Understanding Innovation

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Design Thinking Research

Making Distinctions: Collaboration versus Cooperation

Springer

Understanding Innovation

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Preface

This year will mark the 10-year anniversary of the founding of the School of Design Thinking at Hasso Plattner Institute in Potsdam. The d.school, its sister Institute at Stanford University, is even a few years older. In the meantime, both in California and Germany thousands of students with diverse backgrounds have learned and experienced how to tackle wicked problems and complex challenges and come up with innovative, human-centered solutions.

Due to the extensive work put forth at these institutes, Design Thinking has become well known and applied in many areas. More and more organizations have experienced the impact of Design Thinking on their innovation culture. People see how it changes the way they and their coworkers innovate, how they work in a team, and in which way it affects the quality of their output. Moreover, Design Thinking has been acknowledged even more fully by the education sector—both by students and professionals—and been incorporated into curricula and professional development programs.

In short, there is an enormous interest in Design Thinking. Since I have been convinced of its tremendous potential for decades, I am elated about this success, as it holds great potential for the development of our society. At the same time, it is crucial, especially with the rising number of people and institutions and numerous fields of application, to secure and deepen the scientific understanding of the underlying principles of Design Thinking. It is therefore necessary to find out how and why Design Thinking works, what are the reasons when it fails, and what makes it more successful than other management approaches. These are the key questions that drive my support for the Design Thinking Research Program between the Hasso Plattner Institute in Potsdam, Germany, and Stanford University, USA.

Since the implementation of the Design Thinking Research Program in 2008, more than 100 research projects have been conducted, our understanding of this field has advanced, and new insights and tools have become available. The research program and its investigation of the technical, economic, and human factors was the logical consequence of simply teaching the design thinking method. Researchers at both institutions, with diverse backgrounds in disciplines such as engineering, humanities, neurology, or economics, examine how the innovative processes that originate in small, multidisciplinary teams can be improved and developed in the future.

This publication assembles the findings of the eighth and final year of the first funding period of the research program. Equally successful as in previous years, this year's findings on new forms of collaboration have made it an easy decision to continue my support of the research program.

The results of the research are, however, not meant to be discussed exclusively in the scientific community. The discoveries made as well as the newly developed approaches and tools in design thinking should be available to all who seek to support and advance to drive innovation, be it in companies or society.

Palo Alto, CA
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Hasso Plattner

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Introduction: Reflections on Working Together—Through and Beyond Design Thinking

Larry Leifer and Christoph Meinel

1 In the Pursuit of Breakthrough-Innovation, Is It Necessary to Make a Critical Distinction Between Collaborating and Cooperating?

Given

A team-of-teams organization demands collaboration.
A command-control organization demands cooperation.

The Challenge

How might we make the distinction actionable on a day-to-day, session-to-session basis within the enterprise? Can a culture of extreme collaboration co-exist with a culture of extreme cooperation?

Can we summarize the challenge as the distinction between agreeing and agreeing to DISAGREE? Can we pivot skillfully between these behaviors and remain civil? Does the distinction extend to coordinating?

'Zusammenarbeit' is the German term that describes all forms of working together. The word does not transport the nuances and implications, and strengths and weaknesses that characterize different modes of how people actually work together. But also in English, the terms 'cooperation' and 'collaboration' are often

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used interchangeably (sometimes also conflated with 'coordination') or are at least not very carefully distinguished from one another. The fact that we do not pay much attention to this distinction when we speak (or write) may point to several issues. For one, it suggests that we may not be terribly clear about how to choose an appropriate form of working together. Moreover, it implies that we are also not very good at switching between different modes as the necessities of our task or the phases of our project change.

The issue of making accessible distinctions has become more important in recent years as the challenges we face today seem to demand more and more collaboration. However, we almost exclusively "teach" people to cooperate. In formal education, we often prime young people to agree with one "correct" definition of things. In turn, organizational cultures in enterprises often reward cooperative behavior. In contrast, applying the design paradigm invites/demands multiple working definitions depending on context, especially a human context. It demands the ability to agree to disagree, to hold different opinions about the nature of human needs, human wants, the problem at hand, as well as to allow for reframing.

The evolution of humanity might offer an example to visualize this distinction, as is shown in Fig. 1. We can assume that in our more primitive states, creative collaboration was a daily necessity. As humankind moved into industrialization our cultures developed to be dominated by the efficient cooperation model of Taylorism, and the command control structure became the default mode.

Design Research tackles the issue of making this distinction with new metrics and a heightened awareness of the intentional bias at the core of our pursuit of breakthrough innovation in business, government, and academia.

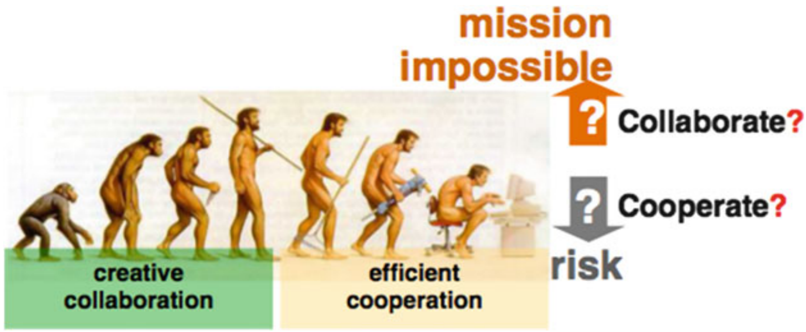

Fig. 1 The evolution of how we work together from an archeological point of view might look like this: The first half of our development had to be overwhelmingly driven by collaboration. Every meal, every stranger, every turn of the weather demanded creative collaboration—agreeing to disagree until something worked or a breakthrough occurred. Whereas the second phase of our evolution seems to be dominated by efficient cooperation, doing what we are told to do, in school and on the job

Cooperation Among Humans

"Language allows humans to cooperate on a very large scale. Certain studies have suggested that fairness affects human cooperation; individuals are willing to punish at their own cost (*altruistic punishment*) if they believe that they are being treated unfairly. Sanfey et al. (2011) conducted an experiment where 19 individuals were scanned using MRI while playing an ultimatum game in the role of the responder. They received offers from other human partners and from a computer partner. Responders refused unfair offers from human partners at a significantly higher rate than those from a computer partner. The experiment also suggested that altruistic punishment is associated with negative emotions that are generated in unfair situations by the anterior insula of the brain."[1]

Cooperation Among Animals

"Cooperation exists in non-human animals. This behavior appears, however, to occur mostly between relatives. Spending time and resources assisting a related individual may at first seem destructive to the organism's chances of survival but is actually beneficial over the long-term. Since relatives share part of their genetic make-up, enhancing each other's chances of survival may actually increase the likelihood that the helper's genetic traits will be passed on to future generations.

Some researchers assert that cooperation is more complex than this. They maintain that helpers may receive more direct, and less indirect, gains from assisting others than is commonly reported. Furthermore, they insist that cooperation may not solely be an interaction between two individuals but may be part of the broader goal of unifying populations."[2]

Collaboration

"Collaboration is the process of two or more people or organizations working together to realize or achieve something successfully. Collaboration is very similar to, but more closely aligned than, cooperation", and both are an opposite of competition. "Most collaboration requires leadership, although the form of leadership can be social within a decentralized and egalitarian group. Teams that work collaboratively can obtain greater resources, recognition and reward when facing competition for finite resources.

Structured methods of collaboration encourage introspection of behavior and communication. These methods *specifically* aim to increase the success of teams as they engage in collaborative problem solving.

Forms, rubrics, charts and graphs are useful in these situations to objectively document personal traits with the goal of improving performance in current and future projects. Collaboration is also present in opposing goals exhibiting the notion of adversarial collaboration, though this is not a common case for using the word."[3]

[1] https://en.wikipedia.org/wiki/Cooperation (March 27, 2017)

[2] https://en.wikipedia.org/wiki/Cooperation (March 27, 2017)

[3] https://en.wikipedia.org/wiki/Collaboration (March 27, 2017)

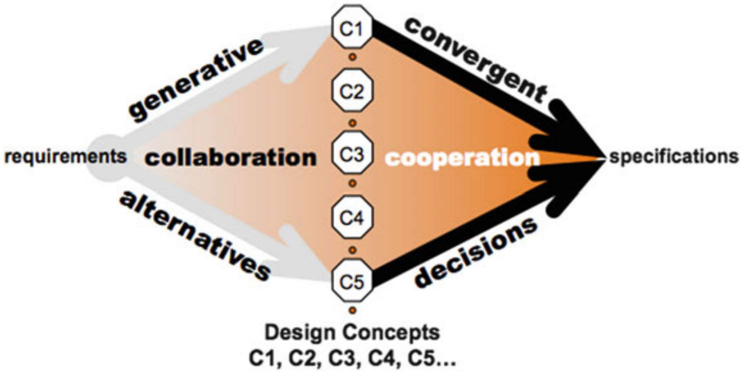

Fig. 2 Design thinking in practice demands an iterative cycle of creative collaboration, agreeing to disagree until some of those concepts (ideas) are really worth further attention. Then follows tangible prototyping to yield informed decisions based on human experience with the prototypes. With the design challenge re-framed and a workable prototype in hand we can proceed to use efficient cooperation to "MAKE IT REAL"

Collaboration between the Hasso Plattner Institute, Potsdam, Germany, and Stanford University, Stanford, California, USA, is a notable example of the pursuit of breakthrough innovation through design research. We agree to disagree on many issues and then work closely together to converge on verifiable scientific validation of design thinking paradigm elements (Fig. 2).

2 The HPI-Stanford Design Thinking Research Program

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

2.1 Program Vision and Goals

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

The program pursues the goal to advance design thinking theory and knowledge within the research community and ultimately improve design practice and education by gathering scientific evidence to support design activities. It seeks to yield deep insights into the nature of human needs and the protocols that design thinking researchers might apply to achieve "insights" versus "data." Beyond conveying a mere descriptive understanding of the subject matter, this program aims, for example, to develop metrics that allow an assessment and prediction of team performance to facilitate real-time management of how teams work. Scientists study the complex interaction between members of multi-disciplinary teams, with special regard to the necessity of creative collaboration across spatial, temporal, and cultural boundaries. They design, develop, and evaluate innovative tools and methods that support teams in their creative work. The projects tackle the common questions of why structures of successful design thinking teams differ substantially from traditional corporate structures and how design thinking methods mesh with traditional engineering and management approaches.

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

Special interest is placed on in the following guiding questions:

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

Over the past years dozens of research projects have been conducted, our understanding of this field has advanced and new insights and tools have become available. And they are not only intended for scientific discourse. With this book series they are made known to the public at large and to all who want and need to drive innovation, be it in companies or society.

2.2 Road Map Through This Book

In this eighth program year, scientists from HPI and Stanford University have again conducted various research projects on design thinking. Their results are compiled in this book, divided into four parts that illustrate the variety of design thinking research accomplished within the Hasso Plattner Design Thinking Research program. This volume begins with a historic perspective on the theoretical foundations of design thinking. In the chapter **"Theoretical Foundations of Design Thinking. Part 1: John E. Arnold's Creative Thinking Theories"** Julia P. A. von Thienen, William J. Clancey, Giovanni E. Corazza and Christoph Meinel revisit design thinking history with the aim of explicating scientific understandings that inform design thinking practices today. The four following topic areas explore and further develop various frameworks, methodologies, mindsets, systems and tools. All in all, the contributions shed light on and open up deeper insights into how to support the collaboration of design teams in order to systematically and successfully develop innovations and design progressive solutions for tomorrow.

The articles in the section **"Modelling and Mapping Teamwork"** focus on team interaction. The first chapter presents a quadratic model for team performance that allows for monitoring, improving, and reflecting on design teams at the individual, interactional, and environmental levels. Furthermore, the effect of breaks (characterized in terms of three dimensions) on design thinking teams are examined.

"Tools and Techniques for Productive Collaboration" are at the center of Part II. Here, a broad range of approaches to foster productive collaboration are presented. A field experiment on Mechanical Novel—a system that crowdsources short fiction stories on Amazon Mechanical Turk—suggests a model of how coordinated crowd efforts can be made useful for complex work. A tool for sharing works-in progress rather than sharing results is proposed, as well as a prototyping platform for remote collaboration that uses augmented reality. A framework for prototyping interactive, connected devices based on widely available single-board Linux computers, holds great potential for benefitting interaction designers. It encourages the use of computer as material to create new interactive devices. Aimed at transforming source code into valuable, tangible communication artifacts for programmers and domain experts, the next chapter proposes a new approach to provide a mapping of existing data sources into the object-oriented programming environment. In contrast, the last project unveils the creative potential that lies in low coherent turns in design conversation.

Part III of this volume, **"Teaching, Training, Priming: Approaches to Teaching and Enabling Creative Skills!",** examines ways and instruments of teaching design thinking and enabling creative skills. After prior, intensive theoretical work, researchers present a prototype MOOC for design thinking education. Further research examines the effect of group training on the enhancement of individual creativity. The third chapter presents two design methods that actively prime designers to exhibit or accentuate certain skills during the conceptual design process. The study concludes that both implicit and explicit priming are promising techniques that can be used to enhance design skills. The last chapter provides a theoretically founded and practically experienced approach on how to conceptualize places for design thinking and foster creative collaboration.

Finally the book addresses how design thinking is put into practice. Part IV, **"Design Thinking in Practice,"** focuses on the application of design thinking, taking a closer look at how it is applied in different organizational environments, considering a number of variables and how they interact with design thinking. Researchers also present the application of design thinking in health IT systems engineering, examining the use of technology to capture "a digital story" of patients' needs during the course of care and studying the impact of human augmentation on team performance. The next chapter takes a look at the development process of the digital documentation system Tele-Board MED (designed for medical encounters), reflecting on its failures and successes along the way. The following chapter reports on a semi-automated approach for recovering design thinking methodology used that allows proceeding from a qualitative to quantitative analysis of the design thinking methodology used. From the point of view of creative computing, significant accessibility barriers for prototyping electronic devices exist in current tools. In order to make design thinking more accessible in this field, there is a need for a new tool set.

2.3 Part I: Modelling and Mapping Teamwork

In **"Quadratic Model of Reciprocal Causation for Monitoring, Improving, and Reflecting on Design Team Performance"** Neeraj Sonalkar, Ade Mabogunje, and Mark Cutkosky state that design team performance is a complex phenomenon that involves person, behavior, and environment parameters interacting with each other over time. The authors propose a quadratic model for team performance that allows for monitoring, improving, and reflecting on design teams at the individual, interactional, and environmental levels. Moreover, the team describes the development of the model based on cases of student behavior from a graduate level design course. Further, they discuss the model's implications for design practice and design research.

Franziska Dobrigkeit, Danielly de Paula, and Matthias Uflacker took as their starting point the nature of activity breaks as a fundamental part of our working life, a subject which has already been studied in various settings. The article **"Breaks with Purpose. A Three-Dimension Framework to Map Break Characteristics and Their Effects on Design Thinking Teams"** investigates the importance and impact of activity breaks on design thinking teams. The research is based on a series of interviews conducted with design thinking team members and coaches in combination with observations of their behavior during and after breaks at the HPI School of Design Thinking. The analysis shows that breaks in this setting can be characterized in terms of three dimensions, the activity level (active or passive), a social dimension (group or individual) and the distance to the project (related or unrelated to the project).

2.4 Part II: Tools and Techniques for Productive Collaboration

Crowdsourcing systems accomplish large tasks with scale and speed by breaking work down into independent parts. However, many types of complex creative work, such as fiction writing, have remained out of reach for crowds because work is tightly interdependent—changing one part of a story may trigger changes to the overall plot and vice versa. Taking inspiration from how experienced authors write, Joy Kim, Sarah Sterman, Allegra Argent Beal Cohen, and Michael S. Bernstein propose a technique for achieving interdependent complex goals with crowds. With this technique, the crowd loops between reflection, to select a high-level goal, and revision, to decompose that goal into low-level, actionable tasks. In the first chapter, "**Mechanical Novel: Crowdsourcing Complex Work through Reflection and Revision,"** the authors embody this approach in Mechanical Novel, a system that crowdsources short fiction stories on Amazon Mechanical Turk.

Joy Kim, Maneesh Agrawala, and Michael S. Bernstein propose an online creative community where sharing process, rather than showcasing outcomes, is the main approach taken in sharing creative work. Based on this modus operandi, the authors present Mosaic—an online community where illustrators share work-in-progress snapshots showing how an artwork was completed from start to finish in their chapter **"Mosaic: Designing Online Creative Communities for Sharing Works-in-Progress."** In an online deployment and observational study, artists used Mosaic as a vehicle for reflecting on how they can improve their own creative process. They developed a social norm of detailed feedback, and, at the same time, gained greater confidence in sharing early versions of artwork. Through Mosaic, the authors argue that communities oriented around sharing creative process can create a collaborative environment that is beneficial for creative growth.

While many systems have been designed to support collaboration around visual thinking tools, less work has investigated how to share and collaboratively design physical prototypes—an important part of the design process. The chapter **"Investigating Tangible Collaboration for Design Towards Augmented Physical Telepresence,"** written by Alexa F. Siu, Shenli Yuan, Hieu Pham, Eric Gonzalez, Lawrence H. Kim, Mathieu Le Goc, and Sean Follmer, describes preliminary results from a formative study on how designers communicate and collaborate in design meetings around physical and digital artifacts. Addressing some limitations in current collaboration platforms and drawing guidelines from their study, they introduce a new prototype platform for remote collaboration. This platform leverages the use of augmented reality (AR) for rendering remote participant and a pair of linked actuated tabletop tangible interfaces that act as the participants' shared physical workspace. They propose the use of actuated tabletop tangibles to synchronously render complex shapes and to act as a physical input.

In **"The Interaction Engine"** Nikolas Martelaro, Wendy Ju, and Mark Horowitz present a framework for prototyping interactive, connected devices based on widely available single-board Linux computers. After outlining the hardware and software components that make up the general Interaction Engine framework, the researchers discuss its benefits for interaction designers and provide an illustrative case study of the Interaction Engine in use. In describing the framework and case studies, the authors aim to shift the designer's thinking of computer as product to computer as material to create new interactive devices.

Programmers collaborate continuously with domain experts to explore the problem space and to shape a solution that fits the user's needs. In doing so, all parties develop a shared vocabulary, which is, above all, a list of named concepts and their relationships to each other. Nowadays, many programmers favor object-oriented programming because it allows them to directly represent real-world concepts and interactions from the vocabulary as code. However, when existing domain data is not yet represented as objects, it becomes a challenge to initially bring existing domain data into object-oriented systems while keeping the source code readable. While the source remains comprehensible to programmers, it can be a struggle for domain experts who often have a non-programming background. In "**Making the Domain Tangible: Implicit Object Lookup for Source Code Readability"** Patrick Rein, Marcel Taeumel, and Robert Hirschfeld present a new approach for provide a mapping existing data sources into the object-oriented programming environment. They support keeping the code of the domain model compact and readable while adding implicit means to access external information as internal domain objects. This should encourage programmers to explore different ways of building the software system quickly. Eventually, their approach fosters communication with the domain experts, especially at the beginning of a project. When the details of the problem space are not yet clear, the source code is a valuable, tangible communication artifact.

The sixth chapter, **"' . . . and not Building on That': The Relation of Low Coherence and Creativity in Design Conversations,"** by Axel Menning, Benedikt Ewald, Claudia Nicolai, and Ulrich Weinberg explores the relation between coherence and creativity in design conversations of innovation teams. Low coherent segments in a conversation can be understood as the linguistic equivalent of shifts in the focus of attention while designing. Shifts in focus have a positive influence on ideational productivity. The authors therefore reason that low coherent speaker turns function as creative stimuli in team conversations. They illustrate how this works in practice with a case study of an innovation team observed in the wild.

2.5 Part III: Teaching, Training, Priming: Approaches to Teaching and Enabeling Creative Skills

The increasing demand for learning and experiencing the human-centered approach of design thinking has led to a need for more and broader educational formats. In "**The DT MOOC Prototype: Towards Teaching Design Thinking At Scale"** Mana Taheri, Lena Mayer, Karen von Schmieden and Christoph Meinel investigate how design thinking can be taught to a massive, global audience through the use of digital education. The chapter contains a description of the design thinking MOOC prototype *Inspirations for Design* and its theoretical base. Results from the test of the pilot version are reported and discussed. Moreover, the researchers deduce ideas for an *Inspirations for Design* iteration and future digital design thinking learning units and propose adaptations for the openHPI platform to facilitate design thinking education in a MOOC environment.

Creativity is an important construct driving society and innovation forward. Many organizations have adopted team-based work in order to increase innovation and creativity under the assumption that groups of people tend to produce more creative ideas than individuals. Research has so far shown mixed results with some findings enhancing creativity in teams and others having the opposite effect. "**Creativity in the 21st Century: The Added Benefit of Training and Cooperation"** presents a short literature review of team creativity and how it relates to possible neural networks. In addition, Naama Mayseless, Manish Saggar, Grace Hawthorne and Allan Reiss have integrated key findings from their current research implementing a group training protocol to enhance creative capacity.

Priming has been used by behavioral psychologists to learn more about human judgments and decisions. Jinjuan She, Katja Holtta-Otto, and Erin F. MacDonald offer two studies and a literature review that highlight how designers use priming to fine-tune their skills in **"Priming Designers Leads to Prime Designs."** In the past, designers used priming exercises to help them generate more features, novel features, and uncover latent customer needs during conceptualization. This paper presents two newer design methods that actively prime designers to exhibit or accentuate certain skills during the conceptual design process. Taken together with findings from other researchers, they conclude that both implicit and explicit priming are promising techniques that can be used to enhance design skills.

In an effort to increase employee motivation, team performance, innovation management, and the overall innovativeness of the whole organization, more and more companies have begun to leverage the so far unused potential of place. At the same time, companies often struggle with the proper conceptualization of the place at issue. In "**From Place to Space: How to Conceptualize Places for Design Thinking,"** Martin Schwemmle, Claudia Nicolai, Marie Klooker, and Ulrich Weinberg first provide relevant theoretical foundations and then explain the conceptualization of a design thinking place based on the example of HPI D-School Potsdam. This theoretically founded and practically experienced approach will provide the reader with a basic knowledge of how to conceptualize places for design thinking and addresses both researchers and practitioners.

2.6 Part IV: Design Thinking in Practice

Dozens of for profit and not for profit organizations across a wide range of sectors explicitly employ design thinking as a core innovation methodology. This demonstrates how versatile the tools and frameworks are. It also presents an opportunity to better understand how the organizational environment impacts the application of design thinking. In "**Mapping and Measuring Design Thinking in Organizational Environments"** Adam Royalty and Sheri Shepard cover two studies that explore organizational environments. The first study is the development of a mapping technique called a design thinking ecology. It highlights a number of organizational variables and how they interact with design thinking. The second is a case study of a community of design thinking practitioners across four separate companies. Their collaboration highlights the role each organizational context plays in terms of the individual and of the group as a whole.

"Human Technology Teamwork: Enhancing the Communication of Pain Between Patients and Providers" addresses the urgent need in hospitals to reduce the amount of time that clinicians spend interacting with computers. The aim is to increase direct patient engagement, complex problem solving abilities, and overall patient satisfaction. Lauren Aquino Shluzas and David Pickham explore the application of design thinking in health IT systems engineering. Their research is motivated by a need to (i) enable clinicians to capture data from patients in a more natural and intuitive way, (ii) increase the amount of time spent on face-to-face patient interaction, and (iii) increase the speed and accuracy of tasks requiring acute critical thinking skills for complex medical scenarios. The chapter concludes with an outlook on work directed at enhancing better communication between patients and clinicians in view of the pain experience.

Tele-Board MED is a digital documentation system for medical encounters. It is used as an adjunct to talk-based mental health interventions. Having previously reported various results of Tele-Board MED studies that highlighted the virtues of the system, audiences have sometimes asked about failures along the way. Indeed, there are two good reasons why such occasional failures are more than the entertaining side stories of a project. First, design thinking holds that they are important for learning. Second, innovations in the healthcare sector are known to be specifically challenging. In "**Learning from Success and Failure in Healthcare Innovation: The Story of Tele-Board MED"** Anja Perlich, Julia von Thienen, Matthias Wenzel and Christoph Meinel reanalyze the Tele-Board MED project, zooming in on both successes and failures along the way and tracing their role for the development of the project.

The methodology of design thinking suggests a repertoire of methods and techniques that lead to different forms of the design thinking methodology in practice. Which methods and techniques have been employed is of special interest to stakeholders, such as project managers and researchers. However, the repertoire of these methods and techniques does not reveal much about the order of employed methods and techniques in practice. In their former work, the project team implemented recovery rules that successfully reconstructed the design thinking methodology from captured design thinking project documentation. In "**The Design Thinking Methodology at Work: Semi-Automated Interactive Recovery"** Joachim Hänsel and Holger Giese report on their extended semi-automated recovery approach.

How can we empower anyone to create anything? Traditionally, designers may dream of whimsical ideas and then turn these ideas into physical prototypes.

However, in the area of electronic prototyping, the tools needed to create functional devices may not be accessible to everybody. In "**Abracadabra: Imagining Access to Creative Computing Tools for Everyone"** Joel Sadler, Lauren Aquino Shluzas and Paulo Blikstein show that typical electronics prototyping tools have significant accessibility barriers for the everyday novice. This work underscores the need to find new ways of designing creative computing tools with greater accessibility for the everyday dreamer.

3 Outlook

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

We would be delighted to get in contact with our readers for further discussion and an exchange of ideas. We invite you to visit our websites. At www.hpi.de/dtrp you will find the latest information on previous and present research conducted within our program. Learn more about all projects and the researchers behind them.

Moreover, the website thisisdesignthinking.net offers an easily accessible overview of current developments in design thinking. This pool of examples and interviews, enriched with scientific explanations, helps to localize all existing expressions of design thinking, including their advantages and disadvantages. For educators, the website serves as a source of inspiration for recharging their teaching materials, explanatory models and perspectives on current problems in design thinking practice. Please get in touch with us to share your experiences and stories via thisisdesignthinking@hpi.de

We invite you to engage in dialogue with us on your ideas, questions, experiences and insights. May this publication serve you as a deep-dive into design thinking tools, methods and metrics. We hope you enjoy the read and that this book becomes a source of inspiration for your own work.

Acknowledgements We thank all authors for sharing their research results in this publication. Our special thanks go to Dr. Sharon Nemeth for her constant support in reviewing the contributions.

Theoretical Foundations of Design Thinking

Part I: John E. Arnold's Creative Thinking Theories

Julia P.A. von Thienen, William J. Clancey, Giovanni E. Corazza, and Christoph Meinel

Abstract Design thinking is acknowledged as a thriving innovation practice plus something more, something in the line of a deep understanding of innovation processes. At the same time, quite how and why design thinking works—in scientific terms—appeared an open question at first. Over recent years, empirical research has achieved great progress in illuminating the principles that make design thinking successful. Lately, the community began to explore an additional approach. Rather than setting up novel studies, investigations into the history of design thinking hold the promise of adding systematically to our comprehension of basic principles. This chapter makes a start in revisiting design thinking history with the aim of explicating scientific understandings that inform design thinking practices today. It offers a summary of creative thinking theories that were brought to Stanford Engineering in the 1950s by John E. Arnold.

Design thinking is an approach to creative problem solving that is widely recognized as a valuable route to human-centred innovation (Plattner et al. 2009; d.school 2010a; Kelley and Kelley 2013). It has been called a methodology (Grots and Pratschke 2009; Meinel and Leifer 2011; d.school 2015), a culture (d.school Paris 2016; Weinberg 2016) and a philosophy (Katz 2016). The general agreement seems to be that design thinking is a very successful and thrilling practice over and above something more, something in the line of a deep understanding of innovation processes. However, this deeper understanding appears rather hard to explicate. When Hasso Plattner advanced the first two university-based design

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thinking education institutes worldwide—the d.school that started to operate in 2005 at Stanford University and the D-School that was founded in 2007 by the Hasso Plattner Institute at the University of Potsdam—he also started a research program "to understand why and how the Design Thinking method works on a scientific basis" (Plattner 2011, p. v). Ever since, numerous empirical research projects have set out to uncover the regularities, principles, potentials and boundaries of design thinking based innovation work (Plattner et al. 2011, 2012a, b, 2014, 2015, 2016). Reflecting on these activities, Leifer and Meinel (2015) assert that through "cumulative work of a global design thinking research community [. . .] [we] have started to understand the underlying principles" (p. 2).

While never part of an official research project, inter-communal exchange (cf. acknowledgements) spurred joint interests in the history of design thinking—a history that holds the promise of opening an additional and quite valuable door to understanding why and how design thinking works. In particular, it is our hope that historical studies can help the community explicate rather comprehensively the "surplus understanding" that people attribute to design thinking in addition to its being a productive and exciting practice.

At Stanford's Mechanical Engineering department, prior to the teaching of design thinking, at least three earlier concepts informed innovation curricula (von Thienen et al. 2016a). These were *creative thinking*, *visual thinking* and *ambidextrous thinking*. Notably, all of them refer to "thinking". Such a terminological tradition highlights a key concern that design thinkers have embraced up to the present. While design thinking education endows students with methodologies for creative work, a primary goal is still to elicit mindset changes that aid creativity (e.g., Kelley and Kelley 2013; Roth 2015a).

The first historical concept, *creative thinking*, figured centrally in *Creative Engineering* seminars launched by John E. Arnold at Stanford University from the 1950s onwards. Ever since, a strong continuity of methodology, culture and philosophy can be observed up to present-day design thinking classes (Carleton and Leifer 2009; Roth 2015a, b; von Thienen et al. 2016a). To some extent, this continuity is personified by people such as Bernard Roth, Academic Director of Stanford's d.school, and Larry Leifer, Director of the Hasso Plattner *Design Thinking Research Program* at Stanford, who have personally accompanied all theorizing and educational experimentation ever since John Arnold's seminars.

This chapter seeks to make a start in revisiting design thinking history with the aim of explicating theoretical understandings that inform present-day practices. In particular, we attempt to condense Arnold's theories on creative thinking in a few basic claims, relating his terminology to present-day design thinking vocabulary where this seems appropriate. Such an endeavour obviously entails constructive work, as much as we would like to present a purely descriptive review of history. To be as true as possible to Arnold's personal intentions, we complement all interpretations with original quotes. We also wish to encourage every reader to access Arnold's (1959/2016) primary writings, which are very readable in and of themselves.

Furthermore, it must be acknowledged that the approach adopted here appears locally constrained. Our analysis focuses on Stanford University, while design thinking is clearly a world-wide development. At the same time, this research addresses a highly influential institute and gives ample opportunity to recognize contributions from around the globe as they impact Stanford practices and theorizing.

In this chapter, we present a *Part I* study of Stanford's design thinking history, addressing the first historic concept that informed innovation curricula in ways that clearly relate to present-day practices: *creative thinking*. As Part II of the series, we expect to provide an introduction to Robert McKim's need-based design theory, followed by studies of other key innovation concepts: *visual thinking* (Part III) and *ambidextrous thinking* (Part IV). A more traditional narrative of history might then be the final outcome (Part V) in this collaborative research field.

Teachings on *creative thinking* can be clearly traced to one person at Stanford, namely John E. Arnold, because his successors quickly moved on to subsequent concepts. This chapter seeks to explicate Arnold's understanding of *creative thinking* and his pedagogical approach, paying special attention to elements that likely influence present-day design thinking practices. Arnold's last known relevant work, *Creative Engineering* (1959/2016), was compiled at Stanford and can be assumed to provide the latest development of his theorizing; it will serve as nearly the exclusive source of reference. Notably, Arnold's works cover many subjects beyond *creative thinking*. A more comprehensive discussion of his ideas and legacy is provided by Clancey (2016). This chapter also skips a treatment of Arnold's innovative teaching practices at the Massachusetts Institute of Technology (MIT), for which Arnold (1953/2016) provides detailed materials.

We will start with a short introduction to John E. Arnold (# 1) and then summarize his theories on the creative mindset (#2), thinking modes (# 3), problem types (# 4) and creativity blocks (# 5), his definition of creativity (# 6), theory of the creative process (# 7), classification of creativity approaches (# 8), education theory (# 9) and usage of the term "design thinking" (# 10). We will also review some advancements of Arnold's framework and discuss a striking difference between his teaching approach and present-day design thinking education (# 11).

1 John E. Arnold: Collaborator, Experimenter and Visionary

John Edward Arnold, born in Minnesota on 14 March 1914, received his B.A. degree in psychology at the University of Minnesota in 1934 and his S. M. degree in mechanical engineering from the MIT in 1940. In 1942 he joined the MIT staff as an instructor, became an Assistant Professor in 1945 and Associate Professor in 1949. He offered the courses "Creative Engineering" and "Product Design" at the MIT and later at Stanford University, where he was appointed Professor of Mechanical Engineering and Professor of Business Administration in 1957. He was founding

Director of the Design Division at the Mechanical Engineering Department. At age 50 he died of a heart attack while travelling in Italy on sabbatical.

In his theorizing, Arnold integrated a cornucopia of influences. First, he personally collaborated with leading creativity experts, famous up to the present. For instance, the psychologists Joy Paul Guilford and Abraham Maslow, the philosopher Robert Hartman and the architect Buckminster Fuller: all came as guest lecturers to his Stanford class on *Creative Engineering*. The first three even contributed essays specifically written for Arnold's seminar, summarizing their research on creative thinking and implications for practice. Arnold was also a well-versed reader and included in his framework insights from Heraclitus, Aristotle and Schiller to recent figures of his time such as Wallas, Osborn, Wertheimer, and Bruner. He regularly held seminars for the industry and was very familiar with innovation processes used there, including General Electrics and General Motors. Case studies of outstanding innovators, diverse empirical creativity studies and Arnold's personal, effervescent experiences as an educator, who liked to experiment with different teaching approaches, all informed his theories.

Creative Engineering (1959/2016) describes in detail two major pillars of Arnold's creative thinking framework. One is an elaborate compilation of methods that can be serviceable along the creative process. The second is a set of theories about creative thinking. In the latter, a description of the creative mindset figures prominently. Arnold asks: What distinguishes a person who achieves creative, innovative solutions from someone who achieves less in these areas? As one might expect, methods shall help students expand their creative problem solving competencies. But, maybe more importantly, practicing methods shall impact the mindset in favour of creativity. This chapter is concerned with Arnold's theories on creative thinking only and does not review his compilation of methods, which are however discussed by Clancey (2016).

To facilitate future research and help the community build on Arnold's works, we will highlight a number of central theoretical assumptions (A), definitions (D) and include some observations from a meta-perspective, as informed by design thinking research (M).

2 A Theory of the Creative Mindset

Arnold's theory of the creative mindset presented in *Creative Engineering* (henceforth CE) builds to a large extent on Joy Paul Guilford's factor-analytical studies of creativity. Arnold also includes lines of thought from a number of other researchers, among them Abraham Maslow, who compared highly creative and rather rigid people, Carl Rogers, who described creativity as an attribute of healthy humans that would allow people to realize their personal potential, and Dana Farnsworth, who elaborated on emotional prerequisites of creativity. Arnold also weaves in personal observations and analyses.

> The four Guilford factors of (1) problem sensitivity, (2) fluency, (3) flexibility, and (4) originality appear repeatedly in almost all of the literature on creative thinking, imagination, and innovation, although not always under the same names. You would not, however, until Guilford isolated them in his factor studies, know that they have been recognized as basic mental attributes, and ones essential to the creative, imaginative thinker. This is true whether he be a poet, an artist, an engineer, or a physicist. They are part of the inherited potential of each individual, and combined with certain emotional attributes make up the personality of the innovator.
>
> (CE, p. 96)

This review will start with Arnold's interpretation of the factors that he adopts from Guilford. Arnold adds three emotion-centred variables to describe creative mindsets, which will be introduced afterwards.

A1) The creative mindset is characterized by problem sensitivity, fluency, flexibility, originality, daringness, drive and confidence.

D1) Problem sensitivity refers to the inclination of a person to notice and tackle problems next to abilities of framing, defining and communicating problems in ways that aid creative solutions. Starting off with Guilford's definition, Arnold agrees that problem sensitivity includes the ability of a person to notice problems.

> Problem sensitivity, as originally conceived and defined by Guilford was that ability that made men sensitive to their surroundings. Rogers and Mooney speak of this as "openness to experience," possibly a more inclusive term. It is being aware that a problem exists. Sometimes it is no more than a feeling, a hunch, that can't be clearly defined until a great deal more investigation and study is carried out.
>
> (CE, p. 80)

In addition, the problem sensitive person is described by Arnold as someone with a "deep spirit of inquiry, of questioning" (CE, p. 63) who seeks to "improve the things he sees" (p. 63). Thus, faced with questionable life conditions, the problem sensitive person does not only notice a problem, but also develops the interest and intention to follow up on the "hunch"; this person is ready to invest time and effort.

A third aspect that Arnold brings into play is the ability of describing problems in clear and fruitful terms.

> I have found from my own work, however, that problem sensitivity involves more than an awareness of problems, for it also seems to be associated with problem statement [. . .]. Problem statements may limit or free the imagination of the solver. They may precondition his thinking along such narrow and rigid lines that very desirable solutions are precluded. At the other extreme, I suppose they can be so nebulous and ill-defined that no one knows what is wanted or where to start.
>
> (CE, p. 80)

Here, Arnold explicates a central theoretical belief that informs design thinking up to the present. It calls for an optimal balance between focus and degrees of freedom.

M1) Problem framing opens, closes, and structures solution spaces.

In design thinking, Arnold's ideas about problem framing appear to be mirrored in the motto: "Craft Clarity[:] Produce a coherent vision out of messy problems. Frame it in a way to inspire others and to fuel ideation" (d.school 2010b, p. 0). Like the d.school Bootcamp Bootleg, Arnold calls for intriguing problem statements, which provide directions for successive creative activity.

D2) Fluency refers to the number of ideas that a person produces per unit time. "The creative person is more fluent in his ideation than the less creative; he has more ideas per unit time" (CE, p. 84). Arnold's discussion of fluency is to a large extent informed by empirical relationships he observes. Next to the influence of judgmental thinking that will be discussed below (# 3), problem framing is accorded great attention again.

A2) General or loosely constrained problem statements increase fluency; narrow or highly constrained problem statements reduce fluency.

A3) Disregarding practical limitations when generating ideas increases fluency.

> I recently gave my students a short case problem aimed at getting people across the Harvard Bridge [. . .]. Those who tried to think of ways and means of transporting "feeble old ladies" safely across the bridge under the worst possible conditions had a very difficult time of thinking up any suitable solutions. On the other hand, those who realized that the above limitations might have to be applied to the final solution, but who temporarily laid them aside and considered every possible means of getting something from one place to another came up with over 75 different ideas in a little under twenty minutes.
>
> (CE, p. 85)

D3) Flexibility refers to the number of meta-options a person considers per unit time. Meta-options include categories, points of view, approaches, solutions, and so on. Arnold names several domains where flexibility is important, including (1) *Object Use:*

> [Guilford asks] people to list as many uses they could possibly think of for very common, every-day items such as a red brick. People could show a great deal of fluency in their thinking by listing a long column of uses, but they all fell into one category such as construction or ornamentation, they showed little flexibility. Actually there are some fourteen categories under which you might list the uses of bricks and the flexible thinker gives some thought to most of them. Bricks have mass as well as spacial dimensions. They make good doorstops or bookends [. . .]. Bricks have color and they might be ground up to form pigment for paint [. . .].
>
> (CE, p. 85)

Another domain concerns (2) *Work and Solution Approaches:* "Flexibility [. . .] reflects itself in the wide variety of approaches that the creative person chooses to investigate" (CE, p. 85). (3) An *Action-Reflection-Role-Repertoire:*

> Flexibility [. . .] is also the ability [. . .] that allows you to be both an observer and a participator at the same time or in alternation. It is most desirable to have this duality of personality be constant in time if the observer half is not acting as a judge [. . .]. Perhaps the alternating roles would be the safest at first. This would allow you to step back every so often and review what you have done to date and to reconnoiter and determine the best path to continue along.
>
> (CE, p. 86)

With these thoughts, Arnold anticipates the concept of a *reflective practitioner* that was later elaborated by Donald Schön (1983) and thoroughly embraced in the design thinking community (Lindberg 2013). As yet another domain where the creative thinker needs to demonstrate flexibility Arnold mentions (4) *Work Pace:* "Flexibility [. . .] is the ability to change pace used so successfully by athletes" (CE, p. 86). (5) *Perspective-Taking:* Flexibility allows the creative thinker to take on "a number of different vantage points" (p. 86). (6) *Perceptual Inclinations:* Arnold requires great flexibility of the expert innovator who should have "his senses so trained that their thresholds of perception can be varied at will. His powers of free and controlled association must be developed to an extremely high level so that he can search out and find extremely remote relationships" (p. 129).

D4) Flexibility is the opposite of rigidity. A rigid person tends to converge always on the same options. More generally speaking, "the non-creative person's past experience provides him with a comfortable little rut in which to operate and he has great difficulty getting out of that groove" (p. 85). Similarly, the rigid environment favours continuity with the past. In a rigid environment "people resist change and innovation" (p. 87). They prefer "the old, familiar, and seemingly adequate ideas that they have held for some time" (p. 87).

D5) Originality refers to the unusualness of ideas. "It must be obvious that the highly creative person makes more novel and original combinations than the less creative. He consistently brings together 'seemingly disparate' or 'habitually incompatible' ideas or objects [. . .] to form tenable and useful new combinations" (p. 86). Here, Arnold brings into play the concept of "habitually incompatible ideas" from Arthur Koestler (1949), meaning ideas that most people normally would not associate with each other, though it is possible to do so.

Next to the Guilford-factors, Arnold also discusses attributes that Carl Rogers and Abraham Maslow assign to creative thinkers as opposed to rigid thinkers. These include *openness to experience*, *being playful*, *humorous*, *not afraid of fantasy* and having an *internal locus of judgement*, i. e. non-conformity, not depending universally on what other people hold to be right or wrong. Yet, Roger's and Maslow's works inform Arnold's interpretation of other mindset variables rather than entering the framework as disjunctive elements.

Besides the re-interpreted Guilford factors, Arnold highlights three variables that focus specifically on motivational or emotional processes. All of them are related to an issue that he discusses regularly in his theorizing: Being an innovator is challenging because innovation projects often encounter obstacles or even straightforward resistance from people who defend the status quo.

M2) A creative mindset requires emotional and motivational attributes that help to overcome innovation hardships.

Innovators need strong impulses to engage in their work despite all the hardships this often entails. Specifically, Arnold highlights boldness in the face of risk (daringness), enthusiasm for problem-solving (drive), next to believing in oneself and one's vision (confidence).

D6) Daringness refers to the willingness of a person to challenge the status quo and risk the untried. Notably, this often includes social risks, as other people may prefer the status quo or may be sceptical about a novel solution they have little experience with.

> The creative person has to be daring. He [. . .] must constantly take calculated risks in his attempt to find better solutions to the problems that face mankind. He cannot stick to the safe, the tried and true, the prosaic approaches, and he must pioneer in new areas in a very daring fashion. Creating, unfortunately, also involves destroying. The man who is seeking a new, better solution to an old problem [. . .] wants to destroy a present, possibly adequate solution. As John Steinbeck has pointed out, many people resist change and innovation not so much because they fear the new approach, but because to accept the new they must first give up the old, familiar, and seemingly adequate ideas that they have held for some time. The creative individual, then, must be a leader, he must be daring.
> (CE, p. 87)

D7) Drive refers to the emotional energy and enthusiasm with which a person pursues her creative project, specifically when facing hardships. Arnold observes that truly creative thinkers love to solve problems. "Many studies have been and are being made on motivation, initiative, and so forth, and the new insights give us a more complete picture of their phenomena. For the most part it seems however, that the highly creative person just loves to solve problems. The great inventor invents because that is what he likes to do best; the great painter creates great works of art because that is what he likes to do" (CE, p. 87). "Drive [. . .] connotes a very definite enthusiasm for work; again this love of problem solving" (p. 87). However, as creative work often confronts obstacles, drive also refers to emotional energy that is maintained in times of hardship.

> Many people have indicated that they feel that this [drive] is the prime requisite of all creative workers. Edison, for example, has said that invention is two percent inspiration and ninety-eight percent perspiration. I am not quite sure that he had the percentages accurately distributed, but I do know that there is a great deal of work associated with the polishing and re-polishing of an idea before it becomes an acceptable, tangible result.
> (CE, p. 88)

D8) Drive is observable as perseverance, specifically when facing hardships or immediate but moderately helpful solutions. A person who lacks drive likely fails to carry the "problem through to completion and test" (CE, p. 92)—and even more so when faced with obstacles. Or the person will accept "a workable solution [. . .] [instead of] searching for a better one (grabbing the first idea that comes along)" (p. 92).

A4) Drive is a major predictor for creative achievement.

> A number of patent attorneys (176), research directors (78), and inventors (710), were asked to list the mental characteristics that were necessary and vital to the successful innovator. The patent attorneys and research directors listed originality and imagination, analytical ability and perseverance at the top of the list, and in that order. The inventors, on the other hand, changed the order slightly, and I am inclined to agree with them. They listed perseverance as number one by a wide margin, and then originality and imagination and finally analytical ability. Without the drive to carry a project through to completion, in spite of all obstacles, the idea has little or no value.
> (CE, p. 104)

D9) Creative confidence refers to positive beliefs held by a person about her own innovation capacities and the value of her creative project. "There are so many ways in which a good idea can be destroyed or made quite impotent that confidence in one's cause [. . .] is a prime requisite to innovation" (CE, p. 88).

A5) Confidence is an important moderator variable that affects whether or not people maintain drive in the face of obstacles; with high levels of creative confidence people retain more drive in times of hardship.

Two case studies illustrate the role that Arnold attributes to confidence in the course of creative activity. Discussing Land's invention of Polaroid pictures and Gillette's invention of disposable razors, he summarizes: "In both cases, reason and analysis (the experts) said that it couldn't be done. [. . .] In both cases, a certain amount of confidence, or intuition or faith provided the emotional energy or drive to carry the project through and make the big dream come true" (p. 104).

While not part of his theory of the creative personality, Arnold also discusses how creativity and happiness relate to each other. He holds that "to be happy one must be creative" (p. 64).

A6) Happiness requires creativity.

D10) Happiness depends on personal achievements in the sense of making contributions to society and realizing personal potential. "The definition that I like best is that happiness is the first derivative of your achievement curve. When you are progressing, making positive contributions and using your talents to the full, the slope of the achievement curve is positive and you are happy. The opposite situation results in a negative slope and unhappiness" (p. 63f.). "One must make positive contributions to society, must maintain an achievement curve with an overall positive slope if one is to be truly happy. This is one more good reason for why we should try to be creative" (p. 64).

In the design thinking community, this theme is advanced in *The Achievement Habit* (Roth 2015a), where readers are encouraged to express and develop their creativity as part of self-actualization.

3 A Theory of Thinking Modes

Once more building on—and putting his own spin on—Guilford's analyses, Arnold lays out his understanding of different thinking modes. "Dr. J. P. Guilford [. . .] first hypothesized the three modes of thinking as analytical thinking, judicial thinking, and creative thinking" (CE, p. 80, cf. also Guilford 1950). According to Arnold . . .

A7) There are three basic modes of thinking: Analytical, judicial, and synthetic.

D11) Analytical thinking detects the features and structure of an entity. "Analyzing is the taking things apart in the search for truth and recognizable relationships" (CE, p. 129). As sample fields of study that primarily require analytical thinking, Arnold names pure logic, mathematics, and system analysis.

D12) Judicial thinking compares two or more entities and often ascribes value. However, "effective judgments cannot be made completely independent of analysis. This must almost be obvious. When one is comparing, making value judgments, rating, classifying, deciding, and so forth, it is essential that keen analysis be made of each of the components involved" (p. 66). As sample fields of application, Arnold names jurisdiction and quality control, as “both of these areas of activity depend primarily on making good judgments, making right decisions” (p. 73). The terms ***judicial thinking*** and ***evaluation*** are used synonymously.

D13) Synthetic thinking combines two or more entities into something new. It is “the bringing together of two objects or concepts for the purpose of making a new combination or whole” (p. 66). As sample fields that require synthetic thinking, Arnold names machine or product design, art, music and philosophy.

D14) Creative thinking combines analytical, judicial, and synthetic thinking in regulated ways. Thus, creative thinking is not a thinking mode in itself but a combination of thinking modes. Creative work needs a careful “balance between analysis, synthesis, and evaluation” (p. 129). This includes up-regulating and down-regulating the thinking modes at will. Especially in the idea generation phase it is important to dispense judicial thinking. One reason is that “fluency is definitely facilitated or inhibited by the absence or presence of simultaneous evaluation. Evaluation must be restrained temporarily while one is thinking up ideas or hypotheses” (p. 84). However, after the solution space has been saturated with a great number of diverse ideas, judicial thinking is essential. “The solutions obtained can form a complete spectrum from bad to good. [. . .] [T]he choice of the best possible solution depends upon careful evaluation of the many presented for consideration” (p. 129).

4 A Theory of Problem Types

Closely related to the theory of thinking modes, Arnold presents his theory of problems.

A8) There are three basic types of problems: Analytical, judicial and synthetic.

“Problems can be classified into three quite distinct groups: analytical, judicial, and synthetic” (p. 65). Arnold believes “that the three types of problems [. . .] stem from the three basic modes of thinking, analysis, evaluation, and synthesis” (p. 65). However, to distinguish between different problem types, other criteria are suggested.

A9) Problem types can be distinguished based on (a) the number of concepts that need to be considered in problem and solution statements next to (b) the number of correct answers.

D15) Analytical problems (a) are characterized by precise problem and solution statements that use only a small number of concepts and (b) they have only one correct answer.

> Analytical problems are stated quite precisely and involve, both in statement and solution, a relatively few basic concepts which lead to one, and only one, right answer. [. . .] What is the sum of 2 plus 2? Who won the Battle of Hastings in 1066? [. . .] In all cases, correct processes of logic or experiment will yield the one right answer; all other answers are wrong.
>
> (CE, p. 65)

D16) Judicial problems (a) are characterized by complex problem and solution statements that require intricately refined concepts and (b) they have more than one correct answer. Paradigmatic examples are drawn from the field of jurisprudence.

> The problems of judgment are somewhat more complex. It takes many more words and concepts to describe them, in fact, to all but the legally trained mind, the verbosity of legalese is extremely confusing. Not only must you describe in great detail the "things" that must be evaluated, but you must also be just as meticulous in stating the bases for judgment, the rules, the laws that must be followed.
>
> (CE, p. 65)

Many answers can be defended as right, and answers that were considered right once can be turned down later on. "In the law a higher court can reverse a lower court decision, and in the Supreme Court minority reports are frequently submitted" (CE, p. 65). Another example would be beauty contests where "it must be a rare event when there is complete agreement between the judges" (p. 65).

D17) Synthetic problems (a) are characterized by an open spectrum of concepts that can be invoked for problem and solution statements and (b) an infinite variety of possible solutions from bad to good. "The problems that involve synthesizing [. . .] may involve an almost infinite number of concepts and a complete spectrum of possible solutions. The cross products of the various factors that might be combined in any one problem are almost limitless" (p. 65). On behalf of the solutions Arnold holds that there are

> many right answers, many wrong ones and all possible combinations in between. Moreover, this spectrum is never completed. No matter how poor the worst solution existing in the spectrum is, a still worse one can be found; and in the same manner, but perhaps with more effort, a still better solution than the best one existing can be found.
>
> (CE, p. 65)

With the category of synthetic problems, Arnold anticipates "wicked problems," a concept later coined by Rittel (e.g., 1972; Rittel and Webber 1973) that is much attended in design thinking research (e.g., Buchanan 1992; Lindberg 2013; von Thienen et al. 2014, Ney in preparation). Notably, Arnold's classification is conceptually more economic; he invokes only two criteria to distinguish between different problem types, while Rittel uses ten criteria.

Solving problems with more than one correct answer requires creativity; hence they are also called "creative problems".

M3) Creative problems centre on basic human needs that are either not satisfied at all or badly satisfied at present.

M4) Solving creative problems means to improve ways of meeting basic human needs.

Notably, in Arnold's problem conception solving a creative problem means to satisfy basic human needs. Being sensitive to problems—as part of the creative mindset—is already interpreted as seeking to better satisfy basic human needs. "The highly imaginative person is one who is motivated by a deep spirit of inquiry, of questioning. He is constantly asking himself how he can improve the things he sees.

He is concerned with how the basic needs of man can be better satisfied" (p. 63). The goal of creativity is to "better satisfy some basic need of mankind" (1956, p. 8). Here, addressing basic—instead of variable and superficial—human needs means to dig deep into a problem, seek a broad perspective and understand the general issues that are at stake. Traffic organization is one example that Arnold invokes to illustrate varying problem scopes and the needs they bring into focus. A customer might ask for a small car to ease parking in a crowded city. The 'need for a small car' is everything but a general, fundamental need. Arnold follows up with a question: Why does this person need to use a car and find a parking space for it? His answer is that people "must be kept mobile—yet not be overly frustrated" (CE, p. 94). The needs 'to be mobile' and 'to not suffer frustration' are already much more basic. Yet, Arnold digs even deeper and asks: Why do people need to be mobile? Here, the answer is that "man must be able to communicate freely" (p. 94), which arguably brings into focus a yet more basic need than mobility. (The subject of basic needs and how to identify them in the context of design thinking is treated in detail by von Thienen et al. (2012a). Clancey (2016) elaborates on Arnold's philosophy of design where human needs that shall be addressed by design often bear on social or societal challenges.) The idea that creative solutions satisfy human needs is also part of Arnold's creativity definition and discussed further below (# 4).

5 Theory of Creativity Blocks

Creative mindsets, thinking modes and problems are central elements in creative activity. With his theory of creativity blocks, Arnold starts a systematization of factors that hinder creative work.

> It is possible for an individual to have a rather highly developed potential for creative activity and who is potentially able to balance his ability to analyze, synthesize and evaluate, and to have the necessary initiative and drive to complete his novel ideas, yet to find himself in situations where it is almost impossible for him to work efficiently and effectively. These factors that tend to inhibit and prevent productive and creative activity we will call blocks.
> (CE, p. 88)

D18) Creativity blocks refer to factors that antagonize creative activity. Arnold suggests to "loosely group them under three headings, loosely because the things that affect thinking and action rarely if ever appear in pure culture. The headings I would suggest are *Perceptual Blocks*, *Cultural Blocks*, and the *Emotional Blocks* to creative activity" (CE, p. 88f.). They range from short-term or rather specific blocks, such as not knowing enough about a specific field of inquiry, to general, stable and often personality-related blocks, such as seeking to be a "well-adapted" member of the community who never deviates from common practices.

D19) Perceptual blocks antagonize the understanding of problem and solution spaces by making information unavailable or distorting it. People "fail to get true, adequate, and relevant information about the outside world" (p. 89). Sample blocks are a "failure to use all of the senses in observing" (p. 92), "difficulty in narrowing the problem too much (paying little or no attention to the environment)" (p. 91), "difficulty in seeing remote relationships (inability to transfer)" (p. 92) or "difficulty arising from not recording 'trivia[']" (p. 92).

