

MURPHY: Right. I also feel like there are people who will just be like, "Cool, this thing's just like Siri." That's not wrong… There are people who might pick up on that.

STUART: True. I know with my Echo [i.e., Amazon Alexa], I tried asking just like random internet questions, and failed three out of five times, and then said, "Forget it." I haven't tried that again.

MURPHY: Yeah exactly. I think that's—

STUART: So, what expectations will people have? What's the metaphor? Our hypothesis is that, at least my hypothesis is that people will probably find some kind of metaphor. I just don't know what fits.

MURPHY: Right.

One of the reasons why developers at Roboto experienced so much ambiguity during this phase of development is because they were using *illustrative prototypes* such as sketches, drawings, spreadsheets or computer simulations to develop features. Although these prototypes served as boundary objects that facilitated coordination and communication within diverse groups (Bechky, 2003a; Carlile, 2002), they only conveyed limited information about the final experience of the product; thus, developers could only make incremental progress on features. To make more significant progress, they had to wait for more advanced prototypes to be developed later in the process. The following discussion, in which a group of designers are describing different "fidelity" prototypes (month 3), reveals this insight.

> MURPHY: I know that prototyping can take all sorts of forms and fidelity too. Are we at a place where the prototype could even be… developed?
>
> STUART: Not to punt on it, but I wonder if we could say, "Okay, this phase results with a level one prototype. This phase is a level two. This phase a level three." Basically, low-fidelity, mid-fidelity, high-fidelity. We could say… "Look, earlier in the process, it's all low speed and low-fidelity. As you get later in the process it's still low speed, but fidelity becomes a little more increased."
>
> LANCE: I think it's a great idea. Let's think about it more as related to—not about time, in terms of when you need to get it done—but in terms of objective… The objective is learning. We might do several low-fidelity things in a year from now, even though we're already into high-fidelity, in order to figure out how to finish [our work for] that week.
>
> STUART: Good point. Good point... Each prototype has a question and has an answer.
>
> LANCE: Are we trying to answer a light question, a serious question? What level of fidelity helps us answer that?... Now is the time where we challenge our assumptions. Then when we start radiating out to the next layer; it becomes clearer because we have this good foundational element.

This discussion suggests that prototypes had two important characteristics for developers at Roboto: (1) they were boundary objects that facilitated positive group dynamics under ambiguous conditions (e.g., Bechky, 2003a; Carlile, 2002), and (2) they were concrete objects that conveyed increasingly "high-fidelity" information to developers. These two characteristics helped me, as I analyzed the data, disentangle the group dynamics that took place across time as groups developed individual features. The cyclical iteration of interpreting existing ideas, generating new ideas, and implementing ideas through prototypes was consistent throughout the entire development process; consequently, groups engaged in descriptive and symbolic collaboration during all phases of development. However, what changed was that prototypes became increasingly higher "fidelity" over time, allowing groups to develop increasingly clearer concepts of the overall product. In Phase 1, groups mostly used illustrative—or "low-fidelity"—prototypes; therefore, they used a broad range of diverse metaphors when developing these prototypes. When this dynamic repeated itself across all features of the product, a highly *ambiguous concept* for the overall product emerged.

Phase 2: Developing a Clarified Product Concept. As developers continued making progress on features during the first 10 months of the process, they began developing *isolated prototypes*, which were collections of ideas from a single feature that were implemented on a functioning robot. These prototypes had the potential to convey "medium-fidelity" information to groups, which could have helped them develop more coherent concepts for individual features. But at first, developers encountered significant resources constraints that hindered their ability to make this kind of progress. The following discussion, in which a designer, product manager, and software engineer are trying to review ideas for the Photography feature (month 9), demonstrates how these constraints affected the development process.

> HUNTER (software engineer): Hey Robo, show me the album. … [silence]… Hey Robo, take a picture… [silence]… Hmm, that worked before.
>
> LUKE: Your paperweight looks much more elegant than mine ever did.
>
> HUNTER: Well, alright. So you can go to the album, you can delete things, you can look at things, you can touch them and remove them.
>
> NATALIA: So, the [software engineering] team is fully aware of how Photography is performing right now... I'm sure everybody's aware of it on the other teams too. So, it's a matter of prioritizing work because we can't really move forward in terms of programming, adding features, changing content, and adding assets if the performance is not there… We can run Photography in the simulator for what it is. But if we can't do our own user testing, or any of the other things that we want to do, then it's kinda pointless. So, performance is our biggest headache right now.

Hunter, begins by giving several commands to the robot: "Hey Robo, show me the album… Hey Robo, take a picture." Each time he encounters silence, prompting Luke to facetiously interpret the product as a "paperweight." The group's issue was that they confronted unexpected technical constraints that completely halted their ability to make progress on the Photography feature. As Natalia describes it, "we can't really move forward in terms of programming, adding features, changing content, and adding assets if the performance is not there." Although they could have "run Photography in the simulator," Natalia believes that it was "kinda pointless" at this stage of development. In response to these constraints, she suggests that they begin "prioritizing work" for the feature (line 7).

This discussion reflects a broader theme that was occurring across all features at the time, which was that developers were struggling to create more advanced prototypes because they were trying to develop too many features at once. Consequently, a small group of product managers began surveying each group in the organization (i.e., designers, software engineers, component engineers, etc.) to determine how much work they needed to complete on each feature before they could launch their product to market. This effort brought several constraints to the fore within Roboto, which triggered the first watershed event that forced developers to prioritize features of the product. The following discussion amongst executives reveals the challenges that they faced at the beginning of this process (month 11).

LANCE (executive): There's just one thing that we should be cognizant about at some point. There's a whole bunch of things that we consider core to the experience, whether it's turn-taking and a bunch of other stuff in this bucket, that all requires time and effort to do. That's a big chunk of time.

CALEB (executive): It's the old iceberg metaphor again. There's all that stuff that's under the water line that we have to do, and all we're doing now is basically arguing about the tip of the iceberg above the water line.

EVERETT (executive): I agree with the things you have identified in the bucket Lance… but Cadence just raised a super-important point that may be relevant… Cadence, go ahead. You started talking about marketing.

CADENCE (executive): Yeah, I understand our general desire to have initial core frequency-of-use stuff, but we may also choose things specifically because it sets a tone for the market, so that Robo is going to be awesome for this whole category of X.

CALEB: I totally agree with that. I think the challenge is going to be then how do we weigh those things as trade-offs, because we can't do it all? How do we trade off that value against some of these other values?

EVERETT: As of right now, if we had to craft a message about these top nine [features], it would be difficult… because I don't think you can take these features and slap a label on it like "communications hub" and have people understand what the hell we're talking about. I think we can say it's for a social robot, it's ideal for family usage, and then about controlling your environment. I know that's a little abstract, but we're building a platform so it's tough to get that silver bullet mono-message.

The biggest challenge these developers are facing is that they are trying to converge onto a smaller subset of features, but they do not have well-defined goals or criteria to help them make this selection. For example, Lance argues that "there's a whole bunch of things that we consider core to the experience… that all requires time and effort to do," whereas Cadence argues that "we may also choose [features] specifically because it sets a tone for the market." This tension provokes Caleb to ask, "then how do we weigh those things as trade-offs, because we can't do it all?" It seems that the primary reason why they do not have well-defined goals or criteria yet is because they do not have a shared understanding of the overall product concept. As Everett describes it in line 14, "I don't think you can take these features and slap a label on it like 'communications hub' and have people understand what the hell we're talking about." However, he seems to suggest that developing a concept—or "that silver bullet mono-message"—could help them develop the criteria that are used to converge onto a smaller subset of features.

Over the following 3 weeks, dozens of developers got involved in trying to develop that "mono-message" concept for the product. Throughout this time, they engaged in both descriptive and symbolic collaboration as they made sense of various ideas, sub-features, and features of the product. These interactions often lasted several hours or stretched across multiple meetings, because this process was a highly ambiguous situation that required developers to (a) consider many diverse representations of ideas, (b) overcome strong disagreements about ideas, and (c) disentangle many interdependent ideas when trying to select or eliminate features. Eventually, they identified two concepts that they believed could guide their thinking for the overall product, which was captured in the following discussion among a group of designers (month 11).

TEDDY (designer): In terms of the guiding light experience, I think Robo as a character in the experience is crucially important. In my mind, that is what differentiates us from [Amazon] Alexa. We've said that a million times. Alexa, you're going to buy an Alexa for X, but Robo is going to be this personified thing that lives inside your house. I think that is what sets us apart, period. If we do our jobs correctly, Robo will be an amazing experience because of the *character*.

STUART: Cool. Anything about people, in terms of… I guess it's kind of implied here a little bit, but how important is it that this satisfies the favorites in your household, versus like other people?

TEDDY: That's part of our assumptions, which I think ... Our guiding light I think is Robo is for the family. I think that's really important. That Robo's goal is to bring people together and help make relationships more meaningful. Right?

STUART: Yeah. That's just it. Our goal is for Robo to bring people together.

Teddy summarizes these two concepts—or "guiding lights"—for the overall product in lines 1 and 8. The first was "Robo as a character in the experience… this personified thing that lives inside your house," and the second was "Robo is for the family… Robo's goal is to bring people together to help make relationships more meaningful." It is important to note that both concepts already existed for the product. The first was closely associated with the Character feature, and the second was closely associated with Messaging feature, as Everett describes in another meeting (month 11): "The reason Messaging was included as a feature originally was because Robo's ultimate purpose is to create an intimate social network." Therefore, the first watershed event ended when developers at Roboto developed a *clarified concept* for the overall product, which comprised a subset of two concepts that were chosen from the wide range of ambiguous concepts that existed during the first phase of development.

Phase 3: Developing a Coherent Product Concept. With these two concepts in mind, developers continued engaging in descriptive and symbolic collaboration to make progress on features and develop more advanced prototypes. Like before, they confronted several unexpected resource constraints that forced them to re-adjust their goals, but nothing that required them to make a major revision to the product such as what occurred in month 11. Eventually, they developed an *integrated prototype* that included multiple features implemented together on a functioning robot. This prototype became an "alpha version" of the product in month 17, which was used in Roboto's first usability test that was conducted in users' homes rather than in the office. This test consisted of 25 external participants using the robot for about one week, and it represented a significant milestone for developers at Roboto.

However, it also began the second watershed event that triggered another intense period of reflection within the organization. During the first three days of the test, developers convened in a “war room” for several hours each day to review external feedback from participants. Some of the feedback was positive, as a designer named Erik describes in one of the meetings (month 18): “My [participant] was really impressed with the animation, like the body motions and capability. They described that as something very new.” But most of the feedback was negative, and a consistent theme emerged that the product did not provide enough “utility” to users—as discussed by two designers and a product manager on the third day of the test (month 18).

> TEDDY: Well, I asked her, "If you could have features for your daughter, what would they be?"… She said, "You know, playing kids music or saying, 'Hey, show me YouTube videos.' Or Robo could say, 'Good morning. Do you want to see a video?' Or, 'Here, I have a funny video for you. Do you want to see it?'"
>
> VICTOR (product manager): I’m not super surprised by that. At the end of the day, what are people used to—tablets, right? They're like, okay, if I'm going to entertain my kid with Robo, what are they going to say—*but* the status quo—unless you show them something better? We’re currently not showing them anything better.
>
> STUART: This is where I don't think the word "utility" necessarily helps us. This is like, if you're bored in your kitchen, and you're like, “I'm bored, I'm doing something. I want the robot to do something.”
>
> VICTOR: Yeah… I think a lot of this actually comes from our philosophical thinking—this 70-30 split—where we treat these as two separate things. We're like, “But character's a differentiator. Don't build utility.” Then it's like, “Wait, but no one has a reason to actually use the thing.” It's because we built all this personality into an idle state that looks really cute and purrs, but we haven't thought about infusing that with anything that's useful, because we have thought of character as categorically separate from utility.

This discussion reveals an important dynamic that unfolded at Roboto. Throughout the development process, developers experienced a tension between two goals that they called “differentiation” and “utility.” In month 11, they identified two “guiding light” concepts that were each aimed at achieving one of the goals: “Character” was aimed at making the product more differentiated on the market, and “bringing families together” was aimed at providing more utility to users. Then, throughout Phase 2, they developed increasingly more advanced prototypes that they believed were consistent with these two concepts (e.g., Seidel & O'Mahony, 2014). However, the usability test revealed that the integrated prototype that they developed at the end of Phase 2 was actually inconsistent with these concepts, as a designer named Mike describes in one of the war-room meetings (month 18): “The most glaring thing that stuck out was this feeling that it's too distracting and *not bringing families together*. In fact, they were trying to have dinner, and the kids were focusing on Robo and not the family conversation.”

Therefore, the external user feedback disrupted the shared product concept that they had developed in month 11. When confronted with this new source of ambiguity, developers began reflecting on how they got so far in the development process without having an accurate understanding of the product they were building. In the following discussion, a group of designers describe how prototypes may have played an important role (month 18):

TEDDY: Do you think we’re in this place right now just because it's actually in the hands of users for the first time?

STUART: Well, we've been testing every other week. A lot of these things aren't new.

MATTHEW (designer): Yeah, but it's the first time that face ID, voice ID, conversations, all these things that have been ... it’s the first feature-rich robot in people home's… with people living with it.

STUART: Yes, a cohesive experience, definitely. I think we've been making all these assumptions. We've just talked too much in the last year… We've spent so much time talking and engineering based on [our] opinions, and then we put it out there, and we’re like, “Oh, it’s not what people want.”

TEDDY: Right. Well, we didn't have a functioning robot before. [Interaction Behaviors] were broken. Remember when we did the [external] demo, and it was all puppeted?

STUART: But even prototypes… you can put those in front of people and still learn some things.

TEDDY: But it's a system. It's an ecosystem of things you can do. It's like, we can guess the best way to design a feature… yeah, he can send messages and he can take photos. But when you actually are there living with it, you walk up to it, and actually *experience* greetings, the whole thing is different.

This discussion suggests that there were important differences between prototypes that they developed throughout the process. The isolated prototypes from Phase 2 allowed developers to “guess the best way to design a feature” (lines 12–13), but they failed to convey high-fidelity information about the entire “cohesive experience” (line 6)—when all features were integrated together. As Teddy describes it in line 12: “it’s a system. It's an ecosystem of things you can do… when you actually are there living with it, you walk up to it, and actually *experience* greetings, the whole thing is different.” When this high-fidelity information was combined with the external user feedback from the usability test, developers were able to re-conceptualize the product through symbolic collaboration. The following discussion among designers reveals an important moment when a new concept for the overall product emerged (month 18).

> MATTHEW: What's the minimum viable utility? Like, what's the least amount of utility you can get that unlocks the value?
>
> TOBY (designer): Yeah, I think it’s way more than it has now... I mean just like—
>
> STUART: I think it's the personal assistant idea. Let me explain what I mean by that. Reminders, schedule, maybe weather. That's the information that matters to someone in their home. There might be a couple other things. But for a family: “What is going on today in this house? Remind me to get the blah blah blah.”
>
> TOBY: And he does it with a smile and maybe a funny comment.
>
> STUART: A little bit of usefulness, yes. Someone who's just there. They're your *friendly personal assistant*: “Anything I can do for you? Remind me about this. Okay.” That kind of very basic stuff—take a note from me, those kinds of things. I think that's a very basic utility that's useful... then there's a little joke.
>
> TOBY: Character is how he adds a little color to his utilitarian interactions. It's not the end in itself… Character isn't having an answer to, “Are you sad? Do you wish you had arms? Do you wish you had legs?” It's remind me to take out the trash, and later he says, "Don't forget to take out the trash. It smells in here." That's where his character comes through and where he'll be different than Alexa.

In this discussion, Toby and Stuart are generating new ideas about how they can achieve a “minimum viable utility” for the product. Before the usability test, they had mostly thought of concepts associated with “differentiation” (i.e. character) as being separate from concepts associated with “utility” (i.e., bringing the family together). As Victor described it in line 10 from the discussion above: “We're like, ‘But character's a differentiator. Don't build utility.’ Then it's like, ‘Wait, but no one has a reason to actually use the thing.’ It's… because we have thought of character as categorically separate from utility.” But now that they have developed an integrated prototype, they can develop a *coherent concept* that synthesizes previously disparate concepts into a new concept that did not exist in the organization before. Stuart calls it a “friendly personal assistant” in line 8, which Toby elaborates upon in line 11: “Character is how he adds a little color to his utilitarian interactions. It's not the end in itself… It's remind me to take out the trash, and later he says, ‘Don't forget to take out the trash. It smells in here.’ That's where his character comes through and where he'll be different than Alexa.”

This discussion captures the moment at which the coherent concept of a “friendly personal assistant” emerged at Roboto, but this concept did not necessarily permeate throughout the entire organization right away; instead, it permeated more slowly. Over the following six months, developers began focusing their effort on refining features to achieve both character and utility; by month 24, they had developed a second integrated prototype that became a “beta version” of the product, which was then used in a second usability test held in month 25. The external feedback they received from this test confirmed that the prototype was consistent with the “friendly personal assistant” concept. Therefore, by the time I withdrew from Roboto, developers had successfully constructed a coherent representation of the social robot and were preparing to launch it to market, which occurred five months later in month 30.

3.4.3 The Emergent Innovation Process for Groups

The events that unfolded at Roboto reveal an emergent innovation process—summarized in Figure 3.1—that describes how groups can discover a coherent representation of a product at the very end of the development process rather than defining it at the very beginning of the process (cf. Seidel & O'Mahony, 2014). This process consists of a cyclical iteration of activities that includes generating new ideas, implementing new ideas through prototypes, and interpreting existing ideas, and there are two ways for groups to engage in this cyclical process: descriptive collaboration, which includes communication through interpretive vignettes and generative vignettes, and symbolic collaboration, which includes communication not only through such vignettes, but also through interpretive metaphors and generative metaphors. Both modes of collaboration help groups construct a shared representation of individual features, but symbolic collaboration plays a particularly important role in helping groups develop a shared understanding of the overall product concept over time.

At the beginning of the emergent innovation process, groups use illustrative prototypes (i.e., sketches, simulations) to make progress on various ideas of individual features; thus, engaging in symbolic collaboration leads to an ambiguous concept for the overall product. As groups advance to developing isolated prototypes (i.e., prototypes of individual features), symbolic collaboration allows groups to develop a clarified concept for the product. Finally, when they advance to developing an integrated prototype (i.e., a prototype with all features), they

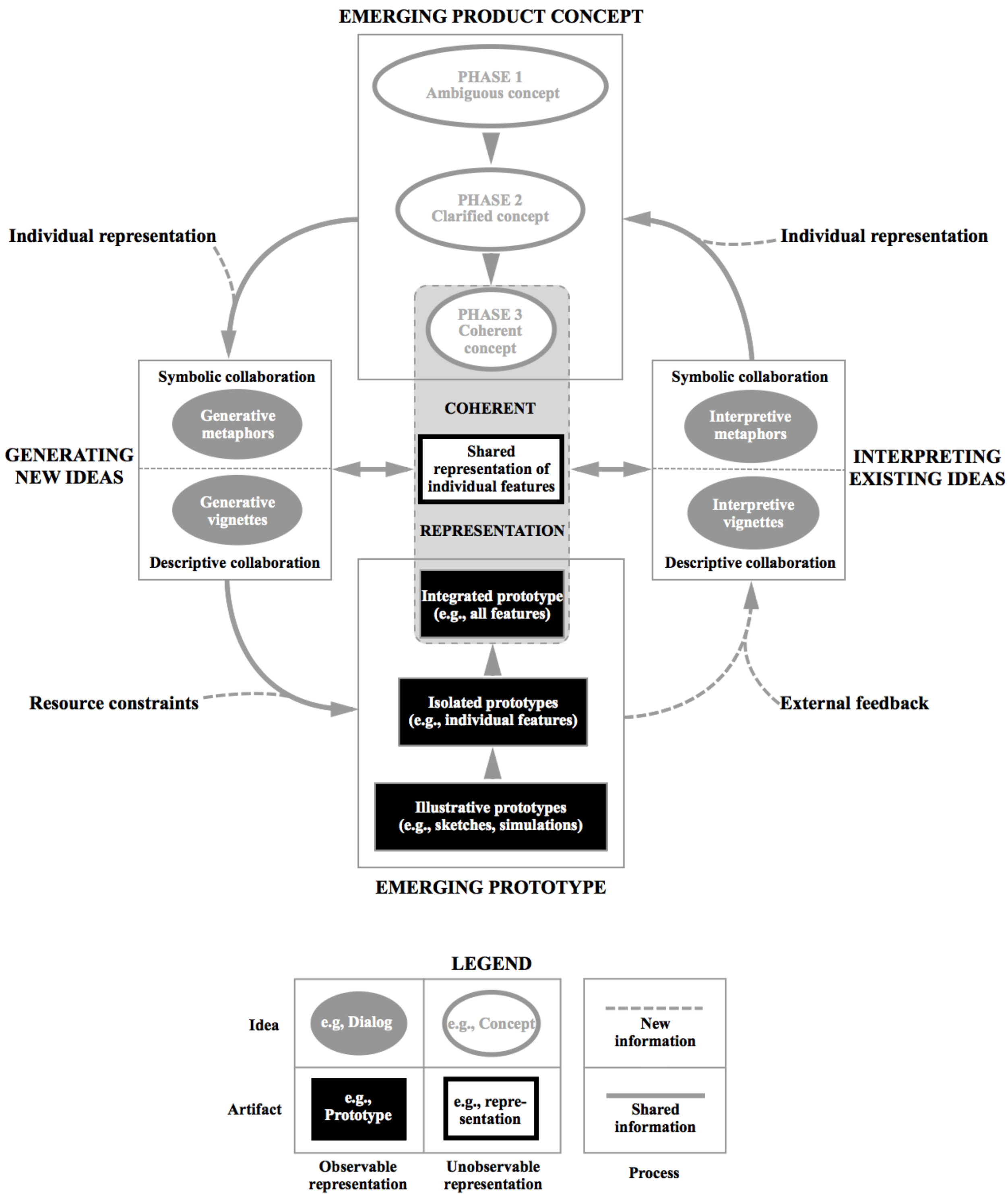


Figure 3.1: The Emergent Innovation Process for Groups to Discover a Coherent Representation of an Innovation Over Time

use symbolic collaboration to develop a coherent concept for the product. At the end of the emergent innovation process, groups can construct a coherent representation of the product by achieving consistency between the integrated prototype, the overall product concept, and the shared representation of all individual features of the product.

This process also is heavily influenced by external forces that can provide new and unexpected information to groups at any time during development. When generating new ideas, group members can use their unique internal representations to introduce new ideas to the group that can be implemented in future prototypes (Amabile, 1983; Newell et al., 1962; Newell & Simon, 1972). When developing these prototypes, groups can confront several resource constraints on factors such as time, materials, finances, knowledge, or individual skills of group members that limit development (Cromwell et al., in press). Prototypes themselves can also convey new information to developers, which can be augmented with external feedback. Finally, when developers interpret prototypes, they can draw from their unique internal representations to identify new ways of representing ideas or features that they had not thought of before developing the prototypes.