D20) Cultural blocks refer to social influences that antagonize the progress or flexibility of creative activity. "Our culture influences our thinking and our activity. [. . .] Certain things are done in our society, other things are very definitely tabooed" (p. 90). A person falls victim to a cultural block when she allows herself to be driven by a "desire to conform to an accepted pattern" (p. 92) and thus limits her own flexibility. A creative process may fail to get started in the first place when the person finds it "not polite to be too inquisitive and not wise to doubt everything" (p. 92). In research and engineering, a sample cultural block can be having "too much faith in statistics" (p. 92).

D21) Emotional blocks are emotions that limit the person's ability to develop and/or exploit her creative potential. "The emotional blocks are by far the largest grouping, and they include all our fears, and most of the defense mechanisms that we build up in order to make our lives seemingly more tolerable" (p. 89). Sample emotional blocks are the "fear of making a mistake or making a fool of yourself" (p. 92), an "over-motivation to succeed quickly" (p. 92), a "lack of drive in carrying [the] problem through to completion and test" (p. 92) or having "difficulty in rejecting a workable solution and searching for a better one (grabbing the first idea that comes along)" (p. 92).

6 Defining Creativity

As for all practical purposes, Arnold holds that . . .

D22) A solution is creative when it is novel and useful. This definition he invokes frequently, with some variation of vocabulary. He concerns himself with "novel and more useful solutions" (p. 83), "new and useful ideas" (p. 106), "useful new combinations" (p. 86) etcetera. However, for academic purposes, he invokes a more refined definition.

> Now it is not just any synthesizing process combined with analysis and evaluation that I would like to call creative activity. There are certain restrictions and qualifications that I should like to make. The creative process is primarily a mental process whereby one combines and recombines past experience, possibly with some distortion, in such a fashion that the new combination, pattern, or configuration better solves some need of mankind. In addition, the end result must be tangible, something you can see, feel, or react to in some way, it must be forwardly oriented in time and it must have synergetic value.
>
> (CE, p. 66)

Here, from the perspective of design thinking research, the strong concern for human needs—which even enter Arnold's definition of creativity—is once again striking.

D23) A creative solution is useful when it (better) satisfies a human need. This concern for human needs runs through all of Arnold's theorizing. For example, creative work “is concerned with how the basic needs of man can be better satisfied” (CE, p. 63). New solutions are developed to “better solve some need of man” (p. 77) and he takes for granted the goal that “our innovations *better* satisfy some need of man” (p. 67, emphasis in original). Arnold’s strong concern for human needs does not only match present-day design thinking values, but is also remarkable from a historical perspective. For instance, in Dubberly’s (2004) historically organized compendium of design models, the first approach that talks about satisfying needs dates from 1967.

Another point that Arnold emphasizes repeatedly is that creative work needs to yield a tangible result in the end, “something you can see, feel, or react to in some way” (p. 66). In his definition of creativity, the quick transition from a “mental process” to “tangible end results” already points to the importance of prototyping in design thinking.

D24) The creative process ends not with an idea but with a tangible outcome. Arnold gives two major reasons why tangible outcomes are important. First, a lot of creative mastery may be necessary to translate an abstract idea into a practical and workable solution. “There is ‘many a slip ‘tween the cup and the lip’; there are many ’bugs’ that must be worked out of the best conceived ideas; there is ample opportunity for high level creative activity in the development of a prototype” (p. 67). Second, thinking up ideas is usually a rather benign process. By contrast, trying to implement a new solution often stirs up forces of continuity that try to defend the old status quo. “Many people resist change and innovation [. . .] because to accept the new they must first give up the old, familiar, and seemingly adequate ideas that they have held for some time” (p. 87). “Without the drive to carry a project through to completion, in spite of all obstacles, the idea has little or no value” (p. 104).

D25) Creative solutions are forwardly oriented in time. This criterion shall serve “to distinguish between wholly judicial activity and that which should properly be called creative. A good share of legal activity, for example, is centered around solving problems of the past” (p. 68). A judge might thus face the “past problem” that someone undertook a criminal act, which needs to be addressed by society. For creativity in a strong sense, Arnold holds that people rather need a concern for and a “vision of the future” (p. 68). While Arnold considers the criterion of future-orientation “probably an academic restriction” (p. 67), the idea continues to inform creativity discussions. The aspect of planning ahead and designing solutions that impact the future is coherent with present discussions on the relationship between creativity and anticipation (Corazza 2017).

Finally, Arnold mentions that creative solutions must display “synergetic value” (p. 66). Yet, he admits that this “is a big word for the old concept that invention is characterized as a new combination of old parts whose new value is greater than the sum of the individual parts” (p. 68). Thus, it appears to be mostly a reformulation of the more common criteria that creative solutions are novel and useful.

As an important qualification, Arnold adds that the criteria he provides in his definition of creativity shall serve as ideals that guide and motivate creative activity, while the overall goal will be achieved only occasionally.

A10) Creativity criteria provide ideals to strive for in creative work.

Above all, "the *better* stipulation is a difficult one to meet and it may have to be thought of for a while as an ideal to strive toward but not quite reach, that is, for the most of us. The genii of all times achieve the goal occasionally" (p. 67).

> The person who is just starting to learn to apply the creative process will find it very difficult at first to meet all the qualifications that we have set up for true, high level creative activity. But he should not be discouraged. If, in arriving at his solution, he does meet some of the factors we have listed, his work in some measure may be classified as creative.
> (CE, p. 72)

Thus, Arnold also introduces levels of creativity and creativity metrics.

A11) Creativity criteria help to assess creative achievement: The more criteria a solution fulfils, the higher the level of creative achievement is.

> Probably one of the most difficult things to do [. . .] would be to try and define the various levels of creativity that we know must exist. If we are very strict and stick to the very rigorous definition first given and insist that all the limiting conditions be met, we would probably have only a few categories that would include only the works of men of demonstrated genius. This would be just the upper end of a spectrum which is undoubtedly continuous. Removing the qualification that the new combination must exhibit synergism would increase quite markedly the number of acts that might be called creative; and then, one by one, removing the other restrictions until we finally reach the point where any new combination, new, that is, to you, might be classified as rather low-level innovation.
> (CE, p. 72)

7 A Theory of the Creative Process

The creative process is fundamental in Arnold's framework. He considers it to be a key element that creativity phenomena in different domains have in common.

> I think that the creative process itself is unique and also is a universal process that applies to all kinds of creative activity, whether you are an artist, or a poet, or a composer, or an engineer, in the military, in the business world, in the professional world, teaching, and so forth. If you are being creative, if you are looking at and solving problems in a creative fashion, you are using a similar process in all cases. The tools you work with, of course, vary from individual to individual, from group of activity to group of activity [. . .].
> (Arnold 1956, p. 7)

A12) The creative process is to a considerable extent domain-general.

One key element in Arnold's understanding of creative activity is that it is a process of problem solving. Indeed, prior to lecturing on "creative thinking", the concept of "creative problem solving" dominated his teaching (cf. Arnold 1953/2016,1956).

It is the process a person follows, rather than the problem (s)he works on, that determines for Arnold the degree of demonstrated creativity.

> It is possible, perhaps in more cases than not, to successfully solve multisolutional creative type problems in anything but a creative fashion. The machine designer who chooses from the many possible fastening devices to use a spline in attaching a gear to a shaft is tackling

> a creative problem in a routine prosaic manner. On the other hand, a scientist may be faced with a highly analytical problem (by definition), searching for the one right answer from nature, but if he solves it with an open mind, great imagination, daringness, and enthusiasm, he is being highly creative. The process you use is the deciding factor in large measure as to whether or not you are creative. The problems you work on and occasionally even the products that result can be worked on and solved by non-creative techniques. Pure chance, for example, could produce seemingly creative results.
>
> (CE, p. 71f.)

A13) Whether or not a person is acting creatively depends mostly on the process (s)he follows.

As a minimum requirement, Arnold's suggestions may be summed up to the following definition of a creative process:

D26) The creative process is a process of problem solving in which the creative agent seeks a novel solution to better satisfy basic human needs—capitalizing on a creative mindset and balancing all three thinking modes along the way. Notably, this understanding of creative processes is very remote from concrete process steps or methodologies. In fact, Arnold discusses a great variety of design models and methods that people can adopt. This includes process models from Wallas, Osborn, Gordon or General Electrics and methods such as the area method, attribute listing, brainstorming and morphological analysis (cf. Clancey 2016 for a more comprehensive overview). Arnold also discusses an approach he uses regularly in his own projects. Like present-day process models of the d.school (2010b), the "stages" that Arnold differentiates are primarily considered as mindset modes rather than sequential process steps. "The four key words that I find especially useful for my thinking: Question, Observe, Associate, and Predict. [. . .] I don't actually like to think of them as steps of a process that are followed in a certain definite sequence. To me these four words represent attitudes of the mind" (CE, p. 117).

Arnold advises his students to familiarize themselves with numerous methods and to experiment with them. While to Arnold creative activity is always a process of problem solving, the invoked methods will vary by domain, problem, and person.

> It is probably not necessary to give this warning, but to assure that there are no misunderstandings, remember well that there is no one right answer to creative problems. The search for aids to problem solving is a highly creative task. The approaches suggested in this chapter are not sacred and they should be modified and changed to fit the individual needs of the person using them. They are not the one right answer. It is hoped, in fact, that you will never rely on one or two rigid patterns, but that you experiment just as much with the processes by which you solve problems as you do with the problems themselves.
>
> (CE, p. 96)

Here, Arnold submits his understanding of methodology, which design thinking education continues up to the present. Leading educators stress carefully that design thinking itself is something quite different from, and goes far beyond, the methods that are taught in class. This subject will be explored in more detail below (# 9).

From a theoretical point of view, notably, Arnold uses the term "process" sometimes to reference a domain-general activity of problem solving, and sometimes to reference very concrete behaviours, which vary from one creative activity to the next.

8 A Classification of Creativity Approaches

One way in which Arnold analyses different forms of creative activity, highlighting differences and similarities of creative processes that he considers important, is by invoking a classification of creativity approaches. Depending on the chosen approach, Arnold expects as the outcome either incremental or disruptive change.

A14) There are two types of creativity approaches, *organized* and *inspired*, and combinations hereof.

D27) Organized creativity approaches follow a step-by-step rational. "The group of organized approaches is so named because they usually exhibit a logical, orderly, step-by-step type of problem solving technique" (CE, p. 73). In this category, Arnold mentions the *Empirical* or *Trial-and-Error Approach* and the *Rational Approach*. "The empirical approach, frequently [also] called the Edisonian approach, consists mainly of an endless number of trial-and-error experiments" (p. 73). An example would be Edison's search for incandescent filaments, where "it has been said that [. . .] he tried over sixteen hundred different materials, even including Limburger cheese" (p. 73). By contrast, with the rational approach "a lot of wasted motion and effort is prevented by a more thoughtful approach to the problem solving situation. [. . .] Careful thought is given to the statement of the problem and the setting up of [. . .] hypotheses to be later tested by experimentation" (p. 75). An example is Migley's invention of "a better refrigerant in 3 days time. Most of this time was spent in contemplating the periodic table and synthesizing, analyzing and evaluating mentally. After he had decided what the new combination should be, he made one and only one experiment, and, fortunately, this experiment verified his hypothesis and Freon was developed" (p. 75).

D28) Inspired creativity approaches build on intuition, fantasy or other loosely controlled psychological processes; they are characterized by relaxed ties to that which is considered possible, advisable or state of the art in the domain of creative work. In this category, Arnold distinguishes between the *Big Dream Approach* and the *Flash-of-Genius* or *Insight-Based Approach*.

> The big dream approach [. . .] is carried out by asking yourself the biggest question you possibly can, by dreaming the biggest dream that you possibly can, by sort of soaring off into space with a grand idea, and then expending every possible effort to answer this big question, to make this big dream come true, to get some tangible tie between your flight into space and solid reality.
>
> (CE, p. 76)

The *Flash-of-Genius* is about "insightful behavior. It ranges from the common experience of trying to remember a forgotten name to Archimedes running naked down the street shouting 'Eureka'" (p. 76). Despite its name, which seems to allude to unalterable intelligence characteristics, the approach is associated with a learnable process.

> In most creative work the best way to court insight is to thoroughly immerse yourself in your problem, to have a clear understanding of the nature of the problem, all its data and all its limitations [. . .]. After periods of unproductive hard work, it is then suggested that you forget the problem completely. [. . .] Suddenly, when you least expect it, a day, a week, or a month later, an answer will pop into your mind. Why and how no one knows, but this is the flash of genius.
> (CE, p. 76)

This description of the flash-of-genius is reminiscent of Wallas' (1926) creative thinking model, which invokes the steps of preparation, incubation, illumination and verification.

Arnold attributes quite different effects to the two types of creativity approaches he distinguishes.

A15) Organized creativity approaches bring about incremental change.

A16) Inspired creativity approaches bring about disruptive change.

"Inspired [. . .] approaches [. . .] are those closely associated with the art of creativity rather than the science. Big leaps in knowledge are apt to occur using these approaches, as compared with the slow but steady step-by step advancement made using organized techniques" (CE, p. 73).

Edwin Land who worked for Polaroid provides an example for the inspired approach.

> His biggest dream was a camera that would give a full color picture in a matter of a few seconds after exposure. In trying to make this big dream come true, he ran into a number of seemingly insurmountable difficulties. So, he stepped down a dream [. . .] and finally settled for the original sepia-toned print that first came on the market. [. . .] At this point he turned the models over to his research staff and they, using the controlled, empirical approach, have made steady improvements of the original invention. [. . .] A large, creative step was made using the big dream approach. This was a functional innovation and looking back through the history of invention, it seems that a large share of the functional changes were brought about in this fashion. Less creative acts, improvements to the big dream, are usually made in a step-by-step fashion, following one or more of the organized approaches.
> (CE, p. 76)

Arnold's categories of organized versus inspired approaches appears to some extent analogous to Maslow's distinction between secondary creativity (where disciplined rule-following yields gradual progress) versus primary creativity (where unconscious, unconventional thinking yields disruptive breakthroughs). This distinction is elaborated in Maslow's CE essay (1959/2016).

D29) Combined creativity approaches use elements from the organized and the inspired approach. Again, Arnold gives two examples, *Serendipity* and the *Scientific Hunch*. "Combining the flash of genius with the controlled empirical approach gives rise to a process that has brought back an old word into popular usage—serendipity—the happy faculty of stumbling upon things of value when looking for something else" (CE, p. 76f.). For this approach, Arnold turns to the mindset of the innovator.

> I believe, like the Greek, Heraclitus, that you never find the unexpected unless you are looking for it. You do not stumble upon things of value unless your mind, at least subconsciously, is prepared to recognize it. You must be sensitive to problems and to solutions; you must be keenly observant and highly associative in your thinking so that these things of value will be recognized when they are seen.
> (CE, p. 77)

Another approach is the *Scientific Hunch*, which Arnold describes "as a combination of the rational approach and the big dream approach. [. . .] It is not wholly rational, for frequently it is nothing more than an emotional feeling, a 'hunch' that such-and-such will occur if I carry out steps A, B, and C" (CE, p. 77).

While the combined approaches mentioned by Arnold merge only one approach from the inspired and organized category each, design thinking appears to systematically combine all of the discussed approaches. It also iterates and advances them.

M5) Design Thinking combines inspired and organized creativity approaches systematically and comprehensively.

Big Dreams, big questions, and big ideas figure centrally in design thinking. However, they are not associated with a random soaring off into space. Rather, a strict emphasis on the "user need" as focal point of attention throughout the whole project continuously provides purpose and orientation. *Insights* are also a key element in design thinking, for example, as part of POV-madlibs (d.school 2010b, p. 21). Methodologically, they are certainly courted by immersive experiences, while setting the problem aside does not appear to be necessary in all cases. An *Empirical Approach* is adopted as design thinkers embrace a "bias towards action". Iterating prototypes can be considered an advanced version of trial-and-error where "errors" become a tool to learn quickly (Roth 2015a; von Thienen et al. 2017). The *Rational Approach* is continued through careful problem statements including How-might-we-questions (d.school 2010b, p. 26), design principles (p. 25), POVs (p. 21) or POV analogies (p. 22).

9 A Theory of Creative Thinking Education and Meta-Cognitive Control

As a visionary educator, Arnold experiments with curricula and reflects upon the beliefs that guide his teaching (cf. Arnold 1953/2016, 1959/2016; Clancey 2016). One central assumption is "that it is possible to materially increase the degree to which one realizes his total potential by understanding, practice, and exercise. The increase can vary from ten percent to several hundred percent" (CE, p. 79).

A17) Creativity education increases creative achievement.

Arnold also believes:

A18) Creativity education increases creative potential.

In particular:

A19) Practicing creativity methods serves to advance creative mindsets.

As part of his method compilation, Arnold explicates numerous beliefs as to which methods help to develop which mindset attributes. “These techniques, when applied conscientiously and repeatedly, will help awaken and strengthen your own creative potential. The checklists, for example, will spur the questioning spirit, and attribute listing and morphological analysis will help develop the powers of observation in the search for generic, basic relationships” (p. 96).

In a manner that very much anticipates present-day design thinking education, Arnold’s courses are intended to endow students with “confidence as well as competence” (p. 71). They shall create enthusiasm for problem-solving and strengthen the creative mindset. Though methods—and gaining experiences in their usage—figure centrally in class, it is anything but a teaching aim to create rigid method users.

A20) Education shall endow students with creative confidence as well as competence—and not with inclinations of rigid method use.

One pedagogical intervention to foster goal orientation rather than rigid method usage is to allocate long periods of time for clarifying problems prior to seeking solutions. This is a pedagogical strategy design thinkers have retained up to the present.

> Creative men [. . .] [spend a] larger proportion of their time [. . .] in reorienting themselves, in searching for problem statements and definitions, in getting a clear picture of what they wanted to do—and a relatively short time in actually carrying out the solution.
>
> This is one thing that I think is typical of people who are goal oriented, rather than technique or method oriented. Most students, for example, if you give them a problem to do [. . .] jump right away into some kind of procedure on how to solve it. They don’t sit down and try to think “What am I trying to do? What is the goal I am aiming for? [. . .]” They start looking for some method. [. . .]
>
> I am sure that if a great deal more time were to be spent in actually formulating a basic, generic, very broad, comprehensive picture of what you are trying to do, one would be much more effective in arriving at an outstanding solution.
>
> (Arnold 1956, p. 28)

In addition, it is a central part of Arnold’s teaching approach to regulate the success and failure experiences students have in class, in order to build up their creative confidence.

A21) Education shall create experiences of success and failure for students, which enhance their creative confidence.

> Properly motivated and willing to take a chance, the creative worker must, in addition, have self-confidence in his own ability to come up with a new and better solution. This is an extremely important emotional attribute and can only be developed through experience and exercise. It has been said that nothing breeds success like success. And this is probably true, but the corollary that failure breeds failure need not be true. If through continued application failures can be corrected, high orders of self-confidence can be developed. Actually, the fear of making a mistake is a very devastating emotional block to creative activity. People should realize that progress is made through failure as well as through success. I have had better success in training creative designers by helping them develop this spirit of self-confidence than I have in imbuing them with special design techniques or tricks of the trade.
>
> (CE, p. 87)

This regulation of experiences has been carefully advanced in the design thinking community. The subject is not only accorded great attention in many design thinking treatises (e.g., Kelley and Kelley 2013; Roth 2015a; von Thienen et al. 2017), it also informs recent discussions on how to define creativity. As part of his *Dynamic Definition*, Corazza (2016) provides a critical discussion and reformulation of creativity criteria such as to acknowledge that a person and her process can be called creative even in the case of failing or otherwise inconclusive outcomes. Creative achievement is only the final outcome for which to aim. Students need to learn how to handle possible frustrations along the way; they are a normal part of creative activity.

Furthermore, a number of additional abilities that Arnold seeks to strengthen in students may be summarized as increased "meta-cognitive control," though he did not use this term himself.

M6) Education shall endow students with meta-cognitive control for creative activity.

D30) In creative activity, meta-cognitive control is the ability to identify and regulate factors that impact creative progress. As an important element of preparation, Arnold highlights that "we must not only study the creative process, but we must also study ourselves as the only creative instrument our species has." That is, like an instrument that generates creative outcomes when calibrated well, students shall learn how to calibrate themselves in order to maximize their creative progress.

One of the ways in which today's design thinking community builds on Arnold's ideas about meta-cognitive control is by providing "mottos" that guide design activity. In Arnold's framework

Meta-cognitive control for creative activity includes

- *Monitoring, regulating and balancing the three thinking modes.* In particular, it is important to dispense judicial thinking during think-up sessions. In the course of the whole creative process, however, mastery of all thinking modes is essential. In present-day design thinking culture, a sample motto that is used to increase meta-cognitive control of thinking modes is "defer judgement" (d.school 2010b, p. 28) as invoked specifically in the first half of the process.
- *Monitoring and carefully selecting communication means.* Here, Arnold differentiates between three types of communication:

> the language of the written and spoken word, the language of symbolic logic or mathematics, and lastly, the language of vision. In order to originate ideas, to preserve them for his own later use, or present them to others, he must use one or more of these languages. The more articulate he is, the greater will be his own efficiency and easier will be his task of convincing others of the merit of his ideas.
>
> (CE, p. 128)

One of the present-day design thinking mottos that continue this theme is "Show Don't Tell [:] Communicate your vision in an impactful and meaningful way by creating experiences, using illustrative visuals, and telling good stories." (d.school 2010b, p. 0).

- *Monitoring and adapting one's creative process including "stages", aims, broadness of scope, pace, and tools.* Using process models for orientation, carefully selecting the broadness of one's design challenge and its content, exhibiting "the ability to change pace" (CE, p. 86), being versed in numerous design methods for all stages of the process or "having many tricks in your bag" (CE, p. 86) are central preconditions for this type of meta-cognitive control. These ideas bear strong resemblance to the design thinking motto "Be Mindful Of Process [:] Know where you are in the design process, what methods to use in that stage, and what your goals are." (d.school 2010b, p. 0).
- *Noticing and overcoming creativity blocks.* In particular, the creative thinker should beware of perceptual, cultural and emotional blocks. One way in which design thinkers continue this line of thought is by highlighting mottos such as "Fail early and often" (Meinel and Weinberg 2013), which in this case should help to regulate a key emotional block, namely fear of failure.

10 The Term "Design Thinking" in Arnold's Framework

While "design thinking" is usually thought of as a rather recent term, it was already used by Arnold. His concept of design thinking resembles the modern one, but is also different in some respects. A similarity is that Arnold, like us today, speaks of design thinking in the sense that people intentionally develop and invent things and design solutions.

D31) Design thinking means to approach the world as a designer who intentionally develops or invents novel solutions.

A difference is that Arnold distinguishes between several kinds of design thinking. He suggests four areas in which developments and innovation can take place. "There are four general areas or fields of design activity. These areas are: (1) increased function [. . .]; (2) higher performance level [. . .]; (3) lower cost [. . .]; and (4) increased salability" (CE, p. 118). To him, design thinking covers all four areas, and projects ranging from small-scale to large-scale. Today, we usually refer to "design thinking" only in the case of large-scale projects in area (1).

When someone pursued a project in the first design area and thus made an increased-function-innovation, Arnold explains that "new needs were filled [. . .] or old needs were satisfied in an entirely new way" (p. 104). The large-scale addition of function amounts to disruptive change: given sufficient scope, functional innovations mean "a large, creative step" (p. 76). By contrast, a higher level of performance and lower costs are typical cases of incremental developments.

D32) A solution is disruptive when it satisfies a formerly unmet need, or satisfies an already addressed need in an entirely new way, and thus creates a large-scale addition of function.

D33) A solution is incremental when it better satisfies an already addressed need in an already established way.

Arnold suggests that flexibility is ideal, i.e., considering all areas of design opportunities.

> It is rather interesting to look over the developmental history of any product or family of products and try to classify the changes into one of the four areas. It might be a good idea for each one of you to do that for your own company's products. Your group, too, might have gotten into a rut and is inadvertently doing all of your *design thinking* in one area and is missing good bets in other areas.
>
> (CE, p. 119, our emphasis)

11 Selected Advancements of Arnold's Creative Thinking Framework and Differences to Design Thinking

Many ideas that Arnold contributed were later picked up and elaborated by his successors. To name just a few examples, a need-based theory of design, visual thinking, relaxation, humour, and playfulness were elaborated by Robert McKim (1959/2016, 1972). James Adams continued consulting activities; he advanced the concepts of creativity blocks and thinking languages (1974). Merging science, engineering and art next to the subject of self-development figured centrally in Faste (1994 and unpublished). Re-designing and studying teamwork, prototyping culture, creative self-confidence and process mastery are some of the key concerns advanced up to the present by Stanford's visionary educators (e.g., Leifer 1998; Kelley and Kelley 2013; Roth 2015a). Katz (2016) picks up philosophical themes.

There are two issues where one might expect a 180-degree-turn from Arnold's creative thinking framework to present-day design thinking. However we will argue that in both cases there is actually a great deal of continuity. Yet, in a third area we do see a major change.

First, design thinkers embrace a bias to action and sometimes express irritation on behalf of their own name. Even the d.school Bootcamp Bootleg (2010b), which is a central method-compilation for the design thinking community, raises this issue upfront. "Bias Toward Action[:] Design thinking is a misnomer; it is more about doing that [sic] thinking. Bias toward doing and making over thinking and meeting" (p. 0). By contrast, Arnold presents a comprehensive framework on the subject of thinking. Yet, Arnold's framework includes strong antecedents of the bias to action. "Without the drive to carry a project through to completion, in spite of all obstacles, the idea has little or no value. This is probably why some research directors have been overheard to say that ideas are a dime a dozen, they want men who are doers not thinkers" (CE, p. 104). Arnold agrees wholeheartedly and this is the reason why he constantly demands that creative thinkers need to make their thoughts tangible. In addition, it is by now very clear that human thought is both embodied and embedded, and as such there is no clear-cut separation between thinking, action and the surrounding environment, while there remains a distinction between abstraction and concrete realization.

Second, Arnold's framework focuses on individuals, while the design thinking community is generally convinced that "innovation is a team sport" (Schar 2011, p. 1). It is indeed true that Arnold's theoretical framework "emphasizes the individual" (CE, p. 78). Yet, his method compilation covers different approaches for creative teamwork in great detail and discloses Arnold's profound personal experiences with them (see also Clancey 2016 for a comprehensive discussion of this subject). In particular, a work approach of the Design Synthesis Group led by William Gordon is elaborated on multiple pages, annotated with personal impressions and bears a striking resemblance to present-day design thinking practices. For instance, Gordon was strongly concerned with the energy-level of teams in think-up sessions.

> There are a number of tricks that can be used to relieve the fatigue. [...] Gordon frequently uses one trick which I believe is very novel and effective, and that is to provide one less chair than the number of people attending the session. This means that one man stands or sits on the edge of a desk or even on the floor. Should any man seated in a chair get up to move around or leave the room for any reason the unseated man quickly takes the vacated chair and so there is a continual, though imperceptible movement throughout the session, therefore no one becomes physically or mentally fixed during the three hour period.
> (CE, p. 111)

Design thinking continues this concern for "imperceptible movement", such that "no one becomes physically or mentally fixed" and people maintain a high level of energy. However, today's solution seems a little less awkward and thus might be considered more elegant. Teams are provided with high chairs and high tables so that they are standing almost as much as they are sitting; mobile furniture keeps the teams moving (Doorley and Witthoft 2012; von Thienen et al. 2012b). This is one way in which design thinking facilitators manage "the group's performance and energy" (d.school 2012, p. 2) today.

Also, the subject of delaying a search for solutions is deeply engrained in design thinking traditions.

> Bill Gordon felt that the main weakness of the Osborn-type brainstorming sessions was a solution too soon arrived at. Brainstorming starts producing solutions right at the start. To prevent this, Gordon devised a different type of group approach in which only the chairman of the group knows the nature of the problem being discussed [...]. Suppose the problem is to find a new way to park automobiles in a crowded city. The subject the chairman might choose to describe the discussion might be "storing things". [...] Someone might mention how bees store their honey. Conceivably this could be a possible solution to the problem. Some sort of a honeycomb structure for parking cars, or, another person might say that things are often stored by hanging them up. This might lead to a solution in which cars are hung on hooks like sausages. [...] Finally, when he senses that the group is close to the best solution, Gordon reveals the exact nature of the problem. The session is so conducted that by the time the problem is revealed to them, a high level of excitement runs through the group.
> (CE, p. 110)

Arnold challenges his audience to advance this methodology. "While I believe Osborn's technique discloses the problem much too soon, Bill Gordon waits much too long, and a compromise of some kind must be arrived at. Both systems have points of extreme merit, and attempts should be made to combine them" (CE, p. 112). Indeed, design thinking seems to offer such a combination. The whole team knows the nature of the problem right from the start. However, everybody delays a search for solutions until entering the ideation phase in the middle of the process.

Next to a cornucopia of continuing developments, there also seems to be a profound disruption between Arnold's approach and design thinking. For Arnold, innovation education is deeply entwined with an awareness for and development of innovation theory. By contrast, in design thinking the role of theories is commonly much less pronounced; great emphasis is instead placed on the refinement of education practices. By the time design thinking education institutes are founded, the approach is "only" recognized as a successful practice while its theoretical background appears quite invisible. As Plattner, Meinel and Weinberg hold in 2009, "it will remain a task of subsequent publications to submit profound theoretical concepts and conclusive theories that allow for a thorough understanding of design thinking and its components. We expect that the design thinking research program [. . .] will make important contributions in this regard" (p. 8, our translation).

The change in teaching philosophy becomes manifest in the writings that students likely draw on over the years. Arnold's works include extensive theorizing and ample literature references. His successor Robert McKim (1972) offers fewer explicit theories, more exercises and still extensive literature references. The soft systems guide (Koberg and Bagnall 1972) that is occasionally used for education purposes later on reduces the theory content even further; it is very practically oriented and still provides literature references. The Bootcamp Bootleg (d.school 2010b) is exclusively practice oriented and offers no literature references whatsoever. It is prototypical in that it fully does away with theory.

Today, design thinking facilitators design education experiences as much as students learn to design experiences for users (von Thienen et al. 2016b). The "look and feel" of formal school or university education is strictly avoided. Frontal lectures are short and rare (Kelley and Kelley 2013; Roth 2015a). Theories are usually not mentioned at all. Libraries or large collections of books are avoided and even considered a hallmark of "design thinking anti-spaces" (von Thienen et al. 2012b); they would suggest to the student that there is a whole lot to learn and know before (s)he can be a good innovator and thus would seem to antagonize creative confidence and a bias to action. Instead, design thinking education encourages a quick closing of knowledge-gaps through immersive experiences and teaming-up with experts from diverse knowledge domains. Thus, a core teaching belief appears to have changed.

M7) Arnold's Teaching Belief: Creativity education needs to draw on explicit creativity theories.

M8) Common DT Teaching Belief: Creativity education is a practical matter; it does not need to draw on explicit creativity theories.

Amazingly, design thinking education appears to advance creative mindsets—in the sense described by Arnold—even without explicitly invoking theories. In particular, studies on education effects (e. g., Royalty et al. 2012; von Thienen et al. 2016b) show that design thinking trainings elicit a great amount of daringness, drive and creative confidence in students almost immediately, and lasting beyond the completion of classes. What might be a minor downside of the presently embraced approach of detaching from libraries, literature references, and generally from theories is that, to some extent, the community itself seems to have lost sight of "why and how the Design Thinking method works on a scientific basis" (Plattner 2011, p. v). Calls for balancing context-dependent design thinking knowledge and context-independent knowledge of the traditional sciences are brought up with increasing frequency and insistence (Leifer and Meinel 2015; Mabogunje et al. 2016). We appear to face a pendulum effect here. The disavowal of theory was an experiment to see how far it could go, to understand how and to what extent confidence, enthusiasm, and daringness to try out ideas might be developed first. To be sure, this experiment has been a fruitful one. Education practices have achieved a high degree of refinement. At the same time, theoretical frameworks—at least available on demand—will likely play a greater role again in the future. We believe the optimal point is represented by a personalized balance between sound theoretical foundations and immediate practical tools and methodologies. In the past, theories provided fertile soil. Design thinking practices grew upon scholarly insights and reflections.

Leifer and Meinel (2015) acknowledge the fruits of empirical studies that were launched in the last years. "Now that we have the roots of the scientific comprehension of design thinking we can expect to continuously improve our understanding of ourselves" (p. 3). The authors of this chapter hope that historical design thinking research as reported above can also contribute to this vision.

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Part I
Modelling and Mapping Teamwork

Quadratic Model of Reciprocal Causation for Monitoring, Improving, and Reflecting on Design Team Performance

Neeraj Sonalkar, Ade Mabogunje, and Mark Cutkosky

Abstract Design team performance is a complex phenomenon that involves person, behavior and environment parameters interacting with and influencing each other over time. In this chapter, we propose a quadratic model for team performance that allows for monitoring, improving, and reflecting on design teams at the individual, interactional and environmental levels. This model is an extension of Bandura's theory of reciprocal causation and a synthesis of concepts from psychology, semiotics, improvisational theater, evolutionary biology, design thinking and innovation practice. We describe the development of the model based on cases of student behavior from a graduate level design course, and discuss its implications for design practice and design research.

1 Introduction

Imagine a design team in a company working intently to create a new medical device. The team interacts with patients, medical professionals and scientists; develops new insights and concepts; builds and tests multiple prototypes, and engineers a solution that works for the users and could become profitable for the company. This phenomenon of designing is a complex social-technical activity that ranks among the few professional pursuits that actively demand creative exploration while building on knowledge from multiple disciplines.

A number of theories and models have been proposed by researchers in order to explain design activity (Chakrabarti and Blessing 2014). However, many of these models remain in the research field and are not easily accessible to practitioners. At the same time, practitioners who follow process models such as design thinking,

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agile methodology, etc. have developed a professional vision (Goodwin 1994), a way of perceiving design situations that goes beyond the technical rationality of these process models. This professional vision remains unarticulated and inaccessible to researchers studying the design activity.

Therefore, there is a need for a model that (1) captures our current understanding of design activity, specifically one that includes the professional vision of the practitioners; (2) is useable by practitioners in their daily practice; and (3) is improvable by practitioners thus contributing to its further refinement. In this chapter, we propose one such model that builds on Bandura's theory of reciprocal causation.

2 Research Objective

Our research objective was to create a model of teams engaged in design activity, that fulfills the following requirements.

1. It collects and represents the existing knowledge about design team activity.
2. It allows design researchers to ask new questions and investigate new research directions.
3. It serves as a guide to the professional vision of a design practitioner or coach.
4. It motivates the development of tools and methods for continuous improvements in design team performance.

3 Model Development Process

The development of the model was precipitated by our research on design team interactions. Our objective was to develop a diagnostic instrument that could be useful to design students and practitioners. With this aim we studied the possibility of using the Interaction Dynamics Notation to provide feedback to design teams (Sonalkar et al. 2016). Our studies revealed that feedback on team interaction behavior by itself was insufficient to impact design team performance. We needed to take into account the context in which this interaction behavior occurred. This led us to initiate a study on the nature of context in design activity and to create a course for advanced graduate students to explore the context conditions that could influence design behavior.

3.1 Literature Review

The literature review yielded the following context conditions that we considered relevant for team interaction behaviors.

1. Directional conditions: Since a team is defined on the basis of individuals working towards a shared goal (Katzenbach and Smith 1993), the nature of this goal and the extent of goal alignment among team members becomes an important condition that can influence interaction quality and team performance.
2. Design task conditions: This category refers to the nature of the design problem and the tasks that a team undertakes as they go about addressing the design problem. The nature of design problems varies widely between 'tame' or structured problems and 'wicked' or ill-structured problems (Rittel and Webber 1973). A team addressing a wicked problem may perform its task differently than a team addressing a tame problem. Moreover, the type of task—concept generation, framing, need definition, prototyping would influence the quality of interaction patterns in a team.
3. Individual conditions: This category refers to the state of each participating individual. This includes individual dispositional characteristics, energy level, individual beliefs and attitudes, degree of process expertise, degree of domain expertise. There exist past studies from design research on individual dispositional characteristics (Wilde 2008; Kress and Schar 2011) and degree of process expertise in terms of novice vs. expert designers (Ahmed et al. 2003; Atman et al. 2007). However, domain expertise, individual beliefs and attitudes and energy states have not been formally analyzed.
4. Artifactual conditions: Artifactual conditions refer to whether the designers are starting from scratch (blank sheet) or from a prototype, and the nature of the prototype representation they are working with. There exists prior research that shows that tangible media plays an important role in design activity (Brereton and McGarry 2000; Edelman and Currano 2011).
5. Relational conditions: Relational conditions category refers to the nature of relationships among the team members. These include—familiarity with team members, status dynamics for each session, and hierarchy between team roles. Past studies in design research has examined student teams (Valkenburg and Dorst 1998; Leifer 1998) with flat hierarchies and industry teams (Baird et al. 2000; Cash et al. 2013) with pronounced vertical hierarchies without explicitly studying hierarchy in a team as an influencing factor on team performance.
6. Environmental conditions: The environmental conditions category refers to the factors external to the team that may have an influence on team interactions and team performance. These include availability of work media, ambient temperature and lighting conditions, and the level of visual stimulus in the work environment. Design research has recently started addressing design spaces and their impact on design (Weinberg et al. 2014).

The context conditions listed above though relevant lacked a cohesive conceptual framework that could be used to better understand the causal relationships between the various conditions, the behavior of the participants, and the descriptive state of the artifact at any time.

This led us to seek to develop a model of design activity that includes both the context and the behavior occurring in a design activity.

3.2 Investigating Design Context and Performance Through a Graduate Design Course

We developed a graduate level course called ME306: Engineering Design Theory in Practice in order to learn first-hand from students, the factors that influence them in their efforts to achieve high performance in design thinking. We investigated the design context conditions experienced by the students as well as developed activities to help them improve their design thinking performance by using the Interaction Dynamics Notation research from the current project, and other research theories and frameworks. The course was organized along four dimensions of design—design as social activity, cognitive activity, physical activity and learning activity. ME306 was offered three times at Stanford University, in Fall 2016, Spring 2016 and Fall 2017. A total of 14 students at graduate level or advanced undergraduate level with experience in design projects, and 6 auditors participated in the course.

The course pedagogy included a number of active and interactive elements followed by individual reflection of learning experience. The pedagogy elements are listed below:

1. Watching video of high performance design teams
2. Watching video of self in design teams
3. Role playing
4. Students engage in multiple projects to apply theories to practical situations
5. Reflection
6. Public sharing of reflection
7. One-on-one meetings

Overall, the course had the following specific attitudinal goals:

1. Appreciation of design as a process that has scientific underpinnings
2. Self-efficacy in improving individual design process
3. Self-efficacy in improving team design process

The first was accomplished through the use of an external representation—the Interaction Dynamics Notation. The second was accomplished through a six-step process. (1) Direct engagement in an activity so as to form an internal experience. (2) Individuals' reflection on the experience. (3) Sharing the reflection with others. (4) Listening to others' direct experience. (5) Viewing videos of similar situations in other cultures. (6) Reading about the views of researchers who have written about the phenomenon. The course enabled us to gain a deeper understanding of conditions that influence a designer in her design team performance. The following four cases point to some of these conditions and how designers either accepted or addressed these conditions to improve their performance.

Case 1: Self-efficacy belief
Joe is a mechanical engineer and has always been very concerned about his grades. He scored high on his GRE scores and wrote a good essay to earn a spot at Stanford. During the course, Joe had to draw. However, Joe was very uncomfortable drawing.

All his course mates easily drew sketches to share their ideas. Joe froze during these moments. During the reflection in one of the class sessions, Joe shared his struggle and went on to explain how he overcame it. He said he was good at poetry. Why not think of the process of drawing as being similar to how he composes poems? This was an aha moment for Joe. Thereafter it was difficult to stop Joe from sketching.

Case 2: Personal Reflection
Mark is a mechanical engineer and has always prided himself as being a good team player. He has been part of several teams and has felt very positive about the experiences. Up to this point Mark had never watched a video of himself in a team. And even if he had, he was not equipped to analyze the interactions. During the mid-term, Mark was able to use IDN to observe his own interactions. To his dismay, he found that he actually did not contribute any ideas to the team. How could this be? He had been there and it had felt good. On deeper reflection, Mark reflected that the value he held most dearly was being a good listener. Mark now saw how his ideal had gotten in the way to contributing ideas to a team. Mark resolved to become more participative. Specifically, by offering more ideas and not being intimidated by blocks.

Case 3: Motivation
John is also a mechanical engineer. It was his last quarter before graduation. During his more than 5 years stay at Stanford he had become comfortable in using his natural ability for drama and acting to express his thoughts. Before drawing or writing, he would most often act things out. John was explicit about not wanting to change his style. Hence he did not use the activities from the course to change his beliefs or his personal design methods.

Case 4: Cultural Conditioning
Luke got very good grades in his undergraduate degree from a University in the US, and has now become very interested in Design thinking. During his reflection he expressed his preference for C–K theory (Hatchuel and Weil 2003) because it gave him a sense of structure. He found the role-playing exercises terrifying. He revealed that in his home country, he could not say something until he was very sure about it, as he felt like he was constantly being judged. When he was assured that he was not being judged in this course, he found it hard to believe. He began judging us, as to why we wouldn't judge him? When he was asked how he might structure the class in a way that would work for him, he suggested that it might be a good idea for us to hang out at the pub more regularly and have beers together. Despite the discomfort he felt in the class, Luke persisted and did not drop out.

These case observations pointed to the importance of personal beliefs, desires and intentions of the individuals participating in the design activity. The course helped us realize that we needed a model that included person as a key parameter in the design activity. Bandura's model of reciprocal causation which considers the person, behavior and environment as equally influencing each other was a fitting candidate to provide a point of departure for building a design model. Through detailed deliberations on how Bandura's model of reciprocal causation needs to be modified to suit the design activity context, and how the different experiences of

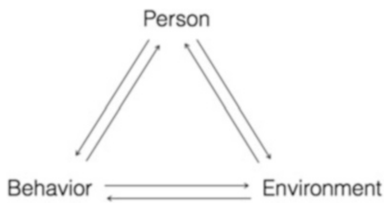

Fig. 1 Triadic model of reciprocal causation

students in ME306 could be reflected in such a model, we developed the Quadratic model of design activity. The following sections give an overview of Bandura's model of reciprocal causation, and then describe the Quadratic model of design activity and its implications for design practice and design research.

4 Bandura's Model of Reciprocal Causation

Bandura proposed a model of human behavior in which internal personal factors in the form of cognitive, affective and biological events, behavior and environment events all operate as interacting determinants that influence each other bi-directionally (Bandura 1999). This model, called the triadic model of reciprocal causation forms the basis of the social cognitive theory proposed by Bandura (Fig. 1).

Bandura developed the Triadic model of reciprocal causation based on his research on development of self-efficacy beliefs in individuals. He realized that earlier psychological models either considered behavior to be determined by environmental stimulus, or by internal cognitive processes that they did not have influence over. Bandura found that "human mind is generative, creative, proactive, and reflective, not just reactive." (Bandura 1999). Behavior is both an outcome of personal factor and environmental influences, but by behaving in a specific way, they in turn influence their personal beliefs and the environment they operate in. Social cognitive theory built on Bandura's triadic model of reciprocal causation recognizes core features of human agency such as intentionality, forethought, self-reactiveness and self-reflectiveness (Bandura 1999). Hence, the triadic model is a suitable starting point for modeling design activity which involves intentional and reflective action.

5 Quadratic Model of Reciprocal Causation

We adapted Bandura's triadic model of reciprocal causation to a team engaging in design activity. Considering a team of three as a starting point, we called the model a Quadratic model of design activity. It extends Bandura's person-behavior-environment interaction to person-behavior-environment-artifact. Bandura's notion of environment included constructed environment. However, since the development

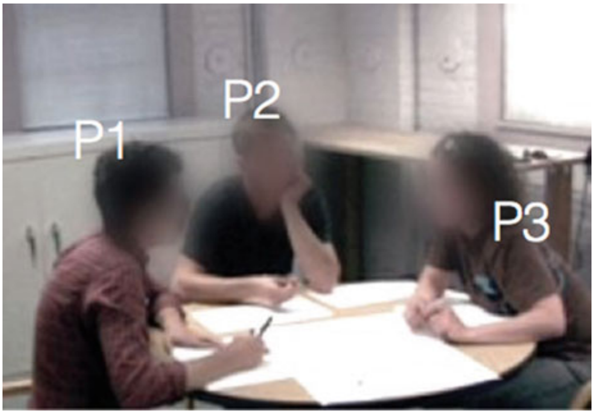

Fig. 2 A team of three designers

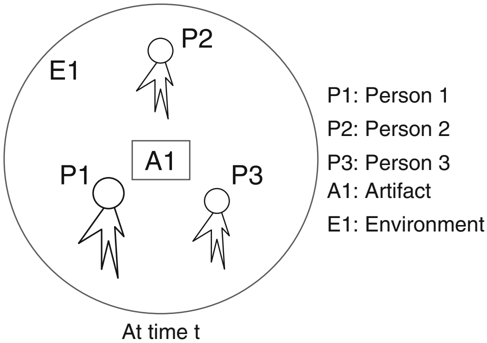

Fig. 3 Person, environment and artifact at time t

of an artifact is a central concern of designers who actively engage with it, we considered artifact as a separate element from the environment in which design activity occurs. Similar to Bandura's model, the four elements—person, behavior, environment and artifact parameters all change over time. The context conditions for team interaction behavior that we discussed earlier are now expressed in terms of person parameters, environment parameters and artifact parameters. We realized that the Quadratic model gives a more concise description of what we earlier called 'context conditions'.

Consider a design team of three person working at a given time t shown in the figure (Fig. 2).

The situation which consists of the three person interacting with each other and with artifacts in a given environment could be represented as follows (Fig. 3).

As design activity progresses from time t to t', the three persons P1, P2 and P3 display behaviors B1, B2 and B3 respectively that changes the situation as follows (Fig. 4).

From time t to time t', the artifact changes from A1 to A2, the environment changes from E1 to E2 and each of the persons involved change as well P1 to P1',

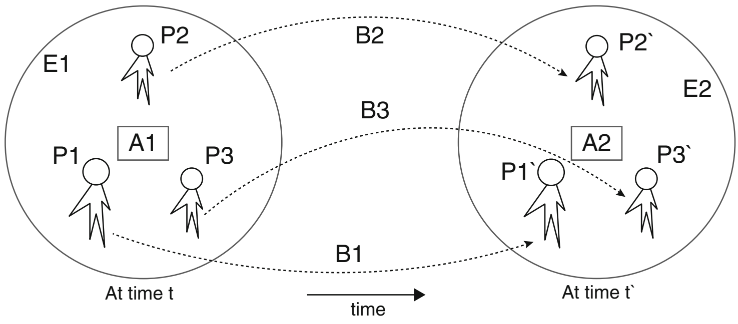

Fig. 4 Person, environment and artifact changing with behavior occurring from t to t'

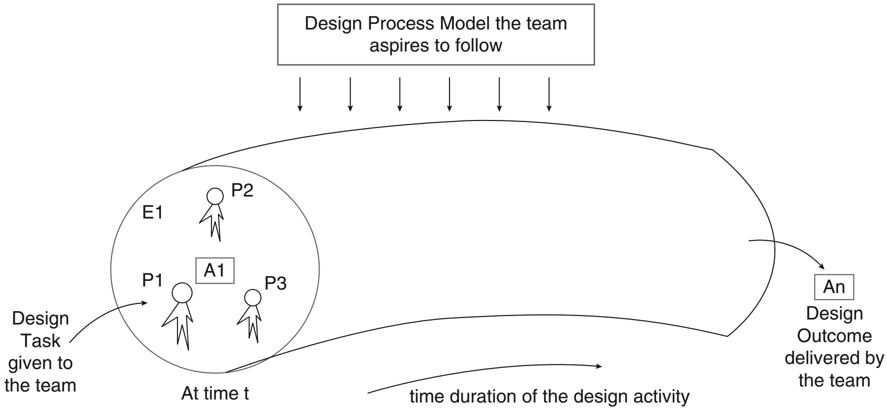

Fig. 5 Design activity represented by the Quadratic model

P2 to P2', and P3 to P3'. The change in person reflects the learning that occurs from time t to t'.

Thus, designing is depicted as a continual change over time in each of the entities persons, behavior, environment and artifact prompted by the design task assigned to the team and influenced by a process model such as design thinking or agile software methodology that a team aspires to follow. Figure 5 depicts this view of design activity.

The quadratic model is not a model of a prescribed process. It is a model of design activity as it is unfolding over a period of time. The model is designed to augment a practitioner's or a coach's in-the-moment perception and action when participating or coaching a design activity. The following section explain each of the components of the model in greater detail.

5.1 Person

A person in the Quadratic model is identified by multiple parameters some of which are stable over the duration of design activity, and others which change over time. Prior research on personality preferences of designers has used established cognitive style inventories such as Myers Briggs Types Indicator based on Jungian cognitive theory (Wilde 2008; Kress and Schar 2011), Kirton's Adaption Innovation inventory (Jablakow and Booth 2006), Herman Brain Dominance Indicator (Schar 2011) and the NEO Five Factors inventory (Kichuk and Wiesner 1997). The objective of this body of work has been to characterize a designer along stable dimensions of cognitive or affective preference. These could be indicative of the stable parameters that denote the cognitive and affective tendencies of a person in the Quadratic model.

The second category of parameters involves the knowledge that a designer acquires in the course of her education and professional practice. Design is a knowledge intensive activity. Knowledge here includes both disciplinary knowledge pertaining to a domain of design such as biomedical engineering, automotive engineering or software engineering, as well as process knowledge both explicit and embodied. Knowledge may change over time, but could be reasonably expected to be constant over the course of a single design project.

The third set of person parameters are those that pertain to specific design situations and may change during the course of a design activity. These include beliefs, desire, intention and resistance. The Belief-Desire-Intention (BDI) model was proposed by Michael Bratman (1987) as a way of explaining intended action. The BDI model was later used to developed a software architecture for programming intelligent agent in Artificial Intelligence. For design activity, the distinction that Bratman made between desire and intention holds particular value. Design is in best cases an intentional activity. Following Bratman, the Quadratic model consider desire as a visualization of an outcome *state*, which could be an artifact or experience. Intention on the other hand is the visualization of immediate *action* that a designer is about to take. Thus, we say an action is intentional when a designer developed a conscious intention and followed through in it. An action undertaken without conscious visualization could be called unintentional or mindless action. For Bratman the intention was further distinguished from desire by the inclusion of commitment to action that is created through a visualization process. Finally, beliefs are statements about the state of the world or herself that a person holds with degrees of certainty. The fourth parameter that is included here is resistance. The concept of resistance comes from the work of Steven Pressfield (2002). Pressfield, a noted author of fictional novels identified and characterized the forces of obstruction that arose when he started doing his creative writing. These included distraction, procrastination, and self-doubt. The concept of resistance gives an opportunity for designers to articulate the obstructions that they are overcoming in order to proceed with their design activity (Fig. 6).

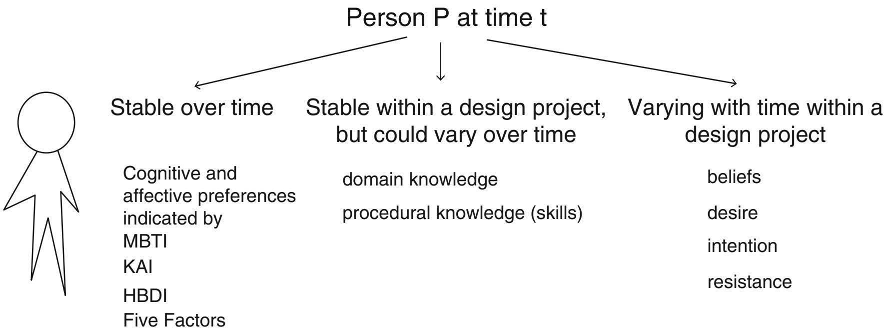

Fig. 6 Parameters that are included in the person element in the Quadratic model

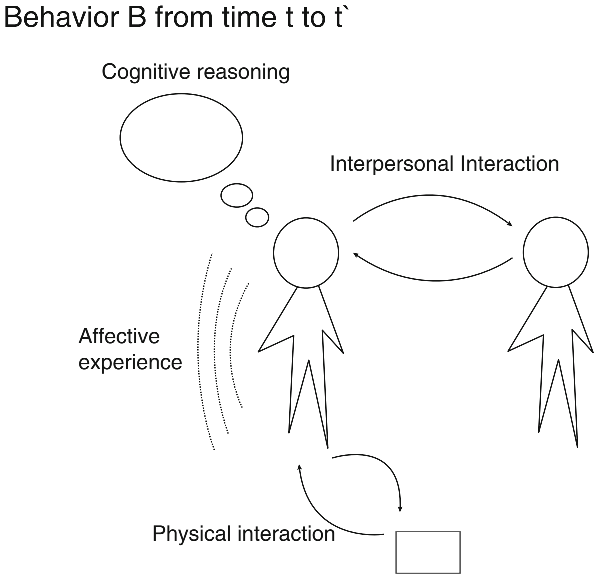

Fig. 7 Four types of behavior considered in the Quadratic model

5.2 Behavior

Behavior in the Quadratic model is defined as actions displayed or undertaken by an individual in response to person, environment or artifact. These actions include cognitive reasoning, emotional or affective responses, and interactions with either other people or with media in the environment or artifact element (Fig. 7).

Cognitive reasoning: Cognitive reasoning in design has been the subject of study since the early days of design theory and methodology research. Section 3.1 describes the key reasoning strategies in design.

Affective experience: Affective experience in design activity has not been actively studied till recent years (Sonalkar et al. 2011). Malte Jung published one of the first studies on emotions in design teams and showed a direct correlation between affective performance and the technical performance of design teams (Jung 2011, 2016; Jung et al. 2012). The Quadratic model includes affective behavior in order to let practitioners, coaches and researchers develop an awareness of emotions displayed by themselves and others in a team.

Interpersonal Interaction: Interpersonal Interaction of a designer includes interactions with others on a team or with external stakeholders related to the design project. This behavior is manifest through face-to-face interaction or through communication media. The other form of interaction that a designer engages with is with media when documenting or prototyping. Media interactions are an essential part of design activity which relies on such interactions for developing and realizing a concept from an abstract idea to a tangible product.

In the Quadratic model, behavior occurs over a period of time and is a process entity, whereas the rest of the entities in the model—person, environment and artifact are state entities. The interaction behavior (either with people or media) and the affective behavior is visible to others and is amenable to observation by researchers or coaches. Significant elements of cognitive behavior and affective experience are invisible to the naked eye and could be revealed through processes such as question-asking, reflection, and self-disclosure.

5.3 Environment

Environment in the Quadratic model consists of three parameters given below.

5.3.1 Physical Environment

The physical environment is the space in which a design activity is physically situated. This could include a design studio, a design classroom or even a space in the field where interactions with users are conducted. The role of physical environment in design activity was popularized by the Design Thinking movement both in design education (Doorley and Witthoft 2011) and design research (Weinberg et al. 2014; Nicolai et al. 2016). The physical environment in the Quadratic model is denoted in terms of affordances it allows for specific design activity. For example, the presence of whiteboards and similar writing surfaces allows for collaborative sketching, and the presence of moveable furniture allows for reconfiguration of the space to suit different design activities.