Each time the group iterates through one cycle of this process, they are likely to learn new information that can alter the course of development. Most times, this information is small and trivial—but still valuable—thereby helping groups make incremental progress on the product. Other times, the information can be large and substantial, requiring groups to make dramatic changes that can—at times feel like devastating setbacks—but also lead to watershed events that yield significant progress in short periods of time (Gersick, 1988, 1991). These events are likely to take place during major transition-points of the emergent innovation process, such as when groups transition from developing illustrative prototypes to isolated prototypes, or when they transition from isolated prototypes to integrated prototypes. Each transition can be accompanied by a new reconceptualization of the product, which evolves from an ambiguous concept in Phase 1 to a clarified concept in Phase 2, to, finally, a coherent concept in Phase 3.

Once groups reach this final phase of development, they can construct a coherent representation of the product, leading to a fairly stable process that yields steady and predictable improvement over time. However, it is still possible for groups to experience new watershed events that significantly alter the course of development, because there are always new and unexpected events occurring in the environment that can introduce new information to the group. If groups experience a new watershed event, they may need to transition back to earlier phases of the process, and they can continue engaging in the emergent innovation process to work their way back toward constructing a new coherent representation of the product.

3.5 Discussion

The emergent innovation process that I induce from an ethnography of developers of a social robot provides a stark contrast to models of innovation that have been described in prior literature. In the following sections, I discuss how my study makes contributions to literatures on (a) creativity and innovation in groups, (b) the process of constructing a shared representation of an innovation in groups, and (c) how to develop accidental, surprising, or serendipitous discoveries of innovations in organizations. I conclude with a note about the limitations of this study along with potential opportunities for future research to expand upon my findings.

3.5.1 An Alternative Model of the Innovation Process

Existing literature on creativity and innovation is primarily built on a deliberate model of the innovation process (Amabile & Pratt, 2016; Cromwell et al., in press; Mumford et al., 1991; Perry-Smith & Mannucci, 2017; West, 2002). A consistent theme in prior research is that many of the factors that enhance divergent processes for innovation fundamentally undermine convergent processes for innovation in groups (Bledow, Frese, Anderson, Erez, & Farr, 2009; Miron-Spektor, Erez, & Naveh, 2011; Taylor & Greve, 2006), which explains why diversity can be simultaneously beneficial for activities such as generating ideas (Kurtzberg & Amabile, 2000; Paulus & Yang, 2000; Sutton & Hargadon, 1996) and detrimental to activities such as evaluating, selecting, and implementing ideas (Harvey, 2013; Hulsheger et al., 2009; Miron-Spektor et al., 2011). To cope with these tensions, scholars argue that defining problems is crucially important to establishing the success of groups—particularly because it can help groups cultivate a shared set of goals that helps them resolve conflict and stay motivated when developing solutions to a problem (Anderson & West, 1998; Gilson & Shalley, 2004; Hulsheger et al., 2009; Reiter-Palmon, in press).

My primary contribution to this literature is that I propose an alternative model of the innovation process that explains how groups can fully develop a solution for an innovation *before* defining the problem or cultivating a shared set of goals. To avoid the issues with group conflict that can arise from such an approach (Cronin & Weingart, 2007; Leonardi, 2011), I describe a sequence of activities that are different from the activities of the deliberate innovation process. While deliberate innovation includes a cyclical iteration of generating ideas, evaluating ideas, and implementing ideas; the emergent innovation process includes a cyclical iteration of generating ideas, implementing ideas, and interpreting ideas.

At first, the difference between these two processes may seem superficial, because when the activities of the deliberate innovation process are linked together in an iterative cycle, it can produce a process that looks similar to the emergent innovation process. For example, in deliberate innovation, groups often evaluate ideas after implementing ideas to determine whether or not ideas satisfy all the problem criteria. If the ideas fall short, groups can generate new ideas or elaborate upon existing ideas to make progress toward developing a solution for the final outcome; they can even change the problem itself at this point in the process. Therefore, the activities that take place after implementing ideas in deliberate innovation can look nearly identical to the activity that I call "interpreting ideas" in the emergent innovation process.

However, there is a key difference between these two processes that has an important effect on the way that groups can develop innovations in organizations. The deliberate innovation process includes several activities such as defining problems, generating ideas, and evaluating ideas before ever implementing ideas as a prototype. As a result, there is an underlying assumption that groups must resolve their differences and eliminate ambiguity *before* implementing ideas. This can be difficult for groups to do, however, because innovations are fundamentally ambiguous and can have multiple valid representations (Kaplan & Tripsas, 2008; Weick, 1990). When innovation groups implicitly adopt the assumption that they must eliminate ambiguity before implementing ideas, they can engage in intense debates that surface irreconcilable conflicts, which may completely undermine their ability to work together effectively in the future (Baer et al., 2013; Cronin & Weingart, 2007; Kaplan, 2008; Kurtzberg & Amabile, 2000). By the time they even start evaluating prototypes, the group may already be permanently fractured (Drazin et al., 1999; Leonardi, 2011).

By contrast, the emergent innovation process emphasizes that ideas should be implemented early in the innovation process—before evaluating ideas and defining problems—because prototypes have the potential to convey new information to groups that they could not foresee ahead of time. The underlying assumption of this model is that groups should resolve their differences and eliminate ambiguity *after* implementing ideas. This allows groups to explore more diverse representations of ideas and problems throughout the development process. Consequently, the emergent innovation process may be more suitable for groups operating in more ambiguous conditions, such as when they are developing a breakthrough innovation

(Grodal et al., 2015; Kaplan & Tripsas, 2008), searching for new problems to solve with existing ideas (Baker & Nelson, 2005; Sonenshein, 2014), or adapting to sudden changes in environmental conditions (Brown & Eisenhardt, 1997; Eisenhardt & Tabrizi, 1995).

Furthermore, the difference between these two processes may actually have less to do with the *sequence* of activities that groups engage in during the development process and more to do with the *mindsets* that groups adopt as they engage in these activities. When groups adopt a deliberate innovation mindset, they seek clear direction on goals and objectives before taking action; thus, they want to avoid ambiguity and will try eliminating it through debate before implementing ideas (Drazin et al., 1999; Kaplan, 2008; Leonardi, 2011). When they adopt an emergent innovation mindset, they seek more information and are willing to determine goals and objectives after taking action; thus, they are more likely to embrace ambiguity and try resolving it through collective interpretation of prototypes after implementing ideas (Bechky, 2003a; Carlile, 2002). Therefore, a subtle shift in mindset can lead to a significant difference in the way that ambiguity affects group dynamics for the innovation process. With a deliberate mindset, ambiguity can undermine group dynamics, and with an emergent mindset, it can potentially enhance group dynamics.

3.5.2 A General Model of Constructing and Maintaining a Coherent Representation

A separate but related stream of research focuses on how diverse groups can work together effectively by constructing a shared representation of an innovation (Bechky, 2003a, 2003b; Carlile, 2002, 2004; Hargadon & Bechky, 2006; Majchrzak et al., 2012; Okhuysen & Bechky, 2009). According to this research, people with diverse cognitive perspectives must collaborate with each other throughout all stages of development, which can create many coordination, communication, and conflict issues that undermine group dynamics throughout the development process (Baer et al., 2013; Cronin & Weingart, 2007; Dougherty, 1992; Edmondson & Harvey, 2017; Leonardi, 2011). To alleviate these issues, groups can use a combination of prototypes, metaphors, and narratives to construct a coherent representation of an innovation at the beginning of the process and maintain it throughout all stages of development (Seidel, 2007; Seidel & O'Mahony, 2014).

My primary contribution to this literature is that I propose an alternative model of developing an innovation that shows how groups can construct a coherent representation of an innovation at the *end* of the development process rather than constructing it at the *beginning* of the process, and yet avoid the coordination, communication, and conflict issues that can arise when groups are working under such ambiguous conditions. This cyclical model shows how groups can continuously process new information as they construct a shared representation of individual ideas and features, which can eventually—over time—aggregate into a coherent representation of the overall product.

This model, at first blush, seems to contrast with Seidel and O'Mahony's (2014) model in many ways. According to their model, groups can engage in several group dynamics to maintain coherence across prototypes, metaphors, and narratives over time. The first is *collective scrutiny*, which involves reconciling different perspectives and developing a shared understanding of each practice within the group. The second is *linking to constraints*, which involves identifying technical and market limitations that can restrict the development of an innovation. By engaging in these two dynamics continuously throughout the process, groups can determine when one practice is no longer relevant to an innovation, leading them to use *active editing* to replace the practice with a new version of the practice. Together, these dynamics enable groups to shift between different prototypes, metaphors, and narratives over time (Seidel, 2007), but still maintain coherence across them throughout all stages of development.

However, upon closer examination, my model elaborates Seidel and O'Mahony's model in many ways to illustrate a more detailed process of how groups maintain a coherent representation of an innovation over time. First, I describe two modes of collaboration (*descriptive collaboration* and *symbolic collaboration*) that captures the same effects that collective scrutiny has on the process. Second, I account for the limiting effects that *resource constraints* have on the development of prototypes, which captures the same effects that linking to constraints has on the process. Finally, I describe how engaging in descriptive collaboration contributes to an emergent progression of prototypes (*illustrative prototypes*, *isolated prototypes*, *integrated prototype*), and how symbolic collaboration contributes to an emergent progression of product concepts (*ambiguous concept*, *clarified concept*, *coherent concept*). Together, these dynamics capture the same effects that active editing has on the process.

My model also builds on their model to create a potentially broader and more general theory of innovation in groups. Perhaps most importantly, my model *begins* when groups experience high levels of ambiguity and *ends* when they have constructed a coherent representation of an innovation—as opposed to a model that both begins *and* ends with a coherent representation. Thus, my findings demonstrate how groups can overcome the initial state of ambiguity of an innovation to construct an initial coherent representation, and I show a more detailed process by which groups can maintain that coherence over time. I also distinguish between two types of information that influence the process differently. The first is *shared information*, which reflects information that is collectively held within the group, thereby helping them construct a shared representation of ideas, features, and eventually the product. The second is *new information*, which reflects information that can potentially disturb the development process and alter the collective understanding of the innovation within the group. This allows me to show how various factors such as *individual representations*, *resource constraints*, and *external feedback* can all influence the process of constructing a coherent representation similarly, but at different points in time.

3.5.3 A Model of Emergent Innovation in Groups

One important implication of my findings is that groups can construct a coherent representation of an innovation (i.e., develop a coherent solution) without necessarily constructing a shared representation of an innovation (i.e., defining a shared problem). A fully shared representation exists when all group members have shared elements, operators, assumptions, and—above all else—goals for an innovation (Cronin & Weingart, 2007). In other words, a shared representation exists when group members have a shared understanding of both the ideas that make up a solution and the goals or criteria that define a problem. Most scholars argue that diverse groups can work together effectively when they have a shared understanding of the problem (Cronin & Weingart, 2007; Edmondson & Harvey, 2017; Okhuysen & Bechky, 2009), which can subsequently help them develop of a shared understanding of the solution (Gilson & Shalley, 2004; Kurtzberg & Amabile, 2000; Seidel & O'Mahony, 2014). However, my findings challenge this assumption by revealing a process that unfolds in the opposite direction: groups can first develop a shared understanding of the solution, which can subsequently help them develop a shared understanding of the problem.

Although this may seem puzzling in the context of the literature described above, it establishes a connection to another stream of literature that examines how people can develop surprising, accidental, or serendipitous innovation in organizations (Andriani, Ali, & Mastrogiorgio, 2017; Austin, Devin, & Sullivan, 2012; Cattani, 2005, 2006; Garud & Karnøe, 2003; Merton & Barber, 2004). For example, some scholars have described a "Geneplore" model of creativity (Finke et al., 1992), which begins when people *gene*-rate ideas for a potential solution without having a clearly defined problem in mind, and then proceed to ex-*plore* those ideas in the context of various problem domains until a problem and solution emerge together simultaneously. Similarly, von Hippel and von Krogh (2016) describe innovation as a process of identifying viable "need-solution pairs," which occurs when people identify a need and solution at approximately the same time—in a "eureka" moment—without engaging in a sequential process of defining problems and then developing solutions.

Although there has been research investigating emergent styles of innovation at the organizational and individual levels of analysis (see citations above), to my knowledge there has been no research investigating emergent innovation within groups. This presents a fundamental puzzle, because most prior literature on group-level innovation argues that groups must have shared goals in order to overcome the various coordination, communication, and conflict issues that can arise when diverse members collaborate with each other. However, in a more emergent process, the goals are discovered at the very end of the development process, and therefore groups cannot have shared goals until after they have developed the solution. Thus, the question becomes: How do groups work together effectively when developing an emergent innovation?

My findings provide an answer to this question by demonstrating how groups can engage in a cyclical iteration of activities until they have developed a coherent solution for an innovation, which can subsequently go on to be "looking for a problem." By couching my theoretical framing and analysis in literature on creativity and innovation in groups, I draw connections between literatures that have described two innovation processes that seem entirely different from each other and conflict in many ways (Cromwell et al., in press): The deliberate innovation process begins with constructing a well-defined problem and is followed by developing a solution (e.g., Amabile & Pratt, 2016), whereas the emergent innovation process begins with developing a coherent solution and is followed by defining a problem. Further understanding the differences and similarities between these two processes can provide a rich opportunity for future research to expand our knowledge about how to develop innovations in organizations.

3.5.4 Limitations and Future Research

Conducting an ethnography on developers of a social robot provided me with a rare opportunity to collect in-depth data on several group dynamics related to the process of constructing a shared representation of an innovation before the problem has been defined. However, there are several aspects of my study that may limit the generalizability of my findings to other settings, which provides opportunities for future research to build upon the emergent innovation process that I develop in this study.

First, the developers of the social robot were operating under extremely ambiguous conditions because they were developing a breakthrough innovation. This may have produced findings that are not typical in most innovation settings. For example, spending more than 18 months developing a product without having a clear understanding of the goals and criteria that the product was meant to satisfy may be rare. Furthermore, developers of the social robot experienced many resource constraints throughout the development process that hindered their ability to make quick progress on the project. While these dynamics allowed me to observe a more detailed process of emergent innovation over time, other settings that have less ambiguous situations with fewer resource constraints may be able to (a) construct a coherent representation of an innovation in less time, (b) construct a coherent representation without progressing through all three phases of development found in my study, or (c) define a problem for an innovation and construct a shared representation of an innovation earlier in the process, thereby ending the emergent innovation process. Understanding the dynamics that facilitate these alternative pathways of development could provide opportunities for future research to identity new group dynamics related to the emergent innovation process.

Second, the social robot was a highly complex technology product that integrated a large number of features, sub-features, and technical components into a single outcome (Clark, 1985; Griffith, 1999). This may have led to a more choreographed progression of prototypes and product concepts in this setting compared to other settings. For example, I found that developers were able to develop a clarified concept of the overall product shortly after they developed the first isolated prototypes; and they were able to develop a coherent concept of the product shortly after they developed the first integrated prototype. In other settings where groups are developing less complex products, the emergent innovation process may unfold according to a different progression of activities. For example, groups may be able to develop a coherent concept for the product much closer to the beginning of the process (Seidel & O'Mahony, 2014), making the emergent innovation process unnecessary. Future research can further explore when and why groups are likely to engage in the emergent innovation process versus the deliberate innovation process, which may establish important boundary conditions for these different models of innovation.

3.5.5 Conclusion

Existing theories of innovation in groups emphasize the importance of defining problems and constructing a shared representation of innovations at the beginning of the development process, because groups operate most effectively when they eliminate ambiguity and have a shared set of goals to pursue. Under these conditions, groups are more capable of coordinating their effort, communicating with each other, and resolving any conflict that arises as they synthesize their divergent perspectives into novel and useful outcomes. However, this perspective overlooks many of the situations in which groups must operate under more ambiguous conditions—such as when they must overcome ambiguity to define problems or construct a shared representation for an innovation, or when they must embrace ambiguity to pursue new and surprising opportunities. The model of an emergent innovation process that I develop in this paper takes a first step down the path toward better understanding how groups can engage in these emergent activities for innovation in organizational settings.

CHAPTER 4

The Social Process of Developing a Social Robot: A Model of Dynamic Problem Solving in Groups for Breakthrough Innovation

Johnathan R. Cromwell

Abstract

Developing a breakthrough innovation can be a highly ambiguous endeavor that requires people with diverse cognitive perspectives to collaborate for extended periods of time under open-problem conditions (i.e., when the problem is ill-defined). However, prior research advances two competing models of the innovation process that suggest different ways for groups to address open problems. The first is a deliberate innovation process, which argues that groups should define a problem *before* developing a solution; the second is an emergent innovation process, which argues that groups should define a problem *after* developing a solution. In this study, I explored group dynamics under open-problem conditions in a two-year ethnography of an organization that developed one of the world's first social robots for the home. My findings reveal that groups did not engage in two stages of collaboration in sequential order—as prior research suggests—but instead fluidly iterated between three stages of collaboration that differed based on the extent to which problems were open. I summarize my findings in a model of dynamic problem solving in groups that illustrates how the continuous collaboration of groups that iterate between three stages of collaboration cumulates into the co-evolution of problems and solutions over time.

4.1 Introduction

Breakthrough innovations are highly novel and useful products, processes, services, or ideas that are an important source of revenue for organizations (Amabile, 1988; Kanter, 1988; Oldham & Cummings, 1996; West, 2002). These innovations often require people with diverse cognitive perspectives to collaborate with each other throughout the development process (Dougherty, 1992; Drazin et al., 1999). Consequently, scholars have conducted extensive research on group dynamics related to various activities of the process such as generating ideas (Baer et al., 2010; Harvey, 2014; Kurtzberg & Amabile, 2000; Perry-Smith & Shalley, 2003; Sutton & Hargadon, 1996), evaluating ideas (Harrison & Rouse, 2015; Harvey, 2013; Harvey & Kou, 2013; Rietzschel et al., 2006), and implementing ideas (Alexander & van Knippenberg, 2014; Hulsheger et al., 2009; Miron-Spektor et al., 2011).

However, one of the most challenging aspects about developing a breakthrough innovation has received little attention in prior research. Breakthrough innovations are characterized by high levels of uncertainty and ambiguity (Grodal et al., 2015; Suarez, 2004; Tushman & Anderson, 1986), meaning that there are often multiple ways for groups to interpret an innovation (Carlile, 2004; Dougherty, 1992; Edmondson & Harvey, 2017; Hargadon & Bechky, 2006; Kaplan & Tripsas, 2008; Weick, 1990), which can lead to competing perspectives on how to define problems and develop solutions during the development process (Baer et al., 2013; Cronin & Weingart, 2007; Leonardi, 2011). Most innovations begin as an "open" problem (Unsworth, 2001), meaning that the problem is ill-defined and groups must collaborate to find, discover, or formulate a problem (Dillon, 1982; Getzels & Csikszentmihalyi, 1976; Reiter-Palmon, in press). When developing a breakthrough innovation, collaborating under open-problem conditions can be more challenging because of the heightened levels of ambiguity.

However, recent reviews show that there is a dearth of literature studying group dynamics under these conditions (Anderson et al., 2014; Shalley & Zhou, 2008); consequently, group dynamics related to developing a breakthrough innovation are still poorly understood.

Scholars have advanced two competing models of the innovation process that can potentially explain how groups approach open problems while developing a breakthrough innovation (Cromwell et al., in press). The first is a *deliberate innovation process*, in which groups focus on constructing a well-defined problem at the beginning of the process (Reiter-Palmon, in press), and then engage in a cyclical iteration of activities such as generating ideas, evaluating ideas, and implementing ideas until a final solution has been developed (Amabile & Pratt, 2016; Mumford et al., 1991; Perry-Smith & Mannucci, 2017; Wallas, 1926). There is strong empirical evidence showing that groups engaging in this process can be highly effective at developing breakthrough innovations (Singh & Fleming, 2010; Taylor & Greve, 2006).

However, it is still unclear how groups collaborate to define problems during the early stages of this process. One study suggests that groups are effective when they evaluate a *large number of problems*, because it helps them identify the best problem to focus on during the rest of innovation process (Frishammar et al., 2016). By contrast, another study suggests that groups are effective when they evaluate a *small number of ideas* from different perspectives, because it helps them build a strong shared understanding of a problem before generating ideas later in the process (Harvey & Kou, 2013). Both techniques may be helpful when developing a breakthrough innovation, but it is unclear how groups can navigate the tensions between evaluating a large number of problems (i.e., a divergent process) and evaluating small number of ideas (i.e., a convergent process) when defining a problem.

The second model is an *emergent innovation process*, in which people first focus on generating ideas at the beginning of the process, and then explore those ideas in the context of various problem domains until a problem and solution emerge together (Finke, 1990; Finke et al., 1992; Ward, Smith, & Finke, 1999). This model has received little attention in prior literature on creativity and innovation (Anderson et al., 2014; Shalley & Zhou, 2008), but it is consistent with another stream of research showing that innovations often come from accidental, serendipitous, or surprising discoveries (Austin et al., 2012; Cattani, 2005, 2006; Merton & Barber, 2004; von Hippel & von Krogh, 2016). A well-known example of an emergent innovation is when scientists at 3M accidentally developed a super-weak adhesive (i.e., generated an idea), and after several years of searching, discovered a problem that could be solved by that idea and subsequently developed the Post-it Note (Garud, Gehman, & Giuliani, 2018). Empirical research shows that the emergent innovation process can also be a rich source of breakthrough innovations for organizations (Andriani et al., 2017), but there has yet to be any published research studying how groups engage in this process.

The juxtaposition of these two models reveals a theoretical puzzle that has yet to be addressed in prior research. The deliberate innovation process suggests that groups should approach open problems by first defining a problem and then developing a solution, whereas the emergent innovation process suggests that groups should first develop a solution and then define a problem. Although there is strong empirical research showing that both models can be highly effective at producing breakthrough innovations in organizational settings (Andriani et al., 2017; Singh & Fleming, 2010), they make competing recommendations on what groups should do when confronted with an open problem. Therefore, additional research is needed to better understand how groups collaborate under open-problem conditions while developing a breakthrough innovation.

In this study, I address this research question by conducting a two-year ethnography of an organization that developed one of the world's first social robots[3] for the home. I found that groups did not necessarily follow a strict sequence of stages while developing this innovation—such as first defining a problem and then developing a solution (e.g., Amabile & Pratt, 2016), or first developing a solution and then defining a problem (e.g., Finke et al., 1992). Instead, they engaged in a model of *dynamic problem solving* that included iteration between three stages of collaboration as they continuously gathered external information from the environment. I call these stages *constructing a shared problem*, *constructing a shared solution*, and *constructing a shared representation*. Together, they illustrate how groups can develop breakthrough innovations by engaging in either a deliberate innovation process, a emergent innovation process, or a dynamic iteration between deliberate and emergent innovation, which results in the co-evolution of problems and solutions over time.

These findings expand our view of the innovation process and may help us better understand group dynamics in organizations more generally. For example, innovation projects often require large groups of diverse people to collaborate with each other over the course of several years (Dougherty, 1992; Drazin et al., 1999). During this time, it is important for groups to develop a shared cognition so they can benefit from positive group dynamics while developing an innovation (Klimoski & Mohammed, 1994). However, this becomes increasingly challenging for larger groups because more diverse members become distributed across more diverse teams (Firth, Hollenbeck, Miles, Ilgen, & Barnes, 2014). My findings demonstrate how a large group of diverse people can both develop and maintain a shared cognition over time.

[3] The term "social robot" was coined by an academic sub-field of robotics in the early 1990s. These devices were designed to interact with humans through verbal communication while exhibiting some type of emotional or social intelligence. By the mid-2010s, several organizations were attempting to commercialize this technology as a consumer product, one of which became the empirical setting for this study.

4.2 Problem Solving in Groups

Most theories of creativity and innovation address the individual (e.g., Amabile, 1983; Mumford et al., 1991), and thus are built upon a cognitive model of individual problem solving (Newell et al., 1962; Newell & Simon, 1972). According to this model, a problem exists when people have particular goals or objectives that they want to obtain, but do not know what procedures can be used to reach them. To solve the problem, they first construct a *representation* of the problem, which triggers them to recall any relevant knowledge, experiences, or methods from their memory to use for generating ideas. For example, a problem solver attempting to build a new product called a social robot may represent this product as a "friendly robot," which can trigger her to use knowledge related to friendly robots such as R2-D2, C-3PO, or Wall-E[4] when generating ideas. Next, she can evaluate ideas against the problem criteria and select an idea that best satisfies the criteria. If the ideas fall short, she can either generate new ideas, elaborate upon existing ideas, or change her representation of the problem, thereby triggering her to recall a new set of cognitive resources that can be used for generating new ideas. This process repeats itself iteratively until the problem solver develops a final solution that satisfies all the criteria and helps her reach the final goal state.

Recently, scholars have begun translating this cognitive model of problem solving to the group level of analysis (Baer et al., 2013; Cronin & Weingart, 2007; Reiter-Palmon, in press), which forms the theoretical framework that I draw on for this study. This approach is promising, because it has the potential to bridge an extensive set of research on individual creativity and innovation with another set of research that focuses on team processes and behaviors (see Reiter-Palmon et al., 2008 for a review). Furthermore, studying group-level processes can yield unique

[4] R2-D2 and C-3PO are robot characters from the film series *Star Wars* (1977–2018); Wall-E is a robot character from the film *WALL-E* (2008).

insights that fundamentally alter our view of the innovation process more generally (e.g., Hargadon & Bechky, 2006; Harvey & Kou, 2013).

4.2.1 Limitations of Existing Theory

However, a current limitation of existing theory is that it assumes that people—either individuals or groups—are working on a "closed" problem (Unsworth, 2001), meaning that the problem has been well defined before they start engaging in the problem-solving process described above. Scholars argue that individuals working on a closed problem attempt to construct a clear representation of the problem (Amabile, 1983; Mumford et al., 1991; Wallas, 1926), which helps them generate more novel and useful ideas (Carson & Carson, 1993; Rietzschel et al., 2014a; Shalley, 1991, 1995). In groups, working on a closed problem takes on even greater importance, because it can help them develop a shared set of goals, which is essential to their success in developing an innovation in organizational settings (Anderson & West, 1998; Gilson & Shalley, 2004; Hulsheger et al., 2009; West, 2002).

To better understand these dynamics, Cronin and Weingart (2007) decomposed representations to their fundamental components, which include goals, assumptions, elements, and operators (Newell & Simon, 1972). Goals refer to the hierarchy of criteria that need to be met before reaching the final goal state, assumptions refer to the underlying preferences that people have for different criteria, elements refer to the ideas that people use as building blocks for the solution, and operators refer to the methods that people use to transform ideas when developing the solution. In other words, goals and assumptions are cognitive components that influence how people construct the *criteria that define a problem*; elements and operators are cognitive components that influence how they generate the *ideas that make up a solution*.

One important characteristic of a representation is that it triggers people to recall a particular set of ideas while simultaneously triggering them to focus on a particular set of criteria. For example, a problem solver who represents the social robot as a "friendly robot" will think of several ideas associated with friendly robots (e.g., R2-D2, C-3PO, Wall-E, etc.) while also focusing on several criteria that are associated with friendly robots (e.g., friendly, robotic, helpful, etc.). Therefore, a representation creates *an implicit association* between ideas and criteria that influences the way groups collaborate during the problem-solving process.

According to Cronin and Weingart, all group members approach problem solving with their own cognitive components that are influenced by their particular knowledge and experiences. Consequently, several members can represent a problem in the same way and create a different implicit association between ideas and criteria. For example, a designer and a product manager can both represent a social robot as a "friendly robot," but the designer may draw on her knowledge about human factors to generate ideas that *decrease* the feature-set, which can help satisfy the criteria of making the robot a more "friendly" user experience. By contrast, the product manager may draw on her knowledge about existing products on the market to generate ideas that *increase* the feature-set, which can help satisfy the criteria of making the robot do more "friendly" things for more users.

When differences such as these arise in a group setting, it can lead to several coordination, communication, and conflict issues that undermine group dynamics while developing an innovation (Carlile, 2004; Cronin & Weingart, 2007; Dougherty, 1992; Leonardi, 2011; Okhuysen & Bechky, 2009). To alleviate these issues, scholars argue that it is important for groups to construct a *shared representation* of an innovation (Bechky, 2003b; Carlile, 2002; Hargadon & Bechky, 2006; Majchrzak et al., 2012; Seidel & O'Mahony, 2014). A fully shared representation occurs when all group members have the same goals, assumptions, elements, and operators when solving a problem. However, this is highly unlikely when groups are working on an open problem, and may even be undesirable, because it can lead to group think (Janis, 1971). Instead, group members can be effective at problem solving when they have shared goals and assumptions—and thus are trying to satisfy the same criteria—but have different elements and operators—and thus can generate more divergent ideas during the problem-solving process (Cronin & Weingart, 2007; Weingart, Todorova, & Cronin, 2010).

Therefore, working on a closed problem would seem to be a prerequisite for problem solving in groups, because it helps group members develop a shared set of goals and improves group dynamics while developing an innovation. However, most innovations begin as open and ill-defined problems (Unsworth, 2001), meaning that there are multiple possible goals to pursue and multiple possible solutions that can be developed for each problem (Reiter-Palmon, in press). Consequently, groups must often collaborate when they do not have shared goals, which can be particularly challenging for breakthrough innovations because of the heightened levels of ambiguity (Grodal et al., 2015; Kaplan & Tripsas, 2008; Suarez, 2004; Tushman & Anderson, 1986). Existing theory suggests that group dynamics should completely break down in these situations (Baer et al., 2013; Cronin & Weingart, 2007), and yet, empirical evidence shows that groups can—and often do—succeed in such situations (Andriani et al., 2017; Singh & Fleming, 2010). This raises the question: how do group members collaborate with each other under open-problem conditions?

4.2.2 Addressing Open Problems with a Deliberate Innovation Process in Groups

Some scholars argue that groups can address open problems by using a deliberate innovation process (Cromwell et al., in press), which involves constructing a problem for an innovation *before* developing a solution (Mumford et al., 1994; Reiter-Palmon, in press; Reiter-

Palmon et al., 2008). According to this model, problem construction begins when group members encounter an event that captures their attention and activates several representations that are based on their knowledge and experiences. For example, a group encountering the event of “developing a social robot” may create multiple representations of the product such as “friendly robot,” “assistant robot,” or “social companion,” all of which can have different implicit associations between ideas and criteria. Groups can use a screening procedure to select the best representation or combine elements from several representations to create a new representation. The problem construction process ends when the group converges upon a single representation, which then becomes the focal point for the subsequent problem-solving process (Cronin & Weingart, 2007; Mumford et al., 1991; Newell & Simon, 1972; Reiter-Palmon, in press).

A recent study by Frishammar et al. (2016) finds support for this model, showing that groups can engage in a multi-stage process to develop a breakthrough innovation. The first stage is called *problem mapping*, which includes gathering information about the external environment and identifying heterogeneous goals within the group. The second stage is called *problem creation*, which includes an iterative process of “finding” many possible problems to solve and “framing” the problems to uncover their underlying symptoms; it ends when the group converges onto one problem to create homogenous goals for the group. The final stage is called *problem solving*, which includes an iterative process of “creating” many ideas and “refining” the ideas to fully satisfy the problem criteria; it ends when the group converges onto one solution that will be implemented as the innovation.

Note that the stages of problem creation and problem solving include different activities, but they follow a similar pattern: Both include a step of divergent thinking to identify a large number of possible options followed by a step of convergent thinking to identify the optimal choice. This contrasts with a study conducted by Harvey and Kou (2013), who find that groups engage in different processes when constructing problems versus solving problems. During problem construction, groups evaluate a *small number of ideas* (that is, a small number of possible solutions) because it helps them develop a strong shared understanding of the problem. Then during problem solving, they engage in divergent thinking to evaluate a *large number of ideas* followed by convergent thinking to find an optimal solution to the problem. Therefore, both studies demonstrate how groups can construct problems before developing solutions, but they present alternative views on how this process unfolds.

4.2.3 Addressing Open Problems with an Emergent Innovation Process in Groups

Some scholars argue that people can address open problems with an emergent innovation process rather than a deliberate innovation process (Cromwell et al., in press), which involves discovering a problem for an innovation *after* developing a solution (Finke, 1990; Finke et al., 1992; Ward et al., 1999). To date, there have been no published studies investigating this process among groups, but an individual-level experiment conducted by Finke (1990) reveals the underlying dynamics of this process. In the experiment, all subjects were told to use a subset of three out of 15 materials (e.g., hook, sphere, spring, etc.) to create an invention in one of eight problem domains (e.g., furniture, toys, appliances, etc.). One group was given both the materials and problem domain at the beginning of the task, followed by two minutes to generate an idea for their invention. A second group was given the materials at the beginning of the task and one minute to generate a "potentially useful" idea for an invention; afterwards, they were given the problem domain and one additional minute to explore their idea in the context of the domain before developing a final idea for their invention. Results showed that subjects in the second group produced more novel and useful ideas than those in the first group.

These results suggest that people engaging in the emergent innovation process can be highly effective at developing innovations, but this model has largely been overlooked in existing literature on creativity and innovation and is rarely studied in organizational settings. However, another body of research shows that innovations often come from accidental, serendipitous, or surprising discoveries (Andriani et al., 2017; Austin et al., 2012; Cattani, 2005, 2006; Merton & Barber, 2004; von Hippel & von Krogh, 2016), providing stronger evidence that the emergent innovation process is commonly used for addressing open problems and developing an innovation in organizations.

One of the most well-known examples of an emergent innovation is the Post-It Note that was developed by scientists at 3M (Garud et al., 2018). The process began in 1967 when a scientist named Dr. Spencer Silver was attempting to develop a super-strong adhesive but instead accidentally developed a super-weak adhesive. Rather than labeling it as a failed experiment, Silver began telling his colleagues about the super-weak adhesive because he believed it had potentially useful applications, but he did not know what they could be. Over the next several years, the super-weak adhesive famously became a "solution looking for a problem" (quoted in Lindahl, 1988), until another scientist at 3M—Art Fry—stumbled upon a situation in 1974 when an application for the idea became clear. In his words (Fry, 1987, p. 6):

> I was a member of my church choir and marked hymnal responses with pieces of scrap paper. Invariably they'd fall out of the book or slip between the pages—a big nuisance. My mind began to wander one day during the sermon, and I thought of Spence's adhesive. If I could coat it on paper, that would be just the ticket for a better bookmark. I went to work the next day, ordered a sample of the adhesive and began coating it on paper… In using these bookmarks for notes back and forth from my boss, I came across the heart of the idea. It wasn't a bookmark at all, but a note.

The process of developing the Post-it Note seems to reflect a similar process conveyed in Finke's (1990) experiment. However, an important difference is that the problem and solution emerged after several years of exploration, and the product required several more years of development—including collaboration among developers from several departments (Dougherty, 1992; Drazin et al., 1999)—before the product was finally launched to market in 1980 (Fry, 1987). One of the unique challenges facing groups during the emergent innovation process is that they must learn to collaborate effectively to develop a solution before a well-defined problem has been discovered, meaning that they do not have a shared set of goals and are likely to suffer from significant coordination, communication, and conflict issues throughout the development process (Cronin & Weingart, 2007; Dougherty, 1992; Okhuysen & Bechky, 2009).

In Chapter Three of this dissertation, I developed a model for the emergent innovation process that suggests how groups can overcome these challenges and sustain effective collaboration to develop a solution for a breakthrough innovation before discovering a problem. I found that groups can engage in a cyclical iteration of activities that includes generating ideas, implementing ideas, and interpreting ideas to develop a solution without having a shared understanding of the problem they are trying to solve. However, I also found that groups did not actually discover a problem for the innovation to solve, because I was focused on how groups defined and solved a problem for the overall product. Therefore, it is still unclear how groups collaborate when they attempt to define a problem at the end of the emergent innovation process.

Altogether, existing theory provides a fragmented view on how groups can address open problems while developing a breakthrough innovation in organizations. Scholars studying the deliberate innovation process find that groups can construct problems either by evaluating a large number of possible problem representations before converging onto one representation, or by evaluating a small number of ideas to develop a stronger shared understanding of a problem. Once a problem has been constructed, groups can engage in a cyclical iteration of activities that includes generating ideas, evaluating ideas, and implementing ideas until a final solution has been developed. By contrast, scholars studying the emergent innovation process find that groups must adopt an entirely different cyclical iteration of activities (described above) so that they can develop a solution without having a shared understanding of the problem. Given the various tensions between these competing group dynamics, qualitative inductive research can be valuable for generating new theory that elucidates problem solving in groups (Edmondson & McManus, 2007).

4.3 Methods

In this study, I aim to generate new theory that describes how groups collaborate under open-problem conditions while developing a breakthrough innovation. However, conducting such research presents several methodological challenges. First, developing a breakthrough innovation requires people to make sense of a highly ambiguous situation (Kaplan & Tripsas, 2008; Weick, 1990), which is fundamentally a collective process that occurs through communication and interaction (Walsh, 1995; Weick et al., 2005). Therefore, researchers should collect *observational data* on collaboration processes that unfold in real time (e.g., Hargadon & Bechky, 2006; Harrison & Rouse, 2014). Second, many of the group dynamics that occur under open-problem conditions can be unexpected and rare (e.g., discovering a problem at the end of the emergent innovation process). Therefore, researchers should be *embedded* within an organization so they can collect data on these emergent dynamics in real time (e.g., Baker & Nelson, 2005; Sonenshein, 2014).

Finally, addressing open problems can require groups to use many diverse representations throughout the process (Baer et al., 2013; Cronin & Weingart, 2007; Reiter-Palmon, in press). Therefore, researchers should be *deeply embedded* within an organization so that they can develop an internal perspective that helps them better understand how participants make sense of ambiguous situations and interpret their environment; but they also should maintain a balanced external perspective that allows them to analyze data through a theoretical lens and develop generalizable theory (Emerson et al., 2011; Lofland et al., 2006). I addressed each of these concerns by conducting a two-year ethnography of Roboto,[5] an organization that developed "Robo," one of the world's first social robots for the home.

4.3.1 Research Setting

Roboto was a small startup organization located in the Northeast region of the United States, and it was a representative case study of an organization developing a breakthrough innovation (Yin, 2014). Breakthrough innovations often require developers with diverse cognitive perspectives to collaborate with each other over the course of several years under highly ambiguous conditions (Dougherty, 1992; Drazin et al., 1999; Kaplan & Tripsas, 2008; Tushman & Anderson, 1986), which can present many challenges to groups as they collaborate to address open problems (Baer et al., 2013; Cronin & Weingart, 2007; Leonardi, 2011; Okhuysen & Bechky, 2009). Several characteristics of Roboto provided unique methodological advantages that allowed me to generate new theory that suggests how groups can overcome these challenges while developing a breakthrough innovation.

First, the product was a complex technology product that required collaboration among diverse developers to integrate many features into a single outcome (Clark, 1985; Drazin et al., 1999). Some developers were responsible for developing technical components such as cameras, motors, and a speech recognition system. Others were responsible for developing conceptual features that customers interacted with—such as "Messaging," "Photography," and "Utilities," all of which had dozens of sub-features (described in more detail below). For this study, my primary *unit of analysis* was a sub-feature, and my primary *level of analysis* was a group (Yin, 2014). Therefore, as I tracked the development of various sub-features over time, I observed high

[5] All names of organizations, products, features, and individuals in this paper are pseudonyms.

variation in group dynamics among different developers who got more or less involved in the process depending on the stage of development. When defining problems, groups typically included designers, product managers, and executives; when developing solutions, they included designers and software engineers. In total, I studied group dynamics among 55 developers who collaborated with each other in different permutations over the course of two years.

Second, Roboto was a small startup organization, and all collaborations took place within a single office. Thus, I could collect in-depth data on group dynamics for nearly the entire development process (Langley, 1999). When I began collecting data, Roboto had just raised their first round of venture capital funding and hired approximately 35 employees to begin developing their product. By the time I finished collecting data, Roboto had grown to more than 100 employees and were preparing to launch their product to market. By studying Roboto between these two endpoints in time, I was able to collect a large volume of data on group dynamics under open-problem conditions. I found that groups experienced open-problem conditions when they confronted two different sources of ambiguity while developing sub-features.

The first source of ambiguity occurred when groups began developing a sub-feature, and group members had divergent perspectives on how they should define and solve a problem for the sub-feature. In these situations, groups tended to address open problems by using a deliberate innovation process, meaning that they constructed a problem for the sub-feature before developing a solution. Thus, they oscillated from an open problem to a closed problem. The second source of ambiguity occurred in the middle of developing a sub-feature, when group members confronted divergent perspectives on an idea that had already been implemented as a solution to a problem for the sub-feature. In these situations, groups oscillated from a closed problem to an open problem, and they addressed the open problem by using an emergent innovation process, meaning that they discovered a new problem for the sub-feature after they had already developed a solution for it. By studying group dynamics across these reciprocal processes, I was able to integrate the deliberate innovation process and the emergent innovation process into a more coherent model that I call *dynamic problem solving*.

4.3.2 Data Collection

I collected data at Roboto by using participant-observation methods that are common to ethnographic field studies (Emerson et al., 2011; Lofland et al., 2006). I gained access to Roboto through a personal contact. After meeting with executive leaders and gaining approval for my research, I was given a desk on-site and a company email address, which allowed me to access the online company calendar and cloud-based storage system that was used for managing archival documents. From there, I had autonomy to attend any meetings that I believed were relevant for my research. As described earlier, I focused on attending meetings that included any group of developers working on any sub-feature of the conceptual features for the product.

I also became an active participant at Roboto by working on the "design research team," which was a small group of designers responsible for developing usability tests to better understand how external users experienced their product. I provided expertise on how to design these tests to maximize the quality of the user research conducted at Roboto, but I tried to minimize my involvement in the analysis and interpretation of data, so that my opinions did not significantly influence decisions for the product. This role helped me become more "immersed" in the daily activities, routines, and experiences of my participants, allowing me to better understand what they found meaningful and how they made sense of ambiguous situations (Emerson et al., 2011). This internal perspective was particularly valuable when analyzing data for this study, which required me to have a deeper understanding of the diverse representations that groups used while developing sub-features for the product (Cronin & Weingart, 2007).

One of the unique challenges that I faced at Roboto was that developers were under pressure to bring their product to market as quickly as possible, which influenced my methodological approach. For example, the CEO consistently repeated the mantra of “we’re in a race” at all company-wide meetings; therefore, I could not ask participants to take time away from their busy schedules to conduct formal interviews for my research. To accommodate this constraint, I decided to focus on *group dynamics* under open-problem conditions—as opposed to individual cognitive processes (cf. Stigliani & Ravasi, 2012)—because it required me to focus on communication and interaction patterns to generate new theory (Weick, 2000; Weick et al., 2005). Thus, I developed my findings primarily by analyzing data coming from direct observations and meeting transcriptions, and I triangulated my findings based on supplementary data coming from informal interviews and archival data.

Direct Observation and Field Notes. Over the course of two years, I spent time at Roboto on more than 320 days for an average of 25 hours per week, and I recorded more than 2,200 pages of field notes as I attended meetings, interacted with participants, and reflected on major developments that were related to my research interests. During this time, the nature of my observations changed according to the progress that I made on my research and the progress that developers made on the product. During the first six months, developers were in the early stages of development, and my goal was to understand the processes, procedures, routines, and rhythms of collaboration between different developers. Therefore, I recorded meetings, conversations, and events in as much descriptive detail as possible without trying to interpret them through the lens of existing theory (Emerson et al., 2011; Lofland et al., 2006). I recorded most of my field notes in real time, but when this was not possible, I jotted down short phrases to outline high-level topics that I thought were important or interesting; then at a later time—usually within 36 hours—I returned to my notes to elaborate on the details.

After approximately six months, I developed the initial insights for this study when I noticed a theme emerge in my observations: group dynamics seemed to differ depending on whether developers were defining problems versus solving problems. Thus, I steeped myself in the problem-solving literature (Cronin & Weingart, 2007; Newell & Simon, 1972; Unsworth, 2001), and over the following 14 months, my field notes transitioned from being purely descriptive to being both descriptive and interpretive. At the same time, developers made steady progress on developing the product, but they also suffered two major setbacks that forced them to redefine their goals for each conceptual feature and adjust their resources to meet those goals. These served as important watershed events that allowed me to closely observe groups as they oscillated between closed and open problems for numerous sub-features. In the final four months of my study, developers completed their work for all sub-features that were released in version one of the product. During this period, I spent less time collecting data at Roboto and more time cleaning my data and preparing it for analysis.

Meeting Transcriptions. Early in the project, I gained permission to record meetings that were relevant to my research, and I attended more than 450 meetings as I tracked the development of several sub-features over time. To generate new theory on problem solving in groups, I theoretically sampled meetings with two goals in mind (Eisenhardt, 1989): On one hand, I wanted to include enough depth of data on each sub-feature to capture group dynamics as developers oscillated between open and closed problems over time; on the other hand, I wanted to include a broad scope of sub-features to increase the generalizability of my findings. With these goals in mind, I sampled 95 meetings for sub-features coming from three conceptual features called “Messaging,” “Photography,” and “Utilities,” resulting in 85 hours of transcribed audio. I provide a description of these conceptual features along with examples of their sub-features in Table 4.1, and I summarize the distribution of meetings that I sampled across the features as they underwent different periods of development over time.