5.3.2 Institutional Environment

The institutional environment refers to the rules and norms of the institution the design activity is operating in. Though these are not physical manifestations in the space of design activity, the prescribed rules and the inferred norms of the institution influence design behavior just as a physical environment does through the affordances it offers. The Quadratic model includes these institutional rules and norms so that a practitioner, coach or researcher could develop an awareness of the institutional influence on design activity.

5.3.3 Relational Environment

Relational environment refers to the relationships a designer forms with her colleagues she participates in design activities with. The influence of familiarity and the nature of relationships a designer has with others has the potential to influence design behavior. Even if the physical or institutional environment remains the same, if a designer brings into such an environment someone who has a history of participating in highly creative activities with the designers, the presence of this relationship could change how the designer behaves in that environment. Research on relational influences has not yet been conducted in design field, though Vygostky's work on proximal development in the field of education (Chaiklin 2003) points to the influence of relational environment on learning behavior.

5.4 Artifact

The Quadratic model considers the artifact as distinct from the environment since the intention of the designers is oriented towards manipulating the artifact differently from the environment in which design activity occurs.

The artifact could be the media representation of the concept being developed into a product or an experience e.g. a sketch, a foam model, a CAD drawing or a functional prototype. Prior research has shown that the nature of the artifact influences the behavior of designers (Edelman et al. 2009; Edelman and Currano 2011). Hence the Quadratic model notes the nature of the artifact the designers are working with at a given time t. This nature is denoted in terms of (1) the mutability of the artifact, which refers to the ease with a designer could modify the artifact, and (2) the resolution of the artifact, which refers to the level of refinement or granularity observed in the artifact representation. Thus, a clay model is highly mutable and if built with refinement could be high resolution. A sketch on the other hand, is highly mutable but low resolution.

6 Implication for Design Practice

The Quadratic model could serve as a guide to the professional vision of a design practitioner or coach. Imagine a practitioner, Dan working with the team developing a new medical device that we mentioned at the beginning of this chapter. When Dan assembles with his team to work on prototyping a new concept that the team is considering, he does a quick review of the design situation he is in, using the Quadratic model. He starts with the environment. Is the physical environment conducive for a rapid concept generation and prototyping activity? Dan notices a lack of writing surfaces in the prototyping studio and immediately brings in a few more portable whiteboards, markers and erasers. He then performs a quick reflection on the rules and norms of the institution to check if he senses anything that could negatively influence the design activity the team is starting. He makes a note of his relationships with his team members to see if there is anything at the relational level inhibiting him from expressing his ideas and thoughts openly. Not finding anything inhibiting him, Dan then proceeds to scan the person—himself, using the Quadratic model. He examines his in-the-moment beliefs, desires, intentions, resistance, his capacity to imagination and empathy. Dan notices he is feeling a bit tired, perhaps due to lack of sleep the previous night, and makes a note to do physical warm-up with stretches before he gets into his design work. Dan also scans the artifact media that he would be working with. He checks if the mutability and the resolution of the media the team is working with matches the level of ambiguity they wish to explore in the concept. Since this is an early prototype exploring a very novel conceptual direction, he wants to work at the level of rough sketches on paper, following by some physical role-playing and perhaps a few paper prototypes. When the design activity starts, Dan keeps an eye on the team behavior. Is the team displaying energetic co-creation? Is there enough discussion on each of the concepts being generated? Is the team transitioning between concept and knowledge spaces? This helps Dan contribute to the team activity in a way that augments the entire team's performance.

As Dan participates in a number of design activities in the course of his professional practice and actively uses the Quadratic model, he develops his professional vision, a way of seeing the situation, and an action repertoire that allows him to actively experiment with and improve his design practice. In a similar way, the Quadratic model could be used by a design coach to improve the performance of the design teams she coaches.

7 Implications for Design Research

The Quadratic model provides a situational representation of design activity that retains the interconnectedness of the key elements—person, behavior, environment and artifact. The model provides an opportunity for bringing together the bodies of knowledge about these key elements that are currently isolated from each other, and start building theories of design activity that synthesize across their relevant disciplines. Another contribution of the Quadratic model is that it inspires new research directions within design. For example, studying the relational environment in a team and its influence on design performance vis-à-vis the presence or absence of certain person characteristics.

The Quadratic model thus provides an integrative as well as a generative function for advancing our knowledge of design activity. At the same time, it allows for practitioners such as designers and their coaches to use the model to further develop their professional vision and articulate this vision in a framework that is accessible to researchers for together pushing the performance frontier of design practice.

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Breaks with a Purpose

A Three-Dimension Framework to Map Break Characteristics and Their Effects on Design Thinking Teams

Franziska Dobrigkeit, Danielly de Paula, and Matthias Uflacker

Abstract Breaks are a fundamental part of our work life and have been studied in various settings before. This article investigates their importance and impact within design thinking teams. The research is based on a series of interviews conducted with design thinking team members and coaches in combination with observations of their behavior during and after breaks at the HPI School of Design Thinking. Our analysis shows that breaks in this setting can be characterized by three dimensions: the activity level (active or passive), a social aspect (group or individual) and the distance to the project (related or unrelated to the project). Furthermore, we discuss the effect of these different characteristics on the team and relate our findings to research from other areas.

1 Introduction

Breaks are fundamental to our work life and they have been subject of different research areas before. Special attention is given to breaks as a means to improve workers' health and well-being (e.g., Buchanan 1992; Buchenau and Suri 2000; Häger and Uflacker 2016) at the work place and the effects of breaks on memory, creativity, or ability to focus (e.g., Ariga and Lleras 2011; Baird et al. 2012; Beeftink et al. 2008; Charmaz 2006; Dababneh et al. 2001; De Bloom et al. 2014; Globerson et al. 1989; Lindberg et al. 2011; Lubart 2001). As can be seen by the various effects that are researched, breaks are very versatile. This is a finding we also saw in our previous research on time management in educational design thinking projects (Häger and Uflacker 2016). Our research was based on interviews with

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design thinking team members and coaches from HPI student or professional design thinking education. Breaks with their various activities and effects emerged as one of the major topics during that study. An additional, interesting finding was the emotional effect that resulted from the breaks. For instance, one of the teams mentioned they felt demotivated after a coach cut short a break to give them more work to do, while another team claimed they felt unproductive because they were unable to take breaks. In this way, studying how design thinking teams spend their breaks is fundamental to understanding how to improve the creative process. However, there is a lack of research in the literature about the effects that breaks could have on a design thinking team.

This study aims to investigate breaks in the context of design thinking teamwork and explore what activities are common and how they influence the team. Our investigation is based on the existing interviews, which were recoded for break activities and additional observations of design thinking teams at the HPI School of Design Thinking. Overall, 15 interviews were recoded and three different teams were observed while working in design thinking sessions. This study categorizes types of breaks according to three dimensions: the activity level (active or passive), a social aspect (group or individual) and the distance to the project (related or unrelated to the project). Our findings show that these dimensions have different effects on the team and their performance on the task following their break. Additionally, our research suggests that gradually moving through these dimensions when switching from one task to another (e.g. by introducing a break activity connected to both tasks) can be beneficial for the team performance in the subsequent task. For example, when a team spends a break on a social interaction with other teams, the team members seemed to be more easily engaged in project-related discussions after the break. On the other hand, after spending a break with activities unrelated to the project it takes more time to engage again in work discussions. Whereas team members who spent their breaks on the project were more easily engaged after the break, they became tired more quickly than others who did something else. The result of this study summarizes relevant findings around characteristics of break activities and their effects on team performance. This study thereby contributes to the literature by providing concepts and dimensions that can be used to understand the effects of breaks on human activity. Furthermore, it offers a practical contribution to education and industry by providing a set of dimensions and activities that can help coaches or managers to plan the ideal type of break for the intended type of work.

The remainder of this article is structured as follows: Sect. 2 provides an overview of existing research on breaks. Our research approach is described in Sect. 3 and our general findings around break initiation, activities, purposes and problems are presented in Sect. 4. Section 5 presents the identified characteristics of breaks and Sect. 6 discusses how they relate to the effect the break has on the team or a team member. In Sect. 7 we relate our findings to other re-search on breaks and discuss our findings. Section 7 closes this article with a summary.

2 Related Work

Breaks have been the subject of research in different areas. Medical research considers breaks as a means to improve well-being, creativity and productivity in work environments (e.g., Buchanan 1992; Buchenau and Suri 2000; Häger and Uflacker 2016). Psychology is interested in breaks and their effects on task performance in relation to different kind of tasks (e.g., Ariga and Lleras 2011; Beeftink et al. 2008; Charmaz 2006; Dababneh et al. 2001; De Bloom et al. 2014; Globerson et al. 1989). Creativity research has devoted special attention to breaks with the notion of incubation as a means of enhancing creativity (Baird et al. 2012; Lubart 2001; Madjar and Shalley 2008). This section will introduce some of the research on breaks to provide an overview of what effects breaks can have on the body and the mind.

In research around team work and collaboration breaks are considered a means of enabling socializing between team members but also across teams in an organization. The mere act of leaving one's workplace to go to lunch, or to go to the coffee or copy machine enables chance meetings with co-workers and thus social interaction. These small or larger social interactions lay the ground for successful collaboration and informal communication, which again leads to a better shared understanding with in the team and or company. Kraut et al. investigated collaboration between researchers and in R&D departments, in order to develop communication technology that supports informal communication (Kraut et al. 1988, 1990). In both their works informal communications is presented as one of the major factors that enables collaboration. In Kraut et al. (1988) they discuss the importance of spatial proximity as an enabler for informal communications and thereby for collaboration between researchers. In Kraut et al. (1990) discuss how informal communications support social relations between employees and thereby enable collaborations to occur throughout the organization. In both works, the lunch and coffee breaks are repeatedly mentioned as a means to informal communication. Hinds and Weisband (2003) discuss how shared understanding can be reached and maintained in global teams. In their discussion of the effects of geographical distance on a team, frequent unplanned interactions (e.g. at lunch or the coffee machine) are mentioned as a means of fostering informal communication and thus again to shared understanding within a team. In their study on team engagement during creative processes, Gilson and Shalley (2004) found that socializing during breaks and outside of work also leads to teams engaging in more creative processes (Gilson and Shalley 2004).

Other research on creativity investigates breaks as a means to allow for mind wandering and incubation, which, according to different theories on creative processes (Lubart 2001) are supposed to allow for "aha"-moments when being stuck with a wicked problem. Beeftink et al. investigated the difference between imposed and self-initiated breaks as means to allow for incubation. Specifically, they measured impasses reached and creative problem solved when having no break, having a break at one's own discretion, and having breaks at predetermined times. Their results show that self-initiated breaks lead to solving more problems while reaching fewer impasses. Imposed breaks or interruptions also led to fewer impasses but not to increased problem solving. A comparison of four different break activities during a creative task was done by Baird et al. (2012). They focused on breaks that engage participants in a demanding or in an undemanding task and compared this scenario to a rest break and no break. Baird et al. found that engaging in an undemanding task during a break led to substantial improvements in performance on previously encountered problems. Madjar and Shalley were able to show that working on an intervening task with a difficult goal can stimulate creativity by enabling incubation. Being able to switch between creative and intervening tasks at their own discretion gave participants the ability to take a break if needed and refresh themselves while still working towards a goal instead of simply relaxing.

An experiment on the effects of different kinds of breaks on negotiation results was conducted by Harinck and De Dreu (2008). Their results show that a break in which participants reflect on the negotiation leads to a change in strategy but not to a better common result for the negotiating parties. Breaks in which participants were distracted from the negotiation with a task actually led the partners to higher quality agreements. Harinck and De Dreu argue that turning the mind to issues other than the negotiation or actively engaging in cooperative thoughts can compensate negative effects of competitive thinking.

We found little research that investigated breaks for design thinking teams and activities. An experiment with four different types of breaks during a brainstorming session was conducted by Mitchell (1998). She tested the conditions of no break, a break that repeated the brainstorming rules, a break with written brainstorming, and a break with a completely different activity. The results of her experiment led Mitchel to the theory that in the brainstorming phase too much change in context (just as too little change in context) may slow productivity. She postulates the change during a break in brainstorming should be slight and allow participants to keep focused on the problem. Buchenau and Suri (2000) investigate "experience prototyping" as a way to gain first-hand experiences. They describe using breaks between session of improvised role-playing in order to discuss and capture learnings, to reflect, and to generate further ideas. Oulasvirta et al. report on their experiences with "bodystorming" as a method to carry out design sessions in the original context of the problem to solve. Similar to Buchenau and Suri they report on using breaks as a time to reflect and take notes but also found them to be necessary as "bodystorming" on several locations within one day was exhausting. Schelle et al. (2015) developed a framework to increase engagement in workshops, a setting where a coach is guiding a design team throughout their work, similar to some design thinking sessions. One part of their framework, called the "Energizer", aims at refreshing participants by giving them an active and fun task as a break from the project. This concept was rated positive by facilitators and participants. Break activities they suggest include making something from clay, folding a paper boat, or building something from a small LEGO-set.

Even though most of the presented research was done on very specific tasks outside the domain of design thinking, we believe the presented findings are applicable to design thinking teams and their work. From the presented work it seems that different kind of break activities are necessary in order to achieve a positive effect on a design thinking team, depending on the process phase they are in and the task at hand. Design thinking as described in (Wölbling et al. 2012) requires team work. Therefore, socializing between team members but also between teams is important to achieve a good general atmosphere and collaboration within the team throughout the process. Furthermore, the converging phases of a design thinking process (cmp. Lawson 2006; Lindberg et al. 2011) require the team to come to a mutual understanding of their findings and to agree on what direction to take. Accordingly, this step includes the forming of a shared understanding as well as negotiation between team members. And, last but not least, the diverging phases of the design process, especially the ideation phase require the team to come up with creative solutions to wicked problems (cmp. Buchanan 1992), which requires creative thinking and might need incubation and mind wandering to succeed.

3 Research Method

In our former research on time management tools used in design thinking projects (Häger and Uflacker 2016) we surprisingly found that most interviewed team members identified breaks as a time management tool. In those interviews, breaks were comprised of very different activities and served various purposes. As this finding surprised us, we wanted to take a closer look at breaks and formulated the following research questions:

- RQ 1: What do design thinking teams do during their breaks?
- RQ 2: What effects do different kind of breaks have on the design thinking team?

To answer these questions, we took a two-step approach. First, we used interview coding to recode our interviews with a focus on breaks and break activities. An interview is a two-way conversation between the interviewer and the respondents (interviewee). Here, questions are asked about the phenomena under study to collect information and learn about the participants perceptions, beliefs, and behavior (Nieuwenhuis 2007). This method of data collection was appropriate for this study because the nature of in-depth interviews enable the researcher to collect each respondents' interpretation of his or her experience or reality (Charmaz 2006). Interview coding is a method used to capture what information exists in the interview data, and to learn how people make sense of their experiences and act on them. Coding is the first step of data analysis, as it helps to move away from particular statements to more abstract interpretations of the interview data (Charmaz 2006). Second, we aimed to check and strengthen our findings by observing design thinking teams during their work. The following sections will describe the setup of our research for both methods.

3.1 Interviews

The interviews were originally conducted to understand how design thinking teams manage their time. Between January and February 2016, we conducted 20 semi-structured interviews with persons who are involved with design thinking education at the Hasso Plattner Institute (HPI) in Potsdam, Germany. All interviewees had recent experiences as either coach, program manager or team member of a design thinking team in the context of student or professional education. The initial findings from these interviews were presented in Häger and Uflacker (2016). Since then, we have conducted one additional interview following the original interview guide. This guide, as described in Häger and Uflacker (2016), did not include any question about breaks. Therefore, some interviewees did not talk about breaks. However, due to the semi structured nature of the interviews, the interviewer would ask for more details, further explanations, or would ask clarifying questions after the interviewee mentioned breaks. Overall 15 of the 21 interviews included information about breaks and break activities and thus form the data basis for this research.

Out of these 15 interviewees, two people had recent experiences as being a team member and being a coach. However, the sections of the interviews that discussed breaks referred to their experiences as team members which is why for this research they are counted as team members and not as coaches. Table 1 depicts the distribution of our 15 interviewees in the roles of team member and of coach. Program managers were counted as coaches as they also act in this role as well and their general input on breaks did not differ from that of coaches who are not program managers. For a more detailed description of the interviewees and the programs or courses they were involved in please refer to Häger and Uflacker (2016).

The interviews were transcribed and the transcripts anonymized with a code stating the course and role of the interviewee and a number for later reference (e.g. BasicTrackCoach1). For this research, we recoded the transcripts with a focus on breaks and break-like activities. We did not use a predefined coding schema but let the codes emerge from the data. The following topic clusters emerged from our first round of coding for breaks:

- break initiation,
- activities during breaks,
- purpose of breaks,
- and problems associated with breaks.

The findings of these topics are presented in Sect. 4. Because we realized that there are some dimensions to the break activities as described by our interviewees

Table 1 Roles of interviewees

Role	# of interviewees
Team member	9
Coach	6

we went into a second round of coding for breaks from which the following code pairs emerged:

- planned breaks vs. spontaneous breaks,
- active vs. passive breaks,
- individual vs. group breaks,
- breaks related to the project vs. breaks unrelated to the project.

In Sect. 5 we discuss these dimensions and provide an overview on how they are connected to the purpose of the break in Sect. 6.

3.2 Observations

During the interviews participants discussed break activities (WHAT did they do during a break) and the purposes of their breaks (WHY did they take a break). However, they only rarely reflected on the effects the break had on their work and their team (HOW did the break affect them). In order to validate and complement our findings we observed different design thinking teams during their work, focusing on their break activities and the effects of the break on the team and its work.

We observed a different design thinking team each day for a total of four working days at the HPI School of Design Thinking Basic Track. The basic track teaches design thinking to students from different backgrounds. Accordingly, the team members were all novices to design thinking and the structure of their workdays is preplanned by the HPI School of Design Thinking teaching team, thus resembling a workshop setting. However, the teams are free to take breaks at their own discretion. Notes from the observations were kept in the form of an anonymized protocol, stating work activities breaks and performance levels of team members and the team. During the observations, performance was measured based on the level of engagement of the team members and the number of insights they contributed. These reports were afterwards coded with the codes that had already emerged from our interviews. The findings are described in Sects. 4, 5 and 6 accordingly.

4 General Findings on Break Initiation, Activities, Purpose and Problems

Our interviewees reported very different practices when it comes to taking breaks during their design thinking work. Several team members reported the planning of breaks at the beginning of their work days along with the general agenda for the day. These planned breaks usually included lunch and coffee breaks (one in the morning and one in the afternoon), which is consistent with reports of coaches and program managers that use similar planned breaks in their workshops. Apart from these "standard breaks" team members and coaches discussed two different planning behaviors around breaks. Some teams would plan enough time for each activity to accommodate spontaneous breaks, while other teams planned generous break time to have some buffer in case they need more time for a task. Both approaches aim to achieve a certain level of flexibility in the plan and it might be interesting to look into the differences between the two. Finally, the interviewees mentioned spontaneous breaks that are initiated in different ways:

- One team member asks for a break and the team agrees.
- One of the team members is assigned a role which is responsible for monitoring the level of engagement within the team and is allowed to declare a break if the team is stuck or powered out.
- The team simply drifts into a sort of break mode where everyone is already doing something other than the task at hand (e.g. due to concentration issues).
- Individual people take a break at their own discretion either by going away from the team or by doing something by themselves (e.g. juggling) while the others are engaged in discussion.

On the topic of why they take breaks our interviewees mentioned several very different reasons. The top five reasons for a break, each mentioned by three different interviewees, included:

- allowing for reflection on the process,
- allowing for incubation,
- introducing a change when stuck,
- establishing distance from the team or a person,
- and socializing within the team or across teams.

The lunch break was specifically mentioned several times as a good point in time to reevaluate the plan for the day by reflecting on what is already achieved and how to continue the work day. Our interviewees did not mention "incubation" by name, however they stated the necessity of having some time to themselves at certain points. This was particularly the case after heated discussions, longer inputs, or the peak of a diverging phase to "let the subconscious work," "let the information sink in," or "trigger ideas on the project by doing something completely different."

Using a break as a change of scene when feeling stuck was mentioned in two scenarios. One interviewee reported using a break when being stuck in a discussion to allow everyone a chance to take a step back and see if the discussion can be successfully finished afterwards. Two other interviewees mentioned a break as an opportunity for change when being stuck in ideation. One of the teams took a fun break playing a game and came back to revive their ideation. The other team was looking for an external person to work with them on their ideation. Both teams found their changes helpful and talked about continuing successfully. Getting distance from the team or a person in the team was reported as beneficial after a long discussion. To quote one of our interviewed team members "Sometimes you just can't hear the person talking anymore!". Two further interviewees reported that working all day within the team leads to the need for some personal time or socializing outside of the team. This notion can probably be linked to having time for reflection (alone time) or the need to get a different opinion or point of view (socializing outside of the team). Several interviewees reported spending the break socializing with the team or across teams, spending the time talking about non-project topics.

Other purposes for breaks mentioned during our interviews included, relaxing and recovering after hard work (e.g. strenuous discussions or ideation sessions). This was also seen as a reward for working hard. And last but not least interviewees mentioned the energizing effect of breaks, taken when energy levels within the team are low.

Break activities that were mentioned in our interviews and seen during our observations included:

- eating and drinking (e.g. going to lunch or grabbing a coffee),
- talking to others about non-project topics,
- talking to others about project related topics,
- playing games (e.g. playing table football or doing a warm-up exercise),
- cleaning up the project space,
- thinking about the project/ a question/an idea,
- doing other work (e.g. writing emails or making a phone call),
- going outside to take a walk,
- sitting on the couch, and
- preparing for the next task.

The activities are ordered by number of mentions/appearances. Naturally, some of these activities can (and were) combined, for example interviewees mentioned talking with their team members about off-project topics while grabbing a coffee or thinking about the project while relaxing on the couch.

Throughout our interviews we coded various problems that occurred around breaks. Interestingly in just 4 days of observations we saw incidents of most of the problems we were told about during our interviews. Three team members told us of incidents when they did not take a break because they felt pressured to do more or to achieve a goal. However, they acknowledged that this behavior led them to exhaustion and unproductivity. We could also observe this behavior in one of the teams. That team skipped an afternoon break because they had too much to do. These reports fit in well with a practice for planning workshops, that one of the coaches told us about: He aims at achieving converging results, (reaching a point of view or finishing a prototype) before lunch breaks and at the end of a day. He does that because he believes breaking away from the project for a longer time period in the middle of a converging phase with all that information leaves the participants unsatisfied. A similar problem was mentioned by two other team members who stated that spontaneous breaks simply do not work in their teams. In one case this led to the team just taking lunch breaks and otherwise working throughout their workday, leaving them feeling exhausted and unproductive. In the other team, everybody seemed to drift into a sort of break mode were nobody was concentrating on the project anymore. But since this was not officially a break the team member experienced the time as unproductive. Similarly, one interviewee explained how he could not experience breaks in which his team continued discussing the project as real breaks but rather as a different form of working. This behavior could also be observed during one of our observations where the team was allowed to take breaks at their own discretion. On that day the observed team had only one real break, the lunch break that was planned up front. But instead of taking breaks, team members left at their own discretion or drifted into off-project discussion and tasks. Overall the day seemed less productive for the observer, than other days when the teams had more breaks.

When the teams are actually taking a break, other problems can arise. One interviewee mentioned how in his team, members had the common problem of convening on time after a break. The team would agree on taking a break of a certain length but somehow nobody would get back on time. Two reasons for this behavior were mentioned during the interview: losing track of time during the break activity and the feeling of not yet having enough energy to continue. During one of our observation two team members spent their afternoon break talking to their coach and asking many questions. They arrived after the rest of their team had already continued working. The two late team members did not engage in the team's activity during this task. One team member talked about a moment in his project that highlights the different perspectives on breaks that team members and coaches seem to have: The team solved their current task exceptionally fast and well, so they decided to have a break for the time remaining for the task. After a couple of minutes one of their coaches came and saw that they were not working so he simply gave them other tasks to do thus ending the teams break. The interviewee told us how that really demotivated the team because they were deprived of their reward break. We could observe a similar situation twice. The team would take a break and a coach came and gave them another task to do thus ending the break. One of these incidents was observed with the team that did not have any real breaks because they had not planned any. On that occasion the team drifted into a discussion about movies and was reminded to get back to work by their coach. These episodes fit well with the overall discussion about breaks among the two groups of interviewees. Only one of the coaches/program managers talked about breaks at greater length. While the other coaches/program managers did not talk about breaks at all or just mentioned them from a planning point of view (e.g. time for syncing between coaches or time to do other things). On the other hand, almost all team members mentioned breaks and talked about their activities and purposes. One problem that we observed but did not hear about in our interviews was that after being frustrated with the result of a task, a break could still not help to get out of this frustration and motivation stayed low for the following tasks. During this incident, the participant spent his break discussing his issues with a coach and did not part take in the task following the break until 15 minutes later.

5 Characteristics of Break Activities

As described in Sect. 3 our second round of recoding for breaks led us to coding pairs that can be described as dimensions of break activities that are depicted with the related coding pairs in Table 2.

The level of planning was already discussed at the beginning of Sect. 4. It is important for the initiation of a break but is not reflected in the break activity. In other words, any break can be planned or unplanned it does not change what the team is doing once they start their break. The activity level can range from being low, leading to a passive break, over moderate activity, to highly active breaks. Examples for passive breaks are sitting on the couch or drinking coffee outside in the sun and active breaks could be comprised of taking a walk, playing a warm up or cleaning out the team space. The social dimension ranges from individual breaks with no or few social interactions to very social group breaks with the whole team or even across teams. Examples for individual breaks are taking a walk outside alone, getting some off-project work done on the laptop, or listening to music over head phones. Examples for group breaks on the other hand include activities like going to lunch together as a team, doing a warm-up or playing table football with the team, or exchanging with other teams. The distance to the project ranges from working on the project or discussing project related topics to spending the time completely away from the project physically as well as mentally. Reflecting about the project, plan or process, or continuing a discussion over lunch can be described as a break related to the project, while socializing or getting other work done would be considered a break unrelated to the project.

In the following, we analyze examples of breaks, in order to illustrate how the three dimensions can be used to characterize a break. The situations described were either mentioned during our interviews or seen during our observations.

Example 1: Individual Project Space Clean Up
During our observations, we saw one team member spending the break alone cleaning up the team space. This break can be characterized as "individual", because the team member spent the break alone. It is a project-related break spent physically in the team space and, while cleaning the table, mentally preparing for the next task. Although not a great deal of action takes place, this break would nevertheless be considered more active than passive. Figure 1 illustrates these characteristics in a radar chart with opposing axes. After the break the relevant team member was very engaged in the discussion. However, she left the team after 15 minutes to go and get a coffee.

Table 2 Identified break dimensions and associated coding pairs

Dimension	Coding pair		
Level of planning	Planned breaks	←→	Spontaneous breaks
Activity level	Active breaks	←→	Passive breaks
Social dimension	Individual breaks	←→	Group breaks
Distance to the project	Breaks related to the project	←→	Breaks unrelated to the project

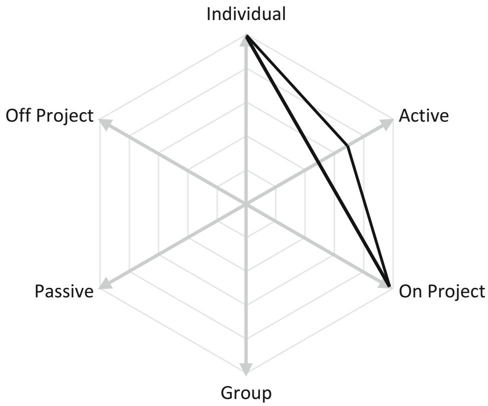

Fig. 1 Characteristics of breaks. Example 1: Individual project space clean-up

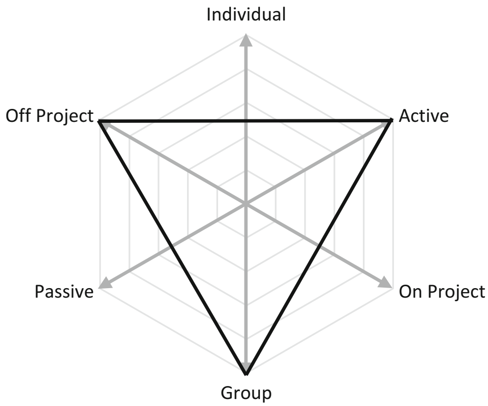

Fig. 2 Characteristics of breaks. Example 2: game of table football with the team

Example 2: Game of Table Football with the Team
During one of our interviews a team member described how his team would take a break to play table football when they were not making any progress despite working and discussing for hours. He specifically mentioned that these breaks were meant to be unrelated to the project, and the team would not talk about the project during the game. It was a group break since the whole team participated. It is also a decidedly active break and, as described by the interviewee, off-project. Figure 2 illustrates the characteristics of this break. The team member described (such) breaks as an opportunity to clear the mind, and to allow the team a fresh start.

Example 3: Lunch with the Team Continuing a Discussion
The episode previously described in Sect. 4 under the topic of problems is another break example. During their lunch break the team would continue the discussion from the previous task and then gradually move on to project unrelated topics for the last third of the break. This group break is partially project-related. It is also partially active (going to the cafeteria) but slightly more passive (sitting and eating).

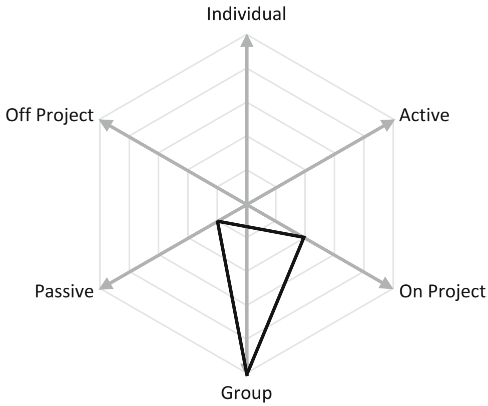

Fig. 3 Characteristics of breaks. Example 3: Lunch with the team continuing a discussion

Figure 3 illustrates the characteristics of this break. As reported in Sect. 4 this break was not experienced as a real break by the interviewee.

6 Mapping Break Characteristics and Break Effects

The identified dimension, activity level, social dimension and distance to the project, seem to determine the effect the break has on the team member or the team. The following sections give examples of effects for each of the three dimensions. The effects were either described during the interviews, or we noticed them during our observations.

6.1 Level of Planning: Planned vs. Spontaneous Breaks

We found no evidence during our interviews and observations that the level of planning influences the effect the break has on the team. Rather certain breaks are normally planned such as the lunch break, while other breaks are necessarily spontaneous (e.g. when being stuck in a discussion or ideation session, in which case these events can obviously not be planned ahead). However, it seems that having enough planned breaks makes it easier for teams to stay focused on the topic as it is clear to everyone when there will be a break. For example, if you know, that there will be a break in 10 minutes you can wait until then to get something to drink.

6.2 Activity Level: Active vs. Passive Breaks

We did not observe extremely passive or active breaks during our observations. However, interviewees made a point of mentioning the energizing effects of an active break like a warm-up exercise or playing table football. Passive breaks were mentioned as helping to recharge after an exhausting task or strenuous discussion. Additionally, passive breaks were associated with individual or team reflection.

6.3 Social Dimension: Individual Breaks vs. Group Breaks

During our interviews and observations, it became clear that individual breaks are often used for personal reasons (e.g. work on other projects, and physical needs, such as getting something to drink or going to the bathroom). Individual breaks take place frequently and sometimes just part of a break is used for personal reasons. We could not observe any apparent effect of being alone during a break. However, it was evident, that individual needs and tasks that were not met during the break disrupted work as people left the team in the middle of discussions. Our interviewees reported using individual breaks for personal reflections and forming an opinion before team discussions. This was described as especially helpful during difficult phases (e.g. when on the verge of moving from a diverging to a converging phase the individual break allows participants to process all accumulated information before discussing further steps). During the interviews, social activities within the team were described as beneficial to team building, which in turn helped the team to cope during difficult phases of the project. Furthermore, group reflections were mentioned as a way to adapt the teams plan and move forward. Social activities across teams were mentioned as a way to exchange ideas and get fresh insights. We observed several group breaks with social interactions inside and across the observed design thinking team and found that apart from enabling social contact and the exchange of ideas, talking to other people seemed a good mental preparation for interviews and discussion. Team members who spent their breaks talking to others before such tasks appeared more engaged than team members who spent their breaks differently.

6.4 Distance to the Project: Project Related vs. Non-project Related

We observed team members doing tasks related to the project during their break. One of these observed team members, who spent the break cleaning the project space, was more easily engaged in the task that followed, iterating the team's idea. However, the team member tired faster than the team mates. Accordingly, interviewees reported on not experiencing these kind of breaks as an actual break. Two other team members observed spending their break related to the project, seemed to be zoned out of their teams' discussion directly after their break and it needed some time for them to participate. In both cases the task that followed required team members to share their personal view on the problem at hand. This effect could be due to the lack of distance to the project and, as a result, the absence of opportunity to reflect on what had been achieved. Thus, the participant was compelled to do this reflecting while the team was already engaged in discussion. During our interviews teams also mentioned reflective breaks, in individual as well as group sessions, as a way to cope with difficult situations. In these cases, the reflective break was usually followed by a discussion that led the team to a clearer understanding of the information, problem or idea or to a change in plan. Notably, several team members and coaches mentioned reflecting over the first half of a work day at the end of the lunch break as a common practice when starting into the afternoon. In these cases, the reflection seems to be a bridging task preparing the team to get into work again after a longer break. A similar behavior can be observed during the check-in task in the mornings, when team members discuss how they feel and what they want to achieve during the day. Breaks off the project give the team a chance to disengage from the project or the team and any associated negative feelings, by providing a distraction in the form of other activities. According to our interviewees, this leads to a clear mind that is prepared to start fresh on the next activity. It also allows participants to break out of situations they feel stuck in. During our observation we found that some time is needed for participants to get back into the topic after they spend their break with activities unrelated to the project.

7 Discussion

Our general findings on breaks for design thinking teams, as presented in Sect. 4, support most of the findings from research on breaks made in other research areas, as described in Sect. 2. During our interviews and observation, we found several occasions of breaks being used to socialize within the team or even across teams discussing non-project topics. These breaks are comparable to the breaks mentioned in the studies about informal communication and collaboration (Gilson and Shalley 2004; Hinds and Weisband 2003; Kraut et al. 1988, 1990). Our interviewees experienced them as helpful for the team in difficult project phases strengthening the finding that these breaks support successful collaboration. Concerning creativity and breaks, we found two break strategies to use when stuck during ideation. Engaging in a game can be seen as an example of incubation as described in Baird et al. (2012) and Lubart (2001). Bringing someone else into the ideation when stuck fits in with the results of Mitchell (1998), where a small contextual change is beneficial to ideation. Our finding that taking a break is a means to step back from a fruitless discussion, and then to allow a successful continuation, is comparable to the negotiation experiment of Harinck and De Dreu (2008). Here breaks in negotiating either lead to reflection and thereby to adjustments in strategy or serve as a motivating distraction. The energizing effects described as an effect of active breaks supports the "Energizer" intervention created as part of a framework for energizing workshop participants in Schelle et al. (2015). The problem of staying frustrated during a break and carrying on the demotivation to the following task, as described in Sect. 4, could be an expression of rumination. The team member observed in this attitude spent the break discussing the negative situation with a coach instead of solving his issues with the team or distracting himself from the negative mood.

The three break dimensions we could identify during this research overlap with break characteristics from a study proposal by De Bloom et al. (2014). They propose to investigate the effects of being in nature versus relaxation during lunch breaks to recover from work. Their measurements include three break characteristics to be filled out by the study participants after their lunch breaks. The characteristics are: enjoyment of the break activity, company of others during the break, and break environment. The company characteristic can be directly mapped to our social dimension. The other two characteristics did not appear specifically during our research. However, the active breaks mentioned in our research are usually associated with fun activities, so our activity level and the enjoyment characteristic could be linked. The break environment characteristic by De Bloom et al. specifically asks whether the lunch break was spent in our outside ones' office as such it could be connected to our dimension of distance to the project as it covers the physical proximity to the participants' work.

We believe that our findings on break dimensions and their effects do not only close a gap in research about practices in design thinking teams, but also provide a framework from which coaches and design thinking teams in education practice can benefit. With this research, we aim to make coaches and team members aware of the importance of breaks and the effects they have on the subsequent activity. The presented dimensions and linked effects can help coaches and teams to choose a beneficial break activity for their situation, especially if they are novices. Additionally, the different break scenarios as presented in this paper can be used as a collection of possible break activities to draw from when considering a break. Naturally this collection should be extended through further studies on break activities. Furthermore, our findings suggest that gradually moving from one task to another, e.g. by introducing a break activity connected to both tasks, can be beneficial for the team performance on the next task. For example, our research shows that spending a break talking to other team members or teams is a good preparation for upcoming interview and discussion tasks. Additionally, post-lunch reflections provide a bridging task from activities unrelated to the project to working on the project again. This would also fit in with the small contextual change theory proposed by Mitchell (1998).

8 Summary

This study aims to investigate breaks in the context of design thinking teamwork and explore what activities are common and how they influence the team. Our investigation is based on existing interviews, recoded for break activities and additional observations of design thinking teams at the HPI School of Design Thinking. Based on the interviews and observations, we categorized types of breaks according to three dimensions: the activity level (active or passive), a social aspect(group or individual) and the distance to the project (related or unrelated to the project).

Even though, our research is based on best practices and our findings reflect the existing research from the other fields, it is not possible to generalize our findings to different organizational settings. Based on that, one limitation of this study is that our sample was restricted to a learning environment that might not reflect how design thinking sessions occur in practice in an industrial context. Since the teams were still learning how to use design thinking practices, their performance and the way they interpret the process might have been affected, which might be another limitation. Additional studies would be beneficial in understanding whether our findings would make sense in an industrial context and with more expert teams.

Future work will address those limitations by validating the three dimensions with experienced design thinking teams working in a large organization. Moreover, we will also investigate the creation of a portfolio with ideal activities that could be performed during the breaks according to the project's goals.

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Part II
Tools and Techniques for Productive Collaboration

Mechanical Novel: Crowdsourcing Complex Work Through Reflection and Revision

Joy Kim, Sarah Sterman, Allegra Argent Beal Cohen, and Michael S. Bernstein

Abstract Crowdsourcing systems accomplish large tasks with scale and speed by breaking work down into independent parts. However, many types of complex creative work, such as fiction writing, have remained out of reach for crowds because work is tightly interdependent: changing one part of a story may trigger changes to the overall plot and vice versa. Taking inspiration from how expert authors write, we propose a technique for achieving interdependent complex goals with crowds. With this technique, the crowd loops between reflection, to select a high-level goal, and revision, to decompose that goal into low-level, actionable tasks. We embody this approach in Mechanical Novel, a system that crowdsources short fiction stories on Amazon Mechanical Turk. In a field experiment, Mechanical Novel resulted in higher-quality stories than an iterative crowdsourcing workflow. Our findings suggest that orienting crowd work around high-level goals may enable workers to coordinate their effort to accomplish complex work.

1 Introduction

Crowdsourcing platforms such as Amazon Mechanical Turk bring together tens to thousands of people to accomplish complex work at massive scale, allowing the crowd to collaborate on goals such as researching purchases (Kittur et al. 2011), classification tasks (Simpson et al. 2014), and even creating music videos (Koblin 2010). Currently, crowdsourcing systems accomplish these types of large tasks by decomposing work into independent microtasks. These microtask systems present work in an assembly line-like structure called a workflow (Bigham et al. 2014), using mechanisms such as iteration (Little et al. 2010a), clustering (Chilton et al. 2013), voting (Little et al. 2010b), and other patterns for splitting work (Bernstein et al. 2010; Kittur et al. 2011; Kulkarni et al. 2012). Because these microtasks are

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independent, crowd workers can complete work without worrying about how their contributions affect others. As a result, large goals can be achieved quickly and at scale.

However, effective workflows are difficult to create in advance. To design a workflow of microtasks, an expert must first form a well-defined problem, then engage in an expensive and time-consuming process where they repeatedly test and iterate on potential workflow designs. Furthermore, the expert may run into common problem-solving barriers such as design fixation (Jansson and Smith 1991), difficulty decomposing work into microtasks (Kim et al. 2014), and fear of failure (Bayles et al. 2012). This process is difficult for crowds as well: systems like CrowdForge (Kittur et al. 2011) and Turkomatic (Kulkarni et al. 2012) have explored how the crowd can dynamically help experts decide how to partition work, but have found that workers require expert intervention (Kulkarni et al. 2012) or a high-level initial decomposition of tasks (Kittur et al. 2011) in order to decompose work without derailing from the intended goal.

In contrast, skilled creators iteratively create and revise goals to develop their vision as they work (Flower and Hayes 1981; Sharples 1999). That is, they know that problems are not always well-defined and that they may need to make many attempts before a solution becomes clear. With this in mind, we introduce a technique for continually updating and executing high-level goals with crowds. Rather than asking the crowd to help decompose a static goal, this technique loops between two phases: *reflecting* on the crowd's progress so far to brainstorm and choose a high-level goal, and *revising* the artifact by decomposing that goal into actionable, low-level tasks through which workers make edits. For example, crowdworkers writing a short story could decide that a story ends too abruptly, and act on that in a specific way by brainstorming a different ending. This new goal can guide workers in deciding how other parts of the story need to change and unlock appropriate parts of the story for editing. Each goal can still be decomposed into microtasks, making this approach usable in existing crowdsourcing environments.

We instantiate our crowdsourcing strategy of reflection and revision in *Mechanical Novel*, a system that coordinates crowd workers from Amazon Mechanical Turk to write short fiction stories. Fiction writing was chosen as a test domain due to the difficulty of defining clear expected solutions (i.e., many different types of stories are acceptable instantiations of an initial idea) and its inherent resistance to being broken down into independent subtasks. For this reason, collaboratively writing high-quality stories has been repeatedly explored by previous work (Mason and Thomas 2008; Foldingstory 2016; Kim et al. 2014; Kim and Monroy-Hernández 2016) but has remained out of reach for crowds without the help of a leader.

In Mechanical Novel, after first creating an initial first draft of a story based on a story prompt, workers *select a goal* by reflecting on their progress on the work so far: workers generate critiques, which includes suggesting a possible direction for how the story could change (e.g., foreshadow the death of a love interest). After voting among these suggestions to choose the next high-level goal to work towards, workers then *execute the goal*. Workers select which parts of the story need to change in order to address the high-level goal, and suggest a specific change for each part of the story they selected (e.g., the love interest says, “I will always be here for you”). This decomposes the high-level goal into specific tasks the crowd can act on. Workers then vote on these low-level suggestions, and revise portions of the story based on these tasks. The process then repeats, allowing the crowd to further improve the story by selecting a new goal to pursue.

In a controlled study comparing an iterative crowdsourcing workflow with Mechanical Novel, Mechanical Novel produced stronger stories as rated by readers. Specifically, Mechanical Novel’s stories had stronger plots (with clearer beginnings, middles, and ends). In iterations on six story drafts with known narrative problems, Mechanical Novel identified and successfully fixed high-level problems with plot and character, in contrast to the iterative workflow’s focus on spelling and grammar.

In summary, this chapter makes the following contributions:

- The *reflect and revise* crowdsourcing technique, which enables crowds to collectively monitor their progress and flexibly contribute work based on high-level goals of their choosing.
- *Mechanical Novel*, an example system that demonstrates this technique in the context of storywriting, a domain that has typically remained out of reach for crowdsourcing systems.
- An evaluation of Mechanical Novel that shows the reflect and revise technique can generate short stories with stronger high-level characteristics (such as plot and character) than stories generated by a control system.

Crowds that are able to collectively articulate and execute high-level goals as they work could enable not just collaborative fiction-writing but a new class of crowd-powered work, including breaking news stories that are revised in real-time as new information appears, or reworking films across several stages or mediums (e.g., from a script to a storyboard to video).

2 Related Work

We focus on developing techniques that allow the crowd to select and act on high-level goals. To inform our design, we examine the strengths and limitations of how crowds work together in existing collaborative environments.

2.1 Collaborating Through Context-Free Tasks

People often divide collaborative writing work by identifying sections of text that are independent from each other, and then working in parallel on a single document or writing in turn (Kim and Eklundh 2001; Noël and Robert 2004). Many crowdsourcing strategies think about tasks in a similar manner. In these, the role of subtasks is to produce sub-results that are mergeable into the final result:

crowdworkers caption sections of a speech by captioning one small snippet at a time (Lasecki et al. 2012); flash teams frame collaborative expert crowd work around sequences of linked tasks and finding appropriate inputs and outputs from one phase to another (Retelny et al. 2014); workers create a music video by drawing one video frame at a time (Koblin 2010); and still other work propose patterns (Bernstein et al. 2010; Kittur et al. 2011; Kulkarni et al. 2012) for breaking down complex tasks into context-free subtasks. These workflows can often produce complex work more quickly or more accurately than a person working alone.

Another approach is iterative crowdsourcing, where, rather than stopping after a result is put together piece by piece, one worker creates a first draft of the task, and later workers improve it with subsequent tasks. This is already visible in wiki and open source collaborations, where contributors base their own work on work by others. In tasks such as writing factual descriptions, transcribing blurry text, and brainstorming, iterative crowdsourcing processes can improve the quality of work over time (Little et al. 2010a).

At the same time, these workflows are fragile because they cannot flexibly react to change. Results put together piece-by-piece or in parallel may not be coherent, and iterative processes may fixate on improving low-quality work rather than restarting to find a stronger concept (Little et al. 2010a). Similar problems can be seen in existing collaborative storytelling platforms online, which are often implementations of round-robin storytelling games (Foldingstory 2016) that do not allow contributors to alter work that has previously been submitted; a new character introduced on a whim by one contributor unilaterally affects all later contributions whether it is good for the story or not. In other words, workflows lack support for reciprocal interdependence (Thompson 1967), where changing one part of the work may necessitate changes to other parts at any time. Mechanical Novel, instead, supports reciprocal interdependence by allowing workers to revisit and amend the high-level goals toward which they're working.

2.2 Crowdsourcing with Global Goals in Mind

To accommodate the unique requirements of complex creative and open-ended work, new crowdsourcing techniques consider global goals (rather than just local ones) by allowing workers to participate in how work is merged. For example, workers can combine the best contributions from multiple past workers (Yu and Nickerson 2011) or repurpose old work for a new goal (Hill and Monroy-Hernández 2013). Other techniques help workers maintain global consistency: in classification tasks, context regarding the taxonomy developed so far is provided to workers as they arrive to complete tasks in order to allow workers to consider existing categories as they classify items (Chilton et al. 2013; André et al. 2014). Context trees (Verroios and Bernstein 2014) recursively merge subparts of a long story to gather an emergent understanding of the larger plot; this strategy explicitly shifts from looking at low-level input to the larger story structure and vice-versa, but does not allow workers to modify the story or summary. Voting on how to keep work consistent and organizing high-level ideas prior to work can also help workers think about work from a global standpoint (Hahn et al. 2016).

Another body of past work focuses on allowing workers to self-coordinate. In these, tasks are generated—either automatically or by a human leader—according to overall requirements and are made available for workers to take. The crowdware paradigm (Zhang et al. 2012) proposes use of a shared todo list of collaboration tasks to solve global constraints in tasks that are hard to decompose (such as planning travel). Apparition (Lasecki et al. 2015) features a self-coordinating crowd, but workers do not directly reflect on their own organizational strategies, nor can they alter the directions laid out by the designer. The MicroWriter (Teevan et al. 2016) similarly focuses on scaffolding direct, co-located collaboration between non-crowd groups, providing a shared space to generate, organize, and act on ideas. This shared space allowed pre-existing groups to benefit from a bottom-up approach of building ideas into written paragraphs through microtasks. Mechanical Novel explores a complementary top-down approach where workers first select a goal based on previous work in order to minimize the effort required to coordinate an unaffiliated crowd.

In other work, leaders and collaborators work together more directly; in animation production (Luther et al. 2013), writing (Kim et al. 2014; Nebeling et al. 2016), and ideation (Chan et al. 2014), leaders distribute responsibility by generating tasks around which collaborators focus their efforts. However, in these systems, individual changes are requested and vetted by the same person, and contributors are often able to directly communicate with the leader. Instead, Mechanical Novel looks at how crowd workers can iteratively collaborate with each other, and introduces a technique for iterating on a central goal without a central creative authority.

Mechanical Novel expands on past research by exploring how evaluating lower-level work against global goals can help crowd workers generate globally consistent output. In addition, workers choose goals themselves. Based on this, we hypothesize that allowing crowdworkers to influence both high-level and low-level work may help workers converge on a common creative direction. By allowing them to revise, we open opportunities for workers to challenge and change the constraints of their work when appropriate.

3 Mechanical Novel

To enable crowds to manage high-level interdependencies as they collaborate on complex work, we introduce a crowdsourcing technique consisting of two phases. First, crowd workers *reflect* to brainstorm and choose a high-level goal to pursue. Second, workers *revise* their work to achieve this goal by decomposing that goal into specific tasks. This process loops to continually improve previous work. We test our technique for crowd reflection and revision in a system for collaborative fiction writing called Mechanical Novel. In this section, we describe the workflow (Fig. 1) that guides the crowd through a collaborative revision process.

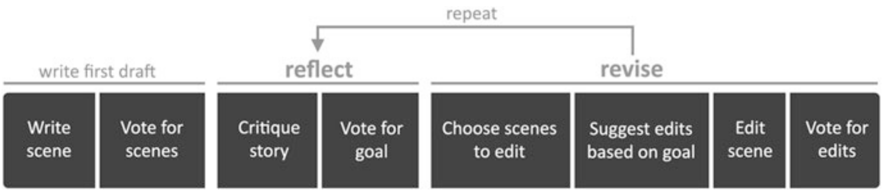

Fig. 1 Mechanical Novel's crowdsourcing loop alternates between high-level reflection to set a goal, and low-level revision to execute that goal

3.1 Designing Workflows Based on Expert Practice

Our technique takes inspiration from expert creative practice. Experts do indeed break down their work into smaller parts, but not independent tasks: rather, they continuously reflect on their work and use that reflection to revise their goals and decide what to do next (Flower and Hayes 1981). An author, for example, does not finish a story after simply linearly filling in a plot outline—they instead write and rewrite while continually reflecting on what their vision is and how to achieve it (Sharples 1999). Similar processes occur across many creative domains such as art, architecture, and writing (Schön 1983; Flower and Hayes 1981; Alexander et al. 1977). This process, looping between *reflecting* on progress to identify a goal and *revising* based on that goal, allows experts to "converse" with their work (Schön 1983) and evaluate options by trying them out (Pecher and Zwaan 2005). However, because crowd workers are typically not domain experts, this strategy needs to take the form of microtasks in order to use it in crowdsourcing systems. Our intent here is not to reduce storytelling to an impassive and mechanic series of steps; in fact, we chose storytelling as an example domain to help us develop the technique we describe in this chapter precisely because it requires a flexible process that can respond to flashes of inspiration and emotional sensibility. Designing for non-traditional work tasks (such as writing stories) may uncover new types of crowdsourcing and collaboration techniques that preserve the ability to respond to creative insight.

3.2 Initialization: Creating a First Draft

For Mechanical Novel to engage in reflection and revision, it must begin with a first draft. The first draft is authored using traditional iterative crowdsourcing strategies. Mechanical Novel initially takes a short prompt describing the overall concept of the story as input, such as "A young boy named Malcolm finds himself alone in a runaway hot air balloon and accidentally travels to a city in the sky." Based on this prompt, the crowd generates the first draft of a story that is six *scenes* long.[1] Scenes are the basic unit of writing work in Mechanical Novel; rather than allowing workers to edit any part of the text they like, the system restricts workers to editing within one scene during any task.

To do this, five workers each independently write a candidate for the text of a scene. Other workers then vote for the best candidate, and Mechanical Novel advances to the next scene. Scenes are written sequentially—from the first to the last—rather than in parallel, to aid workers in coordinating lower-level details such as character names, mood, or writing style. Though this sometimes results in chaotic stories that rapidly change direction, forcing sequentiality ensures that workers concretely define possible creative directions that later workers can choose from when deciding how to improve the story.

3.3 Reflect: Choosing a High-Level Goal

At this point, the crowd has created a first draft of a story, which is likely rife with narrative inconsistencies. To set a high-level goal for subsequent work, we break down the task of reflection into two steps. First, to generate possible goals to pick from, a new set of workers reads the current version of the story and then generates five critiques using the *I like—I wish—what if* method (Fig. 2) (d.school 2016). Using this method, workers each write one sentence about what they liked about the story ("I like…"), one sentence about what they wish were different about the story ("I wish…"), and one sentence suggesting a concrete change to the story that would make it better ("What if…?").

Then, to determine which goal is most pressing or interesting to pursue, other workers then vote for the critique they agree with most. The "what if?" with the most votes becomes the chosen goal for later work (e.g., "What if the story ended with Malcolm learning a lesson about the importance of family?"). In this way, workers identify a new goal for work by reacting to the problems present in the current draft.

3.4 Revise: Translate Goals into Actionable Tasks

The revision phase of work is divided into four steps. Workers first vote to indicate which of the story's scenes they think must change in order to achieve the goal. Voting for more than one scene indicates that there are dependencies in the story that require multiple parts of the story to change at the same time. For each scene

[1]This story length struck a balance between being long enough to make it difficult to coordinate work and short enough to complete in a reasonable amount of time on Mechanical Turk.

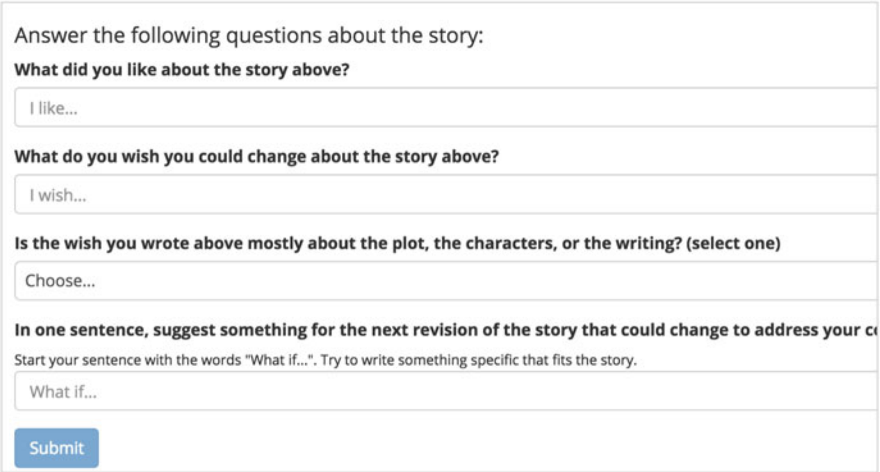

Fig. 2 Workers critique a story, reflecting on what is working and not working in order to choose a goal for their work

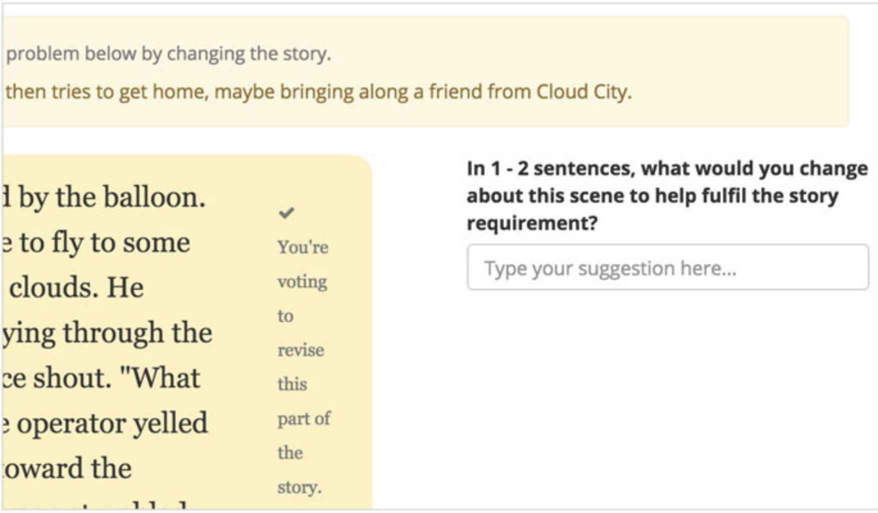

Fig. 3 Workers select scenes to unlock for revision, suggesting how each scene should change to help achieve the goal

they vote for, workers also must write a short one-sentence suggestion for how that scene must change in order to achieve the goal (e.g., "Malcolm should apologize to his grandfather in this scene.") to generate possible revisions to choose from.