Supplementary Data. To complement my observations and meeting transcriptions, I regularly conducted informal interviews with participants and collected archival data such as online documents and pictures or videos of physical artifacts (Yin, 2014). I used informal

Table 4.1: Summary of Data Sampled for Analysis

Feature and Description	Periods of Development	Meetings Sampled	Hours of Obervation
Messaging Included any sub-features that allowed users to manage information within the household such as creating messages, reminders, or lists.	*Months 1–5* [a] Defined goals and designed initial functionality	9	11
	Months 6–10 Implemented initial functionality	10	6
	Months 11–12 [b, a] Revised goals and re-designed functionality	12	12
	Months 13–17 Implemented new functionality	7	5.5
	Month 18 [b] Eliminated feature from product	2	1.5
Photography Included any sub-features that allowed users to use the robot's camera to record media such as creating pictures or video.	*Months 1–6* [a] Defined goals and designed initial functionality	9	9
	Months 7–10 Implemented initial functionality	4	2.5
	Months 11–12 [b, a] Revised goals and re-designed functionality	8	11
	Months 13–17 Implemented new functionality	4	3.5
	Months 18–20 [b, a] Revised goals and re-designed functionality	3	2
	Months 21–24 Implemented new functionality	3	2.5
Utilities Included any sub-features that allowed users to manage basic robot functionality such as volume, alarms, timers, and wi-fi connection.	*Months 3–4* [b] Feature emerged based on work from other features	2	2
	Months 5–9 [a] Defined goals and designed initial functionality	6	5.5
	Months 10–24 Implemented initial functionality	16	11
	Total	**95**	**85**

[a] Indicates a period that included a transition from an open problem to a closed problem

[b] Indicates a period that included a transition from a closed problem to an open problem

interviews to better understand how participants defined and solved problems based on their internal representations; I also compared my interpretation of events to theirs so that I could better understand how they made sense of ambiguous situations and enacted their environment through work on the product (Lofland et al., 2006). I used online documents to capture official company records that reflected decisions made during interactions, and I used pictures and videos of artifacts to capture prototypes that were evaluated during meetings at various stages of development (e.g., Bechky, 2003a; Carlile, 2002).

4.3.3 Data Analysis

In this study, I develop a process model for dynamic problem solving in groups by using an inductive approach that is informed by the grounded theory method (Corbin & Strauss, 2008; Langley, 1999; Locke, 2001). During my time in the field, I iterated between collecting data and reading literature to increase the depth of data collected on key emerging themes and increase the clarity with which I interpreted events as they unfolded in real time. However, I did not formally analyze data until Roboto completed developing their product and were preparing to release it to market. I did this for theoretical reasons, because I did not know which sub-features would be included in the final product; thus, I could not determine which meetings would provide a high variation in group dynamics related to developing a breakthrough innovation until after the product was complete. When I formally analyzed data, I iterated between analyzing data and reading literature with the aim of generating new theory that made novel contributions to literature on problem solving in groups while also being firmly grounded in the data.

Stage 0: Preparing Data for Analysis. The grounded theory method relies on analyzing a large number of comparable "events" that enable the researcher to identify patterns and themes across events. These patterns and themes can then be aggregated into broader theoretical categories, which in turn can be integrated into a generalizable process model that describes different stages of development (Corbin & Strauss, 2008; Glaser & Strauss, 1967; Langley, 1999). In this study, I defined an event as any *interaction* that included a group of two or more people collaborating to develop a sub-feature of either the Messaging (e.g., sending a message), Photography (e.g., taking a photo), or Utilities (e.g., setting an alarm) features. Each sub-feature required groups to define and solve problems throughout the development process; therefore, I treated each sub-feature as an equal unit of analysis, and I aggregated interactions across these sub-features to produce a large number of events to analyze.

Interactions typically began when groups engaged in any of the problem-solving activities identified in prior literature—such as generating ideas, elaborating ideas, evaluating ideas, exploring ideas, gathering information, defining the problem, changing the problem, or choosing a solution (Cromwell et al., in press). They ended when the group came to a collective agreement on what to do next for developing a sub-feature. Therefore, the process of developing each sub-feature can be conceived of as a series of problem-solving activities that were strung together in a linear sequence over time. Before analyzing my data, I coded all transcripts to construct these sequences for sub-features of Messaging, Photography, and Utilities. During this process, I excluded all interactions that were unrelated to these sub-features, and I ignored all generic chatter about things like social lives, company matters, or topics that were unrelated to developing sub-features of the product more generally.

Stage 1: Identifying Micro-Processes of Collaboration. I began analyzing data by focusing on the sub-features for Messaging, because developers experienced the most ambiguity on this conceptual feature, and therefore I expected it to provide the largest sample of data under open-problem conditions. Starting with the earliest interaction in my dataset, I conducted micro-analysis of the transcripts (Miles & Huberman, 1994), coding for various problem-solving activities that have been identified in prior literature (Cromwell et al., in press). However, I found that these activities did not help me identify any patterns or themes for problem solving. For example, I found that groups generated ideas in many interactions, but there seemed to be a qualitative difference in the way they generated ideas across interactions. Sometimes groups generated ideas in an effort to solve a well-defined problem; other times they generated ideas that influenced a problem that was amorphous and emergent. Therefore, I stopped coding data based on existing problem-solving activities and began using open line-by-line coding (Charmaz, 2006) to identify micro-processes of collaboration to develop new categories of collaboration.

Stage 2: Developing Categories of Collaboration. As I continued coding the Messaging data, I gained exposure to different types of interactions, and I used constant comparative analysis to aggregate micro-processes of collaboration into second-order processes (Miles & Huberman, 1994). For example, I found that the micro-process of *suggesting an idea* to the group was similar to the micro-process of strongly *advocating for an idea* to the group, because they both involved cultivating an idea that could become a solution to a problem. Therefore, I aggregated these first-order processes into a second-order process that I called *cultivating ideas*. This technique also helped me resolve the issue that I uncovered in the first stage of analysis, because I found that several micro-processes related to cultivating ideas differed based on the extent to which problems were open. For example, when group members suggested an idea for a closed and stable problem, they were *cultivating ideas* to create a solution; and when they suggested an idea that subsequently influenced how they defined an amorphous problem, they were *cultivating alignment* between ideas and criteria. Therefore, I created second-order processes that comprised similar micro-processes to identify similar interactions that differed based on the extent to which problems were open. I then analyzed data for the sub-features of Photography and Utilities, which helped me prune, consolidate, and refine elements of the data structure until I reached theoretical saturation (Eisenhardt, 1989). The final data structure that emerged from this analysis is presented in Figure 4.1.

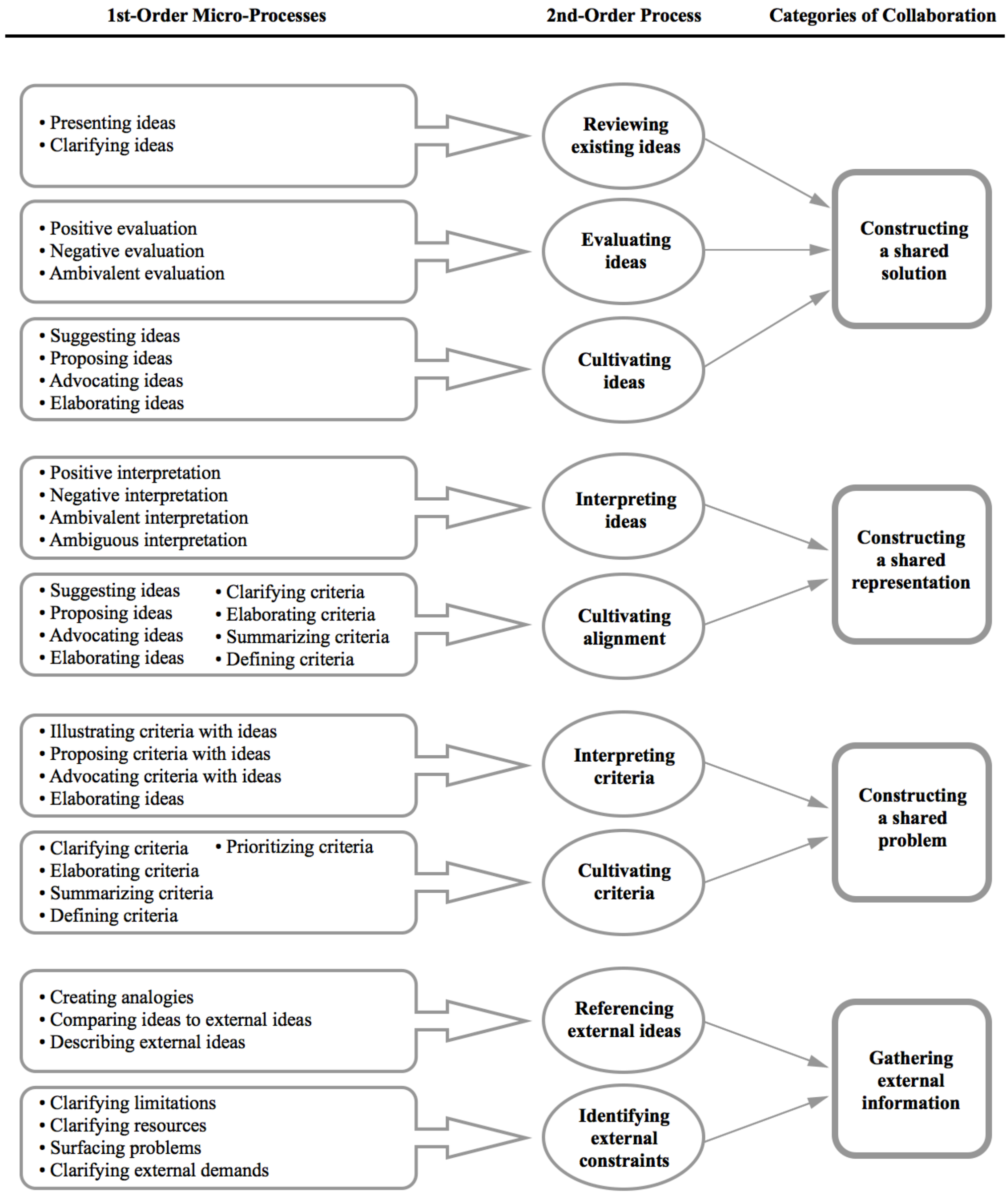


Figure 4.1: Data Structure

Stage 3: Constructing a Process Model. The data structure in Figure 4.1 shows how various micro-processes are embedded *within* broad categories of collaboration, which I labeled (1) *constructing a shared solution*, (2) *constructing a shared representation*, (3) *constructing a shared problem*, and (4) *gathering external information*. At this point in my analysis, I found that groups engaged in all four categories of collaboration throughout the development process, but I was still unsure how they related to each other. Therefore, I re-read transcripts for all sub-features and focused on areas in which groups transitioned between different categories of collaboration over time. During this analysis, I found that groups tended to iterate between the first three categories in a sequential order—thereby reflecting distinct *stages of collaboration*—but they engaged in the fourth category consistently throughout all interactions. Then, I used constant comparative analysis to identify micro-processes of collaboration that facilitated transitions between the three stages of collaboration, and I used chains of logic to integrate all four categories of collaboration into a coherent process model (Miles & Huberman, 1994).

4.4 Findings

In the following sections, I present the findings that emerged from my analysis. Prior literature has described two models of the innovation process that each propose two stages of development. The deliberate innovation process suggests that groups first define a problem and then develop a solution, whereas the emergent innovation process suggests that groups first develop a solution and then define a problem. My core findings are that groups engaged in three distinct stages of development—instead of two—and that group dynamics changed across these stages based on the extent to which the problem was open. When the problem was entirely closed, groups engaged in *constructing a shared solution*; when the problem was amorphous and emergent, they engaged in *constructing a shared representation*; and when the problem was entirely open, they engaged *constructing a shared problem*. First, I present the group dynamics that characterize each stage of development. Then, I demonstrate how groups transitioned between these stages while also *gathering external information*, allowing me to integrate my findings into a model of dynamic problem solving that illustrates how the continuous collaboration of groups cumulates into the co-evolution of problems and solutions over time.

4.4.1 Constructing a Shared Solution

I begin with the stage of constructing a shared solution, not because it was necessarily the first stage of development for each sub-feature, but because it includes the simplest group dynamics that are easiest to follow. This stage began when a group of developers convened to review existing ideas that had already been implemented in a past prototype; therefore, the ideas reflected solutions to problems that had already been defined in a prior interaction. Prototypes ranged from being simple prototypes such as drawings, sketches, spreadsheets, and simulations (Bechky, 2003a; Carlile, 2002; Henderson, 1991) to more complex prototypes such as a fully functioning robot. This stage typically began when one group member presented existing ideas to a group while other members asked questions to clarify their understanding of the ideas. The following discussion, in which a group of designers are reviewing an idea on a spreadsheet about the "alarms" sub-feature of Utilities, highlights this dynamic.

MURPHY (designer): So, alarms, let's go through these ideas. This is me sort of just struggling with alarms.

STUART (designer): Are we promoting Robo to be, sort of like, downstairs? I know he can be anywhere, but like, you're not waking up?

MURPHY: Yeah.

LANCE (designer): Well, it's kinda like a timer, which is different, right?

MURPHY: Right, if we have 24-hour timers—

LANCE: Yeah, but, if I want us to all leave at 7:00PM, I set an alarm for 7:00PM. I'm not gonna set an alarm for the calculation between now and 7:00PM, right?

MURPHY: Yeah, I agree.

This discussion begins when Murphy wants to present ideas that he has been considering for the alarms sub-feature, but first, Stuart and Lance have questions to clarify their understanding of alarms. Stuart asks, “Are we promoting Robo to be, sort of like, downstairs… like, you’re not waking up?” And Lance compares alarms to another sub-feature called timers: “Well, it’s kinda like a timer, which is different right?... if I want us to all leave at 7:00PM, I set an alarm for 7:00PM. I'm not gonna set an alarm for the calculation between now and 7:00PM, right?” After Murphy confirms each question, the group develops a shared understanding of the sub-feature as it currently exists. As the interaction continues, Murphy poses several questions to the group that subtly suggest ideas that can change or modify the sub-feature.

MURPHY: So, how many alarms can Robo set?
LANCE: I think one per user.
STUART: We have this in the documentation too. There's lots of ways to deliver alarms. Sort of like, we know when it's three o'clock, right? That kind of thing.
MURPHY: Yeah.
LANCE: That's a good point there. It's not just, "Goodnight." He might want to say, "Goodnight, I've got an alarm at 8:00AM set. I've got a 3:00AM alarm set for you."
STUART: Yeah.
MURPHY: Can Robo set a recurring alarm?
LANCE: Not for version one.
MURPHY: Custom alarm tones?
LANCE: Not for version one.
MURPHY: Okay. That helps simplify it.

This discussion reveals a key dynamic that took place during this stage of collaboration, which is that groups iterated heavily between three collaboration processes: *reviewing existing ideas*, *cultivating ideas*, and *evaluating ideas*. First, Murphy poses a question to the group that suggests an idea to cultivate alarms: “So, how many alarms can Robo set?” Lance elaborates the idea by saying, “I think just one per user.” Stuart then switches to reviewing existing ideas by asking a question to clarify his understanding of an idea about delivering alarms: “There's lots of ways to deliver alarms. Sort of like, we know when it's three o'clock, right?” Then, Lance elaborates upon this idea to further cultivate alarms, saying "That's a good point there. It's not just, 'Goodnight.' He might want to say, 'Goodnight, I've got an alarm at 8:00AM set. I've got a 3:00AM alarm set for you.'" Stuart then evaluates the idea positively to affirm that this idea should be included in the sub-feature. Murphy then asks the group additional questions to cultivate new ideas for alarms. In line 9 he asks, "Can Robo set a recurring alarm?" and in line 11: "Custom alarm tones?" However, in these cases, Lance evaluates the ideas negatively, saying that they are "not for version one."

Each time the group iterates between cultivating ideas and evaluating ideas, they make a collective decision that helps them construct part of the solution for the alarms sub-feature. When the group reacts positively—such as Stuart in line 8—ideas are incorporated into the solution to be implemented in a future prototype; when they react negatively—such as Lance in lines 10 and 12—ideas are eliminated from the solution. This iterative process reflects the iterative process that has been described in prior literature for the deliberate innovation process (Amabile & Pratt, 2016; Cromwell et al., in press). According to this model, after groups have defined a problem, they engage in a cyclical iteration of activities that includes generating ideas, evaluating ideas, and implementing ideas to develop a solution. A key characteristic of this process is that the problem is entirely closed, just as it is in the stage of constructing a shared solution. The following discussion illustrates a similar dynamic among the designers as they discuss an idea about creating an "indicator" for the alarms, but the conversation is more complex than the previous discussion.

MURPHY: So, there's this idea on line 108 that we haven't really explored that much. Which is, when Robo's just idle, is there some sort of indicator?... I mean, we've talked about just having a single indicator whether it's an alarm, or two alarms, or an alarm and an update.

LANCE: That's a really great question. This is interesting… Sometimes that's good, it doesn't seem annoying because I have an alarm set every day. But, then you might always have something there.

STUART: You know, I’m just throwing this idea out there, but the final 30 seconds of an alarm or a timer or anything, there could be this little warning… So, if you're running a timer and then you say "Oh, set a timer for two hours." And the final 30 seconds you get an indicator—almost like a little countdown.

LANCE: Stuart, hold on for a second there. Robo will remind you about the alarm if you talked about it recently. So… there's no need for him to say, "Okay, I'm repeating it back.”

STUART: We could do that, I don't know. Maybe for the wake-up alarm it doesn't make sense, but in some cases, it might be helpful to just have that final countdown.

LANCE: Yeah, that's interesting. Let's hold that for now, it seems complicated at the moment. But it’s an interesting idea for sure.

STUART: Okay.

Like the previous discussion, the group iterates between reviewing existing ideas, cultivating ideas, and evaluating ideas. Murphy begins by reviewing the “idea on line 108” and then quickly transitions to propose an idea to the group: “we’ve talked about just having a single indicator whether it’s an alarm, or two alarms, or an alarm and an update.” In line 4, Lance reacts with an ambivalent evaluation, recognizing that there are both positive and negative aspects to it: “Sometimes that's good, it doesn't seem annoying because I have an alarm set every day. But, then you might always have something there.” Stuart then suggests another idea about “a little countdown.” After Lance evaluates the idea negatively in line 9, Stuart acknowledges that “Maybe for the wake-up alarms it doesn’t make sense,” but he also advocates for the idea in line 12 by saying, “but in some cases, it might be helpful to just have that final countdown.” Lance continues evaluating the idea negatively by saying, “it seems complicated at the moment,” which Stuart eventually acquiesces to in line 16.

A key dynamic that makes this stage of collaboration different compared to other stages is that people evaluated ideas with fairly simple adjectives. Ideas tended to fall along a spectrum of being “good” or “bad”—or in some cases both “good” and “bad”—and developers did not go into great depth to explain the motivation behind their evaluations. For example, the group above uses words such as “interesting” or “nice” for positive evaluations and “annoying” or “complicated” for negative evaluations. These evaluations functioned as vocal guideposts during collaboration that allowed groups to gravitate toward ideas that reflected a shared agreement. Although disagreements were common, groups did not suffer from intense conflict that derailed collaboration (Cronin & Weingart, 2007). This was likely because groups were reviewing ideas that were solutions to problems that were already defined in a prior interaction, meaning that they had already developed a shared set of goals for the sub-feature. Thus, when disagreements arose, it was easier for group members to acquiesce or compromise during the process—such as Stuart does in line 15 above.

4.4.2 Constructing a Shared Representation

When groups engaged in the stage of constructing a shared representation, they iterated heavily between two collaboration processes that were similar to cultivating ideas and evaluating ideas, but there were important differences in this stage of collaboration that led to unique group dynamics. Cronin and Weingart (2007) argue that each group member approaches problem solving with their own internal representation, which includes an implicit association between ideas and criteria. At Roboto, when the problem was entirely closed—as it was in the stage of constructing a shared solution—groups collaborated while having a shared set of criteria, and thus spent much of their time discussing *diverse ideas* with each other. However, in the stage of constructing a shared representation, the problem was amorphous and emergent, meaning that groups discussed both diverse ideas *and diverse criteria* with each other. The following interaction amongst a group of designers who are discussing how to send three types of messages on the robot—a regular message, quick message, and video message—illustrates this dynamic.

TEDDY (designer): So, we can potentially send three types of messages on Robo: *a regular message*, which is dictation and TTS [text-to-speech]. Then you have the idea of this *quick message*, which are those, "Love you," "Running late," "Thank you," "See you later" kinda things. Tell Stuart I said thanks, that's it. The third type would be a *video message*, which is just communication, it's not content.

MURPHY: The more I think about it, I feel like video messages is a nice outlet to essentially take Robo's character out of the equation. I could leave a message for my wife saying, "Grandpa's wake is on Friday,

> we've got to find a babysitter for the kids," and blah, blah, blah. I don't want Robo being like, "Hey, Grandpa's wake is on (whoops) [indicating a mistake]."
>
> TEDDY: The way I look at it is… [Regular messages] are basically the idea of a TTS, which is short and specific, right? It's like, I gotta take out the dog, walk the dog, take out the trash. [Quick messages], which are short and quick… Just, "Thanks," "I love you," but Robo is more involved in both of these. These are much more Robo-like.

This discussion begins when Teddy describes three ideas to the group, which triggers Murphy to begin interpreting the ideas. *Interpreting ideas* is different from evaluating ideas because it involves identifying specific criteria that can be satisfied by the ideas. When group members evaluate ideas, they only vocalize positive or negative reactions based on how well an idea satisfies shared problem criteria; when they interpret ideas, they indicate a positive or negative reaction to the idea while also vocalizing their own internal representation of the idea, thereby revealing the implicit criteria that they associate with the idea. For example, in line 5, Murphy positively interprets video messages by saying, "I feel like video messages is a nice outlet to essentially *take Robo's character out of the equation*." And in lines 9–12, Teddy identifies several criteria that he associates with regular messages and quick messages (italicized): "[Regular messages] are basically the idea of a TTS, which is *short and specific*, right?... [Quick messages], which are *short and quick*. Just, 'Thanks,' 'I love you,'… These are much more *Robo-like*."

Therefore, each time a developer interprets an idea, they make their implicit association between ideas and criteria more explicit to the group. As the group continues participating in this process, they create a set of shared criteria that are explicitly associated with the ideas that they are discussing. The following discussion, in which three additional members get involved in developing the three types of messages, illustrates this dynamic.

> STUART: And [quick messages] are common, right? That's an important point with the second one, which is that we're saying there's a lot of commonality with the messages that you send in a household.
>
> TEDDY: [Quick messages] also have the potential of being personalized. And then the third one [video messages] is ... I would just say, longer and more specific, or—
>
> TYSON (designer): Like character neutral?

TEDDY: Yeah, it's like you want to do something funny in front of the camera and send to somebody.
STUART: Yeah, I feel like there's something where [regular messages] are more informational, and [video messages] are more like ...
RAPHAEL (software engineer): Personal?
STUART: Experiential, personal, social, yeah.

In this discussion, the group identifies several specific criteria that become associated with each idea. Stuart describes quick messages as being “common” (line 1), regular messages as being “informational” (line 7), and video messages as being “experiential, personal” (line 10); Teddy describes quick messages as being “personalized” (line 3) and video messages as being “longer and more specific” (line 4); Tyson describes video messages as being “character neutral” (line 5); and Raphael describes video messages as being “personal” (line 9). By the end of the interaction, the group has collectively created an explicit association between several criteria and several ideas. They do so by using various micro-processes such as clarifying elaborating, summarizing, and defining *criteria* to help them develop a shared understanding of the criteria for each idea, and they also use other micro-processes such as suggesting, proposing, advocating, and elaborating *ideas* to develop a shared understanding of the ideas. Thus, developers are not just cultivating ideas in this stage of collaboration—as they were in the stage of constructing a shared solution—but instead are *cultivating alignment* between ideas and criteria.

Furthermore, when they begin making decisions about which ideas they want to retain or reject, they also make decisions about retaining or rejecting the criteria that are explicitly associated with those ideas. Thus, developers are not just collaborating to construct a shared solution, but instead are collaborating to *construct a shared representation*, which includes the co-construction of both solutions and problems at the same time. The differences between the stages of constructing a shared solution and constructing a shared representation is similar to the differences that Harvey and Kou (2013) found between “generation-centered” and “evaluation-centered” processes in groups. They found that groups engaging in a “generation-centered” process generated and evaluated a large number of ideas to identify the optimal solution to a pre-defined problem, whereas groups engaging in an “evaluation-centered” process generated and evaluated a small number of ideas to develop a stronger shared understanding of the problem.

The following discussion reveals how this group of developers continued iterating between interpreting ideas and cultivating alignment to eventually agree that the first type of message (i.e., regular messages) should be further developed because it satisfies the criteria of making the robot seem more like an “autonomous, active participant… in the household.”

> MURPHY: I think there's an opportunity for [regular messages], like for people to get in the head space of: "This isn't going to be a message from me to [my son]. I can tell Robo to tell [my son] something in Robo's character, and he'll do it.” It's more like, "Hey Robo, you little autonomous character you, can you just remind [my son] to take the trash out?" Robo would deliver it… It's more like Robo's another actor. It's not a messaging tool. I think that's what the [regular messages] are for me.
>
> TEDDY: That's the way I always thought about it, and even on the app it was ... If you were to get one of those messages that's like, "I have to do X, Y or Z," there would be some sort of visual accompaniment.
>
> MURPHY: You've had the model [Teddy], which I loved so much, the idea of Robo being like sending a message to you on your app. Robo's like, "Hey man, here's a picture of your cat." You're like, "Oh that's cool, so he is this autonomous, active participant in communication in the household."
>
> STUART: I think people will love that. I think people will love being able to text with their robot.
>
> TEDDY: Totally.

This interaction also highlights an important role that this stage of collaboration played in the broader context of developing the product. The concept of a “social robot” was highly ambiguous to developers at the beginning of the development process, meaning that there were multiple valid representations of the overall product (Cronin & Weingart, 2007; Kaplan & Tripsas, 2008; Weick, 1990). However, developers at Roboto had to construct a shared representation of the product within their organization (e.g., Hargadon & Bechky, 2006; Okhuysen & Bechky, 2009; Seidel & O'Mahony, 2014). The interaction above reveals how developers constructed a shared representation of the *individual sub-feature* about sending a message on the robot.

At the very beginning of the interaction, the group interprets ideas with ambiguous criteria such as "taking Robo's character out of the equation" and making messages "more Robo-like." Throughout the interaction, they also interpret ideas with clearer criteria such as "short," "specific," "quick," "personalized," "informational," "autonomous," etc. In doing so, groups established a connection between several specific ideas, several clear criteria, and several ambiguous criteria. Therefore, when they made decisions about which ideas to retain or reject, they also made collective decisions to help them better understand the ambiguous criteria they were trying to cultivate for the overall product. As groups repeated this stage of collaboration for each sub-feature, they could slowly construct a stronger shared representation of the conceptual features, which could help them eventually construct a stronger shared representation of the overall product (see Chapter Three of this dissertation).

4.4.3 Constructing a Shared Problem

In the stage of constructing a shared problem, the problem was entirely open, meaning that groups had a diverse understanding of criteria, and they iterated heavily between two collaboration process—*interpreting criteria* and *cultivating criteria*—to develop a shared set of criteria. The primary difference between this stage of collaboration and the stage of constructing a shared representation came from the way that group members used their internal representations to make sense of a sub-feature. In the stage of constructing a shared representation, groups used *diverse criteria* to help them interpret a *small number of ideas*. They also focused more on ideas during this stage, so that when they converged on a particular set of ideas, it simultaneously yielded a set of emerging criteria that were associated with those ideas. But in the stage of constructing a shared problem, these dynamics were inverted. Groups used *diverse ideas* to help them interpret a *small number of criteria*, and they focused on cultivating criteria, which simultaneously yielded a set of emerging ideas that were associated with those criteria. For example, consider the following interaction, in which a group of executives are discussing different interpretations of the criterion "agency" in the context of the sub-feature for taking a photo.

> CADENCE (executive): Agency, to me, can mean autonomy. He can make it fun in a way, because it's a character… And we should challenge ourselves in terms of what that means, but [agency] is an attribute to him that's unique. He can recognize your face, both in the pictures he takes, as well as the moments.
>
> LANCE (executive): For me, that's a bad experience. If I had a robot in my home, and I asked it to take a picture… I'm expecting it to then take a picture with the camera. If it's kind of like taking your picture at a random moment, if there's this [autonomous] being that's taking a picture, I don't know what's gonna happen. So, in that case, for me, agency means his ability to engage me, his ability to know *when* to take the picture.
>
> CADENCE: Well, I think agency's the difference between being a camera versus a photographer. A photographer brings intelligence to the whole process. A camera just takes the picture.
>
> LANCE: This is good. If I take a single picture of you, I preview the right place. But if I'm a cameraman, I wait for the right moment before taking a picture. So, a single photo also is agency.

In this discussion, the term "agency" is an ambiguous criterion in the group—similar to the way that "Robo-like" was an ambiguous criterion in the previous section. Cadence first tries to clarify the criterion by using more specific criteria such as "autonomy," "fun," and "character," and then she illustrates the criterion with an idea that reflects her internal representation of the sub-feature: "[Robo] can recognize your face, both in the pictures he takes, as well as the moments." Lance has a different representation of the sub-feature, and therefore he proposes an alternative interpretation of the criterion using another idea: "For me, that's a bad experience… for me, agency means [Robo's] ability to engage me, his ability to know *when* to take the picture." In line 8, Cadence proposes yet another idea for the criterion: "I think agency's the difference between being a camera versus a photographer. A photographer brings intelligence to the whole process. A camera just takes the picture." Lance then responds by elaborating her idea: "If I take a single picture of you, I preview the right place. But if I'm a cameraman, I wait for the right moment before taking a picture. So, a single photo also is agency."

In all of these comments, developers are *interpreting the criterion* with several ideas to help them make sense of it. This contrasts with the stage of constructing a shared representation, in which groups identified several criteria to help them make sense of a single idea. Both situations indicate that the group has different representations of the sub-feature, but they reflect inverted methods by which groups make sense of the situation and converge onto a shared representation of the sub-feature. In this stage of collaboration, groups focused on developing a shared understanding of criteria, and they cultivated criteria by engaging in several micro-processes such as clarifying, elaborating, summarizing, and defining criteria to help them construct a shared problem for the sub-feature.

As the group continues the interaction, they continue iterating between interpreting criteria and cultivating criteria until they eventually develop a shared understanding of "agency" in the context of taking a photo on the robot. They begin when Sanjay responds to Lance's comment from above that "a single photo is also agency" (line 11).

SANJAY (executive): I think this is actually confusing. To me, a single photo is: Robo takes a picture of me right now.

LANCE: But he has to figure out where you go in that photo, and he has to do something smart. And he has to figure out even in that short moment.

EVERETT (executive): Let's not use the word "agency." It's got a lot of baggage. It's also a robotics term that means something a little bit more than that. Why don't you just talk about what you seem to mean. I'm gonna paraphrase just to simplify. You seem to mean the "intelligence" that Robo brings to his camera, no matter whether it's multiple photos or not… So, intelligence is gonna be how well he'll crop, how well he'll frame.

CADENCE: So, then it would be things like knowing if your eyes were closed, for instance?

EVERETT: Yes.

CADENCE: Okay, that works.

LANCE: I think that sounds fine.

This discussion begins when Sanjay proposes yet another idea to help him interpret the agency criterion. In this case, his idea counters Lance's perspective: "To me, a single photo is: Robo takes a picture of me right now." This prompts Lance to elaborate his idea to help Sanjay better understand his own representation, only for Everett to interrupt the discussion and redefine the criterion they had been discussing: “I'm gonna paraphrase just to simplify. You seem to mean the ‘intelligence’ that Robo brings to his camera, no matter whether it's multiple photos or not… So, intelligence is gonna be how well he'll crop, how well he'll frame.” By re-defining “agency” to “intelligence,” Everett helps the group resolve their ambiguity and construct a shared problem for the sub-feature, as both Cadence and Lance agree to the change. Note also that when the group converges onto a shared understanding of the criterion “intelligence,” any ideas that are associated with that criterion emerge as potential solutions for the sub-feature. As Cadence describes in line 8: “So, then it would be things like knowing if your eyes were closed.”

This iterative process captures the dynamic that developers adopted each time they confronted ambiguity for a particular criterion. However, the social robot was a complex technology product that had to satisfy multiple criteria. Therefore, developers needed to develop a shared understanding of—not only the meaning of each criterion—but also their order of preferences for multiple criteria that they identified across multiple sub-features (Cronin & Weingart, 2007). In the following discussion, the same group of developers begin prioritizing several criteria that they identified throughout the Photography meeting called “intelligence,” “stereo motion capture,” and “face ID.”

SANJAY: I want to propose an exercise at this stage, which is, if we had to rank these [criteria] and say, "Okay, I have the power of God to snap my fingers and get one of these exactly right," which would it be?

… [Five group members each rank the most important criteria, taking about 5 minutes to complete] …

LANCE: So… stereo motion capture and intelligence?

SANJAY: I would agree, given that we know we’re going to get face ID at some level here.

EVERETT: So, we wanted to get to those core things here, and we just kind of isolated what they are… I think what hurls off this page is the [stereo] motion capture and, to a lesser extent, face ID… So, we've got a great intersection between things consumers can value that's viral and interesting.

SANJAY: Our challenge then is to brainstorm how we can take advantage of [stereo] motion capture?

EVERETT: It’s the right question for you to ask. I've tried to create a two-by-two for this down here [points to whiteboard]. The idea that we're coming up with—a unique media format—on the bottom axis, and the top axis are things that tap Robo’s unique features… The key is obviously to get high feature-uniqueness and a media format that's super compelling. And if it's up here, this is nirvana.

The group begins this discussion with a set of three criteria that they are evaluating, and they end with a clear structure of preferences across the criteria. According to Everett in lines 7–8, "I think what hurls off the page is the stereo motion capture and, to a lesser extent, face ID… so we've got a great intersection between things consumers can value that's viral and interesting." In lines 10–13, he goes on to aggregate multiple criteria into a more complex "two-by-two" problem framework, which becomes an organizing problem that helps them later "brainstorm how we can take advantage of [stereo] motion capture" (line 9).

Altogether, this stage of collaboration began with developers using many diverse ideas to interpret the criterion called "agency" (i.e., "intelligence"), a process that repeated for other criteria such as "stereo motion capture" and "face ID." The stage ended when the group constructed a shared problem that consisted of a shared set of criteria and a clear order of preferences for those criteria (Cronin & Weingart, 2007). Therefore, these dynamics are similar to the dynamics found in prior research studying the deliberate innovation process in groups (Frishammar et al., 2016; Reiter-Palmon, in press), in which groups create a divergent set of representations to identify heterogeneous goals before converging onto a single representation that creates a shared set of goals for the group.

4.4.4 An Integrated Model of Dynamic Problem Solving in Groups

In the previous sections, I describe the characteristics of three distinct stages of collaboration, which can explain findings from prior research on problem solving in groups (Chapter Three of this dissertation; Cronin & Weingart, 2007; Frishammar et al., 2016; Harvey & Kou, 2013; Reiter-Palmon, in press). For example, groups can engage in the deliberate innovation process by first constructing a shared problem and then constructing a shared solution. Or they can engage in the emergent innovation process by first constructing a shared solution and then constructing a shared problem.

However, my findings suggest that the innovation process in organizational settings is richer and more complex than either of these two models suggest, because there is a third stage of collaboration (constructing a shared representation) that sits between the two stages of collaboration that have been described in prior literature. This third stage plays a particularly important role in helping groups resolve ambiguities and make sense of open problems, and it reveals how group dynamics can systematically change as a function of the extent to which the problem is open. These findings suggest that sub-features can evolve through a continuous stream of development as the problem for a sub-feature oscillates from being open to closed—and vice versa—over time. Furthermore, different types of developers may join or withdraw from the development process depending on the stage of development. Thus, each sub-feature can operate at the center of a dynamic hub of activity amongst diverse developers who are continuously collaborating with each other in different permutations over time (Cronin, Weingart, & Todorova, 2011; Mortensen & Haas, 2018).

In this section, I generate theory to describe these group dynamics by tracking the development of one particular sub-feature—the delivery of messages on the robot—during an intense five-week period in which it undergoes a significant revision and re-design. In this particular case, I begin tracking the sub-feature when the problem is entirely closed, and I reveal how it evolves as the problem oscillates from being entirely closed to entirely open and then back again to become entirely closed. During this process, I highlight the key moments that facilitate transitions between the three stages of collaboration described above, and I show how collaboration processes associated with *gathering external information* influence these transitions throughout the entire development process. I summarize my findings in Figure 4.2, which illustrates a model of dynamic problem solving in groups that describes how the continuous collaboration of groups that iterate between three stages of collaboration cumulates into the co-evolution of problems and solutions over time. Note that it is also possible for sub-features to evolve by starting when the problem is entirely open and then oscillate to being entirely closed and then back again to become entirely open. In this case, the transitions between the three stages of collaboration are identical to the transitions shown in Figure 4.2, but they occur in a different sequence than what I describe below.

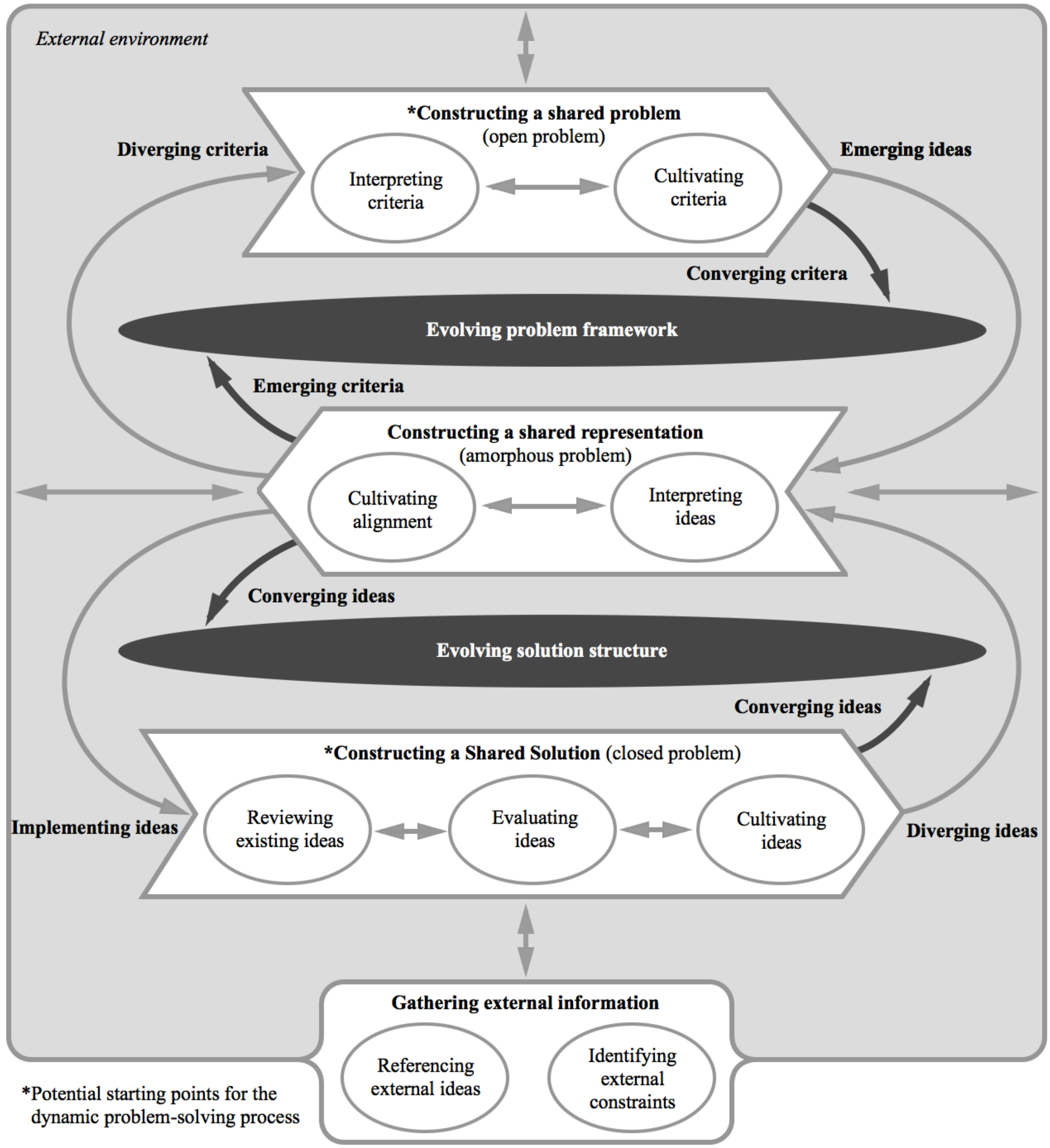


Figure 4.2: A Model of Dynamic Problem Solving in Groups

Oscillating from a Closed Problem to an Open Problem. The process of oscillating from a closed problem to an open problem begins when groups are operating in the lower-left corner of Figure 4.2 when they begin the stage of constructing a shared solution. At Roboto, these interactions always began after an idea had already been implemented in a prototype; thus, the idea reflected a solution to a problem that had been defined in a prior interaction. However, prototypes were often affected by unexpected constraints that developers could not anticipate before they implemented ideas. Therefore, when reviewing ideas during this stage of collaboration, developers often engaged in micro-processes such as surfacing problems, clarifying limitations, or clarifying resources to *identify external constraints*, which could potentially alter the trajectory of sub-features.

For example, the following discussion amongst a group of developers who are reviewing an idea about how to deliver messages on the robot illustrates this possibility. Before this meeting, the group came to a shared agreement that the robot should deliver "transcribed messages," which uses an audio-speech-recognition system to transcribe and display messages on a screen. However, after identifying a constraint with the audio-speech-recognition system, one developer proposes a new idea to replace transcribed messages with "audio messages."

SEBASTIAN (software engineer): Sanjay and I were talking about ideas to simplify Messaging. One was that we would just do audio messages instead of ASR [audio-speech-recognition] transcribed messages.

CRYSTAL (product manager): Yep. Okay, tell me more.

SEBASTIAN: Well, the speech team wants to do audio messages because there's a lot of challenges with the transcription stuff. And they think that they're gonna be shooting arrows in the ASR you're not supposed to. They definitely do not want to do message transcription… So anyways, what do you think?

CRYSTAL: Yeah. Sanjay and I were talking about that today. I'm totally fine with that. But if we're going to cut other significant elements of the program, then it might be worth keeping. What are your thoughts?

MURPHY: I think that would be very disappointing. That essentially turns Robo into an answering machine. I think the whole point of messaging is that Robo becomes an active participant in the messaging process. It's like, "Oh, hey, I heard from Samantha and she's going to be late."… Yes, it would be much easier, but I think it would take a big chunk of Robo's character out of this feature.

SEBASTIAN: I think that is how we would want to do it. But if you have message text on the screen, it probably sets the expectation that if the message got transcribed wrong, then you would be able to edit it, and then we would have to think about how to handle that.

This discussion begins when Sebastian proposes an idea to substitute transcribed messages with audio messages. When Crystal asks him to explain more, Sebastian surfaces a problem with the audio-speech-recognition system that seems to be beyond their control because of technical constraints: “Well, the speech team wants to do audio messages because there's a lot of challenges with the transcription stuff. And they think that they're gonna be shooting arrows in the ASR you're not supposed to.” At first, Crystal responds by saying that she is “totally fine with that,” which reflects a positive evaluation of the idea. If the interaction ended here—or if other group members agreed with Crystal—then they would have been able to *converge on an idea* and implement audio messages as a solution to resolve the ASR-constraint problem.

However, Murphy replies with a strong negative reaction by saying, “I think that would be very disappointing. That essentially turns Robo into an answering machine... it would take a big chunk of Robo's character out of this feature.” Note that this comment reflects a negative interpretation of the idea (rather than a simple negative evaluation), because he identifies specific criteria that would be affected by choosing the audio-messages idea. He acknowledges that audio messages may be “much easier,” but he also says that “it would take a big chunk of Robo’s character out of [Messaging].” If Sebastian had been willing to acquiesce to Murphy, the group could have instead converged on the transcribed-messages idea to undergo further development.

Instead, Sebastian negatively interprets transcribed messages by saying,” But if you have message text on the screen, it probably sets the expectation that if the message got transcribed wrong, then you would be able to edit it, and then we would have to think about how to handle that,” suggesting that they would need to develop a more complex idea for the sub-feature. At this point in the discussion, the group confronts *diverging ideas* that reflect conflicting representations of the sub-feature (Cronin & Weingart, 2007). On one hand, Sebastian believes that the sub-feature should be less complex; on the other, Murphy believes that it should help create a “character” experience for Messaging. Therefore, they are no longer operating in the stage of constructing a shared solution and have transitioned to the stage of constructing a shared representation, which is captured by the curved arrow in the lower-right corner of Figure 4.2.

The conflict shown here actually reflected a broader theme that was occurring within the organization at the time of this interaction. Many developers—such as Murphy—represented the product as a "character" that was meant to be an active *social* participant in the home, whereas others —such as Sebastian—represented the product as a "device" that was meant to be a functional and useful *robot* for users. Given that this product was called a *social robot*, these two representations reflected two extreme ends of a continuum of ways that developers at Roboto tended to represent the product. However, few developers exclusively used one representation at the expense of the other; most developers agreed that the product should contain some elements of the "character" representation and some elements of the "device" representation, including both Sebastian and Murphy. Still, developers often struggled to merge these two representations together when developing sub-features, which often incited conflict during collaboration (Cronin & Weingart, 2007).