Scenes that at least four (out of ten) workers vote for are then unlocked for editing (Fig. 3). For each of the unlocked scenes, a new set of workers vote for the suggestion they think best represents how the scene should change. The suggestions

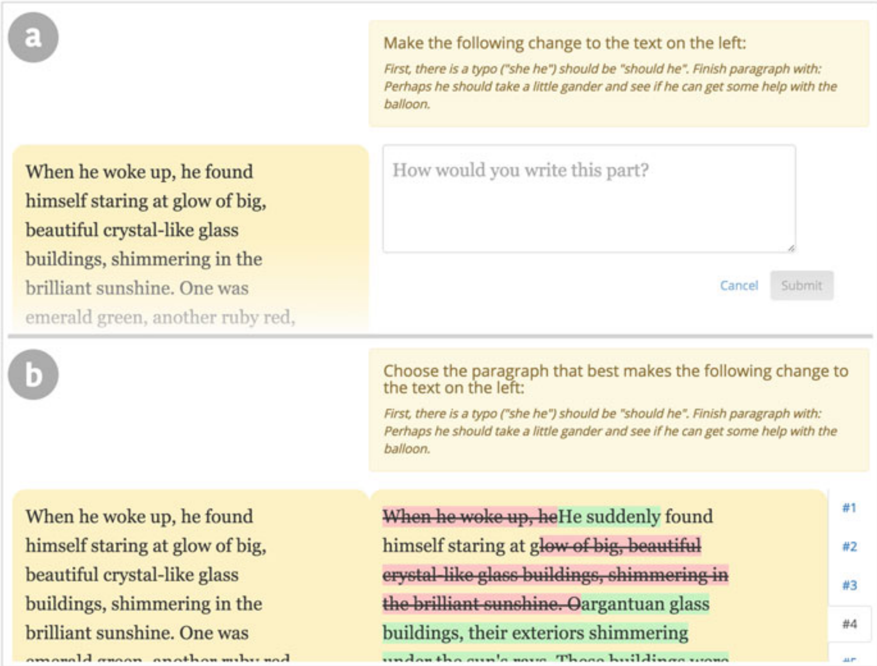

Fig. 4 (**a**) Workers propose changes to the story based on the high-level goal, (**b**) Workers vote on candidates based on the high-level goal

with the highest votes for each of the unlocked scenes become tasks that direct how the story should change.

Mechanical Novel then asks workers to sequentially fix each unlocked scene, presenting to workers both the high-level goal as well as instructions for incorporating the suggestion into the scene. Fixing a scene involves two more tasks similar to those used to write the first draft (Fig. 4); multiple workers propose new versions of the scene based on the task's instructions, then other workers vote for the version that best achieves the suggestion and the higher-level goal. This process is repeated across each unlocked scene. In this way, the high-level goal serves the purpose of restricting the space of possible contributions from workers.

At this point, workers continue to improve the story by returning to the reflection phase, reading the new version of the story and submitting another set of critiques. They then vote for a new high-level goal, split that goal into actionable tasks, and modify the story based on those tasks, resolving different problems with the story with each revision (Fig. 5). Currently, story writing stops after a predetermined number of revision rounds, but in future work, Mechanical Novel could allow the crowd to decide when to end the story (e.g., through votes).

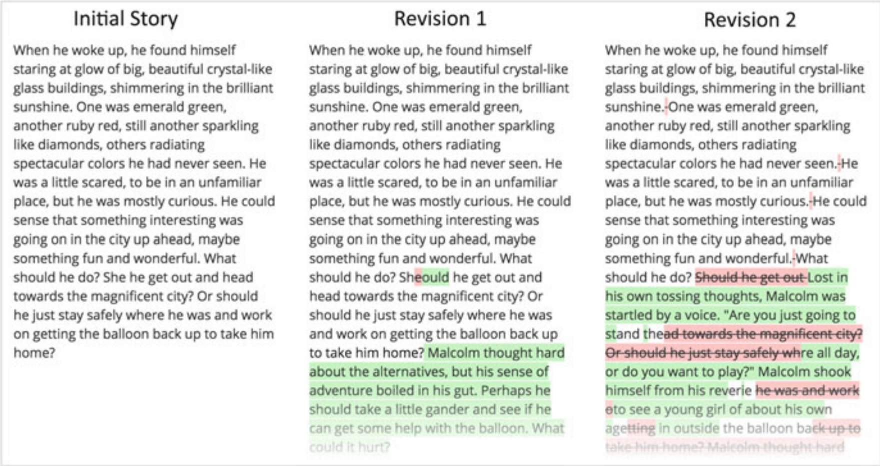

Fig. 5 A section of a story changing through revisions. Workers first expand this section's ending by having the character make a decision about what to do next, then further expand the story by adding a character who helps progress the story

4 Evaluation

Mechanical Novel hypothesizes that structuring work around reflecting and revising high-level goals can allow the crowd to collaborate on complex interdependent work such as fiction writing. In this section, we report on two evaluations exploring whether or not this technique resulted in higher quality stories. In sum, these evaluations find that Mechanical Novel produces stories that were overall preferred over those written using an iterative crowdsourcing strategy, and that it was especially effective at finding and fixing high-level plot issues.

Specifically, the first evaluation gauged how well Mechanical Novel could detect and fix known narrative issues in a series of benchmark stories. The second evaluation compared the quality of stories written by Mechanical Novel and a typical iterative (CrowdForge-style) workflow when given an open-ended story prompt.

Both studies consisted of two experimental conditions (Fig. 6): the *Mechanical Novel* condition, where workers wrote stories by reflecting on a first draft to choose a goal and then revising text, and a *control* condition, where workers wrote stories by voting for which parts of the story to edit and made independent edits to the story's text. The workflows in the Mechanical Novel and control conditions both included tasks where workers unlocked and edited scenes; the workflow for the Mechanical Novel condition included the additional step of reflecting to set a high-level goal.

Figure 6 shows the tasks workers did for each revision of stories in each study condition. All tasks were launched simultaneously on Amazon Mechanical Turk to United States workers with a task approval rating of 90% or higher. Tasks, including

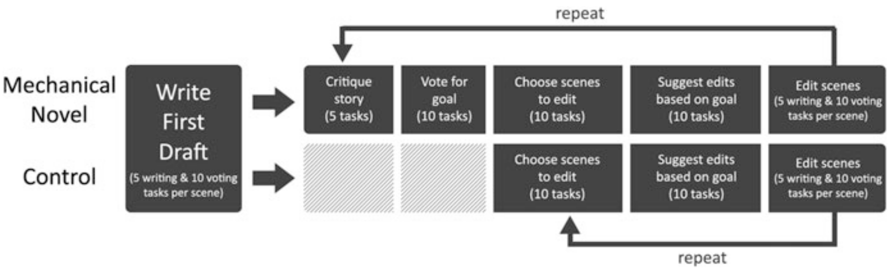

Fig. 6 The tasks launched on Mechanical Turk for each experimental condition

those used to generate first drafts, were estimated to take 2–8 min to complete. Because we wanted to prevent workers from doing tasks from different experimental conditions, we were unable to price different types of tasks individually; instead, we paid all workers based on the longest possible task (priced at $0.85 each to achieve at an hourly wage of at least the federal minimum wage[2] on average, in accordance with Mechanical Turk guidelines for academic requesters (WeAreDynamo 2014)). Workers who participated in our tasks were randomly assigned to one of the study conditions for the entirety of their interaction with the system.

4.1 Benchmark Study

Our first evaluation sought to measure Mechanical Novel's performance on six benchmark stories with known narrative issues. This evaluation helps us understand the kinds of high level goals that Mechanical Novel can set and execute.

We ran the Mechanical Novel and control versions of the system for a single revision cycle over six pre-written benchmark task stories, resulting in 12 stories. Each of the benchmark stories were modified versions of a single short story written by an expert with over 10 years of fiction writing experience (including a crowdfunded, self-published children's novel). Each modified version was changed by the expert to introduce one major problem each (Table 1). We chose both problems that can be fixed independently (such as fixing typos) as well as problems that span across the story (such as changing the way a character speaks) to get a better sense of Mechanical Novel's strengths and weaknesses.

To get a sense of how often workers were able to find problems in the benchmark stories, we tracked the number of times workers correctly voted to change problematic scenes. Two of the authors, blind to condition, then coded edits

[2]The federal minimum wage at the time of this writing was $7.25.

Table 1 The benchmark stories were modified versions of a short story created by an expert, each introducing a common storywriting problem

Problem	Description
Abrupt ending	The ending of the story is replaced with a sudden exclamation that the story was actually a dream all along
Extra characters	Dialogue and actions by unnecessary characters are added throughout the story
Odd dialogue	The main character, who is a child, is changed so that he speaks like an adult
Point-of-view change	The story changes from third-person to first-person narration halfway through
Typos	Grammar and spelling errors are introduced to some of the scenes in the story
Tell, not show	Character's actions are replaced with descriptions of boring or unrealistic behavior (e.g. "Malcolm's mother held a finger to her lips" v.s. "Malcolm's mother told him to be quiet.")

Table 2 The total votes cast by workers choosing which sections of the benchmark stories to edit, as well as the number of votes correctly identifying problematic story sections

	Control			MNovel		
Problem	N	Correct	%	N	Correct	%
Abrupt ending	30	9	30	31	19	61
Extra characters	30	13	43	30	21	70
Odd dialogue	31	15	48	30	20	67
POV change	30	12	40	30	17	57
Typos	30	15	50	32	3	9
Tell, not show	31	7	23	30	7	23

made to each story in each condition to track how often workers were able to fix the correct problem for each condition ($\kappa = 0.93$). This was repeated three times for each story, so each story had three separate chances to fix errors. Workers were randomized into one of the six stories within each condition, and were only allowed to contribute to one of the repetitions.

Results The benchmark study suggested that Mechanical Novel is effective at detecting high-level narrative problems (Table 2). Compared to the control condition, the Mechanical Novel condition resulted in significantly more Turkers correctly voting to change the problematic section of a story for the *abrupt ending* problem ($\chi(1) = 4.82, p < 0.05$) and trended towards correctly identifying problematic sections for the *extra characters* problem ($\chi(1) = 3.33, p = 0.068$) according to Chi-squared tests. The control condition, on the other hand, identified problematic sections containing lower-level issues such as *typos* ($\chi(1) = 10.51$, $p < 0.01$). Both systems were equally good at detecting *point-of-view changes* ($\chi(1) = 1.07, n.s.$) and *odd dialogue* ($\chi(1) = 1.40, n.s.$). In general, this reflects the relative strengths of each approach: Mechanical Novel fixed high-level narrative issues, whereas the section-by-section iterative approach fixed low-level technical problems.

Table 3 The total number of edits made by workers to benchmark stories, as well as the number of paragraphs that correctly corrected problematic story sections

	Control			MNovel		
Problem	N	Correct	%	N	Correct	%
Abrupt ending	8	2	25	3	2	67
Extra characters	7	2	29	4	0	0
Odd dialogue	11	2	18	10	5	50
POV change	5	3	60	4	2	50
Typos	6	2	33	7	2	29
Tell, not show	7	0	0	4	1	25

Likewise, Mechanical Novel's edits suggested that it can correctly address high-level issues relating to plot and character (Table 3), addressing the *abrupt ending* problem 67% of the time and addressing the *odd dialogue* problem 50% of the time. However, the low total number of edits makes it difficult to statistically distinguish Mechanical Novel's performance from that of the control workflow, which fixed these problems 25% and 18% of the time.

There did not seem to be a difference in how well either system was able to successfully detect or fix the *tell, not show* problem; in addition, while Mechanical Novel correctly identified scenes with the *extra characters* problem, it was not able to correct the issue. This perhaps indicates that, while enabling crowds to think about global elements such as character consistency and plot, Mechanical Novel is less effective at enforcing best practices (such as following the writing rule of "show, don't tell") that require workers to be knowledgeable and experienced in a domain.

4.2 Story Writing Study

After establishing that Mechanical Novel allows workers to collaborate to identify high-level goals and to execute them, we wanted to understand how well Mechanical Novel would perform not just in terms of correcting high-level errors but in terms of developing stories from scratch compared to a system representing the state of the art.

In order to ensure we would be able to compare the stories generated by Mechanical Novel and the control system, we seeded each system with the same first draft story text. Crowd workers began by generating five first draft stories—one for each of the five story prompts in Table 4. We then duplicated each first draft to create ten stories total. Five of these stories were then revised by the crowd using the control system, and five of these stories were revised by the crowd using the Mechanical Novel system. All stories underwent five rounds of revision. Workers who worked on tasks that generated text for the story were also asked to provide feedback on the task they accomplished, asking specifically about what their goals were in writing their contribution as well as what they thought was difficult about

Table 4 Each study condition included five stories, each based on the prompts above ("Number 16" was adapted from Reddit's /r/writingprompts)

Title	Prompt
The blue elephant	Kaley is a girl who spends all her time with an old Blue Elephant doll that was passed down from her grandmother. One day, it disappears
John Dough	A cutthroat businessman realizes that he's dead and has ended up in heaven, but he has unfinished business...
The hot air balloon	A young boy named Malcolm finds himself alone in a runaway hot air balloon and accidentally travels to a city in the sky
The high-waisted shorts	Emelia and her high school friends hang out on a normal day, when suddenly, she sees the ghost of a girl wearing beautiful flower-print high-waisted shorts
Number 16	A serial killer has been monitoring his next victim's movements for months. She is a loner and the perfect target. One day she disappears and nobody notices but him

the task. Workers were allowed to contribute to more than one story, but stayed in the same study condition across stories.

To evaluate each story for quality, we asked 215 Mechanical Turk workers who had not participated in any of the story writing tasks to compare a random pair of control and Mechanical Novel stories for one of the story prompts. After being shown each version of the story side-by-side (in random order), workers chose which story they thought was better along several dimensions, such as writing style and presence of story structure (Table 5). These dimensions were based on guidelines from a popular book on story writing (Burroway 2003). They also chose which of the two stories they liked better overall.

Lastly, we conducted a grounded theory analysis of how stories changed in each condition by coding the types of changes made in each condition as well as the feedback we received from the crowd workers who worked on writing tasks. Two of the authors, blind to condition, also independently coded each dataset according to emergent themes and resolved conflicts through discussion (paragraph edits: $\kappa = 0.74$; critiques: $\kappa = 0.86$; task feedback: $\kappa = 0.61$).

Results Five stories were written for the Mechanical Novel and control conditions, resulting in ten stories total written by crowdworkers on Mechanical Turk. Stories took an average of 11.38 days ($SD = 1.42$) to complete (based on the timestamps of the first and last interactions with the story). Stories were generated through a total of 428 Mechanical Turk tasks completed by an average of 224.5 unique workers per story ($SD = 15.63$).

When rating the final stories overall, workers indicated they liked Mechanical Novel stories better (133 votes for Mechanical Novel v.s. 82 votes for the control workflow; $X^2(1) = 12.098, p < 0.01$), according to a Chi-squared test.

Mechanical Novel Stories Developed Story Structure Readers rated Mechanical Novel stories as having significantly more complete plots ($X^2(1) = 28.698$,

Table 5 The questions asked to workers who compared the control and Mechanical Novel stories for each story prompt, as well as the number of workers who voted for the Control story or the MNovel story for each question

Category	Question	Control votes	MNovel votes
Imagery	Which story uses better imagery and description? A story with good imagery has description that is memorable and makes it easier to imagine what is happening in the story	52	162*
Coherency	Which story is more coherent? A coherent story has details that are consistent. The story makes sense and doesn't meander or jump around without explanation	98	115
Plot	Which story has a more complete plot? A complete plot has a beginning, middle, and end, with a conflict that arises and is resolved by the end of the story	67	145*
Originality	Which story is more original? An original story has a clear, interesting story premise	75	136*
Style	Which story better uses writing style to enhance the telling of the story? A story with good writing style chooses a voice and tone that makes sense given the story's content and contributes to the telling of the story	72	143*
Technical	Which story has less grammar and spelling mistakes?	130*	82
Overall	Which story did you like better, overall?	82	133*

$^{*}p < 0.05$

$p < 0.01$)—that is, readers indicated they viewed Mechanical Novel stories as having more of a complete story arc with a beginning, middle, and end compared to their control version counterparts. Readers also rated Mechanical Novel stories as having significantly more original story premises ($X^2(1) = 17.635, p < 0.01$). Considering that Mechanical Novel and control stories for the same story prompt started from the same first drafts, this may indicate that revising stories using high-level goals allowed story ideas to develop in more interesting ways, or that Mechanical Novel stories were more successful at maintaining the story idea established in the first draft.

The Blue Elephant story is an example of how Mechanical Novel was able to generate a more complete story arc. In the first draft of the story, the main character (a young girl) realizes her stuffed elephant is gone, looks all over it, and is finally reunited with it after finding that it has come to life. In the control condition, workers attempted to motivate the main character's actions by establishing that the young girl considers her elephant her best friend. They also add a reason for the elephant's disappearance by having the elephant say he had gone on an adventure.

Mechanical Novel workers, in contrast, revised the story's beginning to include a description of how Kaley received the elephant from her grandmother, which

Table 6 Workers in the Mechanical Novel condition were especially likely to expand characters, while workers in the control condition were more likely to rewrite a scene from scratch

Edit type	Control	%	MNovel	%
Expand characters	3	6*	14	37*
Improve flow	4	7	8	21
Add to plot	11	20	5	13
Clarify or cut text	10	19	5	13
Add story background	2	4	2	5
Change story's tone	1	2	2	5
Rewrite scene	10	19*	1	3*
Correct technical issues	9	17	1	3
Emphasize story's moral	4	7	0	0

$^{*}p < 0.05$

was the same doll her recently deceased mother had when she was a little girl. Workers called back to this backstory in the ending of the story, which reveals that Kaley's love for her grandmother is what brought the Blue Elephant to life, threading a specific theme through the whole story and tying it together.

Mechanical Novel Focused on Story over Proofreading Readers rated the control stories as having fewer grammar and spelling mistakes ($X^2(1) = 10.868, p < 0.01$), indicating that the workers in the control condition seemed to focus more on low-level edits and proofreading. In contrast, readers rated Mechanical Novel stories as having better use of imagery and description ($X^2(1) = 56.542, p < 0.01$) and as having writing styles that better matched each story idea ($X^2(1) = 23.447$, $p < 0.01$). The final versions of Mechanical Novel stories were also significantly longer than the final versions of the control stories ($t(4.77) = 3.65, p < 0.05$), with the Mechanical Novel stories having an average of 1010.6 ($SD = 226.15$) words, while the final versions of the control stories were an average of 623.8 ($SD = 70.47$) words long.

In sum, Mechanical Novel stories seemed to focus on fleshing out the story itself and how it was told, rather than focusing on local fixes such as missing punctuation or awkward sounding sentences. This is corrobrated by the analysis of types of edits that workers made to each story (Table 6). We found that workers in the Mechanical Novel condition made significantly more edits that had to do with expanding on descriptions of characters and how they would act ($X^2(1) = 12.49, p < 0.01$), while workers in the control condition trended towards more edits related to fixing grammar and spelling ($X^2(1) = 3.202, p = 0.074$) and completely reworded paragraphs significantly more often ($X^2(1) = 3.95, p < 0.05$). Table 7 also shows that Mechanical Novel workers favored high-level goals that improved high-level flow throughout the story over low-level goals (such as correcting spelling and grammar) and goals that would substantially change the story's concept (such as reordering paragraphs).

An example of this can be seen when comparing the Mechanical Novel and control versions of the John Dough story. The control story starts out with a

Table 7 The types of high-level critiques that workers made before starting a revision cycle in the Mechanical Novel condition, as well as the number of times a critique of each type was chosen as a high-level goal

Critique type	Suggested	Chosen
Add to plot	74	7
Add story background	16	3
Expand characters	37	2
Improve flow	10	2
Emphasize story's moral	5	1
Correct technical issues	18	1
Reorder or shorten story structure	5	1
Clarify or cut text	11	0
Redo the story's concept	7	0
Change story's tone	3	0

straightforward description of the character's surroundings:

> John Dough slowly awoke from a foggy haze. He sat up and immediately felt a searing pain shoot through the left side of his body.
>
> "Where am I?" he wondered out loud. John did not recognize the room he was in. Everything was white and pristine… white walls, white carpet, white couch and white table, and bright white lights. There was no window, and only a single door at the other end of the room.
>
> —control condition, John Dough

The Mechanical Novel story, however, uses first-person voice to create vivid imagery of the main character's thoughts and feelings as they wake up in an unfamiliar place:

> I awoke with a start, sitting up abruptly. There was a searing pain shooting through my body.
>
> "Where am I?" I thought to myself.
>
> I didn't recognize my surroundings. Everything was white and pristine; white walls, white carpet, white couch, and white table. No windows, a single door across the room… but somehow the room was intensely bright. Strange.
>
> —Mechanical Novel condition, John Dough

Mechanical Novel Allowed Workers to Coordinate Workers in the Mechanical Novel condition encountered less friction in contributing to the story. After analyzing the comments workers wrote (Table 8) after contributing story text (and revisions to text), we found that Mechanical Novel workers were more likely to explain their work as following the suggested changes (as informed by the high-level goal) created by previous workers ($X^2(1) = 9.56, p < 0.01$). Workers in the control condition, on the other hand, trended towards being more likely to try and focus the story's direction by introducing significant plot changes or twists through their local contribution ($X^2(1) = 3.56, p = 0.06$) and also included more critiques of the overall story in their feedback ($X^2(1) = 6.46, p < 0.05$) to justify the text they had written.

Surprisingly, nearly all accepted changes to Mechanical Novel stories were created by unique workers, with an average of 7.8 accepted changes per Mechanical Novel story ($SD = 1.48$) by an average of 7.4 unique workers ($SD = 1.34$).

Table 8 Workers in the Mechanical Novel condition were more likely to follow a high-level goal, whereas workers in the control condition were more likely to correct text or attempt to critique the overall story from within a single paragraph or scene

Feedback type	Control	%	MNovel	%
Description of changes	56	21*	103	40*
Inserted new idea	27	10	41	16
Refined or corrected text	99	36*	29	11*
Followed suggested changes	7	3*	24	9*
Improved story pacing	27	10	23	9
Continued other workers' work	10	4	15	6
Confusion or frustration with other workers' work	13	5	11	4
No change needed	11	4	4	2
Critiqued overall story	15	6*	3	1*
Set up opportunities for other workers	3	1	3	1
Too much work to change	1	0.4	0	0

$^{*}p < 0.05$

Revisions to control stories were distributed among workers similarly, with an average of 9.4 accepted changes per control story ($SD = 1.52$) by an average of 8.8 unique workers ($SD = 1.92$). There was no significant difference between study conditions in the number of unique workers whose revisions were accepted ($t(7.2) = 1.33, n.s.$). In addition, out of the Mechanical Novel workers who participated in more than one task, 62.2% participated in both reflect and revision phases of a story. Out of Mechanical Novel workers who completed at least three tasks, 92.2% did at least two different types of tasks and 70.6% did at least three different types of tasks. In other words, it was not the case that a few skilled workers were dominating story-writing tasks in Mechanical Novel.

Both Conditions Struggled with Coherency There was no significant difference between the control and Mechanical Novel stories in terms of how coherent they were perceived to be ($X^2(1) = 1.357, n.s.$)—that is, all stories were seen as lacking consistency in details (for example, in The Blue Elephant, workers did not resolve whether it was Kaley's mother or grandmother who had passed away). In addition, in their feedback, there was no significant difference between conditions on how often workers expressed frustration with having to struggle against earlier or later parts of the story ($X^2(1) = 0.009, n.s.$):

> That the person who wrote the paragraph before mine paid no attention to pacing and didn't seem to know much about hot air balloons. The "accidentally knocked unconscious" cliche was a bit annoying...
> —Worker, control condition, The Hot Air Balloon

5 Discussion

Through an analysis of how the crowd wrote stories through Mechanical Novel, we found that techniques for setting high-level goals—inspired by expert writers' process—helped the crowd produce stories with stronger narrative arcs and description compared to stories written using a traditional crowdsourcing workflow.

5.1 Enabling Flexibility and Encouraging Diversity

We also found that Mechanical Novel spread work across many unique workers, rather than allowing a few skilled workers to dominate the creative process. This indicates that the reflect and revise technique we use in this chapter provides a steady source of fresh perspectives on a complex task where creative exploration is necessary. The diversity of perspectives that this technique affords may expand the types of work crowdsourcing can support. For example, citizen journalism is recognized for its ability to disseminate news faster and with wider reach than mainstream news organizations. At the same time, much like crowdsourcing, it faces criticisms stemming from its decentralized nature; reports by citizen journalists are difficult to regulate and may not adhere to standards of quality, trustworthiness, objectivity, and ethics. While a professional journalist could help solve these problems, the presence of an expert also negates the value of citizen journalism as an alternative source of timely information. Enabling a crowd of decentralized contributors to revise and reflect together on the news they produce may preserve the ability to quickly propagate information while keeping each other's facts and biases in check through brainstorming and voting for a common high-level goal. In addition, the ability to continually revise and act on new goals may allow crowds to work together in generating stories around events such as natural disasters where centralized information is unavailable.

Reflecting and revising on work is also medium-agnostic and can be implemented as part of a crowdsourcing system regardless of the actual work task at hand. With Mechanical Novel, we found that workers submitted and voted for critiques and edits appropriate for story writing (such as those that focused on plot and character) without having the system specify desired input from the crowd. For this reason, one could imagine that the crowd could use this technique to flexibly support work that moves through different stages of production. Reflections on the script for a crowdsourced film, for example, could lead to revisions of a storyboard or casting choices. Then, the actual task of creating the film could be supported through existing crowdsourcing strategies and interfaces (e.g., Koblin 2010).

However, we also found that Mechanical Novel performed less well than the control system when it came to low-level work (such as correcting grammar and spelling errors). This may mean that reflecting and revising could be used in a complementary way with existing crowdsourcing patterns; for example, find-fixverify (Bernstein et al. 2010) could be used to refine the stories that Mechanical Novel generates.

5.2 Going Beyond Short Stories

At the same time, Mechanical Novel is currently limited by its assumption that the short story being generated is small enough to fit in the working memory of each worker. That is, a worker has to be able to read the whole story and make a critique in order to select a high-level goal for subsequent work. In addition, workers currently must be able to look through the entire story to flag which parts of the story must change in order to achieve the high-level goal. For the purposes of exploring the approach of decomposing crowdsourced creative work based on a goal selected by the crowd, we deliberately limited the length of each story so that it is possible for each worker to familiarize themselves with the story in a short amount of time.

How might this approach be used to generate a larger work? One strategy may be to apply the Mechanical Novel approach recursively, where workers could collaborate on the high-level structure of a story, then dynamically expand on individual chapters or narrative acts. Another strategy may be to make use of a working memory space for the crowd as seen in past work (Lasecki et al. 2013; Zhang et al. 2012) to further help direct work by letting future workers know the creative intent of past workers.

5.3 Designing Collaboration Around Reflection and Revision

Why does the reflect and revise technique work? Too much structure can undesirably limit the work that crowd workers do. An early version of Mechanical Novel allowed crowd workers to set high-level goals by having them brainstorm and vote on an outline, much like Crowdforge (Kittur et al. 2011). Our intent here was to allow workers to concentrate on brainstorming the bigger picture without having to worry about the details of how the story would actually be written. However, we found that workers would work within the outline far too strictly (similar to worker behavior seen in other highly-structured crowd systems (Kulkarni et al. 2012)). This made it hard for workers to explore a wide range of possible creative directions inspired by the story outline; they would not change much from the initial outline that was selected. This may be because crowd workers may err on the side of caution when told to make changes that may or may not be correct in order to avoid having their work rejected.

Instead, we had to design a way for workers to concretely explore possible creative directions. At first, we tried asking workers to brainstorm a theme or moral for the story that would ground later work. Though workers were generally able to select a reasonable theme to guide the next revision of a story, they had difficulty translating such an abstract high-level idea into concrete changes. Instead, critiques provided a way for workers to think about high-level changes in terms of what they wanted to story to specifically look like after revision took place. However, this means that the reflect and revise technique only works to the extent that non-experts can make evaluations. For example, the crowd may be able to select reasonable goals for changing the structure and flow of a research paper, but are less likely to assess a research paper in terms of how it compares to existing literature. Techniques such as scaffolding feedback (Xu et al. 2014) could help support the reflect phase of work in more specialized domains such as science or design.

Lastly, Mechanical Novel was designed around the constraints of Mechanical Turk, which rewards crowd workers for quickness and punishes workers for subpar work quality. A new kind of marketplace—perhaps one that encourages slower, thoughtful work or risky brainstorming—may better support the type of creative work described in this chapter. In future work, experiments that probe into the relative difficulty of reflection compared to revision may help define the optimal incentive scheme such a market should provide. For example, revision may benefit from thoughtful and careful work while reflection may work best when workers are asked to make snap decisions (or vice versa); this, in turn, may require different reward systems (such as rewarding based on quantity versus quality).

6 Conclusion

In this chapter, we enabled crowds to collaborate on complex creative work through a technique where the crowd *reflects* on their work and translates those reflections into concrete *revisions* of the work. When crowdwork is structured around reflection and revision, workers can identify and execute high-level goals even when work cannot be easily split into independent tasks. This approach allowed workers to detect and fix high-level storytelling problems and resulted in higher quality stories than those written using a traditional crowdsourcing workflow. Reflection and revision's focus on high-level work may be an effective complement to existing crowdsourcing techniques.

Mechanical Novel suggests the possibilities that arise if we start to think of crowdwork not just as a collection of tasks to complete but as a collaborative activity that workers themselves can influence. Wisdom—even that of the crowds—comes not from blindly following orders but from dialogue, reflective practice, and revision.

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Appendix

Below is one of the stories that workers wrote using Mechanical Novel.

When Kaley was five, she was given a very special gift by her grandmother, a beautiful blue stuffed elephant. This wasn't just any stuffed elephant—it was a handmade stuffed elephant created for Kaley's mother when she was just a girl, that she had loved dearly. Her mother had passed away when Kaley was a baby and so Kaley was raised by her grandma. The grandmother did her best, but there was always something missing, which made this elephant extra special because it made Kaley feel like she still had part of her mother with her, even though she knew that was crazy. Kaley not only loved her blue elephant because it belonged to her mother, but the elephant also became her best friend. The elephant was always the guest of honor at her tea parties and always slept by her at night and Kaley always felt safe as long as the elephant was with her.

Kaley often asked her grandma to tell her stories about her mother. She would sit on her lap and hold her elephant while grams told her lovely things about her mom. She loved those precious moments and wanted to ask grandma for a story later on. She couldn't wait! Holding her special elephant and hearing these moments from her mother's life was comforting to her.

What Kaley didn't know was that the elephant was indeed a very special elephant, special beyond her wildest imagination. Because Kaley's mom had loved the elephant so dearly, a part of her had lived on through the elephant. On the morning of Kaley's sixth birthday she woke as the sun danced across her bed and was excited for her party that day. "Elephant!" she exclaimed, "Today is my birthday and we shall have guests, and cake and presents!" She turned to hug the blue elephant in excitement, but the elephant was gone. "How strange." she thought to herself as she looked to the side of the bed. No elephant there. She climbed down to look under the bed for the elephant but no elephant there either. She sat back on her heels as she was puzzled at where her elephant could be. "How could it have just disappeared?" she thought to herself. Kaley was soon to find out how and just how special her blue elephant really was.

It's not like blue elephants just get up and walk away on their own.... or do they? Kaley's blue elephant wasn't like other blue elephants, that's why she always wrote his name in capital letters in her diary and when she wrote short stories at school. "Blue Elephant", just like that. That was his name, after all! Kaley's elephant was blue with a long trunk. She got it from her grandma when she was young and it has been with her ever since. She got it on her 5th birthday as a gift. Maybe he did just get up and walk away. I wouldn't be a bit surprised! I better go look for him right now!

Kaley started her search for the Blue Elephant. First, she searched her room looking in every nook and cranny. No Blue Elephant. After a very long day of searching and not finding Blue Elephant, Kaley started to cry. Kaley's mother had an idea.... She gave Kaley some peanuts to put out to help catch Blue Elephant.

Finally Kaley fell asleep for the night. When she woke up in the morning, Blue Elephant was in her bed with a stash of peanuts.

The girl called for the elephant as loudly as she could. He must have heard her, his big ears make it possible to hear from miles away. If he were trapped or something he would surely be able to send a reply with his giant trunk. She wondered where he could be and wandered down the road calling loudly for him. Every few steps she would sit still and listen for him. Then, she thought she heard a muffled reply and put her ear to the ground. She felt the soft thump of an elephant from a far away distance.

Sure enough, Blue was floating gleefully in the pool spraying water triumphantly from his trunk. Kaley could scarcely belief her eyes, but the glee of her imagination took hold and she yelled in joy,

"Blue! Blue! Is that you?"

At the sound of her voice, the little elephant turned his trunk and blew water all over her. Leaving her soaking wet and giggling at her silly little friend.

"How did this happen?" asked Kaley. The blue elephant was delighted to answer her question. "You see, Kaley, it was through your love and adoration that I was able to come to life! If it weren't for you I wouldn't be here. Remember that wish you made the day before since? Well, it came true! The spirit of your grandmother lives on, in me. She wanted nothing but for you to be happy. Because of your love I'm here and will answer anything you ask" Shocked, Kaley took a step back and assessed the situation. "Well, I suppose this wasn't such a bad wish!" She thought about what she would ask but really all she wanted was to tell her grandma that she missed her "I miss you grandma, you were gone too soon…" " Your grandmother would be happy to hear that Kaley and please tell your mother that she loved her no matter how things turned out". " Elephant? Are you going to stay?" " I'm afraid not. Grandma's spirit has given me only a temporary time with you and it's just about to expire" Just like that the dol started to glow and landed in Kaley's hand. Kaley hugged the doll. A doll that she will forever cherish.

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Mosaic: Designing Online Creative Communities for Sharing Works-in-Progress

Joy Kim, Maneesh Agrawala, and Michael S. Bernstein

Abstract Online creative communities allow creators to share their work with a large audience, maximizing opportunities to showcase their work and connect with fans and peers. However, sharing in-progress work can be technically and socially challenging in environments designed for sharing completed pieces. We propose an online creative community where sharing process, rather than showcasing outcomes, is the main method of sharing creative work. Based on this, we present Mosaic—an online community where illustrators share work-in-progress snapshots showing how an artwork was completed from start to finish. In an online deployment and observational study, artists used Mosaic as a vehicle for reflecting on how they can improve their own creative process, developed a social norm of detailed feedback, and became less apprehensive of sharing early versions of artwork. Through Mosaic, we argue that communities oriented around sharing creative process can create a collaborative environment that is beneficial for creative growth.

1 Introduction

Online creative communities today focus on showcasing completed work, creating a climate where creators aim to produce work that is as impressive as possible to attract viewers and fans. In communities like those focused on art (Deviantart 2016), writing (Wattpad 2016), and design (Behance 2016), a creator shares *outcomes* by uploading finished pieces that are rewarded by views, favorites, or comments from others. The more views, favorites, and comments a submission gets, the more likely it is to appear in front of potential fans and other creators. Complementing these outcome-oriented communities, creators carve out *process*-oriented spaces aimed at learning new techniques and receiving feedback from others, sharing in-progress work (e.g., /r/artcrit 2016), creating and curating tutorials (Torrey et al. 2007), or organizing events specifically for tackling creative challenges (Conceptart.org 2016).

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But despite these efforts, creators encounter barriers to receiving thoughtful feedback in these online spaces. These barriers include the inability to tell which users are open to unsolicited feedback (Marlow and Dabbish 2014) and a lack of mentors (Guo 2015). But most notably, simply posting work in the critique section of a creative community requires a creator to compete with finished work posted by others, discouraging the sharing of early work when feedback might be most useful. For example, on DeviantArt, users browse submissions by viewing single-image thumbnails (so that creators must optimize for views by creating single images that result in attractive previews); on /r/DestructiveReaders, a community centered around critiquing writing on reddit (/r/destructivereaders 2016), writers often ask for help by posting a link to their story (mirroring the way content is typically shared on reddit as a whole), omitting useful information such as their goals or what they have tried already; and on creative communities within Facebook and Tumblr, users feel they are spamming the community with unwanted content if they make multiple posts about the same creative work over time.

Instead, what if creative communities were designed to allow creators to share creative process as first-class content? Rather than just sharing finished work, creators could share in-progress snapshots of work to illustrate what they did and why. Effective deliberate practice of a skill involves continually assessing one's creative process based on feedback and exploratory experiments (Ericsson et al. 1993; Schön 1983). Focusing on mastery (Block et al. 1971), rather than performance, can increase self-perceptions of task-oriented confidence, especially for novices (Dow et al. 2010). Focusing on improving one's process can also have a significant effect on the quality of creative output: without engaging in a broad exploration of ideas, creators can experience fixation (Jansson and Smith 1991), but developing multiple ideas in parallel can produce a wider range of ideas and higher quality results (Dow et al. 2010). By designing an environment that rewards sharing early work and clear explanations, instead of just rewarding good outcomes, we may create opportunities for creators to not only learn specific techniques from each other but also enable them to reflect more effectively on their own work.

In this chapter, we focus on painting and illustration as an example of a domain especially dominated by outcome-oriented communities. To look at the types of interactions that arise when creators are instead able to focus on sharing process, we designed and launched Mosaic, an online social art platform where the primary method of sharing artwork is to upload multiple images illustrating the steps taken to complete it. By encouraging creators to show how their work develops over time, we enable an environment that values the communication of ideas and techniques. We launched Mosaic and conducted an observational study in which 49 users created 76 Mosaic projects. These users successfully used work-in-progress steps from others to reflect on their own creative processes and wrote specific feedback for others. In addition, users expressed feeling less apprehensive about sharing early work on Mosaic compared to other creative communities they frequent, in part because Mosaic served as a social environment where it felt normal to do so.

This chapter suggests that building social systems for collaborative learning and growth require different social affordances than those developed for communities centered around sharing outcomes. It contributes online community design patterns and a system that demonstrates examples of such affordances. Mosaic focuses specifically on illustration and art, but these design patterns may generalize to communities centered around many creative domains including music, film, writing, and design. More broadly, we argue that planning, mistakes, experiments, techniques, and inspiration are normally hidden in social computing designs because they showcase finished work—but that these activities are valuable to communities where members may want to learn and support one another in their individual journeys of professional development.

2 Related Work

Mosaic's design draws from previous literature on the design of online creative communities as well as work studying creativity support for both novices and experts. In particular, it is inspired by existing practices for sharing information about creative process and how those practices support (and fall short of supporting) creators' goals.

2.1 Online Creative Communities

Creators who share a domain of interest often come together in communities of practice (Wasko and Faraj 2005); with online technology, creators from all over the world can build relationships with like-minded peers, learn new techniques, collaborate on projects, and work towards establishing their reputation in a community (Nov et al. 2009; Kuznetsov and Paulos 2010). For example, a community might host contests or challenges where participating users create work based on the same theme, or provide social features such as messaging and forums that allow users to collaborate in co-producing work. In addition, an online creative community giving feedback to each other can, in aggregate, provide positive mentoring experiences distinct from traditional offline mentoring (Campbell et al. 2016). The interactions that users engage in on these communities may differ depending on whether users consider themselves professionals or hobbyists (Marlow and Dabbish 2014). Existing communities cover a wide range of interests, including songwriting (Settles and Dow 2013), photography (Nov et al. 2009), animation (Luther et al. 2010), and more. In this chapter, we focus specifically on communities centered around painting and illustration. On these websites, users typically submit an image representing finished work (optionally accompanied by a short description), which allows them to build up a profile page that houses all of their submissions and acts as a portfolio of their activity.

The way these communities are designed has significant effects on how users understand who their audience is (Marwick et al. 2011) and how they interact and work with each other (Erickson and Kellogg 2000). For example, in online design communities, novices use signals of attention (e.g., likes) to determine which pieces of work to learn from and may tune their own sharing behavior to mimic strategies they see being used to share popular work (Marlow and Dabbish 2014). As another example, interfaces that allow users to make judgments about the trustworthiness of others are essential for successful online collaborations (Luther et al. 2010). Leaders of collaborations, too, often bear a large burden to maintain group awareness, but interfaces can mitigate this responsibility by making group activity, signals of trust, and tasks to be completed concrete and transparent to the larger collaborating group (Luther et al. 2013). Models of successful creative processes (Settles and Dow 2013)—information that is normally invisible—could even be embedded in tools to encourage best practices, help creators find suitable collaborators, or help them figure out how to proceed in their work (Matejka et al. 2009).

Other work explores how larger crowds can come together to collaborate directly through the use of competitive marketplaces (99designs 2016; Threadless 2016), combining previous work by others (Yu and Nickerson 2011), leader-generated constraints (Kim et al. 2014), remixing (Hill and Monroy-Hernández 2013), training non-experts (Dontcheva et al. 2014), structuring the iterative feedback process (Xu et al. 2015; Luther et al. 2015), and dynamically coordinating work by specialized experts (Retelny et al. 2014). While we do not focus on direct collaboration in this chapter, Mosaic builds on work that has shown how peer production can be improved through design and explores possible affordances for peer-supported learning and development. The design affordances Mosaic explores in the domain of sharing works-in-progress could be applied to crowd creativity work to enable more effective collaboration.

2.2 *The Effect of the Creative Process on Outcomes*

The process taken to create something can have a significant impact on creative outcomes; for example, prototyping several different designs for an advertisement in parallel (rather than iterating on a single design) results in better-performing ads as well as increased personal confidence for novices (Dow et al. 2010). These immediate effects on self-perception can also improve a creator's long-term ability to persevere (Dweck 2006). Conversely, a process where the creator chooses a design concept too early can result in design fixation (Jansson and Smith 1991), which can limit idea generation, even in experts (Cross 2004). Further complicating the creative process is the observation that a design problem can change as a creator explores solutions (Schön 1983), requiring the creator to be able to flexibly change their goals as they work.

Previous work has looked at specific interventions to the creative process to try and improve creative outcomes. Looking at examples can help an ideator expand their design space by allowing existing ideas to be combined and reinterpreted (Herring et al. 2009), but only when examples have certain properties (Chan et al. 2011; Siangliulue et al. 2015a). The timing of when examples appear in the creative process is also important; earlier tends to be better (Kulkarni et al. 2014), and ideators that are presented with ideas when they are stuck present more ideas than those who are presented with examples at regular intervals. In fact, being presented with examples at regular intervals is worse than being presented with no examples at all (Siangliulue et al. 2015b). Other work has looked at using a shared idea map to help groups generate diverse ideas collaboratively (Siangliulue et al. 2015a), and even aiding in emulating specific expert strategies directly (such as by automatically generating drawing guidelines (Lee et al. 2011)). This body of work shows how influencing the creative process can change creative outcomes, but it is still unclear how to incorporate these findings into creators' everyday practice. This can be especially difficult due to the fact that the process behind shared online work is often hidden. Mosaic, instead, attempts to complement this work by presenting a design for a social environment that helps creators focus on improving not just *what* they produce but also *how* they produce it.

Even without altering the creative process itself, simply reflecting on the creative process may help a creator think about new possible directions. Building a personal history using a timeline interface can provide a vehicle for identifying and reminiscing on key events (Thiry et al. 2013) and drive people to generate new interpretations of the past (Hodges et al. 2006; Petrelli et al. 2009). We may see similar benefits among artists asked to document their practice through Mosaic. In addition, Mosaic users can reflect on their processes with others through the form of feedback, which may help them identify gaps between their intent and how others perceive their work (Feldman 1971). Those who help by participating in this reflective process can also benefit from newly generated insight (Boud et al. 2014).

3 Formative Study

To better understand the challenges that creators face in the creative communities they use to share their work, we conducted semi-structured interviews with ten intermediate-level creators (nine female, one male) recruited through posts in anime, video game, and comic fandom art communities on Facebook, Tumblr, and DeviantArt. Creators' ages ranged from 18 to 39 years old ($M = 27.4$), with occupations ranging from college student, full-time freelance illustrator, and QA developer. All participants had been or currently were active users of DeviantArt, and most additionally created posts about their art activity a few times a week on other social media platforms such as Facebook, Tumblr, Twitter, and Instagram.

Six of ten interview participants described their use of existing social media platforms for sharing art as oriented around exposure; they also described these platforms as not very useful for feedback, but use them anyway because they want to reach as many potential fans as possible. Eight interview participants stated that they occasionally post single snapshots of in-progress work on online communities, but these serve mostly as a social update to engage those who follow them. Three participants mentioned that they had never documented their process in a step-by-step format at all, being unsure as to whether it was something their audience wanted or because they were not confident that they could successfully teach others. One participant mentioned being explicitly told to stop posting in a Facebook community after having uploaded several images about a project in a row.

Attempts at sharing the process behind their own artwork was met with various barriers, with four participants describing the interface design of these existing platforms as the main obstacle:

> You're trying to keep it in one post, but it's so much to keep track of... It was just, I guess, a lot of UIs and everything not really designed for that kind of thing where it's just...
>
> Then on DeviantArt, my god. Trying to get all the screencaps into one gigantic document was just ugh. —P8

Despite only being able to see the final outcome most of the time, the way interviewees viewed other artists' finished work on existing creative communities was in terms of process. Six participants said seeing good artwork fueled inspiration for them, but nine participants also explained that this was paired with a struggle (or even an inability) to demystify how the outcome they were seeing was achieved.

These interviews suggested that despite the popularity of creative communities online, and despite a desire to share and get feedback on process, many creators do not find the social and technical affordances of existing communities appropriate for process-oriented content. Exposing process was seen as helpful behavior that creators wanted to do but could not for technical or social reasons. We address these needs in Mosaic, an online creative community where the main method of sharing work is to expose creative process.

4 Mosaic

We know that orienting learning and creative support around the creative process can result in benefits such as increased confidence and higher quality creative outcomes, but the design of online communities often presents barriers to creators who want to share information about their process.

To explore potential designs for a community that enables social interactions oriented around creative process between artists, we created Mosaic: an online social platform where creators share artworks-in-progress. With the design of Mosaic, we envisioned a community where members are encouraged to share struggles in addition to successes, reflect on possible creative directions, and give and receive feedback informed by a creator's intent and goals for a piece of artwork. In this section, we describe how Mosaic allows creators to improve their own creative processes and those of others.

4.1 Projects and Works-in-Progress

In Mosaic, the main unit of content is called a *work-in-progress* (Fig. 1). The work-in-progress is an image (either a photo or a screenshot) of a creative work that is not yet complete. This image is accompanied by a title and a short caption describing the image. For example, an artist starting work on an oil painting may create a work-in-progress representing their first step (e.g., drawing a sketch). This work-in-progress would include a description of any reasoning behind their step (e.g., why they chose a certain type of subject matter or how they chose a certain visual composition).

Creators can group works-in-progress in a *project* (Fig. 2), which represents a single creative work. That is, an artist working on a landscape painting may post a project representing that painting, adding works-in-progress representing stages of the piece as they go (e.g., Sketch, Mid-tone Wash, Blocking Shapes, Rendering Details). Optionally, creators can flag their project with a request for critique, which signals to other users that they are open to detailed feedback. Mosaic users can search works-in-progress using a search form that matches on text; if a user searches for "sketch," they will be able to view all projects that contain a work-in-progress representing a sketch.

Social features enable artists to view what others are doing. The homepage consists of a feed of recent activity from the Mosaic community as a whole, showing comments, new projects, and updates to projects (that is, new works-in-progress that have been added to a project). Users are also able to follow other users and favorite projects so that they can be notified with an email when a user they follow creates new work or a project they have favorited is updated in any way. Lastly, users are

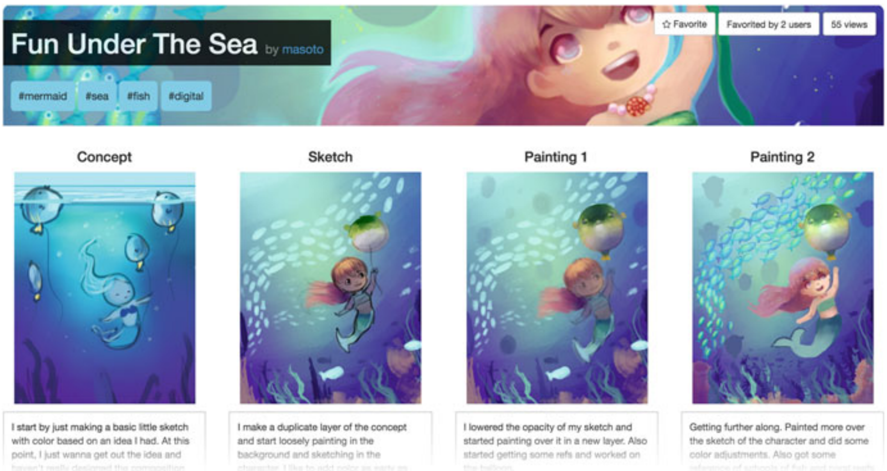

Fig. 1 Mosaic allows artists to share not just completed artwork but also their creative process (*Fun Under The Sea* by masoto)

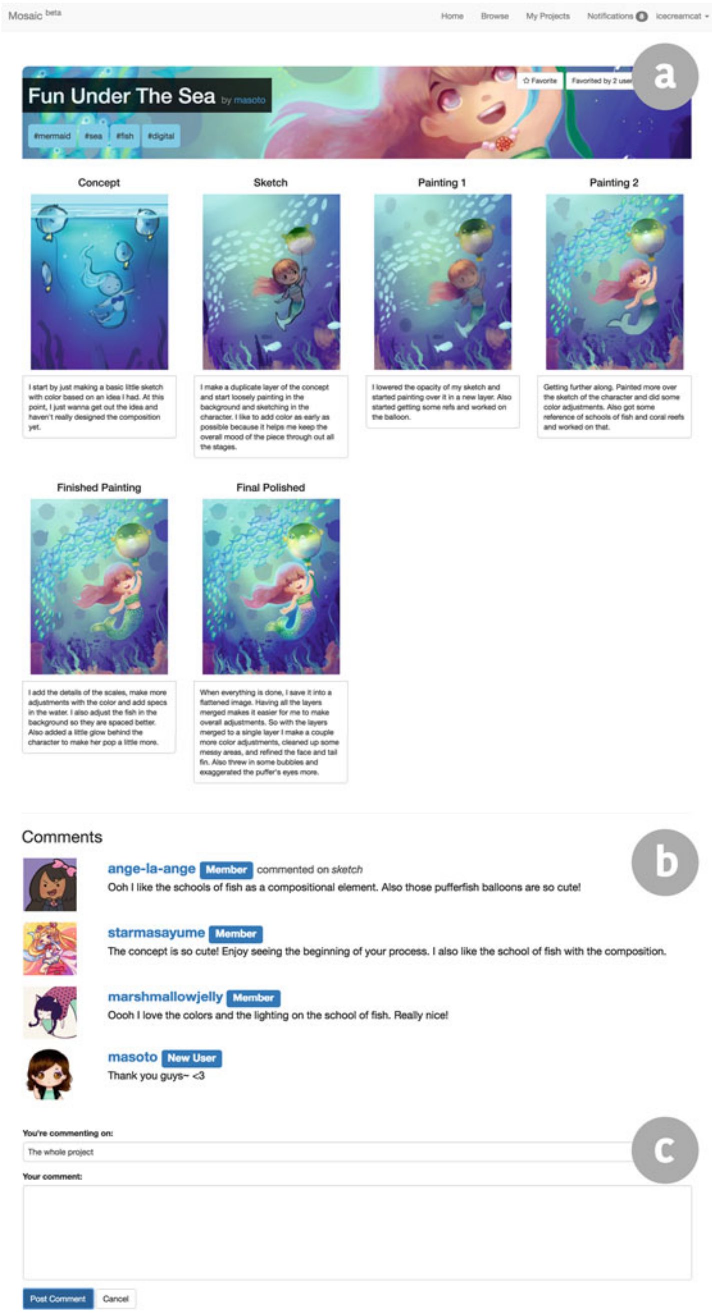

Fig. 2 (**a**) A Mosaic project consists of several snapshots of the artwork as it developed over time, including explanations by the artist describing what they did in each step and why, (**b**) Comments in Mosaic tend to be specific and considerate of the artist's creative intent, (**c**) Other users can comment on projects

able to comment on projects to share encouragement, feedback, or links to external resources.

4.2 Scenario

Making works-in-progress a first-class unit of shareable work normalizes a number of social interactions that are difficult on existing online creative communities. Below, we walk through a scenario illustrating some of the social advantages of using Mosaic to share creative work.

Receiving Helpful Intermediate Feedback Dawn is a novice artist who wants to be a professional illustrator. Though she has taken art classes through school in the past, she recently started taking artwork more seriously. Dawn joins Mosaic and, after being welcomed to the website, is prompted to upload a photo or screenshot of whatever piece of artwork she's currently working on. A few days ago, Dawn started work on small watercolor piece for a friend's birthday, so she creates a new *project* titled "Watercolor Gift" and then adds a *work-in-progress* to this project by taking a photo of her sketch so far and typing a short caption about her thought process behind the sketch.

Haruka is a freelance digital illustrator who is already a member of Mosaic. While browsing projects through the feed of recent activity seen on the Mosaic homepage (Fig. 3), she sees a thumbnail of Dawn's project so far. The piece seems to be of a sketch of a person; Haruka has recently been studying anatomy and decides to takes a look to see if she can learn from this project. After clicking the project, she notices a mistake in the sketch, and leaves a comment.