Therefore, the conflict between Murphy and Sebastian was not resolved in that particular interaction, and it actually persisted within the organization for several weeks. As developers continued working on the sub-feature, they iterated between interpreting ideas and cultivating alignment as they attempted to construct a shared representation of the sub-feature; during that time, the idea of audio messages evolved into an idea about "video messages." However, they failed to cultivate full alignment because video messages conflicted with the "device" representation described above. The following discussion reveals how a group of designers confronted this conflict and responded to it by transitioning from the stage of constructing a shared representation to the stage of constructing a shared problem.

> STUART: To increase the value [of messages]… one of those concepts we were talking about was, there's not really messages. There's just a shared wall... there's a shared album of moments. When you create video messages, they just get added to that wall. Like that Slack-channel model we were talking about.
>
> TEDDY: I agree… But the question I have is the usefulness of Robo in terms of being a sidekick. For me personally, it feels like he's becoming less of a utility and more of a content machine.
>
> NATALIA (product manager): Well, I think you're thinking that because we're focusing on Messaging and Photography right now. But, think of all the other things that could and should be on Robo. So like, "Is there news?" You as a family are gonna need to know the news. Or, you as a family plan a trip: "Hey, what's my current flight status?" You as a family go to the park: "Robo, what's the weather gonna be like today?"
>
> STUART: I think a lot of people are gonna want and expect the sort of like, personal assistant model where it's like, "I have this robot personal assistant who's really smart on my desk." And then it's like, he's kind of talking schedule, talking weather and traffic, and messages just weave really well into that. He's like, "Oh, don't forget about ... you have that thing at ten o'clock." It's as though Robo... is sort of like a robot butler.

This discussion begins when Stuart proposes an idea to the group in an attempt to cultivate alignment between an idea (i.e., "a shared wall") and a criterion (i.e., "value"). However, Teddy negatively interprets Stuart's idea and argues that it conflicts with the criterion of "utility," which was closely associated with the device representation. As he describes it in line 4–5, "I agree… But the question I have is the usefulness of Robo in terms of being a sidekick. For me personally, it feels like he's becoming less of a utility and more of a content machine." However, this seems to prompt Natalia and Stuart to propose alternative interpretations of "utility." In lines 8–10, Natalia illustrates her view with several ideas such as "news," "flight status," and "weather;" and Stuart proposes his perspective with several ideas that are related to "a personal assistant model." As he describes in lines 11–14, "it's like, he's kind of talking schedule, talking weather and traffic, and messages just weave really well into that. He's like, 'Oh, don't forget about ... you have that thing at ten o'clock.'"

Therefore, at the beginning of this discussion, the group is interpreting one idea (e.g., a shared wall for messages) with various criteria (e.g., value, usefulness, utility, content machine) to help them make sense of the idea; thus, they are engaging in the stage of constructing a shared representation. However, at the end of the discussion, they are interpreting one criterion (e.g., utility) with various ideas (e.g., news, flight status, weather, schedule, traffic) to help them make sense of the criterion; thus, they are engaging in the stage of constructing a shared problem. The key dynamic that facilitates a transition between these two stages is that they experience *diverging criteria*, meaning that group members have diverse interpretations of the criteria for a sub-feature. Diverging criteria can also occur when groups have diverse opinions about which criteria to pursue, such as when developers were discussing several criteria for taking a photo earlier in an earlier section. When this occurs, groups follow the curved arrow located in the upper-left corner of Figure 4.2.

Oscillating from an Open Problem to a Closed Problem. The previous section reveals that the group dynamics for developing a sub-feature revolve around the degree to which groups can maintain a shared representation of the sub-feature. A fully shared representation occurs when all group members agree on both the ideas and the criteria for the sub-feature (Cronin & Weingart, 2007). Groups achieve this state when they are located in the lower-left corner of Figure 4.2 and begin the stage of constructing a shared solution. However, the shared representation slowly deteriorates as groups transition to the stage of constructing a shared representation and again to the stage of constructing a shared problem. First, groups suffer from diverging opinions about ideas; then they suffer from diverging opinions about criteria. By the time they reach the upper-left corner of Figure 4.2, they have a fully *unshared* representation of the sub-feature.

By contrast, the process of oscillating from an open problem to a closed problem reverses this process, so that groups first develop a shared set of criteria and then develop a shared set of ideas so that they can eventually return to a fully shared representation of the sub-feature. For example, as the developers from the previous discussion continue iterating between interpreting criteria and cultivating criteria to construct a shared problem, they confront significant resource constraints that prevent them from developing a large number of useful features for the product. Therefore, they introduce the "character" criterion into discussion and begin weighing the tradeoffs between pursuing these two criteria. The following discussion captures the moment at which they construct a shared problem that strikes the right balance between these two criteria, which gives way to a brainstorming session that allows them to develop new ideas to satisfy the criteria.

TOBY (designer): Just to make my point a little clearer from before… Since he's not going to have a lot of features at the beginning, v1 is more about… who Robo is going to be. This is what Robo is, even though he cannot do a lot of things now. So, it's important to really nail what Robo's all about, even if he's less useful.

HUNTER (software engineer): There are quick small things that we can add that are much more realistic to ship. We could do small things like let him use images, reporting sports scores, and basic general knowledge.

NATALIA: Yeah, I think… we need to have that utility aspect to make people's lives easier, but we also need to have a character aspect, and there's those two fronts that we want... Like, we're not going to be able to replace the iPhone, but if you can have a character aspect that, like, he's always in my living room and he's going to give me that information… I think we can leverage that.

… [For the next three minutes, the group discusses what to do next] …

STUART: Alright so we all agree from an experiential standpoint there's the core stuff: the idle, the greetings and all those things. But then, also, that other people want to have something very familiar to put on the back of the box. Robo does x and y. So why don't we think of more of these little skills?

TYSON: What if… I come up with my own ideas and then we throw them all together?

DEREK (designer): Like an individual brainstorming and then get back together?

TYSON: Yeah. It would be great. Group brainstorms are awesome, but they have some limiting factors.

Toby begins this discussion by clarifying his perspective on the "character" criterion, saying "v1 is more about… who Robo is going to be. This is what Robo is, even though he cannot do a lot of things now. So, it's important to really nail what Robo's all about, even if he's less useful." This statement demonstrates how external constraints motivated the group to shift their focus from the "utility" criterion to the "character" criterion, which Natalia summarizes with a clearly constructed problem in line 6: "We need to have that utility aspect to make people's lives easier, but we also need to have a character aspect, and there's those two fronts that we want." After further deliberation, the group concludes that they can satisfy both criteria if they "think of more of these little skills" for the robot, as described by Stuart in line 13.

This interaction demonstrates how groups can produce new *emerging ideas* at the same time as converging on criteria to focus on for the problem. In this discussion, Stuart produces an idea about "little skills" that comes from earlier in the discussion, when Hunter proposes an idea about "small things that are more realistic to ship." Consequently, when developers converge onto a particular set of criteria at the end of the stage of constructing a shared problem, they also select a subset of ideas that are associated with those criteria. This dynamic demonstrates how the construction of a problem can subsequently influence the set of ideas that they develop when trying to solve the problem (Reiter-Palmon, in press; Reiter-Palmon et al., 2008).

In this case, they begin brainstorming to develop new ideas for "little skills" that will help them achieve more "utility." For a complex technology product such as a social robot, these ideas often needed to be interpreted in the context of other criteria. Therefore, the group transitions to the stage of constructing a shared representation, which is captured by the curved arrow located in the upper-right corner of Figure 4.2. Note that during this interaction, the group is no longer focused on the sub-feature of delivering messages. This is because during the stage of constructing a shared problem, they used a wide range of *ideas* to help them develop a shared set of *criteria*. Therefore, they migrated from focusing on ideas related to delivering messages to idea related to little skills on the robot.

However, once they developed a shared set of criteria, they could circle back to apply the newly defined criteria to the sub-feature of delivering messages on the robot. The following discussion captures the moment when a group of designers—one week later—cultivate alignment between an idea for delivering messages (i.e., eliminating the "shared wall" idea) and their newly defined criteria (i.e., balancing "character" and "utility").

DEREK: So, the idea is that any message you send from Robo will send a push notification to people who have the app. And he'll either deliver it himself if they haven't read it yet, or they'll just open the app.

STUART: Murphy, in that scenario, beyond just the fact that Robo is charming and animated and all that, what other reason would you have for sending the message through Robo?

MURPHY: Yeah, that's a good question… I feel like if Robo is actually a character that is like a living person, I can talk to and have him relay things for me to people, I would keep using it... seamlessly.

STUART: And then, maybe he'd capture a list of that stuff over time? Is that cool? Useful?

MURPHY: I mean, yeah. Maybe it's not. What if there's no shared wall?... If I was like, "Hey Stuart, can you tell Natalia that I'm gonna be late for the meeting." You're not gonna be like, "Oh, tuck this away and have this history of all of the things you asked me to tell everyone." Maybe Robo is just a person.

NICOLE (designer): I would love that on the robot. I don't really care about the history.

DEREK: I don't think we need a message list on the robot.

STUART: Yeah… that feels right.

This discussion begins when the group is trying to make the sub-feature of delivering messages more useful. Derek proposes an idea about sending "push notifications to people who have the app" so that people will know when a message has been sent through the robot. And in line 7, Stuart suggests an idea that the robot "capture a list of [those messages] over time," which is a reference to the "shared wall" concept that he proposed a week earlier. However, Murphy interprets these ideas as skewing the sub-feature too heavily toward "utility," and he advocates that eliminating the "shared wall" will actually help the sub-feature satisfy both "character" and "utility." For example, in line 6 he says, "I feel like if Robo is actually a character that is like a living person, I can talk to and have him relay things for me to people, I would keep using it... seamlessly." Several other developers agree.

Note that by selecting Murphy's idea, the group also modifies their understanding of the "utility" and "character" criteria. Rather than viewing them as separate and conflicting—as they did before—they view "character" and "utility" as symbiotic. Therefore, a new shared understanding of the criteria emerges at the same time as when they converge on Murphy's idea. After this interaction ended, this idea was handed off to another designer named Isabel, who was responsible for implementing the idea and developing several prototypes for them to review the following day. Thus, they can transition back to the stage of constructing a shared solution, which is captured by the curved arrow located in the lower-left corner of Figure 4.2.

Tracking the development of this sub-feature of Messaging during this five-week period illustrates the group dynamics that took place at Roboto while developing the social robot. It is important to note that collaboration processes associated with gathering external information played an important role throughout all stages of development. The interactions above show how the process of identifying external constraints triggered the initial conflict between Murphy and Sebastian, which sent a ripple throughout the entire development process. At each stage of collaboration, developers were mindful of the constraints they were facing on the product, which influenced the way they interpreted both ideas and criteria for the sub-feature.

The process of *referencing external ideas* also played an important role in facilitating the development process. Throughout all stages of collaboration, groups used micro-processes such as creating metaphors, comparing ideas to external ideas, or describing external ideas as they attempted to construct and maintain a shared representation of the sub-feature. These micro-processes helped developers generate new ideas (Gentner, 1983; Hargadon & Sutton, 1997; Koestler, 1964; Schön, 1993)—such as when Stuart used the "Slack-channel model" to develop an idea about the "shared wall concept." They also helped developers interpret ideas and develop a shared understanding of the criteria they were associating with ideas (Cornelissen, 2005; Cornelissen et al., 2008; Seidel & O'Mahony, 2014)—such as when Murphy said that the audio-messages idea "essentially turns Robo into an answering machine."

Finally, this example illustrates how the process of developing one sub-feature could influence—and be influenced by—the development of other sub-features. The social robot consisted of dozens of sub-features that were co-developed over time. Often times, developing an idea for one sub-feature could alter the shared understanding of criteria that influenced other sub-features—such as when the group decided to eliminate the "shared wall concept" from the sub-feature of delivering messages.

Therefore, all the criteria that were developed across these sub-features aggregated into a complex *problem framework* that consisted of higher-order criteria such as "character" and "utility," which affected all sub-features, and lower-order criteria such as "short and quick," "personalized," and "longer and more specific," which affected only a few sub-features. Similarly, all the ideas that were developed across these sub-features aggregated into a complex *solution structure*, which reflected a composition of ideas that aligned with the complex problem framework. Therefore, the dynamic problem-solving model depicted in Figure 4.2 explains not only how groups can develop a single sub-feature over time, but also how their continuous development of a single sub-feature *at a time* can accumulate into the co-evolution of a complex problem framework and complex solution structure over the course of several years.

4.5 Discussion

By conducting one of the first studies that deeply examine group dynamics under open-problem conditions while developing a breakthrough innovation, I discovered that the micro-processes underlying the deliberate innovation process and emergent innovation process are similar to each other, enabling groups to seamlessly oscillate between deliberate and emergent innovation over time. My findings elaborate existing theory on the group dynamics that facilitate each model of the innovation process, and I generate new theory by integrating these competing models of the innovation process into a more coherent model of dynamic problem solving in groups. This model describes how groups can continuously collaborate with each other as they iterate between three stages of collaboration and gather external information from their environment, resulting in the co-evolution of problems and solutions over time. Although this model may be particularly relevant for groups developing a breakthrough innovation, it may also provide a more coherent framework to understand creativity and innovation in groups more generally. In the following sections, I discuss these contributions in more detail and highlight opportunities for future research.

4.5.1 Elaborating the Deliberate Innovation Process in Groups

A majority of prior research adopts the deliberate innovation process (Cromwell et al., in press), which begins with finding, defining, or constructing a problem (Getzels & Csikszentmihalyi, 1976; Mumford et al., 1994; Reiter-Palmon, in press), and is followed by an iterative sequence of activities that includes generating, evaluating, selecting, and implementing ideas (Amabile, 1983; Amabile & Pratt, 2016; Mumford et al., 1991; Wallas, 1926). However, details on the group dynamics that facilitate this process are still emerging (Frishammar et al., 2016; Hargadon & Bechky, 2006; Harrison & Rouse, 2014, 2015; Harvey & Kou, 2013). I elaborate on prior research by identifying three stages of collaboration that have different group dynamics based on the extent to which the problem is open.

My findings are consistent with the deliberate innovation process, because groups can begin problem solving by engaging in the stage of constructing a shared problem. However, I also distinguish between two stages of collaboration that can occur after problem construction, which yield different effects on the development of problems and solutions over time. When groups collaborate in the stage of constructing a shared solution, they *evaluate ideas* to determine whether ideas fully satisfy the problem criteria; if ideas fall short, the group can *cultivate ideas* that more fully satisfy the criteria, which can then be implemented for a subsequent round of review and revision. In this stage, the problem is mostly static as people develop the solution, which is highly reflective of existing theories of creative problem solving (Amabile, 1983; Newell & Simon, 1972; Unsworth, 2001). By contrast, when groups collaborate in the stage of constructing a shared representation, they *interpret ideas* to create more explicit connections between ideas and criteria. As members iterate between interpreting ideas and cultivating alignment, new criteria can be added to existing ideas, and vice versa, new ideas can be added to existing criteria. Therefore, the problem evolves in tandem with the solution.

Distinguishing between these two stages may have important implications for several activities of the innovation process. For example, group brainstorming may differ in each stage of collaboration. In the stage of constructing a shared solution, groups may need to generate a large number of divergent ideas, which can then be evaluated positively or negatively as the group converges onto an idea that best satisfies shared problem criteria. In this situation, *nominal groups* may be more effective at problem solving than collective groups, because they are more capable of generating and evaluating a large number of ideas (Girotra et al., 2010; Paulus, Brown, & Ortega, 1996; Stroebe & Diehl, 1994). In the stage of constructing a shared representation, groups may need to generate a small number of ideas that are interpreted in the context of various criteria so that they can develop a stronger shared understanding of the problem. Therefore, *collective groups* may be more effective at problem solving than nominal groups, because they can reframe ideas in the context of multiple criteria to stimulate new ways of thinking (Hargadon & Bechky, 2006; Paulus & Yang, 2000) and help groups satisfy more complex or conflicting criteria (Harvey, 2014; Sutton & Hargadon, 1996).

The differences between these two stages of collaboration also echo differences that Harvey and Kou (2013) found between the generation-centered and evaluation-centered modes of collaboration, which they found to be equally effective at problem solving. Therefore, these two stages have the potential to reconcile mixed findings from prior research on idea generation and evaluation in groups (Harvey, 2013; Kavadias & Sommer, 2009; Rietzschel et al., 2006). Furthermore, these stages are reminiscent of the “cycles” of innovation that Goh et al. (2013) found, in which groups can engage in either a “validation cycle,” which is focused on making small incremental improvements to ideas to better satisfy *existing* criteria, or an "experimentation cycle," which is focused on conducting trial-and-error tests of ideas to better understand *new* criteria. I elaborate on findings from these studies by explaining when and why groups may transition between different stages of collaboration over time and describing how each stage influences problems and solutions differently.

Furthermore, distinguishing between these two stages of collaboration provides a clearer explanation for when and why groups decide to revise the problem after it has been defined, which is widely recognized an important activity in the deliberate innovation process but still rarely studied (Amabile & Pratt, 2016; Mumford, Medeiros, & Partlow, 2012). When constructing a shared representation, members are constantly interpreting ideas, which can help them realize that they do not have a clear understanding of the criteria they are trying to satisfy. This is likely to occur more often when groups are working on open and ill-defined problems (Simon, 1973). Consequently, groups may need to transition to the stage of constructing a shared problem so they can interpret the criteria from multiple perspectives and cultivate a clearer understanding of the criteria, which can lead to higher quality problems (Getzels & Csikszentmihalyi, 1976; Mumford et al., 1994; Reiter-Palmon, in press). Alternatively, people may realize that they want to stop pursuing one set of criteria and pursue another, meaning that they can—again—transition to the stage of constructing a shared problem and cultivate a new set of criteria that can be solved with existing ideas (Baker & Nelson, 2005; Sonenshein, 2014).

4.5.2 Elaborating the Emergent Innovation Process in Groups

In contrast to the deliberate innovation process, scholars have also proposed an emergent innovation process (Cromwell et al., in press), in which people first generate an idea without having a clearly defined problem in mind, and then explore that idea in the context of an open problem domain until a specific problem and solution emerge together (Finke, 1990; Finke et al., 1992; Ward et al., 1999). Although few studies have examined this process empirically (Anderson et al., 2014; Shalley & Zhou, 2008), there is substantial evidence showing that accidental, surprising, or serendipitous discoveries are quite common when developing innovations in organizational settings (Austin et al., 2012; Cattani, 2005, 2006; Merton & Barber, 2004; von Hippel & von Krogh, 2016). This suggests that the emergent innovation process may be responsible for a substantial portion of innovation activity in organizations (e.g., Andriani et al., 2017) that has received little attention in creativity and innovation literature.

My findings are consistent with prior research on the emergent innovation process in groups (Chapter Three of this dissertation), which finds that groups can develop a solution for an innovation before defining a problem for the innovation by engaging in a cyclical iteration of activities that includes generating ideas, implementing ideas, and interpreting ideas. Note that in Figure 4.2, groups can follow this cyclical process by transitioning between the stage of constructing a shared solution and the stage of constructing a shared representation without ever transitioning to the stage of constructing a shared problem. However, an important difference between this study and Chapter Three is that I focus on group dynamics under open-problem conditions for individual *sub-features*, allowing me to study group dynamics under a broader range of open-problem conditions. This allowed me to discover three distinct stages of collaboration that have different group dynamics based on the extent to which the problem is open. In Chapter Three, I focus on group dynamics under open-problem conditions for the *overall product*. Therefore, I discovered that an iteration between interpreting ideas and generating ideas helped developers construct a shared understanding of individual features without having a clear understanding of the overall product. Note that this process is consistent with the stage of constructing a shared representation. Therefore, my findings elaborate on prior research by identifying three stages of collaboration—instead of one—that have different group dynamics depending on the extent to which the problem is open.

My findings on the group dynamics of emergent innovation also suggest a more detailed process by which people develop emerging ideas in organizations more generally (Finke et al., 1992). Finke and colleagues argue that individuals develop ideas by iterating between two activities: generating ideas and exploring ideas. Although they demonstrate that the initial insight for ideas often comes from a single sequence of this process (Finke, 1990), they also acknowledge that ideas must be further elaborated through subsequent iterations of the process. My findings support this general model, as the iteration between generating and exploring ideas reflects the iteration between cultivating alignment and interpreting ideas, but I also add considerable detail to the model. For instance, in organizational settings, it is unlikely that people begin the process by generating an idea in the absence of thinking about a problem at all. Instead, they typically confront an unexpected or accidental event while working on an existing problem (e.g., Austin et al., 2012), which triggers an idea that could potentially solve a new problem (e.g., Garud et al., 2018). During the subsequent exploration and development of the idea, people do not just iterate between two processes (i.e., interpreting ideas and cultivating alignment), but can potentially iterate between up to seven processes that are separated into three stages of development.

Furthermore, Finke and colleagues argue that constraints play a fundamental role—not only in sparking the initial idea—but also in shaping that idea throughout all stages of its development. While there have been numerous studies exploring the effects that constraints have on the quality of the initial idea (Caniëls & Rietzschel, 2015; Moreau & Dahl, 2005; Ward, 1994), there have been few studies investigating how they continuously shape the idea afterwards (Harrison & Rouse, 2014). My findings help illuminate this process by demonstrating how people continuously gather information from the environment through two mechanisms. Referencing external ideas can help people generate new ideas (e.g., when Stuart developed an idea for a "shared wall") and also resolve ambiguity as they interpret ideas and cultivate a stronger shared understanding of criteria (e.g., when Murphy interpreted audio messages as an "answering machine"). Identifying external constraints can trigger the creation of new ideas as people confront unexpected constraints (e.g., when Sebastian developed an idea for "audio messages").

4.5.3 Developing a New Integrated Theory of Dynamic Problem Solving in Groups

By integrating two competing models of the innovation process into a more coherent model, my study synthesizes theory from creativity, innovation, and teams to develop a new integrated theory for problem solving in groups. In this paper, I discuss how problem solving reflects neither a deliberate or emergent model of innovation in isolation, but rather is a combination of the two that reflects different modes of collective thinking at different points in time. Sometimes groups are focused on developing criteria in an effort to construct a shared problem; sometimes they are focused on developing ideas in an effort to construct a shared solution; and other times they are focused on developing both criteria and ideas in an effort to co-construct problems and solutions together. What facilitates the development of innovations over time is the ability of groups to engage in each stage of collaboration and transition between these stages effectively as they continuously gather information from the environment. My study generates new theory on the contours of this process, opening the door to a new avenue of research that can investigate the factors that enhance the quality of this process.

However, doing so requires a fundamental shift in the way that scholars think about problem solving in groups. Specifically, prior literature has studied how groups engage in idea generation (see Anderson et al., 2014; Shalley & Zhou, 2008 for reviews), idea evaluation (Harvey, 2013; Harvey & Kou, 2013; Rietzschel et al., 2006), and to a lesser extent problem definition (Reiter-Palmon, in press) separately. My findings suggest that these processes should not be examined in isolation, but rather in combination with each other. Note that in each stage of collaboration, groups iterate between a *type* of generating ideas and a *type* evaluating ideas, and the characteristics of these processes change depending on the degree to which the problem is open. In the stage of constructing a shared solution, the problem is closed and groups iterate between cultivating ideas and evaluating ideas; in the stage of constructing a shared representation, the problem is amorphous and emergent as groups iterate between cultivating alignment and interpreting ideas; and in the stage of constructing a shared problem, the problem is open and groups iterate between interpreting criteria (with ideas) and cultivating criteria. Therefore, scholars may be able to develop novel insights by examining factors that affect these three processes together rather than separately.

The reason why these sub-processes of innovation are so tightly linked is because the overall process of developing an innovation in groups is based on the extent to which they can construct a shared representation of a sub-feature—and potentially the overall innovation (Chapter Three of this dissertation). However, a representation consists of several cognitive components that influence both the ideas and criteria that are associated with an innovation (Cronin & Weingart, 2007; Newell & Simon, 1972). Therefore, groups can have diverse representations when they disagree on ideas, disagree on criteria, or disagree on both ideas and criteria. Thus, understanding how ideas and criteria evolve in relation to each other is fundamental to understanding how representations within a group converge or diverge over time.

When groups begin an innovation project, they often have diverse representations of the innovation, and their goal is to develop a shared representation. They can begin the innovation process by either attempting to converge on criteria and then converge on ideas (i.e., use the deliberate innovation process), or attempting to converge on ideas and then converge on criteria (i.e., use the emergent innovation process). Regardless of their approach, groups are likely to experience fluctuations in the degree to which their ideas and criteria converge or diverge at different points in time. The model depicted in Figure 4.2 illustrates how groups navigate these fluctuations as they attempt to converge onto a shared set of ideas and criteria over time. The stage of constructing a shared solution demonstrates how they attempt to converge on only ideas, the stage of constructing a shared problem demonstrates how they attempt to converge on only criteria, and the stage of constructing a shared representation demonstrates how they attempt to converge on both ideas and criteria simultaneously. This perspective presents a fundamentally different view of innovation in groups. Rather than viewing the process as a continuous sequence of independent activities (cf. Amabile, 1983; Cromwell et al., in press; Finke et al., 1992; Mumford et al., 1991; Newell & Simon, 1972), my theory proposes viewing it as a continuous sequence of *stages* that include interdependent activities that change as a function of whether groups are attempting to converge on ideas, criteria, or both.

4.5.4 Broader Implications and Directions for Future Research

Studying the group dynamics of developers who built a social robot provided a strong setting to deeply examine group dynamics for the innovation process, but the unique characteristics of Roboto may limit the generalizability of my findings. In particular, this product was a complex technology product that integrated of multiple technical components and dozens of sub-features together into a single outcome. This may have produced unusually high resource constraints throughout the development process that limited the ability of teams to make steady progress on sub-features of the product. Such limitations could have heightened the level of conflict between group members as they vied to compete for scarce resources (Drazin et al., 1999; Leonardi, 2011), or decreased the motivation of individuals to develop the product (Amabile et al., 1996; Amabile & Pratt, 2016). Either factor could have undermined the ability of group members to collaborate with each other as they attempted to construct a shared representation of sub-features for the product.

However, these limitations may also help reveal the baseline collaboration processes that are needed for groups to develop a large-scale project. For example, Roboto consisted of multiple diverse teams comprised of multiple diverse members, all working together toward developing a complex innovation product over the course of multiple years. While there has been an increasing amount of research investigating shared cognition in groups (Cannon-Bowers, Salas, & Converse, 1993; Klimoski & Mohammed, 1994; Mohammed, Ferzandi, & Hamilton, 2010) and coordination processes among multi-team systems (de Vries, Hollenbeck, Davison, Walter, & van der Vegt, 2015; Mathieu, Marks, & Zaccaro, 2001; Zaccaro, Marks, & DeChurch, 2012), there has been relatively little research investigating how shared cognition can help coordinate effort among multiteam systems (Firth et al., 2014). Researchers have traditionally approached these topics with an input-process-output model of team activity (Guzzo & Shea, 1992; Ilgen, Hollenbeck, Johnson, & Jundt, 2005). However, there is growing demand to understand the *dynamic* processes of teams (Cronin et al., 2011), which may be particularly important for emergent team properties such as shared cognition (Kozlowski, Gully, Nason, & Smith, 1999; Marks, Mathieu, & Zaccaro, 2001). However, given the challenges of developing a shared cognition among a group of *diverse members*, the question is: how does a shared cognition emerge among a group of *diverse teams*?

The model of dynamic problem solving in groups has the potential to make contributions to this literature, because it describes how groups can collaborate on a task while the strength of their shared cognition (i.e., shared representation) fluctuates over time. Because I studied a group of 55 members distributed across four teams, my findings have the potential to explain how shared cognition emerges and evolves over time for multi-team systems. Furthermore, by illustrating how groups continuously gather information throughout this process, my findings show how the evolution of shared cognition is both shaped and constrained by the contextual environment (Cronin et al., 2011; McGrath, Arrow, & Berdhal, 2000). I found that the multi-team system at Roboto was able to coordinate their effort throughout the development process primarily by focusing on developing a complex problem framework and solution structure of the innovation. Future research can build upon these findings by exploring how multi-team systems coordinate their effort when they are not developing a concrete object such as a social robot, which is likely to introduce unique challenges that may require alternative coordination processes.

4.5.5 Conclusion

Breakthrough innovations are highly uncertain and ambiguous endeavors that can take several years to develop. During that time, people with highly diverse knowledge must collaborate with each other under conditions in which they may have conflicting perspectives on the goals of an innovation project, or they may be entirely unsure what goals of the project are supposed to be. These conditions present unique challenges for groups to overcome as they continuously collaborate with each other during the innovation process. The model of dynamic problem solving in groups that I develop in this study can bring clarity to this process by illustrating how group navigate through various stages of collaboration as they attempt to converge on a shared problem and solution for an innovation over time. This model integrates several theoretical perspectives of innovation into a new theory of problem solving in groups, which provides a novel theoretical framework for scholars to better understand innovation in organizational settings.

References

Alexander, L. & van Knippenberg, D. 2014. Teams in pursuit of radical innovation: A goal orientation perspective. ***Academy of Management Review***, 39(4): 423–438.

Amabile, T. M. 1979. Effects of external evaluation on artistic creativity. ***Journal of Personality and Social Psychology***, 37(2): 221–233.

Amabile, T. M. 1982. Social psychology of creativity: A consensual assessment technique. ***Journal of Personality and Social Psychology***, 43(5): 997–1013.

Amabile, T. M. 1983. The social psychology of creativity: A componential conceptualization. ***Journal of Personality and Social Psychology***, 45(2): 357–376.

Amabile, T. M. & Gitomer, J. 1984. Children's artistic creativity effects of choice in task materials. ***Personality and Social Psychology Bulletin***, 10(2): 209–215.

Amabile, T. M. 1988. A model of creativity and innovation in organizations. In B. M. Staw & L. L. Cummings (Eds.), ***Research in organizational behavior***, Vol. 10: 123–167. Greenwich, CT: JAI Press.

Amabile, T. M. 1993. Motivational synergy: Toward new conceptualizations of intrinsic and extrinsic motivation in the workplace. ***Human Resource Management Review***, 3(3): 185–201.

Amabile, T. M., Hill, K. G., Hennessey, B. A., & Tighe, E. M. 1994. The work preference inventory: assessing intrinsic and extrinsic motivational orientations. ***Journal of Personality and Social Psychology***, 66(5): 950–967.

Amabile, T. M. 1996. ***Creativity in context: Update to the social psychology of creativity***. Boulder, CO: Harper Collins.

Amabile, T. M., Conti, R., Coon, H., Lazenby, J., & Herron, M. 1996. Assessing the work environment for creativity. ***Academy of Management Journal***, 39(5): 1154–1184.

Amabile, T. M. & Pratt, M. G. 2016. The dynamic componential model of creativity and innovation in organizations: Making progress, making meaning. In B. M. Staw & A. P. Brief (Eds.), ***Research in organizational behavior***, Vol. 36: 157–183.

Anderson, N., Potocnik, K., & Zhou, J. 2014. Innovation and creativity in organizations: A state-of-the-science review, prospective commentary, and guiding framework. ***Journal of Management***, 40(5): 1297–1333.

Anderson, N. R. & West, M. A. 1998. Measuring climate for work group Innovation: Development and validation of the team climate inventory. ***Journal of Organizational Behavior***, 19(3): 235–258.

Anderson, P. & Tushman, M. L. 1990. Technological discontinuities and dominant designs: A cyclical model of technological change. ***Administrative Science Quarterly***, 35(4): 604–633.

Andriani, P., Ali, A., & Mastrogiorgio, M. 2017. Measuring exaptation and its impact on innovation, search, and problem solving. ***Organization Science***, 28(2): 320–338.

Austin, R. D., Devin, L., & Sullivan, E. E. 2012. Accidental innovation: Supporting valuable unpredictability in the creative process. ***Organization Science***, 23(5): 1505–1522.

Baer, M. & Oldham, G. R. 2006. The curvilinear relation between experienced creative time pressure and creativity: Moderating effects of openness to experience and support for creativity. ***Journal of Applied Psychology***, 91(4): 963–970.

Baer, M., Leenders, R. T. A., Oldham, G. R., & Vadera, A. K. 2010. Win or lose the battle for creativity: The power and perils of intergroup competition. ***Academy of Management Journal***, 53(4): 827–845.

Baer, M., Dirks, K. T., & Nickerson, J. A. 2013. Microfoundations of strategic problem formulation. ***Strategic Management Journal***, 34(2): 197–214.

Baker, T. & Nelson, R. E. 2005. Creating something from nothing: Resource construction through entrepreneurial bricolage. ***Administrative Science Quarterly***, 50(3): 329–366.

Bartel, C. A. & Garud, R. 2009. The role of narratives in sustaining organizational innovation. ***Organization Science***, 20(1): 107–117.

Bechky, B. A. 2003a. Object lessons: Workplace artifacts as representations of occupational jurisdiction. ***American Journal of Sociology***, 109(3): 720–752.

Bechky, B. A. 2003b. Sharing meaning across occupational communities: The transformation of understanding on a production floor. ***Organization Science***, 14(3): 312–330.

Berg, J. M. 2016. Balancing on the creative high-wire: Forecasting the success of novel ideas in organizations. ***Administrative Science Quarterly***, 61(3): 433–468.

Bledow, R., Frese, M., Anderson, N., Erez, M., & Farr, J. 2009. A dialectic perspective on innovation: Conflicting demands, multiple pathways, and ambidexterity. ***Industrial and Organizational Psychology***, 2(3): 305–337.

Boje, D. M. 1991. The storytelling organization: A study of story performance in an office-supply firm. ***Administrative Science Quarterly***, 36(1): 106–126.

Brown, S. L. & Eisenhardt, K. M. 1995. Product development: Past research, present findings, and future directions. ***Academy of Management Review***, 20(2): 343–378.

Brown, S. L. & Eisenhardt, K. M. 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. ***Administrative Science Quarterly***, 42(1): 1–34.

Byron, K., Khazanchi, S., & Nazarian, D. 2010. The relationship between stressors and creativity: A meta-analysis examining competing theoretical models. ***Journal of Applied Psychology***, 95(1): 201–212.

Campbell, D. T. 1960. Blind variation and selective retention in creative thought as in other knowledge processes. ***Psychological Review***, 67(6): 380–400.

Caniëls, M. C. J. & Rietzschel, E. F. 2015. Organizing creativity: Creativity and innovation under constraints. ***Creativity and Innovation Management***, 24(2): 184–196.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. 1993. Shared mental models in expert team decision making. In N. J. Castellan Jr. (Ed.), ***Current issues in individual and group decision making***. Hillsdale, NJ: Erlbaum.

Carlile, P. R. 2002. A pragmatic view of knowledge and boundaries: Boundary objects in new product development. ***Organization Science***, 13(4): 442–455.

Carlile, P. R. & Rebentisch, E. S. 2003. Into the black box: The knowledge transformation cycle. ***Management Science***, 49(9): 1180–1195.

Carlile, P. R. 2004. Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries. ***Organization Science***, 15(5): 555–568.

Carson, P. P. & Carson, K. D. 1993. Managing creativity enhancement through goal-setting and feedback. ***Journal of Creative Behavior***, 27(1): 36–45.

Catmull, E. 2014. ***Creativity inc.*** New York: Random House.

Cattani, G. 2005. Preadaptation, firm heterogeneity, and technological performance: A study on the evolution of fiber optics, 1970-1995. ***Organization Science***, 16(6): 563–580.

Cattani, G. 2006. Technological pre-adaptation, speciation, and emergence of new technologies: how Corning invented and developed fiber optics. ***Industrial and Corporate Change***, 15(2): 285–318.

Charmaz, K. 2006. ***Constructing grounded theory: A practical guide through qualitative analysis***. London: Sage.

Chua, R. Y. J. & Iyengar, S. S. 2006. Empowerment through choice? A critical analysis of the effects of choice in organizations, ***Research in organizational behavior***, Vol. 27: 41–79.

Chua, R. Y. J. & Iyengar, S. S. 2008. Creativity as a matter of choice: Prior experience and task instruction as boundary conditions for the positive effect of choice on creativity. ***Journal of Creative Behavior***, 42(3): 164–180.

Chua, R. Y. J., Roth, Y., & Lemoine, J. F. 2014. The impact of culture on creativity: How cultural tightness and cultural distance affect global innovation crowdsourcing work. ***Administrative Science Quarterly***, 60(2): 189–227.

Clark, K. B. 1985. The interaction of design hierarchies and market concepts in technological evolution. ***Research Policy***, 14(5): 235–251.

Clark, K. B. & Fujimoto, M. 1991. ***Product development performance: Strategy, organization, and management in the world auto industry***. Boston: Harvard Business School Press.

Corbin, J. & Strauss, A. 2008. ***Basics of qualitative research*** (3rd ed.). Thousand Oaks, CA: Sage.

Cornelissen, J. 2005. Beyond compare: Metaphor in organization theory. ***Academy of Management Review***, 30(4): 751–764.

Cornelissen, J., Oswick, C., Christensen, L. T., & Phillips, N. 2008. Metaphor in organizational research: Context, mModalities and implications for research – introduction. ***Organization Studies***, 29(1): 7–22.

Coskun, H., Paulus, P. B., Brown, V., & Sherwood, J. J. 2000. Cognitive stimulation and problem presentation in idea-generating groups. ***Group Dynamics: Theory Research and Practice***, 4(4): 307–329.

Cromwell, J. R., Amabile, T. M., & Harvey, J.-F. in press. An integrated model of dynamic problem solving within organizational constraints. In R. Reiter-Palmon & V. Kennel & J. C. Kaufman (Eds.), ***Individual creativity in the workplace***. New York: Academic Press.

Cronin, M. A. & Weingart, L. R. 2007. Representational gaps, information processing, and conflict in functionally diverse teams. ***Academy of Management Review***, 32(3): 761–773.

Cronin, M. A., Weingart, L. R., & Todorova, G. 2011. Dynamics in groups: Are we there yet? ***Academy of Management Annals***, 5: 571–612.

Csikszentmihalyi, M. 1996. ***Flow and the psychology of discovery and invention***. New York: Harper Collins.

Daft, R. L. & Weick, K. E. 1984. Toward a model of organizations as interpretation systems. ***Academy of Management Review***, 9(2): 284–295.

Dahl, D. W. & Moreau, P. 2002. The influence and value of analogical thinking during new product ideation. ***Journal of Marketing Research***, 39(1): 47–60.

Davies, A. 2017. Drivers not wanted: An oral history of the darpa grand challenge, ***Wired***, Vol. 25: 49–53. San Francisco.

De Dreu, C. K. W., Baas, M., & Nijstad, B. A. 2008. Hedonic tone and activation level in the mood-creativity link: Toward a dual pathway to creativity model. ***Journal of Personality and Social Psychology***, 94(5): 739–756.

de Vries, T. A., Hollenbeck, J. R., Davison, R. B., Walter, F., & van der Vegt, G. S. 2015. Managing coordination in multiteam systems: Integrating micro and macro perspectives. ***Academy of Management Journal***, 59(5): 1823–1844.

Deci, E. L. & Ryan, R. M. 1985. The general causality orientations scale: Self-determination in personality. ***Journal of Research in Personality***, 19(2): 109–134.

Deci, E. L. & Ryan, R. M. 1987. The support of autonomy and the control of behavior. ***Journal of Personality and Social Psychology***, 53(6): 1024–1037.

Dennis, A. R., Valacich, J. S., Connolly, T., & Wynne, B. E. 1996. Process structuring in electronic brainstorming. ***Information Systems Research***, 7(2): 268–277.

Dillon, J. T. 1982. Problem finding and solving. ***Journal of Creative Behavior***, 16(2): 97–111.

Dougherty, D. 1992. Interpretive barriers to successful product innovation in large firms. ***Organization Science***, 3(2): 179–202.

Drazin, R., Glynn, M. A., & Kazanjian, R. K. 1999. Multilevel theorizing about creativity in organizations: A sensemaking perspective. ***Academy of Management Review***, 24(2): 286–307.

Edmondson, A. C. & McManus, S. E. 2007. Methodological fit in managment research. ***Academy of Management Review***, 32(4): 1155–1179.

Edmondson, A. C. & Nembhard, I. M. 2009. Product development and learning in project teams: The challenges are the beneftis. ***Journal of Product Innovation Management***, 26(1): 123–138.

Edmondson, A. C. & Harvey, J.-F. 2017. Cross-boundary teaming for innovation: Integrating research on teams and knowledge in organizations. ***Human Resource Management Review***, 0(0): doi: 10.1016/j.hrmr.2017.1003.1002.

Einstein, A. & Infeld, L. 1938. ***The evolution of physics***. New York: Simon & Schuster.

Eisenhardt, K. M. 1989. Building theories from case study research. ***Academy of Management Review***, 14(4): 532–550.

Eisenhardt, K. M. & Tabrizi, B. N. 1995. Accelerating adaptive processes: Product innovation in the global computer industry. ***Administrative Science Quarterly***: 84–110.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. 2011. ***Writing ethnographic fieldnotes***: University of Chicago Press.

Faraj, S. & Sproull, L. 2000. Coordinating expertise in software development teams. ***Management Science***, 46(12): 1554–1568.

Finke, R. A. 1990. ***Creative imagery: Discoveries and inventions in visualization***. Hoboken, NJ: Erlbaum.

Finke, R. A., Ward, T. B., & Smith, S. M. 1992. ***Creative cognition: Theory, research, and applications***. Cambridge, MA: MIT Press.

Fiol, C. M. 1989. A semiotic analysis of corporate language: Organizational boundaries and joint venturing. ***Administrative Science Quarterly***, 34(2): 277–303.

Firth, B. M., Hollenbeck, J. R., Miles, J. E., Ilgen, D. R., & Barnes, C. M. 2014. Same page, different books: Extending representational gaps theory to enhance performance in multiteam systems. ***Academy of Management Journal***, 58(3): 813-–835.

Fleming, L. 2001. Recombinant uncertainty in technological search. ***Management Science***, 47(1): 117–132.

Fleming, L., Mingo, S., & Chen, D. 2007. Collaborative brokerage, generative creativity, and creative success. ***Administrative Science Quarterly***, 52(3): 443–475.

Ford, C. M. & Gioia, D. A. 2000. Factors influencing creativity in the domain of managerial decision making. ***Journal of Management***, 26(4): 705–732.

Frishammar, J., Dahlskog, E., Krumlinde, C., & Yazgan, K. 2016. The front end of radical innovation: A case study of idea and concept development at prime group. ***Creativity and Innovation Management***, 25(2): 179–198.

Fry, A. 1987. The post-it note: An intrapraneurial success. ***SAM Advanced Management Journal***, 52(3): 4–9.

Gardner, D. G. 1990. Task complexity effects on non-task-related movements: A test of activation theory. ***Organizational Behavior and Human Decision Processes***, 45(2): 209–231.

Garud, R. & Karnøe, P. 2003. Bricolage versus breakthrough: distributed and embedded agency in technoloy entrepreneurship. ***Research Policy***, 32(2): 277–300.

Garud, R., Gehman, J., & Giuliani, A. P. 2018. Serendipity arrangements for exapting science-based innovations. ***Academy of Management Perspectives***, 32(1): 125–140.

Gentner, D. 1983. Structure-mapping: A theoretical framework for analogy. ***Cognitive Science***, 7(2): 155–170.

Gersick, C. J. G. 1988. Time and transition in work teams: Toward a new model of group development. ***Academy of Management Journal***, 31(1): 9–41.

Gersick, C. J. G. 1991. Revolutionary change theories: A multilevel exploration of the punctuated equilibrium paradigm. ***Academy of Management Review***, 16(1): 10–36.

Getzels, J. W. & Csikszentmihalyi, M. 1976. The creative vision: A longitudinal study of problem finding in art.

Gilson, L. L. & Shalley, C. E. 2004. A little creativity goes a long way: An examination of teams' engagement in creative processes. ***Journal of Management***, 30(4): 453–470.

Girotra, K., Terwiesch, C., & Ulrich, K. T. 2010. Idea generation and the quality of the best idea. ***Management Science***, 56(4): 591–605.

Glaser, B. G. & Strauss, A. L. 1967. ***The discovery of grounded theory: Strategies for qualitative research***.

Goh, K. T., Goodman, P. S., & Weingart, L. R. 2013. Team innovation processes: An examination of activity cycles in creative project teams. ***Small Group Research***, 44(2): 159–194.

Goldenberg, J., Mazursky, D., & Solomon, S. 1999. Toward identifying the inventive templates of new products: A channeled ideation approach. ***Journal of Marketing Research***, 36(2): 200–210.

Griffith, T. L. 1999. Technology features as triggers for sensemaking. ***Academy of Management Review***, 24(3): 472–488.

Grodal, S., Gotsopoulos, A., & Suarez, F. F. 2015. The coevolution of technologies and categories during industry emergence. ***Academy of Management Review***, 40(3): 423–445.

Guilford, J. P. 1950. Creativity. ***American Psychologist***, 5: 444–454.

Guzzo, R. A. & Shea, G. P. 1992. Group performance and intergroup relations in organizations. ***Handbook of industrial and organizational psychology***, 3: 269–313.

Hargadon, A. B. & Sutton, R. L. 1997. Technology brokering and innovation in a product development firm. ***Administrative Science Quarterly***, 42(4): 716–749.

Hargadon, A. B. & Douglas, Y. 2001. When innovations meet institutions: Edison and the design of the electric light. ***Administrative Science Quarterly***, 46(3): 476–501.

Hargadon, A. B. & Bechky, B. A. 2006. When collections of creatives become creative collectives: A field study of problem solving at work. ***Organization Science***, 17(4): 484–500.

Harrison, S. H. & Rouse, E. D. 2014. Let's dance! Elastic coordination in creative group work: A qualitative study of modern dancers. ***Academy of Management Journal***, 57(5): 1256–1283.