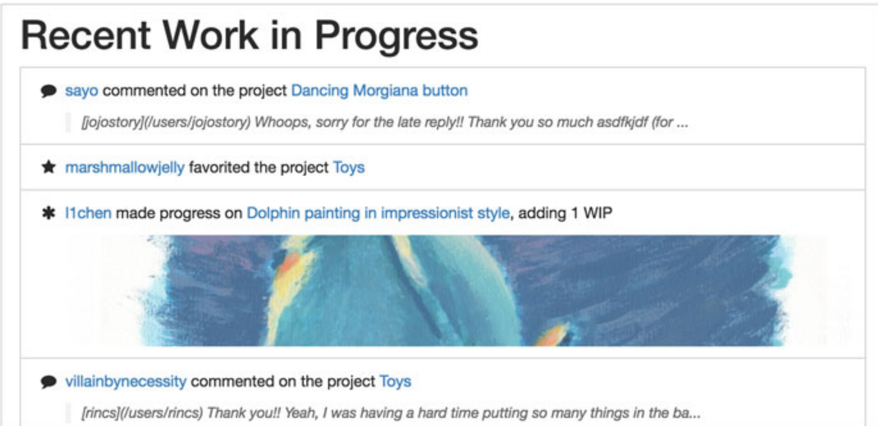

Fig. 3 Users are shown a feed of recent activity when logged in and activity in Mosaic is centered around progress made on projects rather than on finished artwork

Dawn receives an email notification about a new comment and logs into Mosaic. She realizes that Haruka is right about the mistake, and revises the sketch to address the issue. She takes a new photo and adds a new *work-in-progress* to the existing *project*, again accompanied by a caption summarizing the mistake and her solution. She leaves a comment responding to Haruka to thank her for the feedback, and makes a mental note to look out for similar anatomy mistakes in the future.

Later, after adding several more *works-in-progress* photos to her project, Dawn finishes her watercolor piece. She posts the link to her Mosaic project on her social media accounts, noting that she receives a few likes and followers from posting content about her creative process.

Learning New Techniques Dawn is looking to start a new project and starts to browse Mosaic (along with other art community websites) for inspiration. In Mosaic, Dawn clicks on a few watercolor projects that seem visually similar to her own style, but notices from looking at the work-in-progress photos and captions that some of them are created with similar techniques used in a slightly different order. Others show a work-in-progress that shows the use of an additional technique that results in an unusual visual effect that Dawn has never tried before. Dawn feels motivated, and thinks about a project that would let her practice this new technique.

Dawn creates a sketch and uploads it as the first work-in-progress for a new project. However, while trying this new technique on scratch paper, Dawn finds she's having trouble getting it right. She takes a photo of these attempts and adds it as a new work-in-progress, noting in the accompanying caption that she's stuck. Dawn edits her project to flag it as requesting critique, which adds it to a special feed of projects that are occasionally emailed to users who choose to participate in giving feedback. Dawn later receives a clarifying comment from one of these users about the photo she uploaded, which lets her get unstuck.

Secondhand Learning Haruka is similarly struggling with a new technique for a digital painting she is working on. She normally creates illustrations in a cartoony style that makes use of solid colors and clean lineart; Haruka now wants to experiment with a more painterly look with her illustrations, but is having trouble figuring out how to do this efficiently. She uses the search function of Mosaic (Fig. 4) to filter for other projects that use that technique and look similar to her desired result. After finding a few suitable examples and examining their works-in-progresses, Haruka finds that she can use her old style of illustration until she is happy with the colors and lighting, then paint on top of this refine her illustration and hide lineart.

Haruka also knows that one of her favorite artists on Mosaic uses this technique in the same digital painting program as she does, so she leaves a comment on one of that artist's projects asking for more details about how this technique is done in that particular program. The artist later responds, and even updates the work-in-progress captions in their own project to address Haruka's question.

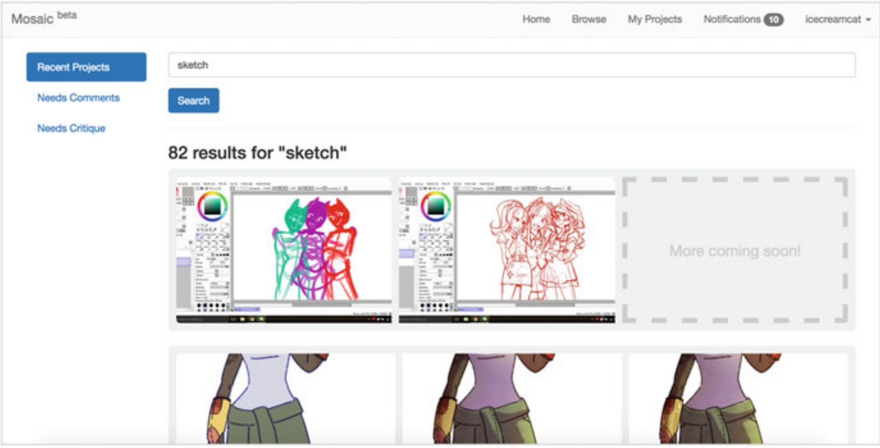

Fig. 4 Users can search for projects by content or by techniques used

4.3 A Focus on Process

The above scenario highlights a key aspect of Mosaic's design: rather than focusing on showcasing final outcomes, Mosaic structures social interactions around units of content that show the process behind creative work. As a result, creators are able to directly ask for and receive help informed by the context of the creator's current skill level and their creative intent. The content shared on Mosaic is directly related to creators' goals to improve their process and learn new techniques. In addition, Mosaic unlocks a number of interactions we know to be useful to creativity, such as being able to express intent (Feldman 1971), receive feedback during the creative process (Siangliulue et al. 2015b) rather than afterwards, reflect on progress (Schön 1983), and determine when to reach out to others (Erickson and Kellogg 2000). Mosaic can be visited at http://www.artsaic.com.

5 Evaluation

We designed Mosaic based on the hypothesis that sharing creative processes is difficult for creators because existing creative communities are designed to maximize the benefits of sharing creative outcomes. Instead, we propose an alternate design for a community designed around works-in-progress and seek to understand the types of interactions between creators that might result from such a design. In this section, we report on an evaluation where we explored how this process of generating and sharing works-in-process strengthens creators' abilities to reflect and allows a community to generate more meaningful feedback and support for its members.

5.1 Method

In order to understand the difficulties artists face when seeking or sharing works-in-progress online, we conducted a field deployment of Mosaic to provide a meaningful example with which artists could compare and contrast against their past experiences. In contrast to a controlled study (which would require growing a control community without the draw of an established user base), a field deployment allowed us to prototype a design for a community for sharing process, to probe for existing practices surrounding works-in-progress and sharing knowledge, and to learn about ways in which Mosaic might disrupt or support these practices. This also allowed Mosaic users to compare their experiences on Mosaic with their current activity in communities they already frequent.

Over the course of 4 weeks, we launched Mosaic as an open beta and invited users from other hobbyist art communities to use Mosaic as a way to give and receive critique and as a platform for hosting and sharing in-progress work. To ensure that artists would be able to provide meaningful feedback to each other, we recruited from communities of artists with roughly similar backgrounds that had a wide range of skill levels (in this case, beginner to advanced intermediate artists from anime/video game/comic fandom communities from Facebook, Tumblr, and Deviantart). During this time, we logged all community activity, including the creation of projects, works-in-progress snapshots, project favorites, user follows, and comments.

Because we wanted artists to create artwork they were personally invested in, we structured this study around the idea of creating a zine that would eventually be printed and advertised and sold to peers and fans in the community. Zines are typically small self-published anthologies of artwork created on a theme and, because of their self-published nature, are an accessible and popular way for creators of all skill levels to promote their work. In many online communities, they are often created as collections of fanart or fanfiction. On a practical level, zines provide opportunities for artists to meet each other and to cross-advertise their work. For this reason, we specifically recruited artists who worked in two-dimensional digital or traditional media. The zine will be compiled as a digital PDF and made available for download online.

Artists who signed up on Mosaic were prompted to upload projects, which they could optionally submit to the zine. One submission per artist was allowed, though Mosaic users were able to create as many Mosaic projects as they liked. We allowed users to post both work they were currently working on as well as work-in-progress snapshots they may have had from previous work. Additionally, a peer voting round was used to select the artists that would be included in the zine, further incentivizing artists to do their best for the study task. The first 30 artists who made submissions to the zine were given a $40 gift card.

We also conducted semi-structured interviews with the same ten artists who were interviewed during our formative study, all of whom were participants in the deployment. Interview questions focused on their background and goals as an artist, the perceived benefits of sharing and viewing works-in-progress, the dynamics between themselves and other users on Mosaic, perception towards feedback both received and given, and attitudes toward the artwork they created during the study period.

In order to understand how creators explained their own work and what motivated them to communicate with each other, we analyzed Mosaic comments and projects as well as the responses from our semi-structured interviews. First, to analyze Mosaic comments and projects, the first author generated codes by looking for recurring patterns in the text written by users for comments and works-in-progress. Using these codes, two researchers independently coded the same randomly selected subset of comments and works-in-progress (works-in-progress: $\kappa = 0.64$; comments: $\kappa = 0.65$) and discussed disagreements in codes. Code definitions were revised to resolve disagreements. The remaining dataset was split in half and separately coded by each researcher using the new codes. Second, we used a similarly inductive approach to develop themes in interview responses. These themes allowed us to understand the relationship between creating works-in-progress and sharing these snapshots with peers, how Mosaic's design might deter or encourage sharing information about creative process, motivations for creating works-in-progress and commenting on others works, and how their experience with the Mosaic community compared with their experience on existing online creative social platforms.

6 Results

The projects uploaded to Mosaic allowed artists to compare their creative processes with each other, leading to both technical insights about how to improve as well as opportunities to validate their approaches to creative problems. Figure 5 shows works-in-progress from a few of the most viewed projects on Mosaic. These projects show the variety of types of information creators chose to share with others, including the both the ideation and technical steps behind an artwork.

During the study period, a total of 46 users created 69 projects, with projects containing an average of 5.26 ($SD = 2.32$) works-in-progress. Out of these, 38 projects were submitted as entries for the zine. During this time, 468 unique users made 1144 unique visits (3489 pageviews) to the Mosaic website, with about 40% of incoming users arriving through links on existing social media sites like Facebook, Twitter, and Deviantart.

6.1 Sharing Process Served as Vehicles for Reflection

Table 1 shows the various types of thoughts that creators documented while creating these works-in-progress, ranging from tutorial-like descriptions of steps taken

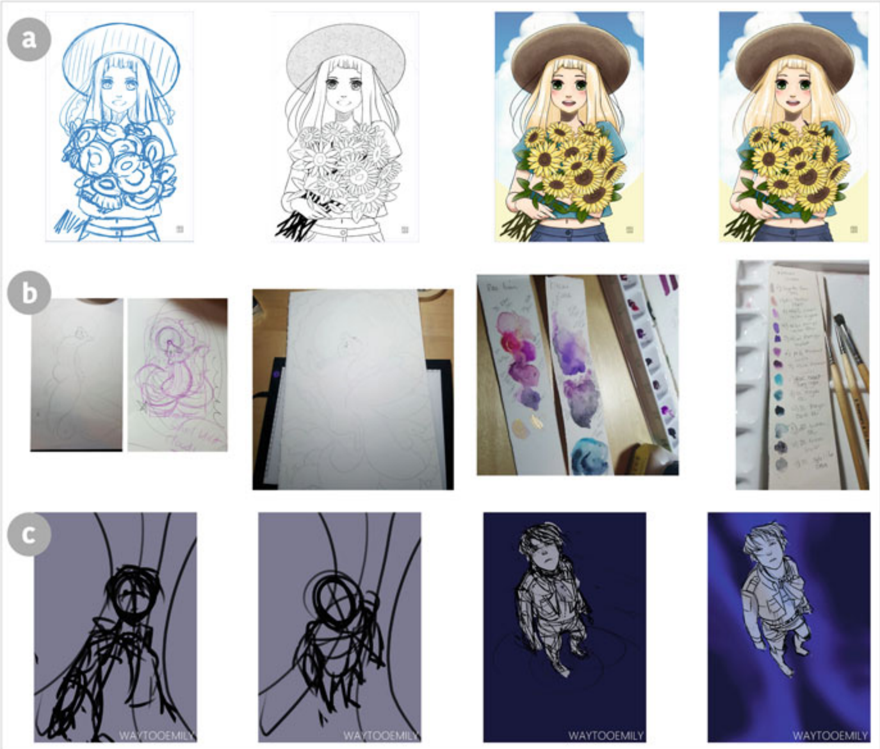

Fig. 5 The first few works-in-progresses from some of the most popular projects on Mosaic. (**a**) Many projects structured themselves around showing significant steps in the progress of the artwork (*Sunflowers* by marshmallowjelly), (**b**) The creator shows an early sketch, as well as organizational tricks they use to remember what colors they use (*Kitsune Lune* by starrydance), (**c**) The creator shows a few early sketches illustrating how they chose a composition for the piece (*Like Satellites and Shooting Stars* by waytooemily)

Table 1 The types of descriptions written by creators to accompany work-in-progress snapshots

WIP type	Count	%	Example
Describing action	177	53	"I brush color onto..."
Justifying action	75	23	"I did this because..."
Intent	37	11	"I wanted a feeling..."
Struggle	23	7	"I'm having trouble..."
Assessment	7	2	"I think it looks..."
Idea	6	2	"The idea came from..."
Ask for help	4	1	"Which option is best?"
Goals for growth	4	1	"I wanted to improve..."

during the creative process, to questions asked in the middle of the process, to explanations of the higher-level goal pursued by the creator.

Creators typically did not wait until finishing their artwork to post their works-in-progress, nor did they stop to upload works-in-progress as they worked. Instead, after saving images as they worked, artists would post one or more images representing substantial progress at the end of a working session (taking a median of 4.36 h in between updates to their project) and reflect on their working session as a whole.

This perhaps explains why only 53% of WIPs were objective descriptions of what was done in the artwork; these works-in-progress tended to focused more on loops of intent-attempt-assess and other internal thought processes than on the actual steps taken to achieve a visual effect:

> Initial sketch. The idea for this started as a quick doodle. It's been unseasonably warm this spring, so I've been wanting to draw something summery and I've been researching sunflowers for the garden so I've had these happy flowers on my mind recently… —Sketch, Sunflowers

Seven participants described realizing aspects about their work they hadn't realized before (such as how long it takes them to complete part of a painting), or slowing down and making more deliberate creative decisions as a result of writing down their reasoning for each phase of the art-making process. Some added that it would be useful to look back at their own processes in the future, saying that it was difficult to remember how their own work began:

> Besides the usefulness of seeing other artists work and a different idea of how they work, [Mosaic] lets you look back at your own and kind of see that, oh, you started that bad. Sometimes you get caught up in that last image and be like, oh, I think it finally came together. It's not too bad. Then you feel like, oh, can I do something like that again? Or you start doing something and it looks horrible, but you don't remember that something else you did looked horrible to begin with. —P2

In other words, Mosaic projects were distinctly unlike traditional tutorials, acting instead more like diaries; they became tools for reflection.

6.2 Feedback Helps Validate Process

Four participants stated that feedback was difficult to get in existing art communities, attributing this to the audience that was drawn by a platform oriented around gaining exposure. The relationship they had built up with others on these sites were more of a "celebrity-fan" relationship, rather than a relationship between artists who can help each other:

> Most of the comments on [DeviantArt] are "Oh, I love it, amazing." Which is great, I'm always grateful that people like my work, but if you're looking for anything specific you're not going to get it there. —P3

For this reason, six artists stated their current preferred method for receiving feedback was to ask artists they know in real life or friends they trusted, but this can quickly exhaust social capital.

Table 2 The type of comments written about projects

Comment type	Count	%	Example
Specific like	64	35	"I like the colors..."
Thanks (creator)	34	18	"Thank you!"
Answer (creator)	20	11	"I did this by..."
Encouragement	18	10	"Looks great!"
Suggestion/critique	13	7	"I would change..."
Intent (creator)	10	5	"I hope it looks..."
Commiseration	6	3	"Painting is hard..."
Technique	3	2	"I'll have to try that..."
Communication	4	2	"Easy to understand..."
Response action	4	2	"I'll make sure to..."
Question	2	1	"How did you..."
Other	7	4	

Mosaic, on the other hand, was described by seven participants as a very artist-centric platform. Users made a total of 153 comments, with each project receiving an average of 2.22 ($SD = 2.19$) comments and with users making an average of 3.85 comments ($SD = 6.08$) each. The median time for comments to appear after a user made an update to a project was 16.52 h, and projects received an average of 0.61 total comments ($SD = 1.32$) prior to its last update. Only 10% of comments were the simple encouragement typically seen in existing online art communities, with most other comments remarking on specific aspects of the process described by the creator, commiserating with the creator about the difficulty of the process, asking questions, or providing suggestions or critique (Table 2). By aiding artists in revealing the process behind an artwork, Mosaic reinforced a social norm of writing specific, relevant feedback:

> [Comments on Mosaic are]... if they say they like something, they seem to actually say what about it they liked... They seem a little bit more... informed as fellow artists. It's not just "Oh, that's cute," or "That's pretty." —P2

Artists were very open to both negative and positive feedback. When asked about the kind of comments they wished they could get more often, five participants said they wanted feedback not to necessarily to improve their work, but to validate whether or not their creative intent was coming through in their output and to see if they were on the right track with their progress. More generally, participants described good feedback as specific, timely (that is, received during the creative process rather than afterwards), and relevant to current goals (rather than suggesting other goals); participants stated they would ignore feedback that was contrary to their creative intent. Mosaic seemed to allow other creators to pinpoint the intent of the creator posting artwork (often because the creator now had the opportunity to explain their goals and reasoning through works-in-progress), leading to more informed feedback from the community as a whole and allowing creators to use other users as a mirror to help them reflect on whether or not they were able to achieve their goals.

6.3 Teaching Through WIPs, Teaching Through Feedback

Creators approached uploading and composing works-in-progress on Mosaic as an informal teaching opportunity, with eight participants describing their imagined audience (Marwick et al. 2011) as other artists at a skill level just below their own or even to “a me from the past” (P5). For the most part, artists documented how they overcame some struggle or achieved some goal, and described their project in terms of teaching what was learned to others. Occasionally, if they found themselves stuck on solving a problem, they would break from this teaching role and ask for help. Overall, however, participants felt that each of their works-in-progress needed to represent substantial progress on the project so that they would have something to say to their audience. Participants were aware of the value of clearly communicating their process, with eight participants saying that posting works-in-progress was only useful when presented in chunks that made sense or when it was complete:

> I actually discarded a few [works-in-progress] that didn’t seem like they made much of a difference in between. I just kind of chose some of the biggest ones you could see. I added this detail or changed colors or added more facial details here. Anything you could see an actual progress to. —P2

This reflects votes from other Mosaic users during the peer voting round to decide which projects would be included in the zine. Voting was open to all Mosaic users; out of 46 registered users, 33 users participated in the peer voting round by selecting the three Mosaic projects they thought should be included in the zine. A Poisson regression showed that projects with the most votes were those which had more works-in-progress ($\beta = 0.114, p < 0.01$), as well as more comments ($\beta = 0.135, p < 0.01$).

Paradoxically, Mosaic users seemed to approach writing feedback as a teaching opportunity as well; five participants mentioned that being able to view other people’s works-in-progress influenced their motivation to write feedback:

> If someone is posting as they work on their work, you actually feel like you’re right there encouraging them if you’re giving them feedback through steps and everything… If they post all their updates and they post when they’re finished, you actually feel a connection because you felt like you were cheering them on the entire time they were working on this thing. Now you see the finished the product and you’re like, “Dude, that’s awesome.” —P8

This may be explained by an underlying ideal of fairness explicitly mentioned by two participants:

> I do think that part of what’s interesting about this site is that you do get to see all these middle steps. It seems a little unfair to not share that if I’m taking that in from other people. —P7

> I think it’s the point of the community, in part, is to give and take critique and I think that’s really cool. —P6

That is, posting about creative process actually afforded reciprocal give and take in a creative community; creators ended up framing their projects as gifts of knowledge to others, but this was also the same mechanism through which people received feedback and help.

6.4 Showcasing Failure is Uncomfortable

The fact that existing communities focus on sharing final outcomes also means that first impressions are important on these websites, further discouraging sharing in-progress work. It is often difficult to bring viewers back to see updates to a creative piece in progress:

> I normally try to upload everything... when I'm done... that way, if people are viewing it, they're not like, "Oh, this is cool but I don't know where it's going. I don't want to come back and look at this," or they'll forget about it. —P4

In addition, six participants mentioned they experience apprehension when sharing their work online due to a lack of confidence in their skills or negative experiences with aggressive commenters from the past. However, six artists also mentioned documenting their process in a community allowed them to contrast their process against others, creating an environment where sharing process was normal and easing fears about posting content:

> [Sharing process] encourages people to share what they know... they don't feel like they're in direct competition because we're all learning at the exact same time, just at different paces. —P8

In other words, posting content on Mosaic became less about trying to prove worth to an audience and more about the journey of each individual creator.

7 Discussion

Through our evaluation of user activity on Mosaic, we learned how a community of sharing works-in-progress can help creators give and receive specific feedback and reflect on their creative practices. Interestingly, we also discovered how creating an environment that encourages sharing process can also help creators feel comfortable sharing unfinished work or asking for help. In this section, we generalize our findings by discussing design implications for future social computing systems and proposing a design space for creativity support tools that encourage useful creative outcomes—such as mistakes, failures, prototypes, and experiments—beyond traditional notions of success.

7.1 A Design Space for Sharing Creative Work

Though Mosaic focused primarily on supporting painting and illustration, its interface for sharing snapshots of in-progress work over time could apply directly to several other domains, including music, writing, and design. This would likely work best for domains where there is a single artifact that represents the whole creative work. Something like film-making consists of writing a script, a casting process, days of actual filming, and more; it is hard to say what a snapshot of work would look like in this case. In addition, Mosaic may best benefit work with a smaller scope; it's easier to share and give feedback on snapshots of a short story, for example, than an entire novel.

At a high level, however, Mosaic expands the space of possible designs for creative communities by broadening the scope of useful artifacts that creators may want to share—namely, creative processes. Doing so increases social translucence (Erickson and Kellogg 2000); social interactions are no longer solely based on the final result but also on an awareness of what a creator has done to the create the work and why certain creative choices were made.

In Mosaic, we saw evidence that the design of a creative community can affect users' views on what type of content is valuable and useful for the rest of the community. Many existing creative communities are *creator-centric*, meaning that they focus primarily on allowing creators to share their own content in publicly viewable portfolios. However, communities can also be *curator-centric*, and focus more on allowing creators (or fans) to showcase or curate the work of others; Pinterest (2016), where users can gather content in themed "boards," is one example of a community designed around social content curation. These design attitudes are not mutually exclusive, as many communities (including DeviantArt) also support curation by allowing users to favorite work by others and organize and share these favorites.

These two axes—whether users are sharing their own or curating others' content, and whether users are focusing on sharing outcomes or process—reveal a design space for online creative communities for sharing work (Fig. 6). The upper-left quadrant contains communities for creators to showcase the outcomes of their own work; the upper-right quadrant contains communities for creators to curate work of others which is commonly used to support creative activities such as collecting inspiration and examples. The lower-left quadrant represents communities that focus on enabling creators to share their own creative processes with each other, and includes communities like Mosaic. The lower-right quadrant represents an open design opportunity: communities that allow creators to curate the creative processes of others. This could simply be the curation and collection of tutorials, or one could imagine a community where creators create customized libraries of socially vetted techniques.

This design space is certainly not comprehensive, but acts as a starting point for thinking about the design of creative communities in a broader way. One could imagine, for example, inverting this design space to focus on negative outcomes

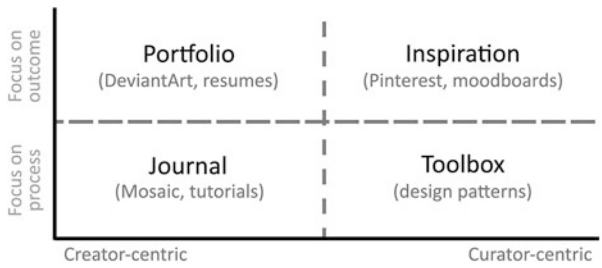

Fig. 6 A design space of possible creative communities based on what creative outcomes are being shared and by who

rather than positive ones: communities that share portfolios of good work become spaces for creators to share their worst failures; creators could collect examples of finished work they do not like to help them scope the range of possible ideas for their next art piece; and creators could even document creative processes that ended in failure (i.e., what not to do), which would be valuable from a learning perspective for both themselves and for others.

7.2 Process as Intellectual Property

Creators who share their work online often worry about *art theft*, where someone reposts their work somewhere else without credit (or while claiming to be the creator). In our formative study, we asked interview participants whether art theft was a concern when posting works-in-progress. Surprisingly, participants stated the consequences of art theft were (while annoying) mostly harmless, and doubted that someone would take the effort to steal their work since they felt they were not particularly famous. This response is likely due to how we recruited participants, since we expressly sought creators with similar backgrounds and skills to make it possible for creators to give feedback to each other. Potential theft may be a more pressing issue for those who consider process part of their intellectual property (indeed, a process can be considered a type of patentable invention). While this might suggest that Mosaic's focus on sharing process is not applicable to domains where sharing early ideas may result in loss of competitive advantage (e.g., startups), one could imagine using a system like Mosaic internally to facilitate transparency and feedback within a team.

7.3 Growing the Mosaic Community

How does a system like Mosaic grow? Maintaining communities like Mosaic can be difficult, as shown by the closure of popular communities that have attempted to focus on process but have transitioned back into showcasing outcomes (WIPs 2016). Mosaic was described by interview participants as making it much easier to upload series of works-in-progress compared to existing painting and illustration sites, and some participants even reported sharing links to their Mosaic projects on their other social media profiles. However, while we were able to find positive effects of Mosaic's design among a community of users who were already actively using Mosaic, observing less active users or people external to Mosaic would give us a better sense of why people do (or do not) participate actively in the Mosaic community or the value they derive from visiting Mosaic as a lurker. For example, is it unrealistic to expect that most creators will take the time to post detailed works-in-progress? Or, do people find they enjoy viewing Mosaic projects without community interaction? In other words, what would the social landscape of something like Mosaic look like at larger scale?

For example, though Mosaic users were able to give specific feedback to one another, there was a large variance in the average number of comments written by users who had uploaded at least one project. It may have been difficult for some users to find projects to give feedback on, as Mosaic's main method to display projects was to display a feed of recent activity from the community as a whole. This problem would only become larger as the community grows. However, an increase in community size may help projects receive more feedback in a timely manner (that is, while the project is still in progress). It may be worth expanding on Mosaic's feature of being able to flag critiques and use this as a signal to push projects wanting critique to other users, or even create a matchmaking service that connects project wanting feedback with users who upload similar projects. As another example, while 35% of comments on Mosaic were specific feedback about what the commenter liked about a creator's work, other types of useful comments such as critiques (7%) and comments on techniques used (2%) were less common. Approaches such as structuring feedback using guidelines or templates (Xu et al. 2014) may further support creators in writing specific and timely feedback for one another.

In addition, how does Mosaic maintain its focus on process as it grows? This chapter focused encouraging community contribution by enabling creators to share their process, but healthy communities also require committed users, regulation of behavior, and procedures for attracting and socializing new members (Kraut et al. 2012). The creators that participated in our study were already familiar with existing art communities and had established art practices; it would be interesting to see how users new to art communities are affected by Mosaic's social norms (as well as how the community reacts when these norms are violated by new users). One possibility is that Mosaic's decision to structure content creation in terms of snapshots of progress will help convey community values. For example, this may encourage new users to describe their work in detail and make it easier for others to identify and act on opportunities to help (Teo and Johri 2014). In addition, we found that Mosaic users approach posting works-in-progress as teaching opportunities; these works-in-progress may thus also act as proof that the artist put a nontrivial amount of effort towards their work. Other users may take this as a signal that the artist will spend a similar amount of effort incorporating any help they receive. In future work, it would be interesting to study a community composed of creators unfamiliar with online art communities and see if Mosaic's design "autocorrects" the behavior of users who are unfamiliar with (or ignore) the social ideals of equivalent exchange expressed by some of our interview participants.

8 Conclusion

In this chapter, we make two major contributions. First, we demonstrate the potential benefits of an online creative community based around sharing works-in-progress creations. We did this by building Mosaic, an online creative community, and conducting an observational study where we interviewed creators about their interactions with each other as well as their artmaking process. Artists described being able to give and receive more helpful feedback on their work and feeling more comfortable sharing unfinished work and mistakes (relative to other creative communities). Second, we generalize the approach we proposed through Mosaic and generate a design space demonstrating opportunities for new types of creative communities by expanding our idea of useful creative outcomes. While not comprehensive, the examples discussed here illustrate the possible ways we can fill the gaps in support for communities of creators left by current systems. By explicitly designing to create space for exploration, process, and failure in creative tools and communities, we may better enable creators to not just achieve but also grow.

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Investigating Tangible Collaboration for Design Towards Augmented Physical Telepresence

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Abstract While many systems have been designed to support collaboration around visual thinking tools, much less work has investigated how to share and collaboratively design physical prototypes—an important part of the design process. We describe preliminary results from a formative study on how designers communicate and collaborate in design meetings around physical and digital artifacts. Addressing some limitations in current collaboration platforms and drawing guidelines from our study, we introduce a new prototype platform for remote collaboration. This platform leverages the use of augmented reality (AR) for rendering of the remote participant and a pair of linked actuated tabletop tangible interfaces that acts as the participant's shared physical workspace. We propose the use of actuated tabletop tangibles to synchronously render complex shapes and to act as physical input.

1 Introduction

The need to collaborate with remote partners to accomplish joint tasks has risen over the years. However, most current technology limits individuals to passively watch video feeds which do not allow for any interaction with the remote physical environment. In particular, they do not support collaborative physical tasks in which two or more individuals work together to perform actions on 3-Dimensional (3D) objects in the world.

For designers, sharing physical objects is particularly important. Design collaboration involves talk, gestures, and the joint creation of design ideas through representations, which include not only sketches but also physical prototypes. Physical artifacts produced throughout the design process serve not only for functional testing but also for communication purposes.

They are helpful in establishing a common ground among those involved in the design and in externalizing or supporting what a designer is relaying verbally to the others (Fussell et al. 2004; Clark and Brennan 1991; Buxton 2009).

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As effective design collaboration involves sharing, exploring, referencing, and manipulating the physical environment, tools for remote collaboration should provide support for these interactions. Buxton (2009) defined three spaces to be considered at the microlevel of collaboration: person space (where one sees the remote person's face, expressions and voice), task space (where the work appears), and reference space (where body language and gesturing can be inferred). Most standard video systems support person space through video feed. Task space is usually abstracted from the physical workspace and only exists in the digital form e.g. collaborative online whiteboard apps. Lastly, reference space is mostly unsupported.

In this work, we address the aforementioned limitations leveraging the use of augmented reality (AR) for rendering of the remote participant and a pair of linked actuated tabletop tangible interfaces for rendering the participant's shared physical workspace or task space. For our implementation, we use Zooids, a tabletop swarm interface with many robotic tangibles.

Our telepresence system aims to brings together person space, task space, and reference space (Buxton 2009) with the hope of increasing the sense of co-presence and the ability of participants to communicate naturally using gaze, gesture, posture, and other nonverbal cues. We hope to contribute not only to the understanding of how physical prototypes are used as part of the design thinking process, but also to enable these benefits over distance.

2 Related Work

Remote collaboration is for most people primarily associated with video chat tools with screen-sharing capabilities (e.g., Microsoft Skype, Google Hangouts, Apple FaceTime, and Cisco Webex). Shared workspaces have, however, long been explored for video and audio across locations. Researchers have investigates collaboration for a wide variety of tasks, such as sharing physical documents using video feeds on a screen, as in TeamWorkStation (Ishii 1990), or projected, as in Video Draw (Tang and Minneman 1991c). Video Whiteboard explored wall-scale shared workspaces, while providing feedback on remote user's presence (Tang and Minneman 1991a). Clearboard went further by allowing for proper gaze estimation of remote users (Ishii and Kobayashi 1992). More recently, these techniques have been applied to applications, such as collaborative website development (Everitt et al. 2003a), remote board games (Wilson and Robbins 2007) and family communications (Yarosh et al. 2013).

2.1 Gestures in Video-Mediated Communication

Past research has shown that co-located partners work more efficiently than distributed partners due to participant's ability to use gestures and support their conversation (Kraut et al. 2002; Fussell et al. 2004). Several projects investigate video-mediated collaboration using surrogates for hand gestures (Tang and Minneman 1991b; Fussell et al. 2004) while others have used video streams and computer vision to register hand gestures and transmit them (Coldefy and Louis-dit Picard 2007; Wood et al. 2016). In our work, we focus on showing user's gestures with low-fidelity but in their 3D spatial context.

2.2 Mixed Reality

As Virtual Reality (VR) and Augmented Reality (AR) have matured, collaborative tools have been extended that can support more than video mediated interaction, drawing on a variety of different display and interaction techniques. Raskar presented a vision of what future collaborative workspaces could look like with AR technology (Raskar et al. 1998). This has also been explored in the context of CAVE based VR, where two CAVES can be linked allowing for VR collaboration (Gross et al. 2003). MirageTable utilized projected AR to give users a view corrected steroview of a collaborative 3D workspace and remote collaborator (Benko et al. 2012).

Beyond head-worn and projected AR, other display technologies have the opportunity to give remote users strong local presence, such as TeleHuman's Cylinder display (Kim et al. 2012) or BeThere (Sodhi et al. 2013), which focuses on handheld AR where remote users can point into a remote 3D scene.

Some of these systems also allow for spatial annotations in the world (Fakourfar et al. 2016; Gauglitz et al. 2014). However, most of the work on this topic has not included physical feedback or tangible interaction.

2.3 Telerobotics

A vibrant research community is addressing engineering and design challenges in representing remote people using telepresence robots (e.g., Tsui et al. 2011; Paulos and Canny 1998). The Personal Roving Presence concept (Paulos and Canny 1998), in particular, was an early exploration into tele-embodiment with different implementations using both screen-based robots and flying blimps. Much research has also explored how these devices can be used in the workplace, and how they influence user's sense of social presence (Lee and Takayama 2011). Our interactions focus on robotics to provide a shared workspace, with less emphasis on the mobility provided by robots for telepresence.

2.4 Tangible Remote Collaboration

Remote collaboration has also been explored through Tangible User Interfaces (TUIs) to address the aforementioned video streams limitations. Typically TUIs have been used for the manipulation of remote physical environments (Brave et al. 1998; Pangaro et al. 2002; Richter et al. 2007; Riedenklau et al. 2012; Leithinger et al. 2014) and the display of information (Everitt et al. 2003b; Ullmer and Ishii 1997; Leithinger et al. 2014). Recently, tabletop swarm user interfaces such as Zooids (Le Goc et al. 2016) have emerged as a promising collaboration platform. They can be used as an information display as well as a type of input/output interface where some agents act as controls or handles while others act as outputs. Few projects, however, have combined AR with remote tangible interaction.

3 User Evaluation

In face-to-face collaboration on physical tasks, people readily combine speech and gesture to support their communication. They can monitor one another's hands and jointly observe task objects and the environment. Although studies of the use of physical artifacts in design exist, less work has explored their specific use in co-located collaboration for design. We conducted a small-scale user study to understand how designers communicate and collaborate in co-located design meetings around representations. We want to understand differences in interaction when the representation takes different forms, specifically as physical and digital 3D models. From these results we wish to draw guidelines for creating physical interfaces for design collaboration which bring together aspects of both physical and digital manipulation.

3.1 Design

Five pairs of graduate student served as participants (ages 22–27, one female). No previous design experience was required. They each received $15 for their participation. Each pair of users completed a task under two different conditions. The task was to sketch a completed house model according to a set of given design goals.

The participants had asymmetrical roles: one was the instructor and the other was the sketcher. The instructor had the design goals as sketches of a completed house model, and his/her goal was to communicate this model to the sketcher. The sketcher on the other hand, had incomplete sketches of the same house and his/her goal was to complete the house model sketch based on the instructor's communication. Participants were seated facing each other but there was a physical separation on the table such that they could not show each other their respective sketches.

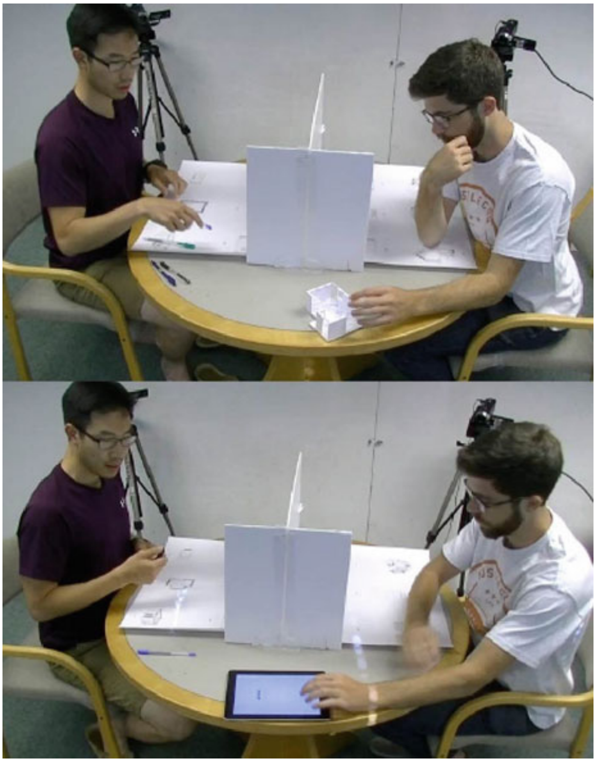

Fig. 1 User study setup. Left participant is the sketcher with the incomplete house model. Right participant is the instructor with the complete house model. On the *top figure*, participants share a physical model of the house. On the *bottom figure*, participants share a digital model of the house

To support communication, the users shared a representation of the incomplete house model. In one condition, the representation was a 3D physical model and in the other condition, the representation was a 3D digital model displayed on an iPad. Users had the freedom to rotate and change views of the model at any time. The complete setup is shown in Fig. 1.

3.2 Materials

Two different two-story house models (with equivalent number of components) were created using the Arckit[1] architectural modeling system. Digital models of the each house were made on Sketchup using the Arckit Digital library. The shared

[1] https://www.http://arckit.com/.

physical model was the incomplete house made with Arckit components, while the shared digital model was viewed in the Sketchup app for iPad.

Instructions for the instructor had all views (front, back, left, right, top, iso) of the completed house model and were printed on a $24'' \times 16''$ sheet of paper. The sketcher received a similar printed sheet with the same house model views (front, back, left, right, top, iso) but with only the first floor present.

Three online surveys were administered through Qualtrics. The first was a pretest questionnaire to collect demographic information (e.g. gender, age, field of study). A post-task questionnaire administered after each task, asked questions about the success of each collaboration. There were free response questions as well as responses made on a 5-point scale ranging from 1 (Very Hard) to 5 (Not very hard). Certain questions were reworded for the Sketcher roles (e.g. Is there anything your partner could have done differently in communicating the instructions?).

An exit interview was conducted upon completion of all tasks. Both instructor and sketcher were present during the same interview. Five questions were asked during the interview, relating to the overall experience as well as role-specific experience.

3.3 Procedure

Participants were given an overview of the task, were assigned roles, and given specific goals for each role. They then completed consent forms and the pretest questionnaire. They were also introduced to the different components that could make and Arckit house model (e.g. wall, window, ceiling). They were shown how they could interact with the Sketchup app for viewing digital models (e.g. pinch for zoom, drag to rotate).

Each task was timed for 20 min and participants were given a 5-min warning. Upon completion, each would complete a post-task questionnaire. They then moved on to the next task with the same time lapse. After both tasks and post-task questionnaires were done, the exit interview was conducted.

3.4 Preliminary Findings

Video and audio from the experiment was analyzed and encoded for gestures. A gesture coding scheme based on that from Fussell et al. (2004) was used and is summarized bellow:

Gesture coding scheme:

- **Exploratory**: Moving and/or rotating the representation
- **Iconic**: Forming hands to show what a piece looks like, or to show how two pieces should be positioned relative to one another.

- **Pointing**: Orienting a finger or hand toward a point in the environment. Reference to objects and locations.
- **Spatial**: Indicating through use of one or both hands how far apart two objects should be or how far to move a given object.

One of our task performance metrics was percentage of task completion. This was determined by analyzing the sketches participants made for each task. To compute percentage of task completion, we counted the number of correctly sketched parts and divided by the total number of components we expected participants to have sketched to achieve the full house model. Percentage of task completion was higher in the iPad condition ($\mu = 0.71$, $\sigma = 0.3$) than in the physical condition ($\mu = 0.59$, $\sigma = 0.26$).

One of the survey questions asked users to rate (on a five-point scale) how difficult they found the task and how much mental effort they had to put in (Fig. 2). For both conditions, sketchers reported having to put more effort when compared to instructors. Instructors rated their effort similarly for both conditions. Other questions asked participants to rate how difficult they found the collaboration and how confident they felt they understood correctly (Figs. 3 and 4). Similar to the previous, sketchers reported more difficulty and lower confidence for the digital condition. Instructors rated collaborating with the digital slightly more difficult but rated their confidence level similarly for both conditions.

From participants' comments, sketchers had a much stronger preference for the physical representation. Instructors and sketchers both commented on the ease of manipulation of the physical model. "Being able to touch the physical representation and rotating it to my will was very helpful." "It was much easier to work with than

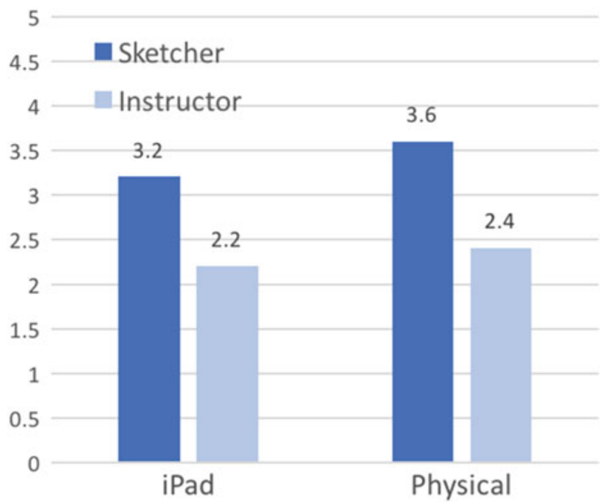

Fig. 2 How hard did you have to work (mentally) to accomplish your level of performance? 1 (Very Hard) to 5 (Not Very Hard)

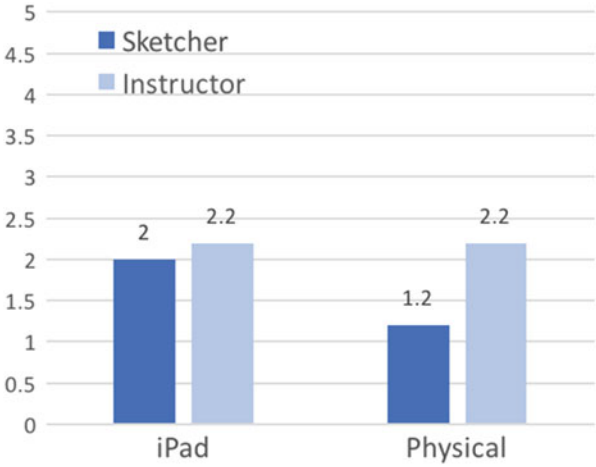

Fig. 3 How confident are you that you correctly understood your partner's design instructions (*or that your partner understood your instructions*)? 1 (Extremely Confident) to 5 (Extremely Insecure)

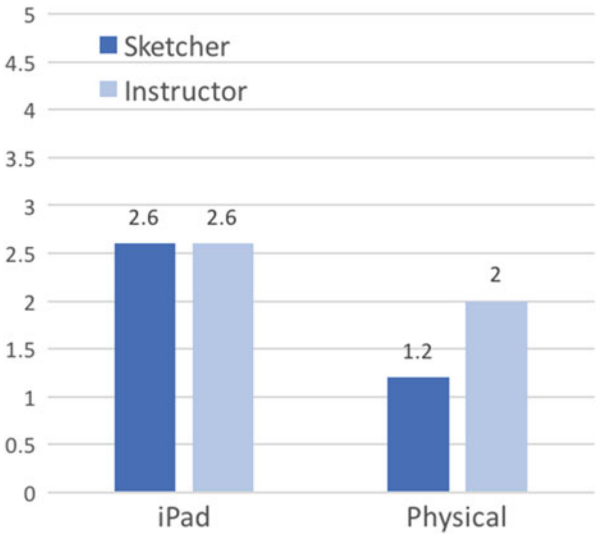

Fig. 4 How difficult was it collaborating with your partner on the design activity? 1 (Extremely Easy) to 5 (Extremely Difficult)

with the iPad for sure. iPad was just replicating what was on paper but 3D model was easier to visualize and communicate." Sketchers also highlighted how the digital made it more difficult for both to interact with it at the same time which may explain why instructors dominated most of the interaction with the representation. "There was one time where we both wanted to point something out on the iPad. There was also times where he wanted information from a certain perspective and I could only describe it to him from another perspective so that made things more difficult."

On the other hand, instructors highlighted how in sharing one perspective, the digital had its advantages. "...the iPad was much more helpful because you can do more with little effort; like zooming, panning and rotating by just moving your fingers and not your whole body." With the digital representation, both participants share one view of the screen and when pointing to a specific part, for example, it is clear what one is pointing at. With the physical, since users are seated facing each other, each has a different view of the representation and when pointing to a specific part, more verbal explanation may be required to clarify what one is referring to. We often found that once instructors had explained a new part of the model for sketching, the sketcher would often repeat the instruction to confirm his/her understanding.

3.5 Implications for Design

Instructors found the iPad to be easier for explaining since it did not require them to hold it in place to show a specific view. The instructor could use both of his/her hands for explaining and the sketcher would still have the same perspective view. However, the sketcher felt more confident in the physical model, noting how it was easier to find an orientation and manipulate the view they wanted. This difference highlights both an advantage and disadvantage of the physical model and directly relates to object orientation. Within the scope of remote collaboration, this could be addressed by providing flexible, user-controlled orientation of the shared workspace. If the remote user is rendered digitally, then physically, there will not be any interference from the local user such that both participant's hands could even overlap on the same physical space. The local user is therefore free to orient the workspace in any way.

Another implication we can draw from this is that there should be support for simultaneous actions from the participants involved. While the one perspective-view from the iPad is beneficial in providing a common ground, it limits simultaneous access to different views of the model. With the physical object, this is not an issue since the user can simply move around if he/she wants another view of the object without interrupting the other user.

Users found the physical model more engaging and easier to manipulate. The more-accessible manipulation allowed them to better understand the model. If both physical and digital representations are used in the workspace, it must enable easy and responsive input for manipulating the object's orientation.

Both sketchers and instructors said having the ability to manipulate and annotate the model would have made the task easier. Adding annotations or changes to the shared representation could be useful in complementing what the users want to convey.

4 Mixed Reality + Remote Collaboration Platform

Based on our user study findings, an interface for physical remote collaboration should be capable of (1) physical input to the remote participant's physical workspace, and (2) representation of the remote participant spatially linked to the shared workspace. In such an interface, designers could easily discuss, annotate, and physically modify prototypes (e.g., of cars or buildings) with remote collaborators all over the world.

Towards this goal, we introduce a low resolution prototype platform (Fig. 5) that uses a head-mounted AR display and many actuated tabletop tangibles, known as Zooids (Le Goc et al. 2016). The AR display is used to spatially render the remote user in the real world. We leverage the use of Zooids as both input and output controls that all together can render complex shapes as well as make changes to the physical space.

We introduce a prototype telepresence platform for remote collaboration that allows physical input/output and also spatial rendering of the remote user in the real world. We leverage the use of many actuated tangibles as both input and output controls that together can render complex shapes as well as make changes to the physical space.

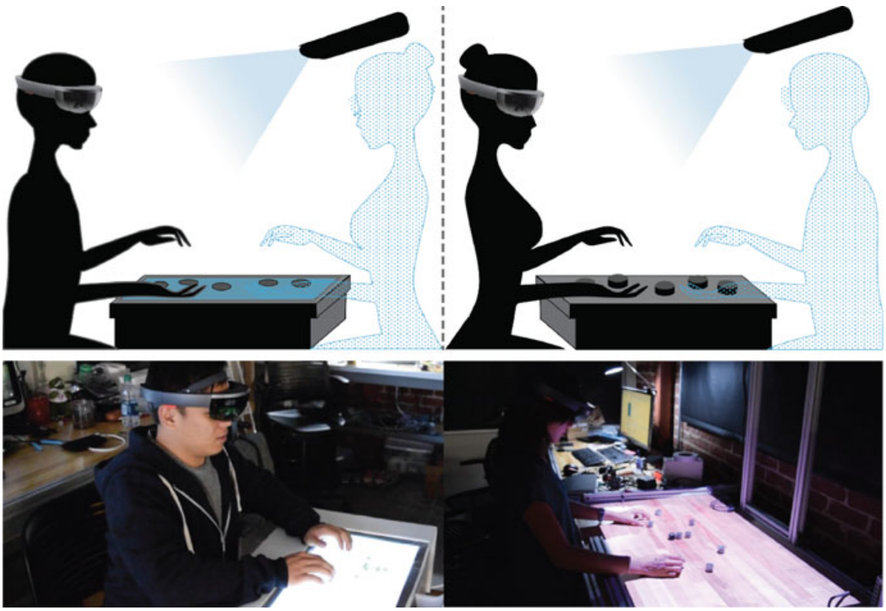

Fig. 5 System diagram (*top*) and actual setup (*bottom*) of the remote collaboration platform. The *left* shows the user with the tablet swarm interface while the *right* shows the user with the physical swarm platform. A depth sensor captures the local user and the Hololens renders the remote participant, seen as a *blue point cloud*

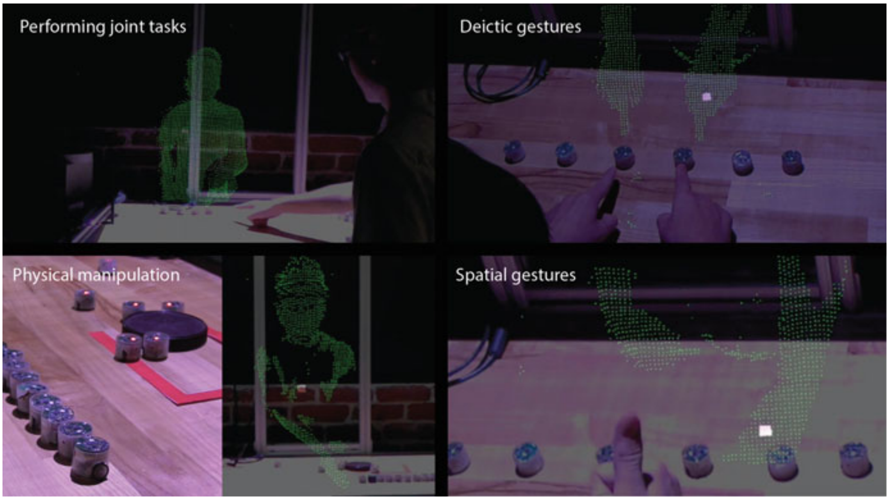

Fig. 6 Example scenarios of our remote telepresence platform

4.1 Preliminary Exploration

We show usage of the remote telepresence platform in four different scenarios (Fig. 6).

Performing joint tasks: In one case, both users jointly move a Zooid along a path. One user moves the physical Zooid, while the other user drags the Zooid on the tablet. This requires coordination and clear spatial understanding of where the remote user's hand is moving, such that the local user can closely follow.

Manipulating the physical environment remotely: In another case, the remote participant manipulates a group of Zooids to insert a disc into a slot. This shows a scenario where the platform enables users to make changes on the remote physical space.

Rendering shapes: Users are also able to jointly draw and modify shapes using the Zooids. This is a simpler analogy to the design collaboration scenario where two designers may be discussing and modifying a model.

Conveying meaning through gestures: Users are able to easily understand commonly used gestures for referencing objects and conveying spatial relationships, quantities, and shapes.

4.2 Implementation

Microsoft Kinect sensors are used to capture the geometry and appearance of the environment of the remote client. The captured Kinect frame was clipped to encompass a tight region where only the person is present and the information was then downsampled to under 60,000 points. Background subtraction is performed after clipping and down sampling based on a weighted sum from an initial calibration that came from taking a static image of the background and with the body tracking data available from the Kinect default libraries. This information is sent to the local client using connectionless network sockets following the standard User Datagram Protocol (UDP).

The local client consisted of a Hololens which received the remote client's data and used it to reconstruct the 3D geometry and appearance of the remote participant locally, thus obtaining the virtual copy. The data was rendered as a one-color 3D point cloud. This point cloud started as a simple flat mesh with zero depth at each vertex. At each frame rate, a shader updated the depth value of each of the point cloud's vertex based on the information received. The analogous procedure was applied on the remote client to obtain and render a virtual copy of the local participant. Thus the real person in each room was able to see and hear the virtual copy of the person from the other room in real time.

The shared workspace between the participants consists of the swarm user interface, Zooids (Le Goc et al. 2016). One participant's workspace includes the physical Zooids while the other participant accesses the Zooids through a tablet application (Fig. 5). The physical and digital Zooids are linked such that movement of Zooids on the local side is reflected on the remote side and vice versa.

5 Limitations and Future Work

Limited resolution and fidelity of the remote participant limits the amount of content that can be virtually rendered. Changing to a color point cloud and incorporating surface normals would result in a more realistic representation of the remote user.

Latency was not strictly investigated. However, there is some inherent latency in the robots physically moving from one place to another, i.e. "refreshing" the workspace. This could place limits in the kind of interactions possible. In addition, network latency was not strictly investigated. This also results in communication delays between client and server, and the graphics rendering pipeline for creating the virtual copy of the participant through the Hololens. Minimal latency is required for real-time interaction.

The scale and number of Zooids in our current system also limits the type of interaction and applications that can be created. With many more, more compelling shapes could be rendered. To better support the remote collaboration side, it will also be important to develop a number of interaction techniques around annotating and manipulating the shared workspace. This could be implemented using the same AR display.

AR resolution and field of view present issues for the system's use. Our current setup uses a one-color point cloud which would not allow the user to show distinguishable objects. Moreover, there is no support for facial expressions which are important in communication. Changing to a color point cloud and incorporating surface normals would result in a more realistic representation of the remote user. Depth perception could also be improved by adding shading and depth-of-field blur. The field of view of the Hololens is also limited, which causes issues for users trying to look both at the Zooids on the table as well as the face of the remote participant.

In future work, we would also like to explore the use of linked shape displays for displaying shared content. Unlike the Zooids platform, these types of input/output devices are not as limited in their vertical displacement. They are also capable of being smaller and having higher resolution (Poupyrev et al. 2007; Follmer et al. 2013).

However, shape displays have limited degrees of freedom of input; users can only push down and pull up on the pins. In addition, the display is continuous, and each pin is a single rigid object. This means that users cannot pick up or physically move parts rendered by the shape display. This limits the degrees of freedom and the expressiveness of input. We address this to some extent with the control of tangible objects, but future systems could also take inspiration from Modular Robotics to use small robotic blocks that could be snapped together and removed from the table (Gilpin et al. 2007). Beyond this even smaller particles, or fluids, could be imagined to give a full sense of shared objects.

6 Conclusion

We have provided preliminary design guidelines for the design of tangible collaboration interfaces. Based on these guidelines, we also introduced a low resolution prototype using actuated tangibles and head-mounted AR displays. Our preliminary findings show benefits from both physical and digital artifacts in design collaboration. This suggests a need to better understand how future work can harness the best of both the physical and digital world in designing platforms that support remote collaboration.

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The Interaction Engine

Nikolas Martelaro, Wendy Ju, and Mark Horowitz

Abstract The Interaction Engine is a framework for prototyping interactive, connected devices based on widely available single-board Linux computers. With microcontrollers, networking, and modular open-source software, these modules enable interaction modalities such as audio, video, tangible, and digital interfaces to be embedded into forms that go beyond traditional computing. In this paper, we outline the hardware and software components that make up the general Interaction Engine framework and discuss its benefits for interaction designers. We provide an illustrative case study of the Interaction Engine in use. We ran workshops to introduce designers to the Interaction Engine framework and we describe the projects where they subsequently employed Interaction Engines to understand issues and opportunities presented by this model. In describing the framework and case studies, we intend to shift designer's thinking of computer as product to computer as material to create new interactive devices.

1 Introduction

We are entering a golden age for interaction design. Concepts that have long existed as mere visions, like Vannevar Bush's Memex (Bush 1989), Marc Weiser's Tabs, Pads and Boards (Weiser 1999), and Apple's Knowledge Navigator (Sculley 1987) are suddenly a commercial reality. High-end commercial products such as the Nest thermostat, Drop Cam security camera, Amazon Echo interactive radio, and Phillips Hue light are inspiring designers to contemplate what else is made possible with networked interactive hardware. What is most exciting is that the basic components that make such concepts possible are accessible to savvy designers, not just seasoned engineers (Hartmann and Wright 2013).

Just as the interaction design community's adoption of embedded microcontrollers has driven a breakthrough in physical computing (Banzi and Shiloh 2014), enabling artists and designers "more creative thought and further iterations" (Gibb 2010), the adoption of lightweight computation platforms can power a similar

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revolution of multimodal connected devices. Various efforts have sought to introduce such platforms to the tangible, embedded, and embodied interaction design community (Berdahl and Ju 2011; Kubitza et al. 2013; Overholt and Møbius 2013; Vandevelde et al. 2015; Martelaro et al. 2016). The emerging design pattern uses networked single-board Linux computers, such as the Raspberry Pi or BeagleBone, with embedded microcontrollers, PC peripherals, open-source software, and connection to cloud-computing services to enable designers to more easily explore a wide variety of novel, connected, post-PC devices (Kuniavsky 2010). Although this framework enables the conception of new interactive devices, there are many challenges that can keep designers from adopting these new tools. We aim to help designers shift their thinking, from seeing computers as product to recognizing computers as malleable materials for enabling interaction.

In this chapter, we articulate the common framework underlying these platforms to allow interaction designers to understand their power and capabilities. We give a name to this computing framework—the Interaction Engine—and detail the various subsystems that make up the platforms and their common interactive functions. We present a case study on the design of an expressive sofa to elaborate on the use of the Interaction Engine in practice. We then describe and detail a series of workshops we led to introduce designers to the Interaction Engine. Finally, we discuss the implications of the Interaction Engine on interaction design thinking and outline a set challenges to address that will help further adoption of this framework within the interaction design community.

2 The Interaction Engine Framework

The name Interaction Engine harkens back to the early twentieth century, when a revolution in increasingly inexpensive and widely available powered motor technology enabled a wide variety of new products from the automobile to the home kitchen stand mixer. An Interaction Engine can similarly be used as a computational material (Landin 2005) to make an object connected and interactive, providing interfaces to the immediate physical world, computation capability, and connection to the larger digital world. One can think of this framework as an embeddable composite material for new device design (Vallgårda and Redström 2007) consisting of a single-board operating system based computer, microcontroller, open-source software, and connection to cloud computing services (Fig. 1).

2.1 Single Board, Operating-System-Based Computer

A single-board Operating-System-based computer serves as the foundational computing unit of the Interaction Engine. These systems are small, inexpensive and accessible to anyone who knows how to use a desktop computer. Currently, the

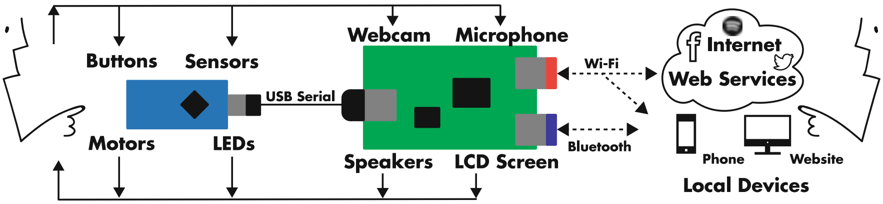

Fig. 1 The Interaction Engine, enabling physical, digital, and networked interactions with people, cloud, and devices

HCI community is using the Raspberry Pi running some version of Linux as its favored default platform; however, for specific applications, another system may be preferred. These single-board Linux computers (SBLC) are being updated on a regular basis; it makes sense to size the specific board to the complexity of the computation in each application. The provision of a standardized Linux OS provides commonality in a diverse and rapidly changing market, while giving designers the ability to choose systems based on computing power, peripherals, and form factor, without much switching cost.

In our design work, we have implemented Interaction Engines using five different systems, ranging from the single-core Raspberry Pi to the 8-core ODROID XU-3. While there are many options for SBLCs available today, most systems are based around ARM microprocessors and provide access to common peripherals such as USB, Ethernet, and audio/video input and output. With the power of a microprocessor, Linux OS, and USB, capabilities such as audio playback, audio recording, graphical display, video recording, networking, and data processing applications are enabled through high-level software. This extensibility can allow designers to quickly explore new, multi-modal interactions by building upon the huge variety of open source software. Designers can speed their development and try out new interactive devices in less time, allowing for more design iteration and exploration. Additionally, since SBLCs provide a low cost and common OS interface, designers can simultaneously bring up many parallel prototypes, eventually leading to better designs (Dow et al. 2010).

2.2 Physical Computing Interface

A microcontroller unit (MCU) often serves as an interface to the immediate, physical world. Although most SBLCs feature General Purpose IO ports (GPIO) which can act as the physical computing interface, these interfaces are not standardized. Often, the embedded Linux community uses separate MCU's for robust, standardized physical computing (Russell 2012; Palazzetti 2015). Although different MCUs have widely varying peripherals such as ADCs, PWM, and various communication interfaces, one critical MCU feature within an Interaction Engine is some form of connectivity and communication, such as serial over USB, with the upstream OS-based computer. We have found the ability to decouple the physical interface from the processing capability to be valuable for modularity, extensibility, and upgradeability. This benefits the design process as designers can develop stable physical interfaces and interchange them with different SBLCs allowing them to use SBLCs that are best for their interactions. In our own projects, we have often added features that require greater computational power or different input/output capabilities in the middle of the project and can simply plug our physical computing interface into a new computer and port the high-level software in little time.

2.3 Connection to the Cloud

While some Interaction Engines operate in a stand-alone autonomous mode, most modern-day devices rely on some degree of external communication. Most SBLCs come with Ethernet ports for wired networking. While this may be useful for fixed exhibits, wireless networking is more flexible. USB Wi-Fi and Bluetooth modules are widely-supported, low-cost options for adding connectivity to local devices such as phones, tablets, and other computing systems. This is done using a built-in web server, which can mediate communication between devices while also providing its own rich multimedia web-interface.

The network interface also allows the Interaction Engine to gather data from the cloud, outsource high-computation tasks, store information remotely, and interact with Web services such as Twitter, Spotify, Amazon AWS, or Internet-of-Things platforms. This connectivity effectively embeds these remote services as material inside an object (Vallgårda and Sokoler 2016). For designers, this is one of the most enabling aspects of the Interaction Engine as the SBLC allows them the use of mature and robust interfaces for allowing designers to interact with the cloud. This provides designers with a huge area of exploration for embodied, tangible interaction with digital services and data by extending potential designs beyond the physical and local world.

2.4 Open-Source Linux Operating System

Embedded Linux has become a popular choice for an operating system in these integrated systems amongst designers. Real-time operating systems (RTOS), like TinyOS (Levis et al. 2005) or Windows CE, have been popular amongst product engineers and are useful for real-time task scheduling and execution (Tan and Nguyen 2009). These RTOSes are used in small multimedia devices such as Siftables (Merrill et al. 2007). However, many of these RTOSes are proprietary, only support the C programming language, and have a steep learning curve. Other embedded OSes, such as Android and iOS, are intended for specific hardware; this hardware is optimized around phone and tablet applications and can be difficult to interface with external microcontrollers.

We feel that, for designers, the use of open source Linux operating systems is a major boon to an Interaction Engine. Designers are free to develop using a variety of high-level applications and programming languages, and to draw upon shared code for low-level functions. These are free and robust in Linux and are not available at all for proprietary real-time operating systems. These tools can greatly speed development of networked and data-intensive applications while allowing designers to rapidly iterate on the interactions they wish to create (Roman et al. 2003). Additionally, this code is often highly portable to new systems, allowing designers to share and extend each other's work. The open code base, shared libraries and code modules, and easier learning curve make Linux-based platforms more ideally suited to the rapid and iterative design practice of interaction designers (Raghavan et al. 2005).

The use of an operating system also provides designers with many standard solutions for common computing tasks, which are not available on lower level microcontroller-based systems. For example, almost all high-level programming languages provide serial interfaces for communicating with MCUs. Many robust, free, open source messaging frameworks exist for real-time web communication, such as WebSockets, ZeroMQ, and MQTT. Aside from communication, most Linux operating systems support a wide array of programming languages for application development, such as Python and NodeJS. This allows designers to add capabilities such as audio processing, digital display, and computer vision using publicly available software modules (Stankovic et al. 2005). As such, the designer can now utilize the capabilities of the entire OS as a design material.

3 Prior Work

Recently, we have seen systems that incorporate single-board computers in interactive design concepts spanning full-body gesture input devices (Chan et al. 2015), wearable polygraphs (Charlesworth et al. 2015), voice-enabled, social museum exhibits (Marshall et al. 2015), body-controlled, networked musical input devices (Tahiroğlu et al. 2015), and Twitter-powered, energy and environment obsessed talking radios (Gaver et al. 2015). The common framework of single-board computers and microcontrollers in these embedded design prototypes gives designers a huge boost in computing power, easy connection to the web, and leverages open-source hardware and software modules for rapid prototyping and design iterations. This allows designers to focus on creating interactions rather than optimizing for computational limitations.

We see these new systems as the latest in an evolution towards increasing computation within interactive objects. We review this development in relation to four prevalent models for physical computing systems: (1) *standalone* systems that run solely on microcontrollers, (2) *tethered* systems where a microcontroller is constantly connected to a multimedia PC, (3) *integrated* systems with a single-board PC integrated, often with a microcontroller, into the designed object, and (4) *eMbedded-Gateway-Cloud* where ultra-low power devices communicate with cloud services via a user's phone. Within each of these models, we take a design-centered perspective, examining key projects, design tools, and design patterns.

3.1 Standalone Systems

Standalone systems based on microcontroller units (MCUs) sense and interact with the world and have limited communication with other microcontroller based objects. Cheap microcontrollers such as the PIC enabled designers to create simple interactive objects such as Resnick's *Cricket* toy blocks and balls (Resnick et al. 1998), Frei et al.'s *curlybot* (Frei et al. 2000) drawing toy robot, Beigl et al.'s sensorized and networked Mediacup (Beigl et al. 2001), and Buechley's LED Game-of-Life tank top (Buechley et al. 2006). The BASIC Stamp was also heavily used as an embedded platform, particularly in education for creating simple robots with basic sensing and actuation capabilities (McComb 2003) and as a basis for early physical computing curriculum (O'Sullivan and Igoe 2004). Although these early systems were enabling, "working with microcontrollers required navigating a steep learning curve. Microcontrollers were general-purpose industrial components, designed to be a starting point for electrical engineers to design complex circuits, not a plaything for artists" (Townsend 2013). This lead to Wiring (Barragán 2004) and subsequently Arduino-based (Mellis et al. 2007) microcontroller development platforms which were specifically targeted for artists and designers and featured well-designed interfaces and useful abstractions. These systems made programming standalone systems more accessible to a wider group of designers. This led to a myriad of new opportunities for interaction designers to explore, such as interactive dresses, gloves, bags, and textiles (Buechley and Hill 2010) using the Lilypad Arduino (Buechley et al. 2008), interactive pop-up books (Qi and Buechley 2010), new tools for computer education (Millner and Baafi 2011), and even Do-It-Yourself cell phones (Mellis and Buechley 2014).

3.2 Tethered Systems

Although microcontrollers enable the creation of many new interactive physical objects, more opportunities are possible when the microcontroller is connected to a multimedia PC (O'Sullivan and Igoe 2004). On their own, microcontrollers have limited processing, connectivity, and interactivity, requiring the use of expensive specialty electronics for functions such as sound generation and network connectivity. Throughout O'Sullivan and Igoe's "Physical Computing," it is recommended that many functions such as sound and speech input and output, graphical display, video, and networking are best left to a multimedia computer while the microcontroller handles physical input and output. This pattern enabled such work as Rozin's "Wooden Mirror" (Rozin 1999), with physical wooden pixels actuated by a microcontroller communicating with a multimedia computer running computer vision code. This microcontroller-plus-PC pattern was also used by those in the new instruments for musical expression (NIME) community to make novel physical music controllers that worked in concert with audio synthesized on computers using software such as MAX/MSP and PureData (Wilson et al. 2003).

This model is used by many Physical Computing toolkits, such as Phidgets (Greenberg and Fitchett 2001), iStuff (Ballagas et al. 2003), calder (Lee et al. 2004), and d.tools (Hartmann et al. 2006). These were developed to provide designers with modular physical prototyping interfaces to control multimedia computer interfaces. These systems helped designers to focus more on the software to create interaction rather than on hardware design.

3.3 Integrated Systems

One of the challenges of the tethered systems pattern is the divide between the physical computing and multimedia computing interface. In practice, designers often use their own computers as the multimedia PC in these tethered designs. In exhibit design, for example, the expense of whole computers can easily be justified as a project expense. Exhibits such as "Dacha Digital Murals, 2008" (Aminzade et al. 2008) incorporate microcontrollers and PC's to create interactive physical experiences with digital light and sound. Often, exhibit designers have used small form factor PC's like the MacMini to accomplish this (Harris-Cronin 2008). Dedicated low-cost computers, such as netbooks, can provide designers with the flexibility of a general purpose computer (Sipitakiat and Blikstein 2013). This was also a short trend within the robotics community (e.g. Willow Garage 2011).

Overall, however, the cost of integrating a traditional computer into each design limits exhibition and long-term deployments, makes replication and scaling difficult, and discourages exploration with new libraries and software packages. Specific toolkits have been developed to address these limitations, including Bug Labs (Gibb 2009), Chumby (Huang 2008), .NET Gadgeteer (Villar et al. 2012), and Kinoma Create (Marvell 2016). These toolkits integrate pre-built hardware and software for physical input/output, driving displays, and networking. Although these systems are excellent for enabling rapid prototypes, they can limit the design opportunities to the specific functional modules provided with the toolkit as well as the form of objects (Mellis et al. 2013).

Nowadays, the design community has converged upon the use of small, low-cost single-board computers, such as the Raspberry Pi and BeagleBone, to provide the features of full multimedia computers, while enabling the computer to be dedicated and integrated into design prototypes. Exhibit designers, for instance, have begun opting for low-cost open source single-board computers and microcontrollers, such as a Raspberry Pi together with an Arduino, in their work (Langer and Alderman 2016; Borthwick 2016). Notable examples using this pattern include "I have a message for you" (Output Arts 2012), a replica of Turing's Delilah speech scrambler, and "Pianette/Sound Fighter," where two pianos were transformed into Street Fighter game controllers. Their smaller size allows them to be embedded seamlessly in smaller objects rather than hidden behind tables and walls. Their lower cost and relatively low power consumption compared to laptops allow them to be used in mobile devices such as The Workers "After Dark" live streaming telepresence robots designed for late night exploration of museums via the web (The Workers 2015).

Platforms such as Satellite CCRMA [for creating new physical music devices with advanced onboard sound generation (Berdahl and Ju 2011)] and UDOO [for creating interactive home automation systems (Palazzetti 2015)] are similar to tethered systems but are able to exploit their low cost and small size, to eliminate the separation between physical and digital computing. Although this difference is subtle, the ability for a full computer to be embedded into a designed object changes how designers think and create new devices; this integrated systems model is the basis for the Interaction Engine.

3.4 eMbedded-Gateway-Cloud

Lest the progression from standalone to tethered to integrated systems seem like the inevitable progress of things, we would like to point out that there is a viable competing model to the Integrated System model. The eMbedded-Gateway-Cloud (MGC) model describes the design pattern of ultra-low power, application specific embedded devices communicating with cloud-based data storage and computing service through a user's smartphone via Bluetooth Low-Energy (BLE) (Hartmann and Wright 2013). This computing model enables a class of connected devices with strict power requirements requiring only limited sensing and actuation. Multimedia interactions are displayed on a phone or website. Examples of products using this model include the FitBit activity tracker (Fitbit 2016) and Amazon Dash Button (Amazon 2016a). These objects often employ advanced microcontrollers such as the ARM Cortex-M series (ARM 2016) with ultra-low power modes where the device spends most of the time in standby and then wakes up periodically to sense, send, and receive data. Devices to help prototype these systems by combining a low power microcontroller and BTLE interface include the TI SensorTag (Texas Instruments 2016), Lightblue bean (Punch Through Design 2016), and mBed nRF51822 (mBed 2016). Early toolkits such as Amarino (Kaufmann and Buechley 2010) and Dandelion (Lin et al. 2010) supported the use of smartphones as gateways for physical hardware. More recently, cutting-edge systems such as fabryq

(McGrath et al. 2015) have further enabled designers employing the MGC model by providing a single development interface for using the phone to connect low-power physical hardware to the cloud.

There are also a number of products, such as Tessel (Technical io 2016), Particle (Spark Labs, Inc. 2016), and Electric Imp (Electric Imp, Inc. 2016), which combine powerful microcontrollers and integrated Wi-Fi to allow direct connection between physical hardware and the web. They effectively bypass the Gateway in the MGC model, but the bulk of the computation and modeling occurs in the cloud rather than at the device or node which the user is close to.

The MGC model is best suited for limited-interaction objects such as the Amazon Dash button, whereas the Interaction Engine's integrated model is similar, but focuses on a different class of untethered devices with more computational and multimedia capabilities. The Integrated Systems model is a framework for prototyping embedded objects, more akin to the Amazon Echo (Amazon 2016b) or Jibo home robot (Jibo, Inc. 2016) than to smart dust.

4 Sofabot Case Study

The SofaBot ($190 without sofa) is part of a larger investigation into how everyday objects can be made expressive and interactive. We used the sofa project to explore both benefits and challenges of using the Interaction Engine framework. This project used an ODROID U3 (Hardkernal 2016a) running a NodeJS web-server to serve a webpage directly from the sofa. The SofaBot webpage pulls a live video stream from a USB webcam using 'mjpg-streamer' (Redmer and Stoeveken 2016) an open source command line tool for lightweight video streaming. The page also reports whether someone is sitting on the couch using analog force sensitive resistors connected via an Arduino Nano. Keystrokes on the webpage allow a person to remotely control the sofa via websocket messages. The webserver in turn sends simple serial messages to the Arduino, which controls 12 V motors that move the sofa. All systems are battery powered, making the unit entirely mobile (Fig. 2).

During our development, we planned to use a Wi-Fi enabled microcontroller such as the Particle, but found that our need for a live webcam stream would require the use of a dedicated IP-camera and would not allow for future development of on-board computer vision-based interaction. We then opted to use a BeagleBone Black, as it incorporated both a Linux OS and well documented physical I/O in the same package. Unfortunately, we found development difficult due to known Wi-Fi issues based on the specific Linux kernel used as well as interference from the HDMI port's ground plane (DiCola 2015). We then used an ODROID C1 (Hardkernal 2016b) and developed all the control software to get the sofa moving in under a week, but began having power issues—the board periodically shut down.

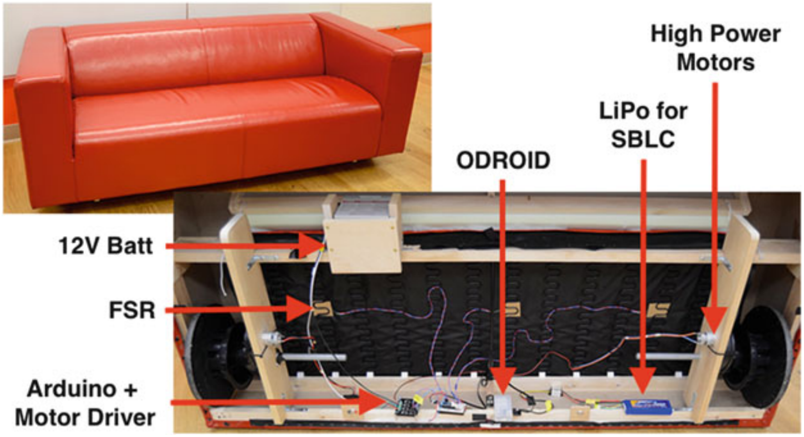

Fig. 2 SofaBot: A web connected sofa built using an Interaction Engine

Fortunately, we simply swapped in the more stable ODROID U3, downloaded the control software from our GitHub repository, and were back up and running within 15 minutes.

This process paints a realistic picture of developing new interactive devices with single-board computers. These computers are often not drop in replacements for laptops and push the designer to better understand the underlying technology. While this may add complexity, and distract from the design of the sofa's interactions, it requires the designer to understand the computer more as a material with specific properties that can be both advantageous or inhibiting to a design. In many ways, the computing elements were treated just like the motors. The sofa's motors were taken from a children's ride-on toy car and were chosen by decomposing the toy into the materials that enable movement of heavy objects, a common strategy for design prototyping (Sheppard 1992). However, many designers often "black box" the computer. By mentally deconstructing the computing systems into separate physical and digital input/output components, we could choose and swap computers based on their properties.

The SofaBot project also highlights strengths of the Interaction Engine framework, showing how existing products can quickly be networked and controlled via the web using a composite of computing tools. When we needed additional features, it was easy for us to switch from one SBLC ODROID board to another, and doing so required no changes to the motor driver circuitry or the microcontroller hardware or firmware. This would have been far more difficult if we had used something like the Arduino Yun or Beaglebone. This modularity has also benefited similar furniture projects in our lab with hardware and software quickly ported to other single-board computers such as the Raspberry Pi.

5 Exploring Interaction Engines with Designers

After our own experience developing the Interaction Engine framework, we were interested in how designers with less experience with embedded systems could benefit from it, what projects they might take on and what challenges they might encounter. We developed and ran four workshops to expose designers to the Interaction Engine's conceptual framework while also providing a concrete set of tools and examples for creating operating system enabled physical hardware. These workshops lasted from 3–6 hours and covered the basics of using single-board Linux computers, microcontrollers, and web software to connect physical hardware to a digital, web-based interface. We collected data and observations from these workshops to improve the framework and to enable new design opportunities.

5.1 Workshop Participants

We held two workshops with 16 master's design students (8 students per session) at an art and design college, a third workshop with 25 Masters and PhD students in Product Design, Mechanical Engineering, Computer Science, and Communications at a research university, and a fourth workshop at an HCI conference with seven teachers or researchers within academic design departments. In our workshops, we found that while participants often had some experience with physical computing or web-programming, most did not have experience integrating single-board Linux computers, microcontrollers, and web software to create physical/digital interactive devices.

5.2 Workshop Tutorial

At the start of our workshops, we always introduced the Interaction Engine Framework, using the image shown in Fig. 1. We described the parts in their toolkit as instances of the microcontroller or SBLC in the diagram but emphasized that these could be swapped for alternatives, based on the design. To introduce designers to working with an Interaction Engine, we developed the equivalent of a "Hello, World!" example to help designers understand the role of each of the Interaction Engine components and to illustrate physical and digital interfaces communicating over a network. Our example, called "Hello, You!" consisted of a physical button which could control the color of a web page and a web page button that could turn an LED light off and on. The tutorial walked designers through interacting with a single-board Linux computer using a console over secure shell (SSH), communicating between the computer and microcontroller using serial USB, and setting up a web server with real-time network communication to create a digital interface that gives someone remote, wireless control of the physical hardware. We designed our tutorial to highlight the specific properties of each computing system and describe the system as a general design pattern, a useful method for teaching novice designers (Chung et al. 2004).

5.3 Our Interaction Engine "Untoolkit"

We developed our workshop toolkit based on Mellis et al.'s conception of an "untoolkit" should "frame the technology for a target audience," "leverage existing hardware and software," and "provide paths for further exploration" (Mellis et al. 2013). We created a kit of parts specifically targeted at interaction designers, leveraging widely available open source tools already common within the interaction design curriculum (Igoe 2014). Our kit included:

- **Single-Board Linux Computer:** Raspberry Pi 2B
- **Microcontroller:** Arduino Pro Micro (ATMega 32u4)
- **Wi-Fi:** Edimax USB Wifi Adapter (802.11n)
- **Web-server software:** NodeJS (Express.js)
- **Web communication:** WebSockets (SocketIO.js)

We selected the Raspberry Pi 2B for its low cost, reasonable computing power, and plentiful documentation and examples. We also chose the Arduino Pro Micro for its wide community support, as well as for its size and varied input and output options NodeJS was selected as the web server framework for its relative ease of use, low system requirements, and its large repository of libraries including `Express.js` for web applications, `SocketIO.js` for real-time WebSocket communication, and `serialport.js` for communication between the single-board computer and microcontroller. Although we developed our own simple set of examples for creating a NodeJS web server with real-time communication to and from an Arduino, this pattern is common in the open-source maker community (Waldron 2012; Hennigh-Palermo 2015; Van Every 2015). Overall, our goal in selecting these specific components was to provide designers with a set of representative tools they could continue using after the workshop.

5.4 Workshop Findings

After our workshops, we interviewed the designers about what they learned. We have compiled our findings into a set of emergent themes.

5.4.1 Getting on the Network

Due to network security at the schools we held the workshops at, we brought our own Wi-Fi router and pre-configured the Linux OS, via a text file, to automatically connect using the `occi` tool from Adafruit (Adafruit 2016). This, in turn, helped ease the transition for participants using their devices at home. Still, many participants found booting into the GUI environment easier to set up the Wi-Fi. The difficulty of getting on the network echoes our experience with other connected development boards.

5.4.2 Understanding Technologies

Many of the designers in our workshops commented on finally understanding what a server actually does. Setting up their own server with communication between a web page and hardware helped designers to understand how the internet functions, helping to demystify web services. Designers also appreciated learning about common technologies they had heard about such as NodeJS, Raspberry Pi and Arduino but were not sure how they worked or could be used for interaction design.

5.4.3 Text-Based Interaction

Using SSH was new for most designers. We often introduced the topic by saying "we are now going back to a way of programming from the 80's." Although it is possible to develop directly on the Raspberry Pi using a GUI, we felt it was important to introduce designers to developing using a text-based console common across many development boards. For code editing, we showed students how to use 'nano' but also enabled the built-in SAMBA file server on the Raspberry Pi so they could edit code on their laptops with a modern text editor. Still, many designers felt wanting for a more graphical development environment.

5.4.4 Distributed Development

Development with an Interaction Engine involves at least three different computers (MCU, server, and client) and requires a shift from programming a single device to programming a distributed system. The framework helped designers manage these messages. One designer stated that they used the framework to envision the code running on each device and arranged their code editor windows from left to right to think spatially about messages moving back and forth between devices. Whereas current day interfaces for writing code are well suited for programming one device, next generation coding interfaces within Interaction Engines might address the flow *between* devices.

5.4.5 Code Stitching

After understanding the back-end messaging and system coordination, many designers across our workshops were excited to connect their physical hardware to beautiful, interactive web user interfaces such as d3.js (Bostock) for visualizing live data from physical sensors or p5.js (McCarthy 2016) for Processing-like interactive multimedia. However, we found that integrating these toolkits was often more difficult than expected. This is similar to problems we have seen from students trying to stitch together many hardware modules on the Arduino. Future systems may help by better supporting module based development.

5.4.6 Demystifying the Computer

The Interaction Engine framework helped students to develop a better understanding of the properties of the computer as a tool for interaction design. Our modular approach helped students understand each part of the system. Feedback from students included:

> Yes—it seems less like black magic and more like, oh yeah, that's just some hardware and some code.
>
> It gave me a better understanding of exactly what's going on inside various interactive objects.

This helped boost designer's confidence toward using these systems:

> It made me realize that I could program them – they seemed less intimidating.
>
> It expanded my comfort range in terms of what I might tackle as a project.
>
> The fact that I was able to do it so quickly, and know that I can use the interaction engine to do it again if I need to gives me a bit of confidence that I might be able to do it in the future.

6 Interaction Engines in the Wild

After our workshops, we followed-up with some designers who decided to employ the Interaction Engine pattern to their own projects. Looking at three of these projects—a networked plant monitoring system, a computer vision enabled art installation, and a web-controlled interactive robot—we discuss the reflections of designers working with an Interaction Engine.

6.1 Networked Plant Monitoring

One designer, a self-taught electronics maker with a formal arts background, is developing a system to allow indoor farmers to collect data about individual plants.

His system uses multiple radio-frequency (RF) based sensor nodes to monitor individual plant data such as soil moisture and temperature. He uses a tablet with an RF unit and RFID reader to tap the plants and bring up data about them from a central server. The user can then add notes about the plant using the tablet and save this information back to the server. For his prototype, he connected the RF-based sensors back to an RF Arduino and the Raspberry Pi. He built an application using the built-in examples on the Interaction Engine that serves a tablet based web page and manages the data for the plants.

By using an Interaction Engine, this designer stated that "*it saved my prototype.*" Although he had the physical sensors and RF working, he did not have a central data server or graphical interface. He first attempted to use Bluetooth and Processing but found that the code libraries were out of date. He then built a simple web application using the Interaction Engine in about 5 hours over two working sessions the night before a project demonstration. This example shows how an Interaction Engine can extend previously built hardware, adding new functionality in little time (Fig. 3).

During the demonstration, the designer said that his main feedback was why his prototype was not in the hands of real users. He felt that his ability to create such a high fidelity, interactive prototype spoke to the power of the Interaction Engine pattern. Had the system been less functional he would have received more feedback about building a better system. Instead, those giving feedback could focus on assessing the design concept rather than on the technology itself.

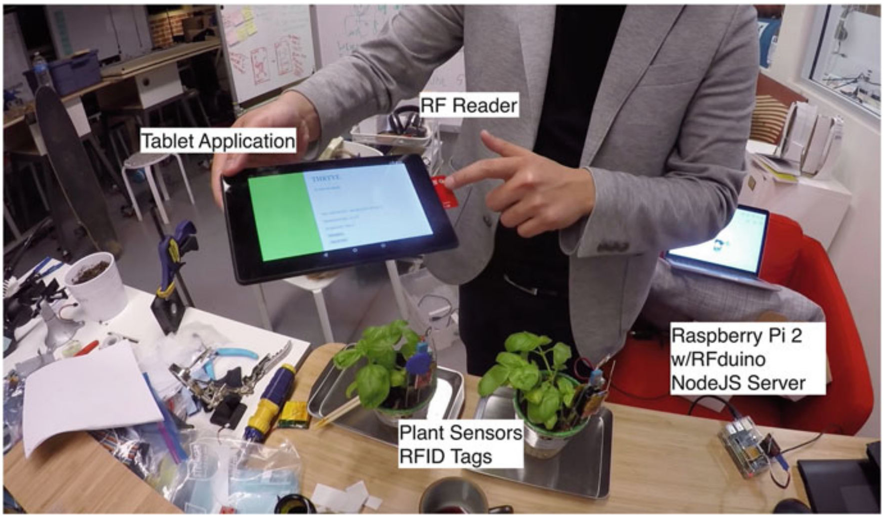

Fig. 3 Networked plant monitoring. The system uses an Interaction Engine model to integrate RF sensor nodes with a data server and tablet based web interface

6.2 Computer Vision Enabled Art

A design student employed an Interaction Engine for their Senior Art Thesis. The project consisted of our Interaction Engine toolkit running a computer vision program to identify faces and highlight them while writing "*I like it when you watch*" underneath them on a projected screen. Once a face was detected, the Interaction Engine controlled a prosthetic attached on a motor driven by a printer belt drive.

This designer extended the capabilities of their Interaction Engine by installing OpenCV (Itseez 2016), an open source computer vision library, and Processing for visual computing. They used the vision data from a Processing based program to control the motor drivers attached to an Arduino microcontroller. Using the Interaction Engine enabled the designer to fully embed the computing elements into the art exhibit. Additionally, the designer could remotely edit and update the software interactions without needing to disassemble part of the exhibit to access the computer. This improved development time and allowed the designer to make more changes (even from their home) to the interaction of the piece without altering hardware.

6.3 Web-Controlled Interactive Robot

An interaction design student built an interactive robot for use in child-child emotion regulation studies based on an Interaction Engine. The robot was designed to be wirelessly controlled from a self-served web interface, allowing a remote wizard to interact with children playing a game. The control page allows the wizard to control the head of the robot (two degrees of freedom, rotate and tilt), view a live webcam stream from the robot's point of view, and play non-verbal sounds (beeps and chimes) via a speaker. The robot was developed using a NodeJS web application communicating with an Arduino over USB. All components ran off a 16,100 mAh USB battery pack.

While developing the robot, the designer needed to make a conceptual shift from their knowledge of Arduino to an understanding of how the server enabled the connection between the Arduino and the web. This process took some time, however, after one debugging session, the designer made a realization the server was what allowed anyone on the web page to control the Arduino. After understanding the importance of the communication, the designer could greatly accelerate her work and begin focusing on the robot's behavior and appearance.

Later the designer shipped the robot to another designer who had not taken our workshop but did have experience with Linux and NodeJS. This designer was able to get the system running within a day and further extended the robot capabilities by adding the cloud-based IBM Watson text-to-speech engine (IBM 2016) to have the robot speak typed messages.

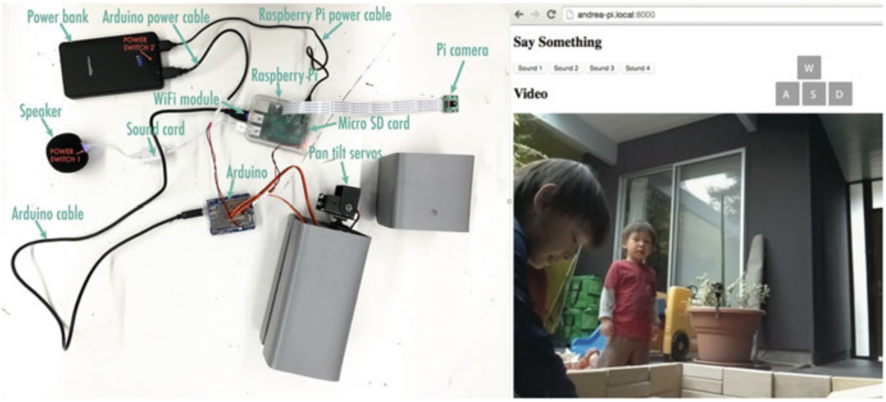

Fig. 4 Ella: A web controlled, interactive robot for child-child interaction built using an Interaction Engine

Overall, using an Interaction Engine allowed the designer to select appropriate software and hardware components for their robot in a piecemeal fashion. This case study also highlights the challenges in shifting to a framework that requires the coordination of many devices and the mental shift a designer must make to effectively use this framework. Additionally, the use of the single-board Linux computer and networking capabilities allowed another designer to easily and quickly extend the functional capabilities using cloud-based software (Fig. 4).

7 Discussion

Users and designers often employ vastly different mental models (Norman 2013), so the transition of viewing computers as products to materials can be challenging (Tullio et al. 2007). We found that the Interaction Engine framework was helpful for shifting the designer's mental model of the computer from a product to a material.

We found that the low cost of the Interaction Engine helped designers to reconsider the way they thought about how computers could be used–they were less concerned about leaving the computer in an exhibit, for example, and less hesitant to connect experimental components or to run new software. This is important, as trepidation about the preciousness of computers can inhibit designers from exploring new uses for them (Acholonu 2012).

The form-factor of the single-board computer itself was a revelation. We learned that many designers had been told that their cellular phones were powerful computers, but that they had assumed this was metaphorical; the discussion about what SBLCs do helped them realize that there really was a computer inside their phones. This, we feel, helped designers to understand the computer as a material rather than as a product.

The interface for the Interaction Engine also helps to shift the designer's mental model. We pushed our designers to interact with their Interaction Engines remotely via a text-based console rather than a GUI, for the pragmatic purpose of not requiring an external mouse, keyboard, and monitor. Most of our designers had never interacted with a computer in this way. Although being introduced to command-line interfaces was challenging for the designers at first, this interface helped designers understand how a computer works underneath the familiar graphical user interfaces.

With its mix of physical computing, operating system based computing, and connectivity, the Interaction Engine allows designers to explore a wide, new range of interactions once limited to desktop computing in a far wider range of user contexts. The components and more importantly, the framework, help to create a cognitive tool that helps support and guide designer's thinking toward new opportunities (Derry 1990). This conversion is not without it challenges, as the designer must begin to think deeply (Jonassen 1994) about what it means for a computer to be a material.

As everyday objects become more imbued with computation and begin to communicate with other devices both near and far, it will become more important for designers to understand how new computing tools can enable new designs. Understanding the various sub-systems within computing systems will allow designers to better appropriate new technologies as they become available (Kay 1998). Although it may be inefficient for final products, the *bricolage* approach encouraged by the Interaction Engine framework allows designers to more easily prototype interactive objects using different connected modules; this may be different from what is preferred for expert electrical engineers or computer programmers (Stiller 2009).

8 Future Work

Although single-board Linux computers and microcontrollers are becoming more usable as design materials, there are still many areas for improvement.

Getting on the Network Getting on the network is still one of the most difficult parts of setting up an Interaction Engine. Though we have used some tools to make this easier, there are opportunities for new design patterns to connect devices.

Modern Interfaces For many designers, Unix and command-line interfaces can have a steep learning curve. While we felt this was pedagogically beneficial, updated graphical interfaces and setup tools will enable wider access to the Interaction Engine's capabilities.

Managing Messages Coordinating messages between numerous computing units can be hard. Improved tools for managing interactions between MCU, SBLC, and the cloud can help simplify development. Additionally, message management systems can be standardized to work across hardware types allowing for subcomponent upgradeability.

Developing for Multiple Devices Jumping between devices can be conceptually difficult as projects become larger. New work in high-level languages for writing code across multiple devices and services like Ravel (Riliskis and Levis 2014) and fabryq (McGrath et al. 2015) will help improve the development process.

Cloud Based Computing Modules As machine learning and artificial intelligence systems become more advanced, it will be important to develop usable interfaces for designers to access these capabilities. Having an OS with standard web communication will allow a new class of interaction design modules to be created and used on a wide range of devices.

9 Conclusion

As computing trends shift and the nature of interactive devices add more networked and operating system based technologies, it will be more important for designers to understand the underlying capabilities of these systems. In understanding the components and conceptual framework of the Interaction Engine pattern, we feel that designers will more readily be able to utilize existing and emerging technologies to their fullest advantage to create better-designed products.

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Making the Domain Tangible: Implicit Object Lookup for Source Code Readability

Patrick Rein, Marcel Taeumel, and Robert Hirschfeld

Abstract Programmers collaborate continuously with domain experts to explore the problem space and to shape a solution that fits the users' needs. In doing so, all parties develop a shared vocabulary, which is above all a list of named concepts and their relationships to each other. Nowadays, many programmers favor object-oriented programming because it allows them to directly represent real-world concepts and interactions from the vocabulary as code. However, when existing domain data is not yet represented as objects, it becomes a challenge to initially bring existing domain data into object-oriented systems and to keep the source code readable. While source code might be comprehensible to programmers, domain experts can struggle, given their non-programming background. We present a new approach to provide a mapping of existing data sources into the object-oriented programming environment. We support keeping the code of the domain model compact and readable while adding implicit means to access external information as internal domain objects. This should encourage programmers to explore different ways to build the software system quickly. Eventually, our approach fosters communication with the domain experts, especially at the beginning of a project. When the details in the problem space are not yet clear, the source code provides a valuable, tangible communication artifact.

1 Introduction

Programmers acquire domain knowledge to better understand the problem space and create a solution that fits the users' needs (Evans 2004). For this, programmers and domain experts form a shared vocabulary to foster knowledge exchange. This vocabulary consists, to a broad extent, of terms describing real-world concepts. For example, the accountant may deal with transactions, the geologist with soil horizons, the biologist with DNA strands, and the cook with ingredients and recipes. To allow programmers to express this vocabulary in code, it is

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beneficial to make use of an object-oriented programming language (Wegner 1987). In such a language, programs are made up of objects, which are virtual representations of relevant artifacts from the domain. In the cooking domain, objects can represent concrete things such as vegetables and also abstract concepts such as recipes. What we can observe and manipulate in the real world, we can express as object behavior and object relationships (Kay 1996). In a cooking simulation, we might want to slice an apple with a knife and add the resulting slices to the dough. Code that describes this process preferably looks like this: `(anApple cutWith: aKnife) do: [:eachSlice|dough add: eachSlice]`. It is usually possible to represent domain concepts as such interacting, message-exchanging objects (Meyer 1997). Consequently, understanding the problem space means understanding the sorts of objects that are required to construct the software system.

Software development is an iterative process (Beck 2000) that benefits from exploratory programming strategies (Sandberg 1988). Even early versions of the software are examined by all parties to clarify requirements and future directions. Once the programmer presents first working prototypes, the domain expert gains a better understanding of how the domain data can be processed by the software.

At the same time, the shared understanding of the objects relevant for the domain improves iteratively during the development. Programmers and domain experts define what certain terms refer to in the context of the application during discussions of the application requirements. In an object-oriented programming language, these terms and definitions are ideally used for identifying and defining objects and messages. Through this domain-specific code, the source code evolves into a written documentation of the domain knowledge. The source code of an application is a suitable documentation as all terms defined in it are relevant to the application and their definitions are what makes up the application. Consequently, domain experts should be able to recognize relevant domain concepts and they should be able to actually *read* the source code. If the shared vocabulary is documented in this way and can be understood, it becomes tangible and a vital subject to discuss and refine next to the application itself.

However, some aspects of the software development process hinder programmers to directly express domain concepts in source code. Among the main challenges at the beginning of each software project, programmers have to learn about the existing information. Typically, there are several databases that store the domain information to be processed. Such databases are full of numerical data and text snippets, which represent domain-specific concepts such as cooking recipes. Programmers have to write code to access these databases and build bridges between variously shaped domain information and the object-oriented world (Papakonstantinou and Garcia-Molina 1995).

It is, however, challenging to create domain-specific objects from existing database data in new systems (Evans 2004). The basic means to access and process data originating from external systems are verbose and impede the readability of domain logic. For example, if programmers want to open files or make Web requests, they will have to invoke several helper objects and process the results to eventually get domain objects. It takes usually several iterations of re-writing source code to improve readability (Fowler 1999).

In the Squeak/Smalltalk programming environment[1], everything is an object. For example, the text snippet `'marcel.taeumel@hpi.de'` is, in fact, an object that represents some text and encodes an email address in this case. Programmers cannot ask this object for its `#authority`, which is `hpi.de`. First, a helper object has to convert the text object into a URL object, which then understands that message: `(Url absoluteFromText: 'marcel.taeumel@hpi.de') authority`. As text is prevalent in existing databases, the conversion of text fragments to domain objects is prevalent. Still, the process of writing such code in a readable fashion is prone to mistakes and takes time. Interestingly, programmers use many libraries that already know about many domain-agnostic structures such as URLs. Only their domain-specific activation is for the most part explicit. Imagine an address book stored in the file named `'friends.txt'`. In that book, the authority of a person's email address can be looked up like this: `('friends.txt' person: 'marcel') email authority`. Unfortunately, programmers have to struggle with many intermediate steps to access and process this data. Many of these steps cannot easily be hidden and remain visible in the code. Without additional efforts, knowledge exchange between programmers and domain experts in terms of code becomes unfeasible.

Based on these observations, we want to investigate various means to reduce programming effort when connecting object-oriented systems to external data sources. If a text looks like an email address, for example, programmers should be able to directly treat it like one in the code. We want to address the following research question:

> In object-oriented systems, how can we support programmers in writing domain-specific code to improve code readability through separating object access from object use?

It is beneficial to offer domain experts a readable form of object-oriented code as soon as possible. This fosters knowledge exchange and helps clarify requirements. Hence, a major goal is to be able to talk to domain experts about the very material that makes up the software system: the source code.

We want to elevate domain knowledge from various data sources to an object-oriented programming system. For this, we employ a set of extensible *predicates*, *resolvers*, and *mappers* to support transparent exploration of objects and their relationships based on primitives such as strings, numbers, or dictionaries originating from external sources. We focus on the self-supporting Squeak/Smalltalk programming environment to benefit from the object-oriented programming paradigm, tools

[1] See http://www.squeak.org for details.

with short feedback loops, and omnipresent run-time information. In our approach, any generic object can be treated as an *identifier* to be resolved, for example, by a Web request. The resulting, usually generic, object will then be mapped to one or more specific objects, depending on predicate matches. If there is no appropriate class to create a domain-specific object, our mechanism establishes a user dialog to create one. Many domain-specific applications can be constructed on top of this mechanism. Since our approach works on generic objects that are already materialized in the system, we can treat any set of objects as a data source itself. This underlines the self-supporting nature of the Squeak/Smalltalk system.

In this chapter, we:

- Present the model of a framework that supports exploration of an object graph based on external data sources.
- Elaborate on several scenarios to clarify the programmer's effort and added value.
- Discuss opportunities and challenges regarding expert communication and system maintenance.

The next section provides background information about how programmers work and think in terms of objects in the programming system Squeak/Smalltalk. We make a clear distinction between generic objects and domain objects. After that, Sect. 3 explains the basic model and components of our approach. We elaborate on object roles, role transitions via resolve and map, as well as the impact on extensibility and code readability. Section 4 builds on several examples, which are provided in the previous sections, to illustrate how three tasks can be solved with our approach. Given many open questions about implementation and long-term maintenance, we discuss our approach in Sect. 5. We conclude our thoughts in Sect. 6.

2 From Generic Objects to Domain Objects

In this section, we elaborate on the improved communication between domain experts and programmers resulting from bringing domain concepts to the software system. We also illustrate how integrating external data can impede this communication.

First, we describe the programmers' situation when working in an object-oriented system. We choose Squeak/Smalltalk as an example system because it has a clear implementation of the object-oriented paradigm. Second, we describe the role of generic objects, how they result from integrating external data, and which issues they cause regarding programming effort and source code readability. Third, we introduce domain objects as a major design goal for programmers when developing software. We give a simple example on how to derive domain objects from generic ones by writing custom classes. Finally, we summarize the main challenges for our approach.

2.1 Objects and Messages in Squeak/Smalltalk

Our approach focuses on challenges of object-oriented software development that occur in the Squeak/Smalltalk programming system (Goldberg and Robson 1983). These challenges and our proposed solutions are, however, not specific to the Squeak/Smalltalk environment and can easily be transferred to other object-oriented programming languages and systems. Squeak implements the object-oriented programming paradigm with a clear meta-model. Its programming tools provide short feedback loops, and the programmer can inspect and manipulate any part of the application anywhere in the user interface.

Squeak implements a clear object-oriented meta-model, as everything in Squeak is an object. The behavior of the system is defined mostly in terms of objects collaborating through messages. Classes are blueprints to construct objects and to describe the messages objects can understand. Hence, Squeak is a class-based, object-oriented system (Wegner 1987, 1990). Still, classes are also objects and so are messages. This leads to a powerful meta-object protocol, where programs can be written that modify other programs—and even themselves. Based on a general understanding of object-oriented applications, the Squeak system includes objects for running programs (such as method, context, process), user interfaces (such as cursor, event, window, button), data processing (such as string, number, collection), and many more. However, the roles of objects may blur, depending on the programmer's current perspective on the system.

Programmers that write Smalltalk code benefit from short feedback loops in programming tools (Sandberg 1988). There are *no text files* to be modified, but only the method objects of a class object. The system browser supports navigation in the system's classes. It can show a text editor for one method in a class. If one method gets modified, it will directly be compiled and integrated into the class. All instances of that class will immediately show the new behavior if that new method is involved. When an object sends a message to another object that does not understand the message, an error occurs. Debugging the system means that the programmer has to figure out why the participating objects made this communication error.

In a Smalltalk system, run-time information is omnipresent. Programmers can type any expression into any text field and evaluate that code. This is especially convenient for objects constructed from literals, such as numbers and strings. For example, evaluating `3 + 4` yields `7`. Classes and other global variables can be referenced by just typing their identifier. For example, evaluating `Rectangle origin: 0@0 extent: 20@20` creates a new rectangle object. `Rectangle` is the global variable, `#origin:extent:` the message. `0@0` creates a point object by sending the message `#@` to a number (literal). However, not all objects can be referred to by their global name. Some objects have to be accessed in a context object. For example, all graphical things on the screen are called “Morphs”. Programmers can just point to a morph with the mouse, open an inspector tool, and start sending messages to that object. Given such a context object in any tool, such as the debugger, the code expressions are enriched with *bindings*. Bindings map identifying objects, typically strings or symbols, to other objects. Then, even the expression (`foo bar`) `baz` can work if there is a binding for `foo` and the bound object responds to the message #`bar` and if the object resulting from that call understands #`baz`.

2.2 Generic Objects

We think about an object being a *generic object* if it belongs to the Squeak base system and not to any particular application domain. Generic objects are often strings and numbers. There are also generic objects that represent a collection of objects or object structures. Examples for generic objects for object collections are ordered collections, sets, associations, and dictionaries. Dictionaries are a collection of associations, that are themselves key-value pairs. Thus, dictionary objects are like real-world dictionaries in the sense of a book for translating foreign languages that contain a foreign word as a key and the translation as the value. We can describe the domain concept of people with their friends like this:

```
| marcel patrick |
marcel := Dictionary newFrom: {
  #firstname -> 'Marcel'.
  #lastname -> 'Taeumel'.
  #email -> 'marcel.taeumel@hpi.de' }.
patrick := Dictionary newFrom: {
  #firstname -> 'Patrick'.
  #lastname -> 'Rein'.
  #email -> 'patrick.rein@hpi.de' }.
marcel at: #friends put:  { patrick }.
patrick at: #friends put: { marcel }.
```

In this example, we create two concrete dictionaries for two people, Marcel and Patrick, and establish the mutual friendship relation by setting each person’s key `#friends` to a collection with a single object: the friend. Since it is a collection, there is room for more friends. Note that `marcel` and `patrick` are variables and the := operator is the variable assignment. These names of the variables are the names under which the two dictionaries are known in this short code section. The {...} notation represents a collection of objects. The message #–> creates an association. Every dictionary responds to the messages #`at` : `put` : and #`at` :, which modify and read the contents.

The problem with such generic objects is that (1) the syntax is verbose, (2) the source code includes identifiers that do not belong to the domain, and (3) behavior cannot be easily added to the object to define new terms in the vocabulary. In theory, it is possible to put anonymous methods as objects into the dictionary and evaluate them. However, such an approach would circumvent the idea of classes, instances, and messages. It is hence discouraged to do so. Instead, programmers work with domain-specific objects like this:

```
| marcel patrick |
marcel := Person firstname: 'Marcel'
  lastname: 'Taeumel'.
marcel email: 'marcel.taeumel@hpi.de'.
patrick := Person firstname: 'Patrick'
  lastname: 'Rein'.
patrick email: 'patrick.rein@hpi.de'.
marcel addFriendMutually: patrick.
```

This creates instances of the class `Person`, which implements the concepts of first name, last name, email address, and the friendship relationship. In this case, the friendship seems to be mutual. Implementation details in the class `Person` should deal with establishing the mutual friendship, specifically by also adding Marcel as a friend of Patrick. Hence, the syntax is clearer and behavior can be added to the concept of a person—now represented as a domain-specific object by having its own class. On the downside, programmers have to create and describe that class.

Generic objects are used by libraries to provide some object-oriented representation when accessing data from outside the Squeak environment. Examples for accessing information outside the environment include file access and Web requests. For example, the *Web client* in Squeak can make an HTTP (Hypertext Transfer Protocol) request. It returns an instance of `WebResponse`, which is a more specific object, but still not specific to the contents it is trying to fetch:

```
| url response contentType content |
url := 'https://www.gravatar.com/avatar
/16d12ad253109aa61366e44ea8ab395e'.
response := WebClient httpGet: url.
contentType := response contentType.  "image/jpeg"
content := response content.          "some bytes"
```

Assuming that the programmers know that the request should deliver a *picture*, they still have to interpret the fairly generic response to create an instance of `Form`. This instance represents the concept of pictures in Squeak. That is, they must write further code that converts the generic object into a specific one. Only then can they use the picture for display on the screen. Given that the message `#displayAt:` shows a picture at the given coordinates on screen, they have to write the following:

```
| picture |
response contentType := 'image/jpeg'
  ifTrue: [picture := ImageReadWriter formFromStream:
          response content readStream.
          picture displayAt: 0@0.]
  ifFalse: [...].
```

This presents several challenges. First, programmers have to write conversion code for any new application whenever they want to access this kind of resource. Second, this code might clutter the domain-specific implementation of the surrounding object. Third, programmers must recall these mapping rules and predicates, causing the cognitive load to increase. Actually, the programmer might just want to write the following:

```
| picture |
picture := 'https://www.gravatar.com/avatar
/16d12ad253109aa61366e44ea8ab395e'.
picture displayAt: 0@0.
```

The variable `picture` should emphasize that the identifier of such a resource could come from any generic object. We could have directly sent `#displayAt:` to the string.

Text can also be used to transfer complex structures between databases, across the Internet. The text-based JSON[2] (JavaScript object notation) format is a preferable solution. JSON looks, to some extent, like the Smalltalk syntax for generic objects shown above. This similarity makes it easy for Squeak to generate generic objects from a JSON string. It uses dictionaries, arrays, strings, numbers, and Booleans. Here is an excerpt response for a Web request to the API[3] of StackOverflow[4] which is a question-answering platform for programmers:

```
jsonString := '{"items":[
  {"answer_count":4, "title":"Help"},
  {"answer_count":50,"title":"Help more"}],
  "has_more":true}'.

jsonDictionary := Dictionary newFrom: {
  #items -> {
   Dictionary newFrom: {#'answer_count' -> 4.
    #title -> 'Help'}.
   Dictionary newFrom: {#'answer_count' -> 50.
    #title -> 'Help more'} }.
  #'has_more' -> true }.
```

Concrete strings and numbers provide only slight cues about the underlying domain. For example, the list of questions is behind the `#items` key in the `jsonDictionary`. The name of the underlying domain concept "questions", however, does not occur at all. If programmers want to write code that looks like concepts in the domain, they have to write new classes that describe these concepts.

2.3 *Domain Objects*

Domain objects have an interpretation specific to the domain for which the software system is created (Buschmann et al. 2007). In Squeak, this means that programmers

[2]See http://json.org/

[3]The Web request was sent to the URL http://api.stackexchange.com/2.2/questions?tagged=Squeak&site=stackoverflow

[4]See https://www.stackoverflow.com

will create new classes that represent the domain concepts. Instances of these classes are then the domain objects. Existing classes in the Squeak system provide a high level of reuse and are agnostic to the domain in which they are used. For example, any chat tool, Web browser, or word processor benefits from text objects, picture objects, or button objects. Such generic objects become domain-specific only through their usage context and actual state they are holding. A text can represent the *manuscript* being written if it contains recognizable letters, words, and whole phrases. Still, programmers cannot always reuse generic classes but have to write custom classes to better reflect domain-specific concepts. There could be good reasons to write a class for Manuscript, which just *contains* (or *wraps*) a text object. It is not advisable to modify base classes because of interference with other applications. A custom class supports many degrees of freedom in describing any domain concept in source code. For example, manuscripts might not just be a large chunk of text but rather elaborate structures with sections and figures. A chat message, on the contrary, might not benefit from such extensions.