Harrison, S. H. & Rouse, E. D. 2015. An inductive study of feedback interactions over the course of creative projects. ***Academy of Management Journal***, 58(2): 375–404.

Harvey, S. 2013. A different perspective: The multiple effects of deep level diversity on group creativity. ***Journal of Experimental Social Psychology***, 49(5): 822–832.

Harvey, S. & Kou, C. Y. 2013. Collective engagement in creative tasks: The role of evaluation in the creative process in groups. ***Administrative Science Quarterly***, 58(3): 346–386.

Harvey, S. 2014. Creative synthesis: Exploring the process of extraordinary group creativity. ***Academy of Management Review***, 39(3): 324–343.

Henderson, K. 1991. Flexible sketches and inflexible data bases: Visual communication, conscription devices, and boundary objects in design engineering. ***Science, Technology & Human Values***, 16(4): 448–473.

Hoegl, M., Gibbert, M., & Mazursky, D. 2008. Financial constraints in innovation projects: When is less more? ***Research Policy***, 37(8): 1382–1391.

Hopkins, C. 2014. Lidar archaeology shines a light on hidden sites, ***BBC***.

Hulsheger, U. R., Anderson, N., & Salgado, J. F. 2009. Team-level predictors of innovation at work: A comprehensive meta-analysis spanning three decades of research. ***Journal of Applied Psychology***, 94(5): 1128–1145.

Hunter, S. T., Bedell, K. E., & Mumford, M. D. 2007. Climate for creativity: A quantitative review. ***Creativity Research Journal***, 19(1): 69–90.

Ilgen, D. R., Hollenbeck, J. R., Johnson, M., & Jundt, D. 2005. Teams in organizations: From input-process-output models to IMOI models. ***Annual Review of Psychology***, 56: 517–543.

Israel, P. 1998. ***Edison: A life of invention***. New York: John Wiley & Sons.

Iyengar, S. S. & Lepper, M. R. 2000. When choice is demotivating: Can one desire too much of a good thing? ***Journal of Personality and Social Psychology***, 79(6): 995–1006.

Jabri, M. M. 1991. The development of conceptually independent subscales in the measurement of modes of problem solving. ***Educational and Psychological Measurement***, 51(4): 975–983.

Jang, S. 2017. Cultural brokerage and creative performance in multicultural teams. ***Organization Science***, 28(6): 993–1009.

Janis, I. L. 1971. Groupthink. ***Psychology Today***, 5(6): 43–46 & 74–76.

Kanter, R. M. 1988. When a thousand flowers bloom: Structural, collective and social conditions for innovation in organization. In B. M. Staw & L. L. Cummings (Eds.), ***Research in organizational behavior***, Vol. 10: 169–211. Greenwich, CT: JAI Press.

Kaplan, S. 2008. Framing contests: Strategy making under uncertainty. ***Organization Science***, 19(5): 729–752.

Kaplan, S. & Tripsas, M. 2008. Thinking about technology: Applying a cognitive lens to technical change. ***Research Policy***, 37(5): 790–805.

Kaplan, S. & Vakili, K. 2015. The double-edged sword of recombination in breakthrough innovation. ***Strategic Management Journal***, 36(10): 1435–1457.

Kavadias, S. & Sommer, S. C. 2009. The effects of problem structure and team diversity on brainstorming effectiveness. ***Management Science***, 55(12): 1899–1913.

King, M. J. 1997. Apollo 13 creativity: In-the-box innovation. ***Journal of Creative Behavior***, 31(4): 299–308.

Kirton, M. 1976. Adaptors and innovators: A description and measure. ***Journal of Applied Psychology***, 61(5): 622–629.

Klimoski, R. & Mohammed, S. 1994. Team mental models: Construct or metaphor. ***Journal of Management***, 20(2): 403–437.

Koestler, A. 1964. ***The act of creation***. New York: Dell.

Kounios, J. & Beeman, M. 2015. ***The eureka factor: Aha moments, creative insight, and the brain***: Random House.

Kozlowski, S. W. J., Gully, S. M., Nason, E. R., & Smith, E. M. 1999. Developing adaptive teams: A theory of compliation and performance across levels and time. In D. R. Ilgen & E. D. Pulakos (Eds.), ***The changing nature of work performance: Implications for staffing, personnel actions, and development***: 240–292. San Francisco: Jossey-Bass.

Kurtzberg, T. R. & Amabile, T. M. 2000. From Guilford to creative synergy: Opening the black box of team-level creativity. ***Creativity Research Journal***, 13(3 & 4): 285–294.

Langley, A. 1999. Strategies for theorizing from process data. ***Academy of Management Review***, 24(4): 691–710.

Leonardi, P. M. 2011. Innovation blindness: Culture, frames, and cross-boundary problem construction in the development of new technology concepts. ***Organization Science***, 22(2): 347–369.

Lifshitz-Assaf, H. 2017. Dismantling knowledge boundaries at NASA: From problem solvers to solution seekers. ***Administrative Science Quarterly***, 0(0): doi: 0001839217747876.

Lindahl, L. 1988. Spence Silver: A scholar and a gentleman. ***3M Today***, 15(1): 12–17.

Lingo, E. L. & O'Mahony, S. 2010. Nexus work: Brokerage on creative projects. ***Administrative Science Quarterly***, 55(1): 47–81.

Liu, D., Jiang, K., Shalley, C. E., Keem, S., & Zhou, J. 2016. Motivational mechanisms of employee creativity: A meta-analytic examination and theoretical extension of the creativity literature. ***Organizational Behavior and Human Decision Processes***, 137: 236–263.

Locke, K. 2001. ***Grounded theory in management research***: Sage.

Lofland, J., Snow, D., Anderson, L., & Lofland, L. 2006. ***Analyzing social settings: A guide to qualitative observation and analysis***. Belmont, CA: Wadsworth/Thomson Learning.

Lounsbury, M. & Glynn, M. A. 2001. Cultural entrepreneurship: Stories, legitimacy, and the acquisition of resources. ***Strategic Management Journal***, 22(6/7): 545–564.

Lucas, H. C. & Goh, J. M. 2009. Disruptive technology: How Kodak missed the digital photography revolution. ***Journal of Strategic Information Systems***, 18(1): 46–55.

Majchrzak, A., More, P. H. B., & Faraj, S. 2012. Transcending knowledge differences in cross-functional teams. ***Organization Science***, 23(4): 951–970.

Marks, M. A., Mathieu, J. E., & Zaccaro, S. J. 2001. A temporally based framework and taxonomy of team processes. ***Academy of Management Review***, 26(3): 356–376.

Martens, M. L., Jennings, J. E., & Jennings, P. D. 2007. Do the stories they tell get them the money they need? The role of entrepreneurial narratives in resource acquisition. ***Academy of Management Journal***, 50(5): 1107–1132.

Mathieu, J. E., Marks, M. A., & Zaccaro, S. J. 2001. Multi-team systems. In N. Anderson & D. S. Ones & H. K. Sinangil & C. Viswesvaran (Eds.), ***Handbook of industrial work and organizational psychology***: 289–313. London: Sage.

McGrath, J. E., Arrow, H., & Berdhal, J. L. 2000. The study of groups: Past, present, and future. ***Personality and Social Psychology Review***, 4(1): 95–105.

McGraw, K. O. 1978. The detrimental effects of reward on performance: A literature review and a prediction model. In M. R. Lepper & D. Green (Eds.), ***The hidden costs of reward: New perspectives on the psychology of human motivation***: 33–60. London: Psychology Press.

Merton, R. K. & Barber, E. 2004. ***The travels and adventures of serendipity: A study in sociological semantics and the sociology of science***. Princeton: Princeton University Press.

Miles, M. B. & Huberman, A. M. 1994. ***Qualitative data analysis: An expanded sourcebook***. Thousand Oaks, CA: Sage.

Miron-Spektor, E., Erez, M., & Naveh, E. 2011. The effect of conformist and attentive-to-detail members on team innovation: Reconciling the innovation paradox. ***Academy of Management Journal***, 54(4): 740–760.

Mohammed, S., Ferzandi, L., & Hamilton, K. 2010. Metaphor no more: A 15-year review of the team mental model construct. ***Journal of Management***, 36(4): 876–910.

Moreau, C. P. & Dahl, D. W. 2005. Designing the solution: The impact of constraints on consumers' creativity. ***Journal of Consumer Research***, 32(1): 13–22.

Mortensen, M. & Haas, M. R. 2018. Perspective—rethinking teams: From bounded membership to dynamic participation. ***Organization Science***, 0(0): doi: 10.1287/orsc.2017.1198.

Mueller, J. S., Melwani, S., & Goncalo, J. A. 2012. The bias against creativity: Why people desire but reject creative ideas. ***Psychological Science***, 23(1): 13–17.

Mumford, M. D., Mobley, M. I., Reiter-Palmon, R., Uhlman, C. E., & Doares, L. M. 1991. Process analytic models of creative capacities. ***Creativity Research Journal***, 4(2): 91–122.

Mumford, M. D., Reiter-Palmon, R., & Redmond, M. R. 1994. Problem construction and cognition: Applying problem representations in ill-defined domains. In M. A. Runco (Ed.), ***Problem finding, problem solving, and creativity***: 5–39. Norwood, NJ: Ablex Publishing.

Mumford, M. D., Medeiros, K. E., & Partlow, P. J. 2012. Creative thinking: Processes, strategies, and knowledge. ***Journal of Creative Behavior***, 46(1): 30–47.

Navis, C. & Glynn, M. A. 2010. How new market categories emerge: Temporal dynamics of legitimacy, identity, and entrepreneurship in satellite radio, 1990-2005. ***Administrative Science Quarterly***, 55: 439–471.

Nemeth, C. J. & Kwan, J. L. 1987. Minority influence, divergent thinking and detection of correct solutions. ***Journal of Applied Social Psychology***, 17(9): 788–799.

Newell, A., Shaw, J. C., & Simon, H. A. 1962. The processes of creative thinking. In H. Gruber & G. Terrell & M. Wertheimer (Eds.), ***Contemporary approaches to creative thinking***: 63–119. New York: Atherton Press.

Newell, A. & Simon, H. A. 1972. ***Human problem solving***. Englewood Cliffs, NJ: Prentice-Hall.

Nicholls, J. 1972. Creativity in the person who will never produce anything original and useful: The concept of creativity as a normally distributed trait. ***American Psychologist***, 27(8): 517–527.

Nijstad, B. A., De Dreu, C. K. W., Rietzschel, E. F., & Baas, M. 2010. The dual pathway to creativity model: Creative ideation as a function of flexibility and persistence. ***European Review of Social Psychology***, 21(1): 34–77.

Okhuysen, G. A. & Bechky, B. A. 2009. Coordination in organizations: An integrative perspective. ***Academy of Management Annals***, 3(1): 463–502.

Oldham, G. R. & Cummings, A. 1996. Employee creativity: Personal and contextual factors at work. ***Academy of Management Journal***, 39(3): 607–634.

Osborn, A. F. 1953. ***Applied imagination***. New York: Scribner.

Paulus, P. B., Brown, A., & Ortega, H. 1996. Group creativity. In R. E. Purser & A. Montouri (Eds.), ***Social creativity in organizations***. Hampton Press: Cresskill, NJ.

Paulus, P. B. & Yang, H.-C. 2000. Idea generation in groups: A basis for creativity in organizations. ***Organizational Behavior and Human Decision Processes***, 82(1): 76–87.

Paulus, P. B. & Nijstad, B. A. 2003. ***Group creativity: Innovation through collaboration***. New York: Oxford University Press.

Perretti, F. & Negro, G. 2006. Filling empty seats: How status and organizational hierarchies affect exploration versus exploitation in team design. ***Academy of Management Journal***, 49(4): 759–777.

Perry-Smith, J. E. & Shalley, C. E. 2003. The social side of creativity: A static and dynamic social network perspective. ***Academy of Management Review***, 28(1): 89–106.

Perry-Smith, J. E. 2006. Social yet creative: The role of social relationships in facilitating individual creativity. ***Academy of Management Journal***, 49(1): 85–101.

Perry-Smith, J. E. & Mannucci, P. V. 2017. From creativity to innovation: The social network drivers of the four phases of the idea journey. ***Academy of Management Review***, 42(1): 53–79.

Putman, V. L. & Paulus, P. B. 2009. Brainstorming, brainstorming rules and decision making. ***Journal of Creative Behavior***, 43(1): 23–39.

Reiter-Palmon, R., Mumford, M. D., O'Connor Boes, J., & Runco, M. A. 1997. Problem construction and creativity: The role of ability, cue consistency, and active processing. ***Creativity Research Journal***, 10(1): 9–23.

Reiter-Palmon, R., Herman, A., & Yammarino, F. J. 2008. Creativity and cognitive processes: Multi-level linkages between individuals and team cognition. In M. D. Mumford & S. T. Hunter & K. E. Beddel-Avers (Eds.), ***Multi-level issues in creativity and innovation***, Vol. 7: 203–267. Boston: Elsevier.

Reiter-Palmon, R. & Robinson, E. J. 2009. Problem identification and construction: What do we know, what is the future? ***Psychology of Aesthetics, Creativity, and the Arts***, 3(1): 43–47.

Reiter-Palmon, R. in press. Creative cognition at the individual and team level: What happens before and after idea generation. In R. Reiter-Palmon & V. Kennel & J. Kaufman (Eds.), ***Individual creativity in the workplace***. New York: Academic Press.

Reitman, W. R. 1965. ***Cognition and thought: An information processing approach***. Oxford: Wiley.

Ries, E. 2011. ***The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses.*** New York: Crown Business.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2006. Productivity is not enough: A comparison of interactive and nominal brainstorming groups on idea generation and selection. ***Journal of Experimental Social Psychology***, 42(2): 244–251.

Rietzschel, E. F., De Dreu, C. K., & Nijstad, B. A. 2007. Personal need for structure and creative performance: the moderating influence of fear of invalidity. ***Personality and Social Psychology Bulletin***, 33(6): 855–866.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2007. Relative accessibility of domain knowledge and creativity: The effects of knowledge activation on the quantity and originality of generated ideas. ***Journal of Experimental Social Psychology***, 43(6): 933–946.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2010. The selection of creative ideas after individual idea generation: Choosing between creativity and impact. ***British Journal of Psychology***, 101(1): 47–68.

Rietzschel, E. F., Nijstad, B. A., & Stroebe, W. 2014a. Effects of problem scope and creativity instructions on idea generation and selection. ***Creativity Research Journal***, 26(2): 185–191.

Rietzschel, E. F., Slijkhuis, J. M., & Van Yperen, N. W. 2014b. Task structure, need for structure, and creativity. ***European Journal of Social Psychology***, 44(4): 386–399.

Roskes, M. 2015. Constraints that help or hinder creative performance: A motivational approach. ***Creativity and Innovation Management***, 24(2): 197–206.

Rosso, B. D. 2014. Creativity and constraints: Exploring the role of constraints in the creative processes of research and development teams. ***Organization Studies***, 35(4): 551–585.

Rothenberg, A. & Greenberg, B. 1976. ***The index of scientific writings on creativity: General, 1566-1974.*** Hamden, CT: Archon Books.

Runco, M. A. & Smith, W. R. 1992. Interpersonal and intrapersonal evaluations of creative ideas. ***Personality and Individual Differences***, 13(3): 295–302.

Runco, M. A. 1994. ***Problem finding, problem solving, and creativity***: Greenwood Publishing Group.

Ryan, R. M. & Deci, E. L. 2000. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. ***American Psychologist***, 55(1): 68–78.

Sanchez-Burks, J., Karlesky, M. J., & Lee, F. 2015. 6 Psychological bricolage: Integrating social identities to produce creative solutions. In C. E. Shalley & M. A. Hitt & J. Zhou (Eds.), ***The oxford handbook of creativity, innovation, and entrepreneurship***: 93–203. Oxford: Oxford University Press.

Schön, D. A. 1993. Generative metaphor: A perspective on problem-solving in social policy. In O. A. (Ed.), ***Metaphor and thought, 2nd ed.***: 137–163. Cambridge, UK: Cambridge University Press.

Schwartz, B. 2000. Self-determination: The tyrrany of freedom. ***American Psychologist***, 55(1): 79–88.

Seidel, V. P. 2007. Concept shifting and the radical product development process. ***Journal of Product Innovation Management***, 24(6): 522–533.

Seidel, V. P. & O'Mahony, S. 2014. Managing the repertoire: Stories, metaphors, prototypes and concept coherence in product innovation. ***Organization Science***, 25(3): 691–712.

Shalley, C. E. 1991. Effects of productivity goals, creativity goals, and personal discretion on individual creativity. ***Journal of Applied Psychology***, 76(2): 179–185.

Shalley, C. E. 1995. Effects of coaction, expected evaluation, and goal setting on creativity and productivity. ***Academy of Management Journal***, 38(2): 483–503.

Shalley, C. E. & Perry-Smith, J. E. 2001. Effects of social-psychological factors on creative performance: the role of informational and controlling expected evaluation and modeling experience. ***Organizational Behavior and Human Decision Processes***, 84(1): 1–22.

Shalley, C. E., Zhou, J., & Oldham, G. R. 2004. The effects of personal and contextual characteristics on creativity: Where should we go from here? ***Journal of Management***, 30(6): 933–958.

Shalley, C. E. & Zhou, J. 2008. Organizational creativity research: A historical overview. In J. Zhou & C. E. Shalley (Eds.), ***Handbook of organizational creativity***: 3–31. Abingdon, UK: Taylor & Francis.

Simon, H. A. 1973. The structure of ill structured problems. ***Artificial Intelligence***, 4(4): 181–201.

Simonton, D. K. 1999. Creativity as blind variation and selective retention: Is the creative process darwinian? ***Psychological Inquiry***, 10(4): 309–328.

Simonton, D. K. 2004. ***Creativity in science: Chance, logic, genius, and zeitgeist***: Cambridge University Press.

Singh, J. & Fleming, L. 2010. Lone inventors as sources of breakthroughs: Myth or reality? ***Management Science***, 56(1): 41–56.

Sonenshein, S. 2014. How organizations foster the creative use of resources. ***Academy of Management Journal***, 57(3): 814–848.

Star, S. L. & Griesemer, J. R. 1989. Institutional ecology, 'translations' and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907–39. ***Social Studies of Science***, 19(3): 387–420.

Staw, B. M. 1990. An evolutionary approach to creativity and innovation. In M. A. West & J. L. Farr (Eds.), ***Innovation and creativity at work***: 287–308. New York: Wiley.

Stigliani, I. & Ravasi, D. 2012. Organizing thoughts and connecting brains: Material practices and the transition from individual to group-level prospective sensemaking. ***Academy of Management Journal***, 55(5): 1232–1259.

Stokes, P. D. 2001. Variability, constraints, and creativity: Shedding light on Claude Monet. ***American Psychologist***, 56(4): 355–359.

Stroebe, W. & Diehl, M. 1994. Why groups are less effective than their members: On productivity losses in idea-generating groups. ***European Review of Social Psychology***, 5(1): 271–303.

Suarez, F. F. 2004. Battles for technological dominance: An integrative framework. ***Research Policy***, 33(2): 271–286.

Suarez, F. F., Grodal, S., & Gotsopoulos, A. 2015. Perfect timing? Dominant category, dominant design, and the window of opportunity for firm entry. ***Strategic Management Journal***, 36(3): 437–448.

Sutton, R. L. & Hargadon, A. B. 1996. Brainstorming groups in context. ***Administrative Science Quarterly***, 41(4): 685–718.

Taylor, A. & Greve, H. R. 2006. Superman or the fantastic four? Knowledge combination and experience in innovative teams. ***Academy of Management Journal***, 49(4): 723–740.

Tripsas, M. 2009. Technology, identity, and inertia through the lens of "the digital photography company". ***Organization Science***, 20(2): 441–460.

Tushman, M. L. & Anderson, P. 1986. Technological discontinuities and organizational environments. ***Administrative Science Quarterly***, 31(3): 439–465.

Unsworth, K. 2001. Unpacking creativity. ***Academy of Management Review***, 26(2): 289–297.

van Burg, E., Podoynitsyna, K., Beck, L., & Lommelen, T. 2012. Directive deficiencies: How resource constraints direct opportunity identification in SMEs. ***Journal of Product Innovation Management***, 29(6): 1000–1011.

Van Maanen, J. 1988. ***Tales of the field***. Chicago: University of Chicago Press.

Verganti, R. 2009. ***Design driven innovation: Changing the rules of competition by radically innovating what things mean***. Boston: Harvard Business Press.

von Hippel, E. & von Krogh, G. 2016. CROSSROADS—Identifying viable "need–solution pairs": Problem solving without problem formulation. ***Organization Science***, 27(1): 207–221.

Wallas, G. 1926. ***The art of thought***. New York: Harcourt Brace.

Walsh, J. P. 1995. Managerial and organizational cognition: Notes from a trip down memory lane. ***Organization Science***, 6(3): 280–321.

Ward, T. B. 1994. Structured imagination: The role of category structure in exemplar generation. ***Cognitive Psychology***, 27(1): 1–40.

Ward, T. B., Smith, S. M., & Finke, R. A. 1999. Creative cognition. In R. J. Sternberg (Ed.), ***Handbook of creativity***: 189–212. Cambridge, UK: Cambridge University Press.

Weick, K. E. 1990. Technology as equivoque: Sensemaking in new technologies, ***Technology and organizations***: 1–44. San Francisco, CA: Jossey-Bass.

Weick, K. E. 2000. ***Making sense of the organization***. Malden, MA: Blackwell.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. 2005. Organizing and the process of sensemaking. ***Organization Science***, 16(4): 409–421.

Weingart, L. R., Todorova, G., & Cronin, M. A. 2010. Task conflict, problem-solving, and yielding effects on cognition and performance in functionally diverse innovation teams. ***Negotiation and Conflict Management Research***, 3(4): 312–337.

Weiss, M., Hoegl, M., & Gibbert, M. 2011. Making virtue of necessity: The role of team climate for innovation in resource-constrained innovation projects. ***Journal of Product Innovation Management***, 28: 196–207.

West, M. A. 2002. Sparkling fountains or stagnant ponds: An integrative model of creativity and innovation implementation in work groups. ***Applied Psychology***, 51(3): 355–387.

Woodman, R. W., Sawyer, J. E., & Griffin, R. W. 1993. Toward a theory of organizational creativity. ***Academy of Management Review***, 18(2): 293–321.

Wuchty, S., Jones, B. F., & Uzzi, B. 2007. The increasing dominance of teams in production of knowledge. ***Science***, 316(5827): 1036–1039.

Yin, R. K. 2014. ***Case study research: Design and methods*** (5th ed.). Thousand Oaks, CA: Sage.

Zaccaro, S. J., Marks, M. A., & DeChurch, L. A. 2012. Multi-team systems: An introduction. In S. J. Zaccaro & M. A. Marks & L. A. DeChurch (Eds.), ***Multi-team systems: An organization form for dynamic and complex environments***: 3–32. New York, Y: Routledge.