Programmers create domain objects from generic objects by either *wrapping* the generic objects or by *unpacking* them. If the generic object does not provide reusable behavior, one can just extract all of the state and map it to instance variables. After the object gets unpacked in this way, it is not useful anymore. If the generic object provides useful behavior, such as messages to derive new information, one should wrap the whole domain class around that object. The wrapping object can easily access state and behavior of the wrapped object as needed. Either way, the source code for constructing the domain object will usually be added to the respective class object as a *construction message* like `Url absoluteFromText: 'marcel.taeumel@hpi.de'`. Here, the `#absoluteFromText:` is a message used to create an instance of `Url` based on a generic string that looks like an email address. Here, the URL is considered a domain object and the string a generic object (see Fig. 1).

2.4 Domain Objects by Example

We want to write an application that manages *questions* and *answers* with a graphical user interface. As a starting point, we want to integrate StackOverflow, which is a Web-based system for the exchange of programming knowledge and experiences. StackOverflow has a website where programmers can ask questions about issues with specific languages, libraries, or systems. Fellow programmers provide answers and the community can rate all answers so that the whole database serves as a useful reference for any programmer that has similar problems. Hence, our object-oriented application should have objects for questions and objects for answers. In Squeak, this means that we will have a class `Question` and a class `Answer`. There is a set of questions and each question can have multiple answers.

We opt for unpacking the generic objects if feasible. The following steps are undertaken:

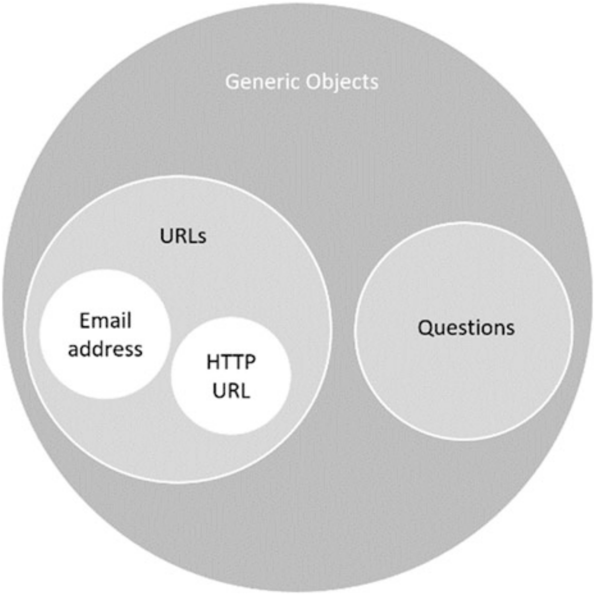

Fig. 1 Objects can be ordered in a hierarchy from generic to domain-specific. Generic objects are not very specific and understand only generic messages. In contrast, an email address is a very specific object that can understand messages particular to email addresses. When integrating data from external databases into object-oriented systems it is necessary to provide a mapping from the generic objects to an object specific enough so it can understand the required messages

1. Perform a Web request to StackOverflow.
2. Create generic objects from the JSON part in the response.
3. Fill the domain objects with information. Discard the generic ones.
4. Repeat the steps until all objects and relationships are established.

The conversion is illustrated in Fig. 2.The following requests retrieve questions and answers:

- http://api.stackexchange.com/2.2/questions?tagged=squeak&site=stackoverflow
- http://api.stackexchange.com/2.2/questions/36008167?site=stackoverflow
- http://api.stackexchange.com/2.2/questions/36008167/answers?site=stackoverflow
- http://api.stackexchange.com/2.2/questions/36008167/answers/36009505?site=stackoverflow

The first request searches for multiple questions, the second fetches a single question, the third fetches all answers for a single question, the last fetches a single answer. Numbers are used to identify questions and answers. Numbers are also used to encode timestamps, such as the point of creation as the number of seconds elapsed since the beginning of 1970. Strings are used to hold a question's contents and an answer's contents. After the conversion, there are concrete objects

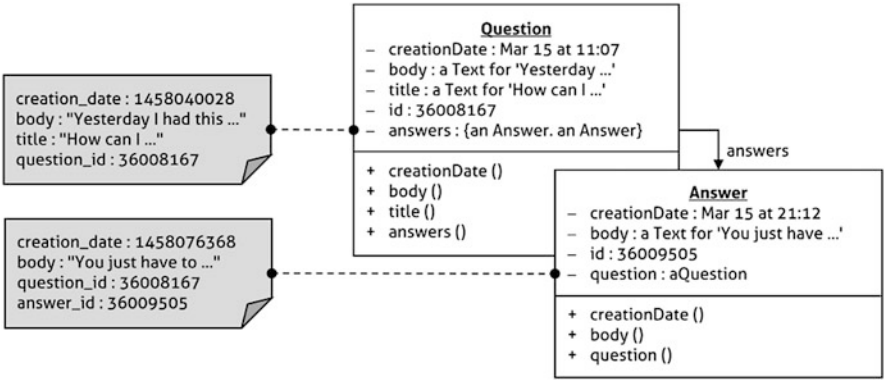

Fig. 2 An example for a mapping from generic information (*left*) to domain-specific objects (*right*). Note that the name of slots was converted from underscore style to came-case. The date was converted from an integer to a date object. The body was converted from a string to a text, which is a string with visual attributes such as color and weight. The relationship between question and answers was added from the outside with an additional Web request. Methods are merely accessors for the instance variables. (UML-flavored object diagram)

for `DateAndTime`, `Text`, `Question`, and `Answer`. Note that underscore style was converted to camel-case to match Squeak's coding guidelines. Note that we did not have to create `DateAndTime` and `Text` because they are part of the base system.

Now that we have custom classes, we can add new behavior to the domain objects. For example, we can add the message `#isGood` if the answer got a high rating by the community. Any derived or computed information can be added this way. If programmers want to modify the domain objects, they have to write back to the external data source. We focus on exploring and understanding domain objects, which should be used in an interactive application.

All these steps are typically just the starting point. Programmers rewrite and improve source code regularly (Fowler 1999). If they recognize a way to better modularize pieces of code, they employ architectural patterns and design patterns. For example, they could put all source code related to querying StackOverflow into a specific class, which they could call `StackOverflowAccessor`. The mapping between generic objects and domain objects might happen in a `QuestionFactory`. Still, this example illustrates how much additional code programmers have to write to bring external data and domain objects to Squeak. All this additional code interferes with the goal of keeping the source code as an artifact that is understandable to both programmer and domain expert.

2.5 Challenges for Object Lookup in Object-Oriented Systems

The source code should look like a textual description of some domain model (Evans 2004). In the code, domain concepts should be discoverable by both programmers and domain experts. Only then is there a chance that code can be used as a tangible artifact to talk about the problem space and the solution space. Also, there is a reduced chance for misinterpretation when talking about possibilities and limitations in the software system. In an object-oriented system, such as Squeak/Smalltalk, programs consist of objects that communicate via messages. Reading source code means reading object names and message names, combined into sentences and whole paragraphs.

However, the traditional practices to get domain objects from databases impede both code reading and code writing. Programmers have to manually create domain classes, manage access of external sources, and transform generic objects into domain objects. Code reading is difficult because traces of the object conversions remain in the code such as in (`Url absoluteFromString: 'marcel.taeumel@hpi.de'`) `authority`. The alternative `'marcel.taeumel@hpi.de' authority` would be more direct and more concise. Code writing is difficult because programmers have to be aware of existing techniques to convert generic objects. In Squeak, programmers have to know about, deliberately choose, and apply existing converter classes such as `ImageReadWriter` to read the binary data of a picture. Programmers must be careful not to simply reuse one conversion scenario in another situation. Building on the StackOverflow example above, programmers might want to interpret other numbers like `1458040028` as a data-and-time object, not only in the context of a question or answer object.

All these intermediate steps, also increase the semantic distance between the initial object and the object that will finally receive the message. The semantic distance is the number of operations we have to perform in order to achieve our goal. Each conversion step makes it harder to directly understand what a line of code expresses. As a consequence, the impression of immediacy in programming can become worse, and this in turn hinders explorative programming (Ungar et al. 1997).

We are looking for a framework or mechanism that supports: (1) a concise description of the rules for resolving artifacts based on identifiers, (2) mapping any generic object into a domain specific one, and (3) triggers to promote clear source code that uses only vocabulary from the problem domain. Domain experts might be capable of reading and understanding that: `(someFramework shouldConvert: genericObjects) soThatEach: [:domainObject | domainObject worksIn: SoftwareSystem]`[5]. This

[5]This is an example to show the possibilities for writing concise expressions in the Smalltalk language. Actually, this expression could be executed if there would be objects, such as `aFramework` and `SoftwareSystem` that understand the messages.

would improve the communication between programmers and domain experts and eventually lead to an effective and efficient software system.

3 Our Approach: Implicit Object Lookup and Exchange

An object-oriented system consists of objects that communicate via messages. Sometimes the programmer intends to have another representation of the object to answer a given message. In some cases, the given object does not understand a certain message and it is vital to exchange the object with a more appropriate one. Otherwise, the execution would stop and the programmer would have to debug the system. So, if a string object *looks* like an email address (for example `'patrick.rein@hpi.de'`), it should be able to respond to the message `#authority`. However, in existing systems strings will not do that.

We describe our approach to add a novel means of object lookup and exchange to any object-oriented system. Our goal is to reduce programming effort and improve code readability, especially in the beginning of the exploration of a domain when the vocabulary between programmers and domain experts changes regularly. Our conceptual model is illustrated in Fig. 3. First, we explain the three different roles each object can take on, as well as the means to transition between these roles. Then, we elaborate on triggers and predicates which integrate these transitions into the ordinary system behavior. We elaborate on the object cache as means to manage object identity. Given the dynamic characteristics of the Squeak/Smalltalk system and explorative programming strategy when clarifying the system specifications, we also show the means to materialize the effective protocol for each object, which is a list of messages understood. Finally, we describe the impact of such an approach on source code readability.

3.1 Object Roles

Any object can take on one of three roles: *identifier object*, *generic object*, or *domain object*. Which role an object takes on depends on the context and the programmers' intent. For example, a URL object can be an identifier to be put into a resolver, which could make a Web request. That same URL object can also be the domain object after being mapped from a string that contains the same data. Consequently, it depends on the situation and the programmers' intent to determine whether one object is preferred over another.

In Squeak, *identifier objects* are usually strings, numbers, URL objects, or UUID objects. They can commonly be used to access additional information about the object they designate from an external database. For example, the text `'patrick.rein@hpi.de'` could be used to look up additional contact information on an address book server. Besides simple objects, one could also use any complex domain object, for example a person object in an address book application, and treat it as an identifier. Either the identity of the object itself, or just parts of its structure might be used to query the external database for additional information. For example, we might use a person object as an identifier for its corresponding social media profiles. For getting this profile from the Web, we only require the email address of the person. Thinking of the person as the identifier for the social media profile is likely to be closer to the underlying problem domain of the respective software system.

Generic objects can consist of more identifier objects or also containers for multiple objects. In Squeak, containers include sets, arrays, and dictionaries. Usually, these containers are agnostic to any particular domain. Still, these generic containers may sometimes be adjusted to domain-specific representations. For example, a set of persons might be captured in a special `FriendSet` class to provide additional properties or behavior to specialize the friendship relationship between the friends. Dictionaries, on the other hand, are a means to structure multiple objects by some keys. This is similar to the way classes describe state in Squeak. However, dictionaries are primarily for storing and accessing structured data and we cannot easily add and invoke behavior on dictionaries. Further, dictionaries require more code for accessing their data in comparison to Smalltalk classes. Because of the cleaner syntax and the potential to add new state or behavior, domain-specific classes are preferable over containers.

Domain objects are the objects that represent the domain concepts. Programmers prefer working with such objects because the resulting source code is more readable. These objects understand domain-specific messages and store domain-specific state. For example, when a generic dictionary that represents an email understands only the `#at:` message, the domain object can respond to the specific `#authority` message. In Squeak, using domain objects can save many abstract messages. This

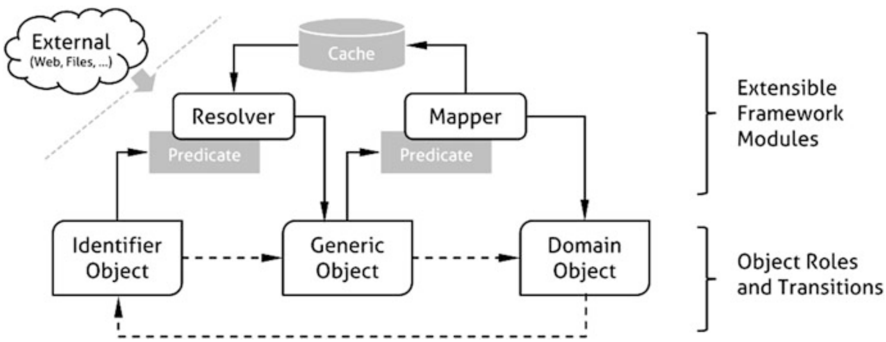

Fig. 3 We propose a mechanism that enriches existing classes with implicit instantiation. It works by implicitly resolving identifiers and mapping generic objects to domain-specific ones. Programmers can add new predicates, resolvers, and mappers to accommodate specific domains. Depending on the purpose, any object can take on the role of an identifier, generic object, or domain object

improves code readability. As soon as new details are discovered in the problem domain, domain objects can be extended with new state and new behavior. In Squeak, all instances of a class get automatically updated if the respective class changes. For example, if you add a new message to the class, all instances will directly understand that message. If you add a new instance variable, all instances will have that, too.

With these three object roles, we try to encode the programmers' intents in different situations. We think that there are three situations where programmers usually access or convert objects:

1. Oh, X is just the name. I have to somehow access the real data from a database.
2. Hm, Y is only a plain dictionary. Useful but it does not understand the important messages. And the dictionary syntax in Smalltalk is kind of verbose.
3. Ok, Z is useful concept, maybe I can use it in this other data source.

This is where our three object roles can extend the programmer's conceptual model about objects.

3.2 Resolve and Map

We propose a system that can automatically look up an object in a database given another object that represents its name. We distinguish between *resolving* and *mapping*, where resolving refers to partially fetching data from outside the Squeak environment and mapping to converting the generic data to domain objects.

A resolver fetches information about a particular identifier from an external data source. This can be the file system, another application on the same computer, or an Internet resource. The resolution process can involve platform-specific details of how to connect to the database, as well as application-specific details of how to correctly query for the desired information. A basic resolver might be one for HTTP requests that can handle various content types such as JSON, XML, or image data.

A mapper converts any generic object into a domain object. Considering the Squeak base system, there can be mappers that can instantiate picture objects, sound objects, or others based on raw data such as strings or byte arrays. For any new concept, programmers have to create or extend existing classes.

Both resolvers and mappers might be applicable in the same situation. Given a response from a Web request, for example, it is not obvious whether a resolver or a mapper should take care of making the first conversion after fetching the information. This flexibility allows the programmer to treat the outcome either as a generic object or as a domain object. The responsibilities of the two mechanisms also becomes clear when considering their operations on a shared *cache*. The cache should be used to skip object resolving and mapping so when an identifier should be resolved the system can directly return the resulting domain object. Only resolvers read the cache and only mappers write into it.

3.3 Triggers and Predicates

At best, our mechanism can be *triggered* implicitly whenever an object cannot understand a certain message *and* the programmers' intentions can be met. For example, resolving and mapping of things should enable the string 'marcel.taeumel@hpi.de' to understand the message #authority. Later as the system evolves programmers might want to explicitly invoke our mechanism to make it more predictable. If the communication with the domain expert is not so frequent anymore, one might sacrifice code readability for the benefit of long term maintainability.

If there are many resolvers and many mappers, there will be no value in using every one of them. That is why we also propose *predicates* to support selecting appropriate and capable resolvers or mappers. For an email address stored in a string, a predicate might be a regular expression that verifies the structure: '([a−zA−Z0−9.]+)@([a−zA−Z0−9.]+)'. Only when a string matches this pattern, the resolver or mapper can be applied to it.

For complex scenarios, the process can be supported by a dialog between the system and the user. If, for example, an identifier does not match any resolvers yet, the user could be presented with a selection of existing resolvers to choose from. Such a dialog with the user makes sense if resolving or lookup is part of an interactive application. If an application runs without an interactive user interface however, the system should always continue without user interaction.

For programming tools, the user would be a programmer. For example, if the programmer navigates a data structure across several databases, the dialog can also be used to choose the database where a certain identifier should be resolved.

There might be several rounds of resolve and map until the desired domain object can be made available. If an object does not understand a message, the resolve-map-cycle continues until at least one object is found that responds to the message. This cycle might also involve several interactive user dialogs. In this context, the resolve-map-cycle can be understood as a planning problem as described in the artificial intelligence domain (Russel and Norvig 2003). The planning goal in this case would be that the object understands the required message. The planning operations are the resolvers and mappers.

3.4 Object Cache

It can be comparably slow to access external resources to bring them into the object-oriented world. A cache can be used to avoid making the same external requests over and over again. More importantly, such a cache allows for managing multiple object identities and names.

The object cache represents a table to map an identity object to a domain object. Given some identifier to resolve, the resolver first tries to look up that identifier in the cache. On a cache hit, the external request is skipped and maybe also the mapping between the generic and the domain object. There can be additional resolve-map cycles, depending on the current use case.

Programmers should not have to actively manage the contents of the cache. Our conceptual model primarily comprises the three object roles as well as means to resolve and map objects with the help of predicates. There can be applications where it is not useful to manage multiple object identities. In that case, the object cache could be disabled.

3.5 Tool Support and Virtual Object Protocol

Programmers should have a good understanding of which objects make up their application. If a piece of source code is too abstract, they can set a breakpoint, run the application up to that point, and inspect run-time state and concrete objects. In Squeak, programmers can evaluate any little piece of text and explore useful results.

With the introduction of our mechanism, programmers need new tool support to explore interactions between objects. Because our mechanism might exchange the original receiver of a message, programmers cannot rely on knowing the actual receiver of a message send. As an object could be replaced by a different representation for each message send, programmers can also not be sure anymore which messages an object understands. The set of messages an object understands is also called the *protocol* of the object. With our approach an object would also have a *virtual protocol* which is the set of messages the object would understand if it was processed by all applicable resolvers and mappers.

We think that it is feasible to ask resolvers and mappers of prospective actions or capabilities. Without actually resolving or mapping an object, the programmer could be informed about the new messages that the object can understand. The string containing an email address, for example, could be enriched with `#authority` if some mapper acknowledges the capability of creating URLs from strings.

Tracing multiple object conversions for a single purpose is also beneficial for making sequences of conversions tangible. Further, for a new domain, programmers are likely to add new resolvers and mappers. Using the example with StackOverflow mentioned above, the connection between answers and questions cannot be derived from a generic resolver for HTTP URLs. There is additional knowledge required that has to be described in the form of a new resolver. If you send `#answers` to a question, a resolver's predicate should check for the prospective message receiver, recognize the domain "StackOverflow" and form an appropriate Web request. Consequently, programmers want to debug resolve-map cycles and check, whether their new resolvers or mappers behave as expected.

3.6 Extensibility and Readability

Our approach will work best if there already are some resolvers and mappers that help to acquire default resources by opening files or making Web requests. For a new domain-specific resource, there is now a place for programmers to describe access and mapping to the object-oriented world. The level of reuse compares with any other modularity mechanism in the Squeak environment. Programmers can specialize existing resolvers or mappers. They can also add additional predicates to existing resolvers or mappers.

By moving the source code away from the domain classes to classes for custom resolvers and mappers, programmers can write source code that directly reflects domain concepts. Even non-programming domain experts might be able to understand it and help express their actual requirements to be fulfilled in a software system.

For a new project, we think that there will an increased need for our mechanism. If the project's specifications mature, programmers are likely to move resolving and mapping code to a place where they have more direct control over it. We do not assume that there will be a very large number of resolvers or mappers for one project. But the available ones will have a large impact on productivity.

4 Scenarios

In this section, we describe several scenarios in which our approach can support programmers to quickly get access to domain objects. We first look at an example for a simple mapping from a local string to an object behaving like an email address. We then look at a scenario in which the string denotes a picture which can be fetched from the Web. Finally, we discuss the mechanism for resolving objects with nested structures.

4.1 Simple: Create Email Address

Task We have a set of strings that are email addresses. We want to convert them into instances of `Url`. An example string looks like this: `'patrick.rein@hpi.de'`. As specified in RFC 2822[6], the part after the @ character is called *domain*. So, instead of `#authority` as in the examples above, we want to send the message of `#domain`, which `Url` objects do not understand by default.

[6] See https://www.ietf.org/rfc/rfc2822.txt

Resolver We need a resolver that just looks up the provided string in the object cache. The predicate for this resolver is always true. It might, however, be restricted to not accept all kinds of identifier objects. Any more complex object such as pictures might not serve as an identifier for this resolver.

Mapper We need a mapper that complements the construction methods in the `Url` class. The predicate is a regular expression: $'([\texttt{a}-\texttt{zA}-\texttt{Z0}-\texttt{9}.]+)@([\texttt{a}-\texttt{zA}-\texttt{Z0}-\texttt{9}.]+)'$. If that predicate matches, the mapper will create the URL object via `Url absoluteFromString: anObject`. The variable `anObject` is one sample in our list of email addresses. The resulting URL object will then be checked against the required message `#domain`. This means that the mappers must have access to the original message send, which is straightforward in the Squeak environment. If the message is not implemented, a template will be generated. The programmer will be asked to fill the template interactively, using the example object as a guidance. The mapper will store the new URL object in the object cache.

Summary The first example works completely inside the Squeak environment. There is no access to the file system or the Internet. Since emails appear in many other domains, there is a high probability that it will be possible to reuse the resolver and the mapper in future tasks. The message `#domain` could be implemented automatically and could pass the call to `#authority`, which URLs already can understand. The option for an interactive dialog, however, renders the mapper usable also for other sorts of unknown messages.

4.2 External: Display a Picture from Gravatar

Task We have a list of URLs pointing to Gravatar, which is a service to host recognizable profile pictures for people. The URLs look like this:

https://www.gravatar.com/avatar/16d12ad253109aa61366e44ea8ab395e

We want to display the pictures on the screen. We know that a `Form` in Squeak represents a displayable object. Such an object understands the message `#displayAt:`, given some screen coordinates. After performing one lookup cycle similar to the one described above with emails, we have a URL object to work with.

Resolver We need a resolver that can fetch Web resources. It can be a very generic resolver accepting any kind of HTTP response and content type. The predicate for this resolver will have to check the HTTP schema in the URL object. The Web response contains binary data of some image format such as PNG or JPEG. It makes sense to return the Web response as the resolved object to be able to write a useful predicate for the mapper.

Mapper We need a mapper that complements the construction methods in the `ImageReadWriter` class. It is basically a factory for `Form` objects with the capability to process various image formats such as PNG and JPEG. The predicate for this mapper checks the content type of the Web response for "image/*". Then, the body of the Web response will be fed into a stream to be processed like this: `ImageReadWriter formFromStream: webResponse contents readStream`. The mapper will store the new picture object in the object cache.

Summary It will not always be obvious whether to put transformation rules into a resolver or a mapper. One of the influential factors is the context that the respective mapper and its predicates require. In Squeak, programmers can access many run-time information by employing introspection of the current message dispatch trace and other meta-programming facilities. Still, the resulting source code will be more readable if information exchange is made explicit.

4.3 Structure: Questions and Answers from StackOverflow

Task We have a set of numbers that identifies questions on StackOverflow. We want to explore question data such as title and body as well was associated answers. Answers also have structured information such as body and rating. There are no classes for `Question` and `Answer` in the Squeak environment.

Resolver(s) We need a resolver that is able to complete the URL to the StackOverflow interface, given the identifying number. For example, `36008167` has to be converted to the following URL:

http://api.stackexchange.com/2.2/questions/36008167/answers?site=stackoverflow

The predicate might check the structure of the number or accept all integers. Then, the resolver makes the Web request or uses another existing resolver to do so. For answers, the resolver has to process the context of the Squeak message dispatch and look for signs of the respective domain concept. For example, if the message `#answers` was sent to an instance of `Question`, it will be obvious.

Mapper(s) We need a mapper that can process a Web response whose contents contain a JSON encoded string. After creating a generic dictionary from the JSON contents, the mapper has to build a class for the respective concept, `Question` or `Answer`. If the mapper cannot determine a good name for new classes, a dialog with the programmer should be established.

Summary The interplay of multiple structured concepts, as here with questions and answers, poses a higher cognitive load to the programmers. They have to orchestrate a group of resolvers and mappers with predicates to bring the external information into the object-oriented system. New tools can help set up, maintain, and debug the resolver-mapper mechanism. Such tools should visualize the traces for predicate matching, resource resolving, and object mapping.

5 Discussion

In this section, we discuss the limitations and further implications of our approach on design decisions and maintenance.

Given a string with an email address, does the `URL` *class or the* `Email` *class represent the domain concept?*

This depends on the information required and the context in which the object is used. `Email` as a subclass of `URL` can add useful behavior and state. If the object is solely used to analyze where people have registered their email addresses, then `URL` is sufficient because it already responds to the message `#authority`. Conversely, if we want to send a letter to the email address, we need additional behavior such as `#send:`.

When does the system stop to do resolve-map cycles? Can there be an endless loop?

As each object can serve as an identifier, the object resulting from a mapper might itself match a resolver again. This can be controlled by keeping track of the current lookup with, for example, an identifier. Resolvers and mappers pass this identifier along with the objects to resolve or map. Then, they can count the cycle number and a maximum lookup depth can set a limit to avoid long or even endless cycles.

How is the object cache structured? Does it have a clean-up strategy?

The cache solely stores domain objects. Generic objects such as dictionaries are not used except if treated as domain objects in a mapper. Only the mapper writes into the cache, given an identifier object from the resolver in the respective lookup process. This way whenever an identifier needs be resolved and mapped, the resolver can directly return a domain object from the cache. Resolvers may have to store context along with identifier objects to make a domain object unique. For example, the string ′`marcel.taeumel@hpi.de`′ can be mapped to an instance of `URL` or `Email`. A least-recently-used (LRU) strategy can be used to manage the cache size. Otherwise, programmers have to account for manual cache clean-up.

Can the mechanism be used to write information back to the external database? Can we modify an object's state?

At the time of writing, our approach optimizes the retrieval and navigation of domain objects. If the lookup origins would be preserved, for example in the object cache, then there could also be a *writer* with custom predicates. The mapper might also have to deal with authentication protocols involved to write into the external databases.

Information might change outside of the current system and the objects representing them might not be up-to-date. How to get notified of updates?

Resolvers and mappers support accessing information stored outside of our current system, an approach that implies the challenge of synchronizing information stored in several places. Technically, this situation could be resolved by creating a central notification mechanism in the system which informs a resolver when a resource has changed. The resolver in turn can then fetch the new information. The mapper cannot simply create a new instance as there might already be a corresponding object. In this case, the mapper has to merge the incoming information with the information in the existing object. The notification mechanism inside the system could detect changes in external databases through polling or, if possible, via registering at an external event source.

If I want to build a Web browser, will a `URL` *instance be an identifier, a generic object, or a domain object?*

Whether an object is an identifier, a generic object, or a domain object depends on the context in which it is used. A Web browser retrieves and displays resources in the Internet. URLs are a standard for designating the location of such resources. Thus, they are an important concept for a Web browser and should be regarded as domain objects. For an application that displays StackOverflow answers, an URL, in contrast, is only a placeholder for other resources such as the profile picture of a user. The URL of the picture is not relevant for the user of the application. The fact that a URL represents the picture is only due to the technical implementation of the StackOverflow system and not inherent to the logic of a question-and-answer system.

The predicates of multiple resolvers or multiple mappers can match a single object. How can I manage such ambiguity?

If the ambiguity can be anticipated by users, they could pro-actively add filters to limit the applicable resolvers and mappers. Filters, however, would add another level of complexity to be managed by the programmer. If the ambiguity of the object cannot be anticipated, then the system itself could present users with all possible interpretations of the object and let them decide. The decision could be stored for future disambiguations.

What if there is no resolver for an identifier or no mapper for a generic object?

Traditionally, the system can indicate that an error occurred in the application. Alternatively, the user might be asked how to correctly interpret the identifier in this context. This might extend the predicates of the existing resolvers and mappers. The user might then provide a small code snippet that resolves the issue for the current context. This snippet could be added to the existing set of resolvers and mappers. While most resolvers have to be written manually, mappers might also be generated automatically through techniques known from *ontology matching* (Euzenat and Shvaiko 2013).

If I am working with many objects that need to be resolved, is there a way to batch-process a set of identifiers?

When the resolvers are triggered explicitly, then the resolver might be able to resolve many identifiers at once. If, however, the resolving is part of mitigating a message which was not understood by the initial object, then it is not possible as the control flow depends on the resolution of this particular identifier.

This mechanism seems to impede maintenance and debugging to a great extent. Is there a way to reduce the level of automatic resolving once the specifications are clearer and corresponding classes exist?

It is possible to migrate to a semi-automatic approach, once the projects requirements become clearer and more stable. Programmers can extract knowledge from the resolvers and mappers and move them into an extra module. They have to rewrite the code which triggered the resolvers and mappers. The new code would execute the resolution as described in the resolvers and mappers most often used in this context. Thus, the interpretation of the identifier object becomes fixed and documented in the source code again. The resulting code's readability might be sacrificed to some extent. This might be sufficient if domain experts are not as involved as in the beginning of the project.

6 Conclusion

We presented an approach to improve the means for quickly and conveniently working with domain objects inside an object-oriented environment, while domain data resides in outside databases. We support programmers to implicitly or explicitly resolve and map identifiers to full domain objects. Additional source code for accessing and integrating external information is separated from the domain logic, which improves readability. Especially in the beginning of a software project, programmers and domain experts benefit from knowledge exchange on a regular basis. We think that our approach might make this exchange more likely to include source code as a tangible artifact in these discussions. With the code expressed in terms of the shared vocabulary, design decisions remain comprehensible, even for non-programmers. As a result, our approach can improve the collaboration between domain experts and programmers to indicate limitations and to reveal future possibilities of a system.

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“... and not building on that”: The Relation of Low Coherence and Creativity in Design Conversations

Axel Menning, Benedikt Ewald, Claudia Nicolai, and Ulrich Weinberg

Abstract The purpose of this chapter is to explore the relation between coherence and creativity in design conversations of innovation teams. Low coherent segments in a conversation can be understood as the linguistic equivalent of shifts of the focus of attention while designing. Focus shifts have a positive influence on ideational productivity. We therefore reason that low coherent speaker turns function as creative stimuli in team conversations. How this works in practice we illustrate with a case study of an innovation team observed in the wild.

1 The Importance of Focus Shifts in Design Thinking

1.1 Divergence and Design Thinking

What is the major aim of applying the Design Thinking framework to wicked problems? This question will yield a range of answers depending on the focus of the research discipline that tries to define what Design Thinking *is*, but there will be one communality. Part of every definition is, in the end, the human-centred Design Thinking process that searches for new, innovative (and, of course, *creative*) ideas, concepts and business solutions. This places Design Thinking as an underlying framework of strategic innovation in the broader sense, however, with a clear focus on idea generation and selection. Innovation cannot be thought of without idea generation. The idea generation stage has been extensively discussed in the research literature. Although what qualifies an idea as such is still a research question under lively discussion, it is commonly agreed that it is desirable to generate a lot of ideas during an ideation phase. In practice, this is reflected, for example, in the brainstorming commandments: “Go for quantity!”, “Build on the ideas of others!”

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and "Encourage wild ideas!" This refers to the ability of "divergent thinking", which also serves as an important indicator of overall creative capability.[1]

The creative capability is needed in both problem and solution space:

- Identifying the problem space in the sense of searching for an openness to a diversity of (expert and layperson) perspectives on the problem, in looking for inspirations from related fields (market, competition, business and consumption) as well as from analogous areas with regard to context, culture, and time; and
- Creating and developing the solution space, in the sense of creating a broad range as well as a variety of ideas for diverse strategic directions and different strategic fields of opportunity.

These dimensions of creative capability are relying on divergent thinking. But advancing the process of designing and innovating is not only dependent on divergent thinking, but also on the ability to make decisions and narrowing down the field of opportunities towards a concrete solution (convergent thinking).[2] Convergent design activities are often connected to selecting concepts from a variety of possibilities at hand based on questions like "what wows" or "what works". (cf. Ogilvie and Liedtka 2011). Only this oscillating movement between divergent and convergent thinking and doing creates a powerful innovation process that can deal with the unknown and identify real and innovative solutions. The importance to "keep moving"—especially laterally—in the design process are by now classical topoi of both (neuro-)cognitive creativity research and design theory.[3]

1.2 Design Fixation and Coping Strategies

This oscillating movement between convergent and divergent thinking sometimes gets restrained. It has been observed that design teams suddenly get stuck in the process of creating a variety of ideas. This phenomenon of "getting stuck" has been coined "design fixation" and is comparable to the phenomenon of "writer's block". It has been described by Howard-Jones and Murray (2003, p. 153) as a "mental state of individuals who are unable to move beyond an idea or set of ideas to produce new ideas". This means that the team explores ideas and possible alternatives in a narrow way, which results in a very limited and likely

[1] For the classical text on creativity as convergent and divergent thinking see Guilford (1950), cf. Christensen and Guilford (1958).

[2] Guilford (1967), Cross (2006).

[3] Cf. the concepts of knowing- and reflection-in-action by Schön (1984), the interrelation of sketching and shifting the focus by Suwa and Tversky (1997), or the constant zooming in and zooming out required to find fitting frames for the problem-at-hand (Dorst 2015) for design theory; as well as Guilford (1950), and the Five Key Concepts of Onarheim et al. (2013) for (neuro-) cognitive creativity.

poor design outcome.[4] This can happen both on an individual and group level as well as consciously and unconsciously. A similar well known example from psychology of groups getting stuck on one idea is the concept of “groupthink”. Coined by Janis in 1982, it describes making non-quality decisions due to mental inefficiencies because of group pressure, wrong assumptions, poor problem frames and inappropriate collective rationalization, just to name a few. “Groupthink” can lead to the suppression of individual ideas and opinions and therefore to poor and inefficient decision-making. It is essential for design teams to be able to circumvent or overcome the phenomenon of “getting stuck” in the design process. Therefore a certain flexibility of mind is required.[5] Flexibility of mind (i.e. the ability for non-linear thinking) is more than just divergent thinking in the sense of going broad and looking for ideas beyond the obvious solution space. It also means taking creative turns and detours, chains of associations, associative leaps and questioning the status quo; all of which is, to a greater and lesser extent, present in concepts of associative creativity or lateral and abductive thinking.[6] To develop and maintain this flexibility, one important aspect is to stay sensitive towards stimuli that allow for a lateral movement in the first place. With lateral movement we mean that the current focus of attention drifts away from the topic-at-hand, breaking the linear thinking pattern.

1.3 Shifting the Focus of Attention to Overcome Design Fixation

One way of breaking out of a “stuck situation” is escaping it. The productive escape from a cumbersome topic is the subject of incubation research. The assumption behind successful incubation is that even if the mind is not consciously busy with the problem at hand, “the mind continues to work on it below the level of consciousness.”[7] This then leads to moments of sudden insight (*Eureka* moments) in unlikely because decidedly not-at-work situation like taking a bath (Measurement of volume of irregular objects by Archimedes), driving (first concept of the Polymerase Chain Reaction by Kary Mullis)[8] or similar. These stories sometimes provide an explanation for the sudden connection that is made via an analogy (invention of the television by Philo Farnsworth or the Post It by Arthur Fry). But despite its notoriety,

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[4]Cf. Jansson and Smith (1991); overview in Crilly (2015).

[5]Flexibility has been identified as an important prerequisite for innovation both individually (Georgsdottir et al. 2003) and organizationally (Bolwijn and Kumpe 1990; Thomke 1997).

[6]See e.g. Osgood et al. (1964) and Lautenbacher (2011) for instances of lateral thinking and Dorst (2015) and Endrejat and Kauffeld (2016) for the importance of abductive thinking for innovation. The concept of lateral thinking stems from De Bono (1968). Association as the cognitive basis of any creative process has been put forward by Mednick (1962).

[7]Nickerson (1999, p. 418).

[8]Cf. Nobel Prize lecture by Mullis (1993).

the concept of incubation is still controversially discussed in science research and not generally accepted as a prerequisite for creativity. In the context of (design) fixation though, incubation has been shown to have some beneficial effects, as it allows the fixation to dissipate or alternative ideas arise.[9]

Instead of waiting for an *Eureka* moment or an alternative solution to appear out of the blue after putting the problem aside, there is a second strategy available: embracing and exploiting ambiguity, leading to new ideas and association. Therefor one has to allow for focus shifts. As focus shift we understand every movement away from the topic-at-hand while still staying connected to the overall problem. Incubation, in contrast, needs a complete escape from the overall problem.

Exploring ambiguity within the same domain can be facilitated via a multitude of techniques (e.g. SCAMPER in Michalko 2010). Mednick in his classic 1962 paper, for example, advocates methods focussed on finding serendipity, similarity, and mediation to stimulate associative creativity. The lateral thinking techniques put forward by de Bono emphasize the importance of irritation and provocation, conscious focus shifts, as well as allowing and actively looking for randomness.

Intentional irritation and variation of habitual thinking patterns as well as change of attentional foci via creative stimuli are important everyday tools to reproducibly create innovative outcomes. Along this line also the many brainstorming techniques like "What would Superman do?", Reverse Brainstorming, Body Storming and Ideation with Objects developed or re-designed at the HPI School of Design Thinking, are employed. The structured exploration of analogies (e.g. via the Charette tool) functions in a similar way.

What these methods have in common is the aim of setting irritating and inspiring stimuli to disrupt not only the default analytical-deductive thinking mode of the creatively untrained, but also trigger concrete explorative topical jumps for already experienced "creative thinkers" in their daily work. The importance of focus shifts, particularly in design, triggered by ambiguity has recently been stressed by Dong and Macdonald (in press):

> It could therefore be concluded that generating a new hypothesis to explain anomalous, ambiguous, or conflicting observations is a form of insight. To create the hypothesis, individuals must relax their present hypotheses, re-structure the elements of their observations, and detach themselves from prior experience to see the problem in a new way, all of which are elements of functional models of insight.

Inference making itself is an explicit and essential part of making sense and finding inspiring departures from interviews and observations in design thinking (e.g. "I wonder if that means . . . " is an established pattern for identifying insights from interviews and observations). But to be able to make new inferences, again the linear reasoning must be disrupted.

We want to study how do these disruptions of the topic-at-hand look like in real design conversations and what their effect is on a design conversation. Do focus shifts indeed lead to new and useful ideas? These are relevant questions

[9] See Nickerson (1999), for a detailed discussion.

to design theory and innovation research as well as the research on cognitive creativity.[10] To understand focus shifts and their effects, we want to approach the team conversation from a process perspective. Therefor we look at the micro-level of design conversations; from speaker turn to speaker turn. This leads to a very high resolution and can uncover dynamics and patterns on the second scale.

2 Low Coherence as a Linguistic Equivalent of Focus Shifts

In our research, we look at the verbal communication of design (thinking) teams as it becomes apparent in video and audio recordings of complete design thinking and innovation projects. This is what we call the "design conversation." This *design conversation* can be structured linguistically in several ways and layers. Generally, we distinguish between content and form of the conversation. We take as our basic formal unit the *speaker turn*. A speaker turn is defined as the sequence of utterances from when a speaker begins to speak until when the speaker ends her or his articulation deliberately or is interrupted by another speaker. This definition is purely phenomenological and not connected to the intent of the speaker itself. On the content level, we structure the conversation in regard to the respective dominant topics of the individual speaker turns ("what is talked about").[11] In this regard one also speaks of the conversation as a *discourse*, which is split into several *discourse segments* along these topical lines (see below). How related single speaker turns are on a topical level can be characterized by their *coherence*. While cohesion describes the lexical and grammatical relatedness in text and talk, coherence is always a *perceived* relatedness. It depends heavily on prior knowledge and the individual understanding of the meaning of the utterances by the "receiver" of it and is therefore an inherently subjective measure. Nevertheless, coherence can to a certain degree be also assessed computationally, due to semantically clever models.[12] High coherence means the speaker turns are closely connected to each other in terms of what they talk about, while low coherence is a sign for rather unrelated turns with regards to their content. It is interesting to note that in team conversations there is always more than one "receiver" of the meaning of speech because a team consists more of two people. Different team members can differently interpret the form of speech. Thus, high coherence in team constellations (many-to-many conversation) is even more difficult to achieve compared to dyadic conversations. All team members as discourse participants have to rely on their own perception of the conversation

[10]Cf. "Future work" in Suwa and Tversky (1997), although the paper is focussed on visual cues only.

[11]Brown and Yule (1983, p. 71).

[12]These computational models have to be trained before on the respective general discourse, as well; just like humans have to learn, what belongs to a topic in a certain discourse. See below for details on the analysis used by us, the Latent Semantic Analysis (LSA).

and its coherence, which is heavily shaped by their personal background, their preferred style of communication and their prior (expert) knowledge, but also the history of the discourse itself and the ambiguity of language and speech acts.[13] They have to infer the state of knowledge of the other participants when speaking and adapt their use of language.[14] The other participants may then in return signal their understanding or the lack thereof. This means that discourse participants always have to take an active role and need to collaborate in order to establish and maintain coherence.[15] The assumption that it is the general tendency of discourse participants to construct coherent meanings is known as the *coherence assumption,* as put forward by Graesser et al. (1994).

Following this, low coherence increases the inference load, i.e. the need for the discourse participants to make inferences.[16] This activity of inferring meaning could also be seen as stimulating for an innovation team. There is, for example, empirical evidence that a low cohesive text has positive cognitive effects for high-knowledge readers precisely because the low cohesion (the lexical equivalent of coherence) stimulates inferences.[17] We hypothesize that there is a similar mechanism at work when design- and innovation teams with a high degree of domain knowledge and contextual information actively try to bridge or incorporate meaning gaps by inferencing and associating.

Low coherence can be created, for example, by a sudden shift in the conversation from one topic to another or a substantial transformation of the topic at hand due to an irritation of the focus on the topic at hand for one or more discourse participants. This can happen via a simple external distraction, but also have internal reasons such as the externalization of an ongoing subliminal train of thought, a sudden association or an idea. The assumption is that once the topical thread of the direct topic-at-hand has been disrupted, a certain space of possibilities to continue the conversation is opened up; bigger than just the initial topic and potentially enriched by external and internal stimuli which caused the low coherence in the first place. So low coherence can lead to new ideas both by hypothetically bridge meaning gaps and by opening up the space of possible alternatives to continue. The effect of both is what we called a focus shift earlier.

Focus shifts are not a linguistic concept of analysis, but refer to changes in the *attentional state* of the conversation. These changes of the attentional state become apparent in the linguistic structure as low coherence as the dominant topic is transformed from one turn to the next. On a text level, this can happen both via a complete cut of the former topical thread (e.g. “let’s stop talking about ...”) or a change of perspective on the topic-at-hand (e.g. “we could look at this topic also from the perspective of the user ...”). Both will be characterized by a sudden drop

[13]Cf. van Dijk (1977a, b).

[14]Lambrecht (1994), van Dijk (2014).

[15]Cf. Tanskanen (2006).

[16]Cf. Grosz et al. (1995).

[17]McNamara (2001).

in coherence because there is no direct or only small topical overlap between the two turns. This drop in coherence is the linguistic equivalent of focus shifts. Low coherence can be seen as the effect or cause of focus shifts, depending the level of observation. On the individual level, low coherent turns can be seen as the effect of a mental focus shift. On the team level, low coherent input interrupts and shifts the focus of attention.

It is therefore surprising, that the relation of low conversational coherence and creative thinking has been studied so little up to now. This may also be due to the fact that it is not trivial to determine low coherence turns in the first place. Only recently powerful techniques like Latent Semantic Analysis (LSA, Landauer and Dumais 1997) have become available to retrieve reliable topic models automatically; one of the pioneers for the application to design conversation is for example the above quoted Andy Dong (2004, 2005).

Let us summarize: we hypothesize that low coherent statements can act as creative stimuli.

These statements create focus shifts and therefore support defixation and the inference of new meaning. To test this, we developed a three-step method. First, we identify low coherent turns in the design conversations by identifying focus shifts (topic jumps or drifts; see below). Second, we zoom in on these focus shifts to explore their characteristics, for which we, third, then offer a classification scheme. How this works will be illustrated by the following case study.

3 Case Study

In this case study we will align the theoretical framework as discussed above in the previous sections with in-situ recorded design conversations of innovation teams. We are using several segments of design conversations in which focus shifts happened to study their effect on the preceding course of the conversation. To identify and objectify focus shifts, we apply a semi-automatic filtration procedure (see Sect. 3.3.2).

3.1 Empirical Data and Data Selection

The raw data consists of in situ video recordings and transcripts from a design thinking project conducted by an interdisciplinary and international student team at the HPI School of Design Thinking (Potsdam). The team worked on a project for 5 days with the challenge of "improving the life of homeless people." Figure 1 shows the team and coach in their space, which is situated in a design studio next to seven other team spaces. The coach is marked with a "Text". The five students have different academic backgrounds (see Table 1), with different experience in design thinking.

Fig. 1 Split screen of the key episode

Table 1 Disciplines of team members and coach

Team member	Background
1	Information systems, business administration
2	Communication design
3	Economics and engineering
4	Anthropology, sociology, business
5	Economics—Innovation management, entrepreneurship and marketing
Coach	Branding, marketing, visual design

For this case study a key episode of the first project day has been extracted. This has been done through post survey evaluation. The team have been asked to submit an estimate about their most relevant 30 min concerning content development and team development. For the selection of the key episode we used the provided information on content development. The chosen key episode has been transcribed and parsed into a total of 457 speaker turns.

3.2 Synopsis of Key Episode

In our key episode the team is complete and a coach is with them. Some of the team members are standing around their team table and some of them are sitting on high chairs at their team table. They have surrounded their team space with flexible whiteboards that they use as a vertical working surfaces but also as a moveable separating wall to other team spaces. On and below their team table they have stored supplies for creative teamwork (e.g. sticky notes, whiteboard markers, sharpies, etc.) They are in the middle of discussing the effects of routines and rituals as well as the impact of work and employment culture on homeless people. They name several aspects like self-respect, dignity and motivation. One person is capturing statements and ideas on the whiteboard. They write down different stakeholders (e.g. buyers of the magazines or organizers of the magazine written, published and sold by a local group of homeless people) on post-its and create a mind map on one of the whiteboards. While discussing the map they start to collect questions to be clarified during their research phase (e.g. how is the selling process of the magazine organized) and share stories and individual experiences linked to their challenge. While doing so they try to develop analogies (e.g. prisoners), extreme users (e.g. subscriptions), different contexts (e.g. being homeless by freedom of choice), different cultures (e.g. being a homeless person in Ecuador) and different times (e.g. being homeless in the future/past). They assign these stories to the categories ‘inspiring’, ‘relevant’ and ‘unexpected’ that one person had written on a whiteboard as a chart for writing stories and ideas on sticky notes and collect them to the board.

3.3 Data Selection and Analysis

We are using a mixed procedure for meaningful probing of low coherent speaker turns. This procedure was first presented by Menning et al. (in press). The initial automated analysis of transcripts is based on Latent Semantic Analysis (LSA, Landauer and Dumais 1997) and extracts potential low coherent turns. These turns are then analyzed and classified with the help of the Topic Markup Scheme (TMS, Menning et al. 2015, 2016). The flowchart below (Fig. 2) illustrates the steps of the filtration procedure.

3.3.1 Latent Semantic Analysis

Latent Semantic Analysis (LSA, Landauer and Dumais 1997) is a statistical procedure which applies singular value decomposition (SVD) to a word-document matrix counting word co-occurrences. SVD is used to reduce this large-dimensional matrix to a smaller number of “topic” vectors. These vectors constitute the LSA model and contain the probability of occurrence of single words for each topic. We used the resulting LSA model to compare text entities based on calculating the cosine similarity of their topic probability vectors. For a detailed description of the preprocessing, the sliding window approach, and the limits of LSA for mid-sized design corpora we refer to Menning et al. (2017).

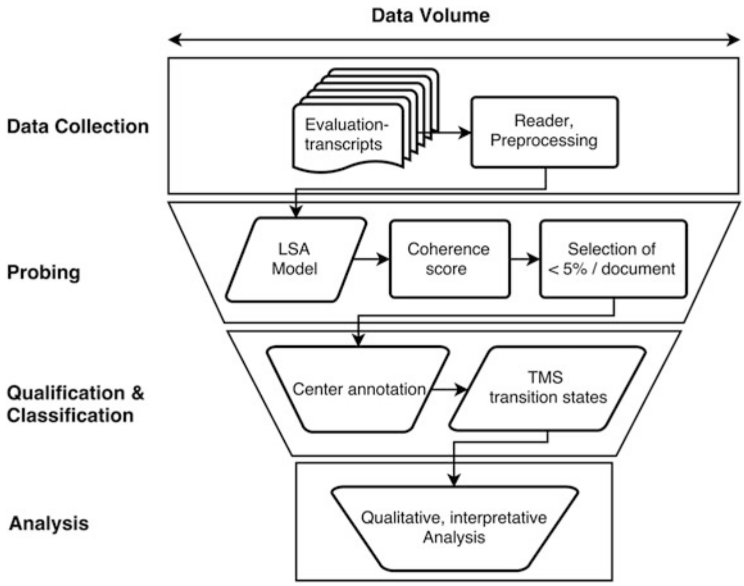

Fig. 2 Flowchart of the mixed method procedure for meaningful probing (in Menning et al. 2017)

3.3.2 Topic Markup Scheme

The Topic Markup Scheme enables a structured manual analysis of perceived semantic relatedness of speaker turns. As mentioned in the previous sections, the assessment of coherence is subjective because it depends on the knowledge and contextual interpretation of the observer.

We argue that especially mid-sized design corpora need an additional qualification procedure in order to retain meaningful coherence data. Thus the preselected turns have been confirmed and further qualified or rejected using TMS.

When assessing coherence, it is important to note that it is not a binary state that either exists or not. Coherence rather happens on a quasi-continuous scale from low to high. For example, Botta and Woodbury (2012) state that every utterance is shifting the focus of attention “somewhat”.

Coherence analysis poses the following question to the human observer. Which reference of a statement has which distance to the preceding reference? At least two kinds of assessments have to be performed. Analysts have to infer the most salient topic for each statement and secondly, they need to find ways to describe the distance between both statements. Clearly, the mutual assessment of coherence needs a well-defined procedure and benchmarks; otherwise it would lead to uncertainty and a high disagreement between analysts. In TMS the assignment of topic center to each turn is based on Centering Theory (CT, Grosz et al. 1983, 1995). The description of the distance between two centers is formalized by rules that make benchmarks unnecessary.

Three analysts were asked to analyze the preselected segments with TMS to have an additional qualification of the results that allows meaningful probing of some distinct low coherent turns. TMS, like CT, is based on the assumption that each turn at a certain time t_n carries exactly one entity, a center C, which is topically more central than others. This center can either be explicit, $C_e(t_n)$, or implicit $C_i(t_n)$.

1. $C(t_n)$ is explicit when grammatical, lexical or close semantic overlap (e.g. references, substitutions, repetition, synonymy) from t_n to t_{n-1} exists.
2. If t_n has no C_e, we define that t_n has a C_i. The $C_i(t_n)$ is either a content word or phrase that shows syntactic or semantic overlap to a C prior to t_{n-1} or we define the $C_i(t)$ similar to the preferred center of CT. In this case, it is the highest ranked entity according to salience ranking.
3. If t_n has no content word, which is the case for one word turns (e.g. "yeah"), we define that the last $C_{e,i}(t_k)$ gets assigned with t_k being a turn prior to t_{n-1}.

All centers were assigned through consensus coding of at least two analysts. With consensus coding, we mean that reasoning was necessary in case of disagreement between analysts. When all analysts agreed after reasoning, the center got assigned. The analysts base the determination of transitions states between two turns on formal rules and therefore it is not a matter of guesswork and individual interpretation. Figure 3 presents how the coherence of subsequent turns can be described in the form of transition states (Continuation, Drift, Integration and Jump).

A turn continues a preceding turn if the center is explicit and shares the same semantic value with $C_{e,i}(t_{n-1})$ (Continuation). A turn t_n is drifting if its center is explicit but does not share the same semantic value with $C_{e,i}$ (t_{n-1}) but with any other content word of t_{n-1} (Drift). A turn t_n is defined as Integration if its center is implicit and relates to a center of a turn prior to t_{n-1} (Integration). If the center of t_n is implicit and cannot be matched with the center of a turn prior to t_{n-1}, t_n is discontinuing and jumping (Jump). For the purpose of this study, we treat Drift and Integration similarly because they shift the topical focus within an existing design issue and we treat Jump separately, because a Jump creates a new design issue.

In conclusion, the TMS reanalysis of the preselected LSA data adds two qualities. It adds the quality of human assessment of coherence and it further classifies low coherent turns.

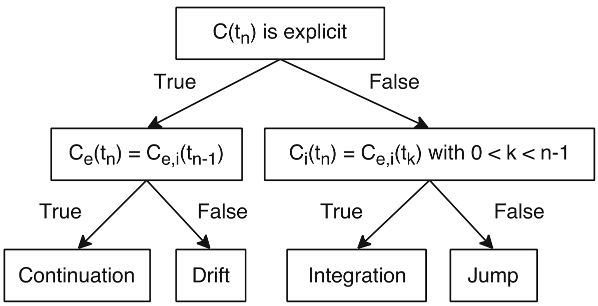

Fig. 3 Overview of the determination of transition states

3.4 Conversation Analysis

Our aim is to analyze the impact of low coherent turns on idea generation. In this section we present the conversation analysis of three samples that have been selected with the procedure as described above. This means these samples carry turns which belong to the lowest five percent of low coherent turns after LSA pre-selection and the low coherence have been confirmed with TMS. Conversation analysis studies conversations 'as primary data of the world-as-it-happens, a direct handle on the details of the real world' (Boden 1990, p. 247). This form of qualitative analysis "considers phenomena such as turn-taking sequences, topic development, assessments, questions and answers, etc." (Oak 2013).

Example 1
Context

The team is gathered around the whiteboard. The team has explicitly agreed to collect different stakeholders. Speaker E: "So what do we start with? Something like the stakeholders? So that we analyze who is involved in this whole... whole err, topic?" Speaker D: "Yeah"; "Yeah, the stakeholders". They talk about possible stakeholders, collect their ideas on sticky notes and arrange them in form of a mind map on the whiteboard (stakeholder mapping). This scene represents a typical divergent design activity in which a variety of possible alternatives is generated. The overall duration of this example is 1 min.

1	E:	Ok, volunteers.
2	D:	Then we also have the situation that the Straßenfeger [name of newspaper] sellers they are coming into cafés and bars and talk to you and come to your table.
3	C:	Ah, at locations where they...
4	D:	Yeah, and others don't do it. So we also should put the owners of those cafés or the workers there... Are they accepted, the homeless people, are they allowed to go inside and talk to people at the tables or not?
5	C:	Yeah, also... yeah, locations. For example the BVG people [BVG is the local public transportation company of Berlin] ... what do they think and what are they... what's the acceptance there?
6	A:	Yeah, or this morning I heard that the people from the Grünflächenamt [Parks Department] ... what's that in English?

Description

In turn 2, speaker D introduces the new topic of sellers entering cafes and bars. This "situation" is new to the group, it is a jump because Ci(T2) is <situation (of Straßenfeger sellers coming into cafés and bars)> while the Ce(T1) is <volunteers>. Therefore Ci(T2) $\neq$ Ce(T1). At this point, <locations> as a disruptive element is established in this discourse segment of the team's design conversation.

In T3 C shows understanding ("Ah"), and she or he acknowledges D's contribution. C further "realizes" <locations> (Ci(T2)) by repeating it. D sets out to ask for more elaboration or clarification of what specifically the relation of these <locations> and “they”, the <volunteers> (Ce(T1)) is. D interrupts C and does not directly respond to C’s questions for clarification because the pronoun <it> does not further clarify the activities of volunteers in these locations. Instead, he continues relating her or his previous utterance with the overall task of this discourse segment, which is to collect stakeholders: “...should put the owners of those cafés or the workers there [mindmap on whiteboard]...”. He continues to justify his contribution by adding example questions the team could investigate through interaction with “the owners of those cafés or the workers” during field research: “Are they accepted, the homeless people, are they allowed to go inside and talk to people at the tables or not?”.

In T5 C is not reacting to “the owners of those cafés or the workers” but establishes again the D’s low-connected contribution: “Yeah, also... yeah, locations...” and begins adding her or his own idea: “For example the BVG people...” [BVG is the name of the Berlin public transportation company]. C also follows up with a possible research questions, which legitimizes her or his idea of positioning BVG people as stakeholders of Strassenfeger sellers. At this point (T6) Person A contributes a new idea: “Yeah, or this morning I heard that the people from the Grünflächenamt [Parks Department]...”.

Interpretation

What is remarkable in example 1 is that with regard to semantic relatedness, <locations> (Ci(T2)) is a foreign element when it comes to identifying stakeholders of homeless newspaper sellers because the team could have simply continued with listing other stakeholder groups.

But as it appears in the segment, <location> is a disruptive element and becomes a vehicle to support collecting more stakeholders. Based on <locations> some team members took a conceptual detour that led to three more ideas about stakeholder to further explore: cafe and bar owners, public transportation employees and the parks and gardens department.

Based on their instant reaction we assume that these ideas came up spontaneously by member A and C just right after they got stimulated with <location>. Without <location> the three mentioned stakeholders would not have made it onto the mind map. This illustrates why we treat some low coherent turns as disruptive stimuli. The effect of <locations> is decontextualisation. This means, seen on a semantic scale from concrete to abstract, <locations> lets the team not only think about specific stakeholder groups but asks about situations in which these stakeholders appear. We can observe that moving to this slightly more abstract level helps the group to create three additional stakeholder groups. The creation of inferences and insights through alternating decontextualisation and contextualisation has been also reported by Dong and Macdonald (in press).

Example 2
Context

The context of this scene is similar to the context of example 1. We are still observing the same team. About 10 min have passed in this key episode (which has an overall length of 30 min). The team has further developed their stakeholder map. They continue to identify interesting fields which they can take into the field research. This is also expressed in the following statement by speaker E: “What’s probably interesting as well?”. The duration of the first part is 30 s, the duration of the second part is 1 min.

1	C:	Maybe we can also find some benchmarks who, umm, work similar like the Straßenfeger . . . maybe there’s something, something similar to the . . . to the, to the Straßenfeger.
2	E:	Or we look on the web for . . . similar things in other countries or in other cities.
3	//C:	Yeah, exactly.
4	E:	Something like Straßenfeger in . . .
5	D:	Yeah.
6	C:	For example, I saw some homeless people who were selling sweets or . . .
7	E:	Or yeah.
8	D:	Like different kinds of those jobs for homeless people.
9	C:	Yeah, exactly. And how do they work, and then we can compare it.
10	E:	Other jobs . . . ok.

63 turns pass, in which the team discusses the content of the newspaper “Motz”, which is usually sold by people in precarious situations.

73	–	(15 s pause)
74	D	Ok, maybe also it would be nice to know . . . err, how do you become Straßenfeger seller? Or Motz seller?
75	C	xxx Where do I have to go as a homeless person to . . . ?
76	D	Yeah. Or are there any restrictions? For example, if they say ok, if you want to do this, you can’t be drunk or something, like, just . . .
77	C	Yeah.
78	D	And I don’t know if they have to buy those papers?
79	B	Err, I think so. Yeah, they have to buy. It’s half price, and then they sell for . . .
80	//C	Full price.
81	//D	Full price. Something like this, yeah.
82	B	Yeah, so they get 50 percent . . .
83	D	Mhm, yeah.
84	–	(6 s pause)
85	D	And also, like, working hours. So they have . . . like, an understanding of . . . they work from, I don’t know, 8 to . . . 8 to 5? And then they have stuff? And then they have free time? Or do they work the whole time? Or just work like, 1 h and then . . .
86	B	I think they are small entrepreneurs . . . Entrepreneurs so they can decide, basically.

Description

In T1 C proposes to find “something similar to the . . . to the, to the ‘Straßenfeger.’” The C(T1) is <benchmarks>. E proposes another research direction: “similar things in other countries or in other cities”. C(T2) is <other countries>. C(T2) is related to the topic <similarity to straßenfeger> but drifts from <benchmark>. In T6 <similar things> gets the first time interpreted as similar job: “homeless people who were selling sweets”. In turn 8 D concludes C’s utterance and externalizes the first time the latent topic: “Like different kinds of those jobs for homeless people”.

Second part of example 2: After a 15 s break D introduces a new question/topic about becoming a “Strassenfeger” seller. T75 continues this topic by rephrasing it and adding the aspect of entry points. T76 continues in adding more detail to the question about <becoming a “Strassenfeger” seller>: it is about restrictions. T78 creates a slight topical change in this sequence. While it contributes to the question of understanding the routines and journeys of “Strassenfeger” sellers, it drifts from restrictions to the newspaper distribution process. T78 marks a new topical subsequence that is explicitly about homeless people buying and selling newspaper. This sequence ends in T86 with B’s analogy, describing the “Strassenfeger” sellers as “small entrepreneurs.” When looking into the video recording at turn 86 one recognizes that B’s gestures “air quotes” or “finger quotes (see Fig. 4).

Interpretation

In example 2 the notion of homeless people as entrepreneurs rises (sequence 1, example 2) and persists (sequence 2, example 2). This notion will remain a persistent opportunity field throughout the whole project. Interestingly it emerges shortly after a topical drift.

In sequence 1 the topic of <jobs> for homeless people is a rather random product of C (T6) interpreting T4 and connecting it with his or her memory of homeless people selling sweets.

D in T8 transforms it into the explicit topic of jobs for homeless people. With regard to the documented outcome of this design project, we know that this topic will persist throughout the project and influence the final concept.

Fig. 4 B gestures air quotes when suggesting “Strassenfeger” sellers as “small entrepreneurs”

In sequence 2 the recurring semantic space of <buying and selling>, <full price>, <50% percent> and <working hours> is densely inspiring. It suddenly creates in B's mind the association of entrepreneurship as an influential idea. The air quotes support B's suggestion to the team to treat this idea as a metaphor. We know from Schön's generative metaphor study that designers use metaphors to "construct meaning" (Schön 1993).

Example 3
Context

This example takes place about 10 min after example 2. The complete team, including one coach is discussing the correlation between homelessness and big cities. Initial turn that creates the design issue are for example 3: "I think what's interesting about that is that, err... we always see homeless people in big cities. We don't see them in a smaller, err, city".

1	B	Yeah. Maybe they help each other. They don't go homeless.
2	F	In small towns.
3	D	Yeah. I was just thinking . . . another thing that I recently read . . . err, IKEA is building those err, really cheap houses for . . . for . . . I don't know if it was refugees, also, yeah I think, or like, areas where they have some kind of crises.
4	A	In their countries? Or . . . ?
5	D	I don't know exactly if they ship them around for their countries or if it's for . . . for here as well. They have some kind of, like, a home . . . home. I think under 1000 euros. This could be, I don't know, something. Maybe they, in the future, they will build like villages. Ok, this would be a ghetto, I . . .
6	A	It's a slum.
7	D	Yeah ok, a slum.
8	A	But it could be a nice slums.
9	D	Yeah, so building slums. Yeah, maybe nice slums.
10	F	I wrote that down.

Description

T1 and T2 are directly contributing possible reasons to the question under discussion in this segment. T3 is breaking with this sequence. It is introducing terms like <IKEA>, <cheap houses>, <refugees> and <crisis>. In T5 speaker D continues with his excursus and ends up with the term <ghetto>. T6, T7, T8, T9 pick up the term <ghetto> and transform it into <nice slum>. F writes <Nice slum> on a sticky note and puts it on the whiteboard.

Interpretation

T3 shifts the focus of attention from current question under discussion. The overall issue of homelessness persists, but context changes from small towns to crisis areas and cheap, prefabricated housing solutions. Speaker D challenges herself with making sense of the low coherent Ikea thought in the given context of thinking about homelessness in small towns. In T5 speaker D ends with <Ok, this would be a ghetto>. It seems that the turn ends in an undesired way. The scenario of Ghetto has certainly a negative connotation and also the <Ok> has almost a resigning tone to it. Although it looks like E hits a dead end with her thought—the dissonant character of it creates attention. The team picks it up and turns it into <nice slums>. Although they cannot turn this dissonance into an idea immediately, they make sure to remember it. F's <I wrote that down> signals the significance of the <nice slum> situation.

4 Conclusion

We have shown that focus shifts and incubation support design thinking and innovation teams when they experience design fixation. The phenomenon of incubation and different proactive procedures like some ideation methods and the use of metaphors introduce ambiguity and support innovators in broadening the focus of attention.

Focus shifts have a direct linguistic equivalent in form of speaker turn pairs which exhibit low coherence. We assume that some of these speaker turns play a crucial role in the process of defixation and idea generation.

When a speaker turn is perceived as low coherent the receiver is forced to infer the relation between the two topical entities in question. Especially in design conversation, this form of "bridging the meaning gap" by inference is a creative activity. Thus, we hypothesize that some low coherent speaker turns in design conversations have a positive influence on ideational productivity. These speaker turns may exhibit different characteristics and effects on individuals. In order to explore and better understand the form and function of low coherent turns it is necessary to get to them. In the second part of this chapter we present a mixed computational and manual procedure which is capable of identifying low coherent turns.

In the case study we have analyzed three conversation samples. The description and interpretation of these samples suggests that low coherence may be a promising indicator in creativity research. We reason, that a systematic and large-scale analysis of low coherence and its effects in design conversation is needed. The implications of such a study may range from creativity assessment to the improvement of ideation techniques.

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Part III
Teaching, Training, Priming: Approaches to Teaching and Enabling Creative Skills

The DT MOOC Prototype: Towards Teaching Design Thinking at Scale

Mana Taheri, Lena Mayer, Karen von Schmieden, and Christoph Meinel

Abstract The increasing demand for learning and experiencing the human-centered approach of design thinking has led to a need for more and broader education formats. In this research project, we investigate how design thinking can be taught to a massive, global audience with the use of digital education. In this chapter, we describe our design thinking MOOC prototype *Inspirations for Design*. We commence by presenting the research and theoretical foundation on which we created the MOOC's didactic design and discuss our aims for testing a pilot version of the MOOC and consequently the MOOC prototype. Results from the pilot version and the MOOC prototype are reported and discussed. We end this chapter by presenting deduced ideas for an *Inspirations for Design* iteration and future digital design thinking learning units and propose adaptations for the openHPI platform to facilitate design thinking education in a MOOC environment.

1 Introduction

Design thinking has gained increasing popularity as a human-centered approach to tackling the complex problems of today's society. Consequently, the demand to learn and teach design thinking has risen. Increasing implementation by educational organizations around the globe is visible; with numerous universities and educational institutions offering various design thinking trainings. While some universities include design thinking training in their curriculum as a workshop or seminar format, others take a more in-depth approach and offer a semester-long program. Despite the increasing number of design thinking education programs, opportunities to learn the method are still limited throughout the world. Not everyone has the chance to attend in-depth programs like those offered at the d.school in Stanford or at the HPI School of Design Thinking in Potsdam (D-School in short). Therefore, there is great potential for teaching design thinking to a broader audience online.

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2 Towards a Design Thinking MOOC

With the introduction of Massive Open Online Courses (MOOCs for short) in 2008, there was great enthusiasm among educators and researchers to test the potential and possibilities of taking education beyond lecture halls (Liyanagunawardena et al. 2014 as cited in Cress et al. 2014, pp. 95–100). Today many universities and educational institutions are offering their lectures in various fields to a broader global audience via digital platforms. In the beginning online courses were feared as competitors to traditional education. Some observers claimed that MOOCs would make the on-site brick and mortar universities obsolete. However, the evolution of MOOCs in the last 5 years shows their real potential. Today MOOCs function over a broad range: as complementary courses, on-site education in flipped classroom formats or in a combination of several modules covering a specific topic.

Whether you are in the camp of those who believe that we only learn in social interactions or a strong believer in the future of MOOCs, the advancement of digitalization and its influence on every aspect of our lives suggests that MOOCs are here to stay and will transform how we teach and learn.

With regard to the increasing popularity of design thinking, its setting has been extended from flexible workshop spaces to the online world. In recent years, the number of MOOCs on design thinking or related topics (e.g., rapid prototyping) has gradually increased (e.g., Design Thinking for Innovation by University of Virginia on Coursera). Based on this development, the aim of our research project *Design Thinking at Scale* is to investigate the potentials and challenges of teaching and learning design thinking in an online environment in a MOOC format. The Hasso Plattner Institute in Potsdam (HPI) is renowned for its in-depth programs that teach design thinking to students and professionals. Moreover, HPI is home to one of Europe's leading MOOC platforms: openHPI (Meinel and Willems 2013). This online learning platform offers numerous courses on topics such as IT and computer sciences all year round. In this research project we have the opportunity to merge these competencies from HPI (the online learning platform and design thinking education) and investigate possibilities for teaching design thinking to a global audience in an online environment.

We commenced our research by looking into the status quo of MOOCs on design thinking through the lens of educational research. Based on our learning from best practices, we created a MOOC prototype about first phase of the design thinking process, namely design research (often called *Empathize* at the d.school in Stanford). In the following we describe the creation of the MOOC prototype and its theoretical basis. We will explain the setup of a pilot version experiment and the testing of our MOOC prototype. Subsequently, we will discuss lessons that we drew from these experiments. Finally, we will conclude this chapter with an outlook.

2.1 Theoretical Background

We began our research by exploring whether it is possible to teach design thinking effectively in an online environment. For this reason we looked into existing design thinking MOOCs through the lens of the established pedagogical framework of the *Seven Principles for Good Practice in Undergraduate Education* (Chickering and Gamson 1987). Apart from their wide application by instructors in traditional course design, these principles have been used by MOOC designers as a guidance to assure quality teaching (Siemens and Tittenberger 2009). The summary and evaluation of all examined MOOCs can be found in Taheri and Meinel (2015).

To obtain an understanding about the courses and their pedagogical approaches, we took the perspective of participant observers, enrolled in courses, and engaged in an adequate number of exercises and discussions. Apart from the instructional design of the examined MOOCs, we also paid attention to the technological features and functions behind the courses' pedagogies. This was especially important since we intended to create a MOOC on HPI's online learning platform openHPI.

Evaluating our assessment of design thinking MOOCs, we realized that it is possible to fulfill the principles that assure high quality teaching and learning in an online environment. Moreover, we cross-examined the technological feasibilities of openHPI in supporting the *Seven Principles* framework.

After learning from best practices and assessing the technological potentials of openHPI, we moved towards designing our MOOC prototype. As a first step, we defined clear learning outcomes for our online course. Therefore, we asked: what are the learning outcomes of design thinking education? In other words, what do people learn as a result of participating in a design thinking training? It is important to mention that there are some disparities among experts on the definition of design thinking (von Thienen et al. 2011), let alone its expected learning objectives (Taheri et al. 2016a).

Although design thinking is taught in unconventional ways and far removed from traditional courses, it is, after all, about teaching and learning. Therefore we looked into more established research fields such as educational research for guidance. We applied the classification scheme of learning outcomes by Kraiger et al. (1993) as a theoretical framework. Kraiger et al. offer a multidimensional view on learning outcomes and suggest that learning may be evident from changes in cognitive, skill-based, and affective states of trainees (see Fig. 1).

We linked the learning outcomes related to design thinking, such as creative confidence (Rauth et al. 2010) and design thinking mindshifts (Goldman et al. 2012), to the framework. The result was the conceptual model for design thinking learning outcomes (see Fig. 2). In this conceptual model, we suggest that design thinking learning outcomes are interconnected. We also postulate that the parallel development of all three domains is important. While developing design thinking mindsets (e.g., human-centeredness), the development of skills that support these mindsets should be considered, too. Likewise while it's important to gain confidence

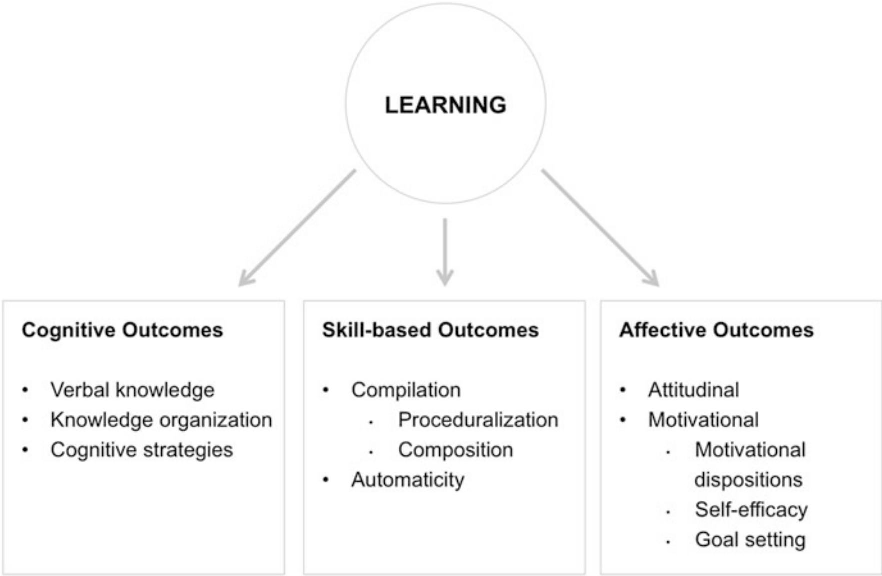

Fig. 1 Classification of learning outcomes (Kraiger et al. 1993)

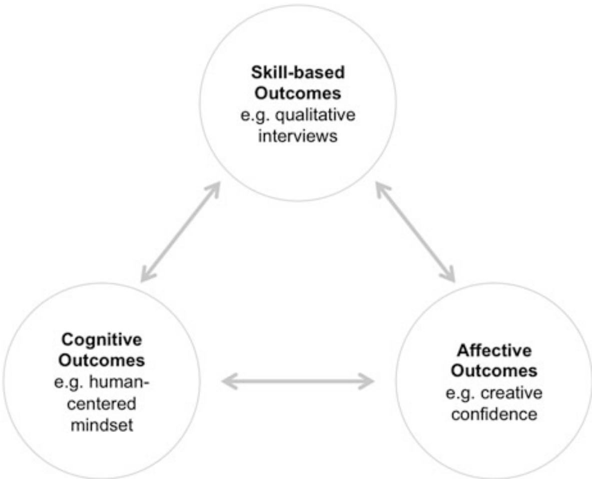

Fig. 2 Conceptual model of the learning outcomes of design thinking (Taheri et al. 2016a)

in one's creative ability, the skill development for transferring this confidence to a real context is also critical (Taheri et al. 2016a, b).

Our aim was to create a course that tackles all three learning outcomes. In the following, we will describe our experimental approach in designing the MOOC.

3 MOOC Testing

We took an experimental approach in designing a MOOC and first created a prototype in order to get feedback and iterate if needed. The intention to test our MOOC prototype is twofold. On the one hand, we intended to test the content and monitor the testing in a safe and closed environment to iterate and improve the format, design, and applicability of this online course before running it on a large scale. On the other hand, we intended to investigate how this new online format for teaching and learning design thinking will be received by novice learners as well as experienced design thinking practitioners. Thereby, we may draw conclusions for the development of further learning units.

There are many ways to illustrate the design thinking process: the six bubbles (HPI D-School Potsdam) and the five hexagons (d.school Stanford) to name just two. Inspired by IDEO.org's presentation of the human-centered process, we decided to introduce the following three phases to represent different working modes in the design thinking process: finding inspirations, creating solutions, and validating with users. Our MOOC prototype focused on the first mode of finidng inspirations and was named *Inspirations for Design.* For the *Inspirations for Design* MOOC, we decided to focus on two basic but important methodsof *Observation* and *Qualitative Interviewing.*

The reason for our choice is twofold. It allows communicating the essence of the method in a simple way to novices and it offers a clear structure for future online learning units (three successive courses). By focusing on teaching two major and powerful skills to finding inspirations, such as being attentive to one's surrounding (*Observation*) or finding insights from meaningful convesrations with potential users (*Qualitative Interviewing*), we explored how design thinking skills can be conveyed through online learning. Accordingly, we plan to create new and more design thinking learning units in this research project (i.e., a consecutive MOOC covering skills that are crucial during ideation and prototyping).

4 Pilot Version of the MOOC Prototype

Before we started producing and finalizing all videos and course content, we decided to test a small part of the MOOC independently from the platform to gain feedback and incorporate it in the first MOOC Prototype test run version. Prior to the MOOC prototype test run in November 2016, we created a pilot version containing one topical session (about *Observation*) which we ran in August 2016. Later in this paragraph, we will present and discuss findings from this pilot version.

This pilot version covered *Observation,* a powerful method of finding inspiration for design solutions. The topical session contained two parts. The first part consisted of a video (approx. 7 min long) introducing the method of *Observation*, specifically the topic of spotting "workarounds" as well as "misuses" and how these can inspire design solutions. We define workarounds as creative fixes that people come up with to fullfil an unmet need. Misuses describe alternative ways of using a product or service that deviate from its usual purpose. The video also presented a real life example of careful observation and how it can lead to a design solution. For this, we picked a student project that dealt with redesigning the bathroom experience of elderly people.[1] The second part of the topical session consisted of an exercise related to the video, in which participants were encouraged to practice what they learned.

The aim of conducting this small pilot version was twofold. On the one hand, we collected user feedback on combining short videos and exercises for skill learning. It was important for us to get feedback on our choice of learning modes as this embodies our strategy for all consecutive and future design thinking MOOCs. On the other hand, we set out to test user acceptance of a new element in the learning routine in MOOCs on openHPI. In most of the platform's MOOCs, video lectures are followed by a self-test with multiple choice questions. We aimed to go beyond this current routine of conducting self-tests by introducing an "exercise" element. This new element was inspired by the teaching methods of the HPI D-School. For example, before going to the field and conducting interviews with users, students are encouraged to conduct a test interview with coaches to get feedback on their questions and interviewing style.

Instead of following up a video lecture with multiple choice questions, we included an exercise covering the topic that asked participants to fill in templates. In this way, participants were not only required to recall and repeat knowledge but also to apply it and thereby make sense of it in different contexts.

We tested the pilot version with a group of students from the D-Camps at the HPI D-School (winter semester 2016). D-Camps are a 2-day assessment workshop for applicants to D-School's Basic Track program. Students were asked to watch a video and work on the exercise that followed. In this exercise, they were first presented with a picture of a workaround and a possible interpretation of the unaddressed need (portrayed by the workaround). Subsequently, we encouraged them to formulate the motivation behind the workaround using the *jobs-to-be-done* method[2] (see Fig. 3). After submitting their descriptions of the displayed workaround, they were presented with a possible interpretation of the scenario. At the end of the testing, students had to fill out a survey.

4.1 Results and Analysis

Demographics of the Pilot Version Sample

In total, 24 students took part in the pilot version of which half were female ($n_f = 12$, $n_m = 12$). Most of them were in their twenties (20–24 years old: n = 10; 25–29 years

[1]The real life examples were derived from ThisIsDesignThinking.net.

[2]The *jobs-to-be-done* method is used to clarify why a person uses a certain product or service (e.g., which job it is expected to do for them).

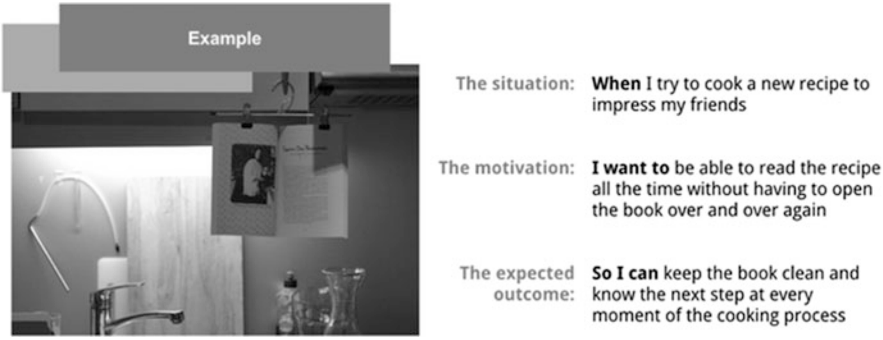

Fig. 3 Screenshot of an example workaround and a provided possible answer

Fig. 4 Frequency distribution for the sample's level of experience with *design thinking*

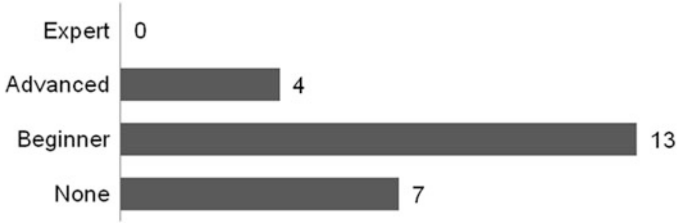

Fig. 5 Frequency distribution for the sample's level of experience with *MOOCs*

old: n = 12; 30–34 years old: n = 2), which is due to the fact that applicants are required to be university students 16 students indicated Germany as their country of origin, the rest came from other countries around the world (e.g., USA, Spain, Luxembourg).

We also asked them about their experience level with a) design thinking and b) MOOCs or other forms of digital learning environments. The distributions are displayed in Figs. 4 and 5. As expected, most of them were new to design thinking as the D-Camp (and the subsequent Basic Track program) is targeted at design thinking novices. In terms of prior knowledge and experience with MOOCs, most students indicated little or no experience in participating in or interacting within an online learning environment. Only four subjects considered themselves to be advanced in online learning.

Evaluation of the Topical Session on Observation
Students considered the topical session to be valuable as a whole, as well as the different teaching and learning formats (video, exercises) themselves. We also asked if the topical session was entertaining and fun for them, all participants agreed except for two who answered the question negatively. It is highly plausible that the MOOC learning format is perceived to be less fun in direct comparison to the highly interactive and energetic atmosphere students experience during the D-Camps. Nevertheless, most learners "agree" or "strongly agree" with these two items. This stance was also reflected in the last question asking subjects about the likelihood of their taking part in a similar online course in the future. Nineteen out of the Twenty-four subjects "agreed" or "strongly agreed" with the possibility of their willingness to participate in such a course. Looking at these results, we can see a clear need for teaching design thinking skills in separate, small topical sessions. We also conclude that participants approve of the topical session on *Observation* in the *Inspirations for Design* MOOC. Not only does this prove the utility of the topical session on *Observation*, but it also shows that such online learning formats can add to an existing curriculum in design thinking. Finally, it furthers the plan to create more topical sessions of this kind in the future.

Didactic Design
Besides the acceptance of the topical session, we asked students to rate the didactic design of the topical session. Results show that providing examples to learners helps them greatly to understand the content of the taught skill set. More than half of them "strongly agreed" that the example of a design thinking challenge helped them to better understand the content. All other questions including "value of the exercise format," "authenticity of the video content," "clarity of exercise formulations," "structure of learning materials," and "match between content level and prior knowledge" received broad acceptance among subjects as well. Overall, the didactic design can be considered well accepted, and especially real-life examples help learners to understand and translate online content to their own context.

4.2 Learning for the MOOC Prototype Test Run

Our aim was to measure the overall perception of the pilot version and its acceptance. The pilot version testing with D-Camp participants allowed us to get feedback on our *Observation* topical session and learning formats and to derive and apply adaptations from it for the full MOOC prototype. The setup of the pilot version outside of the online learning platform allowed us to easily receive direct feedback on the MOOC pilot version.

The overall positive feedback from the testing convinced us to offer a combination of short video lectures and exercises for each week. As a result, we designed the course in a way that offers several opportunities to apply the skills that are introduced in the short weekly videos. In other words, while videos play a central role innumerous MOOCs, our approach is to put more emphasis on practicing and applying knowledge to other contexts while watching less lecture-style instruction videos.

5 MOOC Prototype on openHPI

We ran the MOOC prototype *Inspirations for Design* on the online learning platform openHPI, commencing in November 2016 (see Fig. 6 for MOOC syllabus overview and interface on openHPI). Offering the course on openHPI platform gave us the unisque chance of collaborating closely with the openHPI team, who are experts in creating and delivering MOOCs. In this way, we could minimize technological errors and potential bugs. Hence, we were able to eliminate possible learning biases due to technological failure. For the planned iterated, public version of this MOOC, openHPI also offers us access to its broad international social learning network. While we can make use of openHPI's tools, features and network in the future, findings from this MOOC prototype test run will directly feed back into and profit the online learning platform.

Currently, openHPI primarily offers MOOCs on Information and Communications Technology (ICT) with a focus on video-based teaching and learning material. As described in the pilot version section (see "Pilot Version of the MOOC Prototype"), we extended the teaching and learning mode in our course by adding different types of learning material to the online learning environment of an openHPI MOOC. This idea of mixed learning modes is based on our extensive

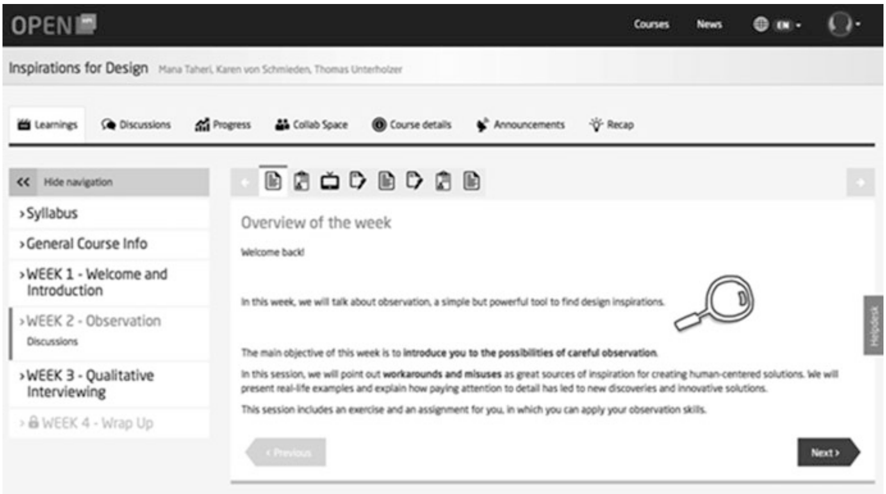

Fig. 6 Screenshot of the MOOC syllabus and interface on openHPI

research examining all existing design thinking MOOCs during our first research year (Taheri and Meinel 2015).

To be specific, this MOOC on design research differs from other MOOCs on openHPI in respect to incorporating exercises and assignments as parts of online topical sessions. The underlying purpose of this mixed learning mode approach is to engage learners and also connect them with each other in the digital learning space. Moreover, these learning activities (exercises, assignments, and peer assessment) require what the educational and learning literature refers to as active learning (Bonwell and Eison 1991). When students learn in an active learning mode, they "engage, think critically, discuss, and problem solve as a natural and expected part of the learning experience" (Staley 2003, p. 5). In contrast to traditional frontal classroom teaching and learning, active learning also requires the learner to acquire "problem-solving orientation, a critical approach and an evaluation of knowledge [with] the ultimate goal [. . . to] elaborate on applications of knowledge and [. . . to] produce new knowledge using cognitive processes" (Niemi 2002, p. 764). Thereby, knowledge is processed at a deeper cognitive level and can subsequently be retrieved longer and can be transferred better to new contexts (Michael 2006). A recent meta analysis from 2014 showed that active learning outperforms traditional lecture learning in classrooms (Freeman et al. 2014). Results indicated that students' performance increases when their educational curriculum follows an active learning approach.

Therefore, we consider online learning elements that foster active learning as the most suitable approach to fulfill our research intentions. This means creating a scalable MOOC to achieve and monitor skill learning and guaranteeing skill transfer of design thinking knowledge to other contexts and design challenges. Table 1 gives

Table 1 List of all used learning modes in the MOOC prototype and theoretical underpinnings

Learning mode	Purpose	Pedagogical basis
Video	Teach knowledge and show examples	Main method of content delivery
Exercise	Rehearse and repeat taught knowledge	Encourage active learning
Assignment	Apply skills to a task and transfer knowledge to a new context	Encourage active learning
Peer assessment	Evaluate others' work and thereby reflect on the task and internalize skills	Develop cooperation among students, give and receive prompt feedback
Discussion forum	Connect, interact and exchange knowledge with peers	Develop cooperation and interaction among students
Skill confidence rating	Measure the confidence and skill level before and after each topical session	Encourage awareness of personal skill development through self-reflection

an overview of the learning modes and features that have been used in this course and the purpose they served.

All in all, by testing these new learning and teaching modes (exercises, assignments, and peer assessments) in the online learning environment, we will provide insights that could lead to possible feature extensions to openHPI.

5.1 MOOC Protoype Setup

The four week test run consisted of a welcoming week (week 1), two weeks of design thinking (research) content (week 2 and 3) and a wrap up week (week 4). Table 2 displays the course content structure with each week's intended learning objectives.

The first week served as an onboarding week. Apart from a short introduction video with the instructors, it contained an animation video that gave an introduction to design thinking and the course. There were no assignments in week 1. The reason for having an onboarding week is twofold. First, to give participants time to get familiar with the learning environment and the platform, and second, to encourage them to get to know their peers and connect with the learning community through a task (not graded). In this task they were asked to upload a picture containing three artefacts from their daily lives (see Fig. 7). Our aim was to make learners feel at ease and welcomed at the online environment and to generate a feeling of community, which is often mentioned in MOOC literature to motivate learners' activity and to prevent dropout (Khalil and Ebner 2014; Rovai 2000). Apart from that, having an onboarding week gave us, as instructors, the chance to observe and monitor initial MOOC participant activities and intervene in case of misunderstanding or confusion.

During the second and third week, learners engaged with the content to acquire basic skills of design (thinking) research, namely *Observation* and *Qualitative Interviewing*. Week 2 contained video content, exercises and a peer-reviewed

Table 2 Course content structure and intended learning objectives

Week	Content	Learning objectives
1	Welcome and Introduction	To get familiar with the platform To connect with the learning community
2	Observation	To understand the power of careful observation To introduce the concept of workarounds and misuses To apply the observation skill to participants' own context
3	Qualitative Interviewing	To introduce the element of a good qualitative interview To apply the interviewing skill to any of three given topics
4	Wrap Up	To summarize the methods introduced in the course To showcase some of the best examples from the participant submissions

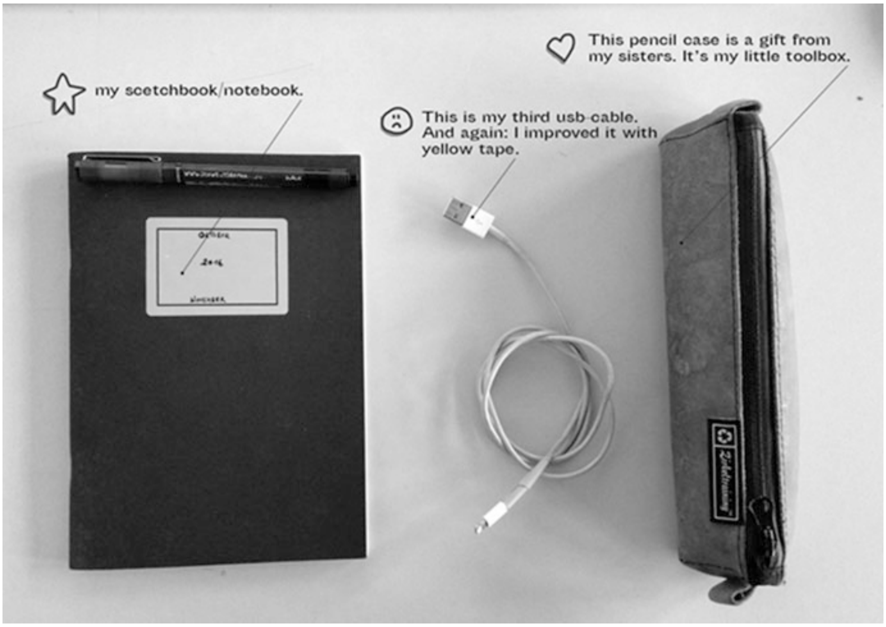

Fig. 7 Example screenshot of a learner's week 1 exercise upload on the discussion board

assignment for learning observation skills. Such skills are intended to spot a workaround in one's work or home environment or to recognize the workaround of someone else, and to infer meaning from this workaround by creating a *jobs-to-be-done* formulation. Week 3 also contained videos, exercises and a peer-reviewed assignment for learning how to conduct good qualitative interviews.

Finally, the last week was dedicated to wrapping up the course and methods we introduced. Since we wanted to maximize our presence in the course as instructors, we postponed the video recording for week 4 to the final third of the course. In this way, we were able to refer to what we had monitored during the course and show some of the assignments that were submitted by learners.

In order to measure the success of our approach in focusing on skill-based learning outcomes, we not only conducted the course evaluation survey (CES), but also introduced skill confidence ratings (SCR) before and after the course content in week 2 and 3 (see "Test Evaluation" for a more detailed description of the evaluation tools). This additional rating might be a possible future supplement to MOOCs on openHPI. We expect that it could help instructors to measure specific skill development.

Since the goal of any training is that participants acquire new skills and knowledge, the focus of designing a learning environment—regardless of online or offline—should be on learning outcomes. When investigating the potentials of teaching design thinking online, we therefore focus on the pedagogies and learning outcomes rather than on replicating experiences.

Test Run Facilitation and Monitoring
During the test run, two researchers observed the MOOC and monitored participant activities and behavior as course instructors. They were attentive to potential misunderstandings, confusion or conflict and answered questions in the discussion forum as well as in private mails.

Another researcher took part in the course as an active participant to experience the MOOC from the learner's perspective. This two-sided monitoring helped us to run the course smoothly and collect feedback on the one hand, and to experience it ourselves as a user on the other.

Participant Recruitment
For this test run, it was important to limit the amount of participants. In doing so, we hoped to guarantee a safe and (number-wise) manageable environment in which to monitor participant actions and behaviors. Although the MOOC is targeted at design thinking novices, we also asked advanced and expert design thinkers to participate. This gave us the possibility to gather feedback from a professional point of view.

Recruitment took place via email. Mails were sent to various design thinking and education networks (HPI International Design Thinking Network, HPI School of Design Thinking Basic Track students, openHPI forum "Future of Digital Education" participants) as well as to interested family members, colleagues, and friends.

5.2 Test Cohort

In total, 119 learners enrolled for the MOOC of which 70 took the pre-course evaluation survey (CES). Although it was not graded, 43 learners participated in the first week introduction task and uploaded pictures on the forum. Thirty submitted the week 2 assignment. In week 3, 20 assignments were submitted.

The pre-CES gave us a good overview of our test cohort. We asked several demographic and background questions. In total, 70 learners filled in the pre-course questionnaire, 40 female, 29 male and 1 other. The biggest group of participants belongs to the age group of 25–34 year olds (n = 33), followed by 18–24 year olds (n = 13) and 45–54 year olds (n = 12).

The HPI Design Thinking network allowed us to also reach out to international testers. Thus, we gained the interest of 29 MOOC participants who spent most of their lifetime outside of Germany.

The test run sample comes from a diverse field of occupation (e.g., education, technology, business, architecture, and innovation). Most learners indicated high English proficiency levels, none or little design thinking experience and only a third had advanced experience with online learning in a MOOC environment (see Figs. 8, 9, and 10 for expertise level results).

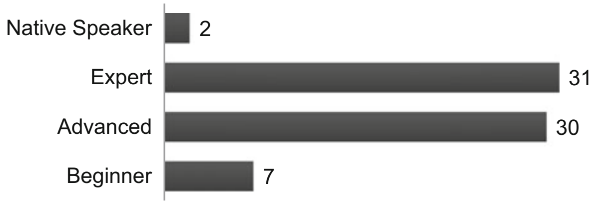

Fig. 8 Pre-course evaluation survey results for participants' level of *English proficiency*

Fig. 9 Pre-course evaluation survey results for participants' levels of *design thinking*

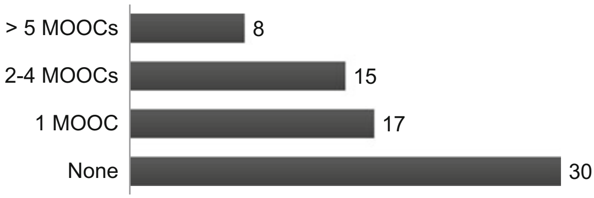

Fig. 10 Pre-course evaluation survey results for participants' level of experience with *MOOCs*

Two thirds of all subjects (n = 46) indicated their interest in taking part in a follow-up qualitative interview with us, which we will conduct for more in-depth research.

5.3 MOOC Prototype Evaluation Measures

We use a mixed-methods approach to evaluate the *Inspirations for Design* MOOC prototype. In this approach we conduct a course evaluation survey (CES), integrated skill confidence ratings (SCR) and qualitative follow-up interviews. All measures used in the pilot version and the MOOC prototype test run and their purposes are listed in Table 3.

Course Evaluation Survey (CES)
We intended to assess participants' satisfaction with the course, and more specifically participants' acceptance of exercises and assignments. Therefore, we conducted a pre and post course evaluation survey. Surveying the acceptance of tasks

Table 3 Overview of all measurement tools used to evaluate the pilot version and MOOC prototype

Measurement tool	Type of measure	Purpose
Task Acceptance Survey (TAS)	QN, QL	Test the pilot version on *Observation* for clarity of the topical session & acceptance of multiple learning modes (video + exercises)
Course Evaluation Survey (CES)	QN, QL	Compare learners' course expectation and satisfaction prior to course start & after course completion; basic demographics
Skill Confidence Rating (SCR)	Pre: QN Post: QN, QL	Examine learners' perceived skill development; receive feedback on unfulfilled needs per topical session (in post SCR)
Qualitative Interviews	QN	Extract insights for MOOC iteration

Note: QN means quantitative; *QL* means qualitative

in exercises and assignments enabled us to receive comprehensive feedback on the learning experience.

We evaluated participants' satisfaction with the course by asking for their expectations prior to the course and we will compare these desired learning objectives with participant ratings after course completion. Because the course was still running during the writing of this chapter, we include preliminary results on learner's expectations from the pre-CES (see "Info About the Test Cohort" for demographic results of the pre-CES). These results are summarized in the following list:

Participant expectations:

- learning more about, deepening or refreshing design thinking knowledge, skills and methods
- getting to know openHPI
- trying out a MOOC
- interest in the MOOC topic approach: how a teamwork method & a creative process like design thinking can work in a MOOC
- experiencing a virtual learning community: connecting with others and exchanging best practice examples
- learning greater interviewing skills through empathy work in qualitative interviews in design thinking
- solving problems in a team
- getting a certificate
- achieving two opposing expectations: gaining more theoretical vs. practical knowledge

The post survey asked if the learners' expectations had been met by this MOOC. Additionally, the post CES contained acceptance and satisfaction questions on the didactic design and the content of the course. Findings were not available at the time of chapter submission.

Skill Confidence Rating (SCR)

Besides the overall course evaluation, we also looked at learners' perception of their weekly skill development with a short pre and post survey we called skill confidence rating (SCR). This rating served to test the direct impact of exercises and assignments on learners' perception of their own skill development. The SCR was integrated to the topical sessions of *Observation* (week 2) and *Qualitative Interviewing* (week 3). In practical application this means that the learners had to fill in the SCR at the beginning (pre) and at the end (post) of a topical session.

In this pre-post self-test, participants had to estimate their confidence with skills that are pivotal to the methods (e.g., "To what extent would you consider yourself being attentive to your daily environment?" for the method of *Observation*).

We incorporated this rating into the general survey setup of existing openHPI courses, as we believe it adds value to our research and analysis in three ways. It enables us to:

(a) interpret the effectiveness of the course content (e.g., analyze the changes in skill confidence through topical sessions)
(b) understand the initial level of participants' skill perception
(c) encourage learners' self-evaluation by triggering more awareness of their learning process

For our course, we expect an increase in all perceived skill confidence scales.

Qualitative Interviews

Course participants that were interested in taking part in a follow-up interview were asked to provide their email addresses in the surveys. We prepared a semi-structured interview questionnaire with adapted focus points for design thinking experts or advanced practitioners, design thinking novices and international participants. Our aim is to gather more in-depth feedback on the course through personal conversation. We will inquire about the needs and challenges of design thinking novices, and international participants in particular, and expect to receive constructive feedback on course and exercise design from the design thinking experts.

5.4 *Prototype Test Results and Learning*

Exercises and Assignments

In general, participants were able to understand and solve the course exercises and assignments. The test run, however, showed that the explanation of more complex and abstract concepts—such as a workaround—are more prone to misunderstandings. Several participants misinterpreted a workaround displayed in the exercise, a

Fig. 11 Example of a submitted assignment on recognizing and interpreting a workaround in the participant's daily environment

circumstance that underlines the necessity for an exercise iteration. Nevertheless, we see a learning effect in the subsequent assignment, in which most participants succeeded in identifying and interpreting a workaround (see Fig. 11).

Skill Confidence Rating (SCR) Results

In total, 49 course members participated in the pre skill confidence rating for the *Observation* session and 24 filled in the post SCR at the end of the topical session (week 2). Two question items assessed participants' confidence with observation skills. For the first question, they had to rate their skill confidence with "being attentive towards their daily environment," with 1 = "not at all attentive" and 10 = "very attentive." The second question assessed how confident participants are with "interpreting what lies behind problems" and was also rated on a scale from 1 = "very difficult" to 10 = "very easy." Overall, the mean for both items increased from pre to post rating (see Table 4 for all mean comparisons).

For the second topical session on *Qualitative Interviewing,* 40 participants filled in the pre SCR and 24 the post SCR. Three question items assessed their confidence with qualitative interviewing skills on a scale from 1 = "not at all confident" to 10 = "entirely confident". For the first question, they rated their skill confidence with "preparing for a qualitative interview", for the second how confident they are with "conducting qualitative interviews" and for the third one how confident they "feel about inferring meaning from [. . .] interview results". Overall, the means for all items increased from pre to post rating (see Table 4).

Table 4 Mean comparison of SCR pre and post rating for all question items per topical session

	Mean	
	Pre	Post
Observation		
1. To what extent would you consider yourself being attentive to your daily environment (before and after taking this week's learning unit on Observation)	$M = 7.29$ (n = 49)	$M = 9.33$ (n = 27)
2. How easy is it for you to interpret what lies behind a problem (before and after taking this week's learning unit on Observation)	$M = 7.38$ (n = 49)	$M = 9.71$ (n = 27)
Qualitative interviewing		
1. How confident do you feel about preparing for a qualitative interview (e.g. writing an interview scheme) (before and after taking this week's learning unit on Qualitative Interviewing)	$M = 6.59$ (n = 40)	$M = 8.30$ (n = 24)
2. How confident do you feel about conducting qualitative interviews (before and after taking this week's learning unit on Qualitative Interviewing)	$M = 6.69$ (n = 40)	$M = 8.30$ (n = 24)
3. How confident do you feel about inferring meaning from your interview results (before and after taking this week's learning unit on Qualitative Interviewing)	$M = 6.77$ (n = 40)	$M = 8.26$ (n = 24)

The sample sizes in the corresponding pre and post ratings were dissimilar. This can be explained by participants dropping out in the course of the topical sessions.

The small sample does not allow for extensive conclusions, but we do deduce that the SCR is a helpful tool for assessing skill development in learners and for encouraging learners' self-evaluation in MOOCs.

Learning

The learning we draw from the test run will serve as a basis to both iterate the MOOC *Inspirations for Design* and to devise new learning units. Concerning the iteration of the course, we will incorporate the participant feedback we received during the course as well as that acquired through surveys and follow-up interviews. In the beginning of the course, participants mainly inquired about issues such as an end-of-course certificate, teamwork, the course instruction language, and the estimated workload. This underlined the necessity to communicate such topics clearly and repeatedly on the course landing page and during the introduction week, especially to MOOC novices. In the second iteration of the *Inspirations for Design* course, we will provide an information graph illustrating all crucial dates and rules.

For MOOC prototype this time, we included subtitles for each video to facilitate the learning experience for participants with a low English language proficiency. Subtitles were provided by Xiaoyin Che within the "Web University" research project at the HPI chair of Knowledge Management and Engineering, using the ASR (Automatic Speech Recognition) tool IBM Watson Speech-to-Text service, SBD (Sentence Boundary Detection), and srt-formatting (Web University 2016). For future iterations, we will maintain the subtitles feature and consider subtitling in other languages as well.

Participant feedback during the course mainly focused on the content of video material, which some participants perceived as too dense. They also expressed difficulties in uploading material to the online platform and identifying icons correctly. This suggests that it would be helpful to add an introductory "guide video" explaining the basics and icons of the platform to MOOC and openHPI novices.

Concerning the creation of new design thinking learning units, we intend to further utilize the side effects of the task design which we experienced in the *Insights for Design* MOOC. Although our initial intention was to focus on and convey particular design thinking skills in the course, we observed a shift in learners' mindsets. The exercises and peer-reviewed assignments did not only encourage MOOC participants to transfer gained knowledge, and thereby trigger deeper learning processes, these tasks also necessitated a type of collaborative learning and created a feeling of belonging and community. More learning unit topics will be chosen according to the demands and necessities voiced by interviewees.

5.5 Evaluation of openHPI Features

Currently, openHPI mainly provides courses focused on IT-related topics. The available features are thus tailored for such courses with a focus on quizzes and uploading (code) assignments. The results of the *Inspirations for Design* test run provide us with insights about possible advancements to the platform, which will expand the scope for MOOCs targeting design thinking topics. Below, we list recommendations for (future) features.

Free Text Option

Based on findings from the first and second research year, we advocate for introducting a free text option on openHPI. Beforehand, the common procedure in openHPI MOOCs was to position quizzes (self-tests) between video lectures. The free text feature enables us to introduce a new and more interactive exercise design. This option will be implemented in 2017 and tested in the next *Inspirations for Design* iteration. We moreover propose implementing flexible quiz formats, which allow embeding pictures in the task statement and a mixed forms of answers.

Peer Review

The assessment of assignments by peer review, a beta phase feature on openHPI, went well for our prototype. In both assessments, students did not report so-called conflicts—for example, accusations that other students plagiarized content—and only one participant complained about unfair assessment by other reviewers. Twelve students nominated assignments by peers for "awards," singling them out as excellent submissions. We propose including the possibility to upload templates in the review phase for a more interactive reviewing procedure in the next course iteration.

6 Outlook

Our threefold mixed-methods approach to analyze the *Inspirations for Design* prototype test run provides us with rich insights about the preparation phase, video lectures, exercise design, time framing, task phrasing, and participant communication. We will incorporate our learning into the first iteration of the *Inspirations for Design* course, aiming to run a public and open version on openHPI.

We likewise obtained insights that will serve as a basis for creating further design thinking online courses, namely topic-specific learning units bridging the gap between real life and online learning. On the one hand, such digital learning units may support learners parallel to an ongoing design thinking education at an institution. On the other hand, they could support novices who participate in an introductory course on design thinking and are now strugglinging with transferring and implementing the method in their own working environment. We will examine the context and coherence of design thinking MOOCs in both scenarios.

Moreover, future iterations of the course and other learning unit prototypes will allow us to test further hypotheses. We are interested to see if the allocation of students to smaller discussion forums, so-called "collab spaces," will increase participant activity and contribution. We will furthermore test the "free text" feature on openHPI and explore possibilities of designing exercises with this new option.

Our research results will thus be transferred to new digital design thinking learning formats, which are constantly being improved. Thereby, we expect to enhance general research on MOOCs as well as design thinking education and to provide feedback for advancement of the platform to the developer and teaching team of openHPI.

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Creativity in the Twenty-first Century: The Added Benefit of Training and Cooperation

Naama Mayseless, Manish Saggar, Grace Hawthorne, and Allan Reiss

Abstract Creativity is an important construct driving society and innovation forward. Many organizations have adopted team-based work in order to increase innovation and creativity under the assumption that groups of people tend to produce more creative ideas than individuals. Research has so far shown mixed results with some finding enhanced creativity in teams while others showing the opposite effect. A short literature review of team creativity and how it relates to possible neural networks is presented. In addition, we will integrate key findings from our current research implementing a group training protocol to enhance creative capacity. Participants in our creativity study underwent a distilled version of Creative Gym, a course that has been taught at the d.school for the past 8 years that is purely focused on individual creativity skill building in a group environment. Students enhance their creative confidence and sharpen their individual design thinking skills through hands-on experiences that are comprised of unconventional hands-on exercises organized around nine core themes that engage our human abilities in intersecting ways. Training was performed in a group environment while improving perspective taking, empathy, synthesizing ideas and developing improvisational skills. Creativity was measured, before and after participant training (Time 1 and Time 2), using standardized assessments of creativity. In addition to neuroimaging markers, other cognitive faculties (e.g. executive functioning) and personality were also assessed before and after training (Hawthorne, et al. Design thinking research. Springer, 2014). We will review the literature on team creativity and present key findings from our current research, using group based creativity skill training.

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1 Introduction

Creativity is an important facet both for individuals as well as organizations, as it can allow for innovation to occur. While traditionally creativity has been regarded and researched as an individualistic trait, today there is a growing interest in the ability of groups to think creatively and produce creative ideas or products (Baruah and Paulus 2009). Many organizations have been implementing team-based thinking styles in an attempt to boost creativity and innovation. This is despite a growing body of knowledge suggesting that groups tend to be less creative than individuals and produce less creative and original ideas (Michael Diehl and Stroebe 1987).

1.1 Creativity: Defined

Creativity can be defined in several ways. In everyday folklore, creativity is seen as related to a variety of concepts including innovation, imagination, and inventiveness. In the academic world, creativity has been traditionally defined as the process that gives rise to novel and useful or appropriate ideas. Other definitions focus on different aspects of creativity and can be derived from the famous "four P's" of this concept. The four P's include: process (refers to the thoughtful and critical activity of producing new solutions or ideas); person (individual characteristics of the person producing the ideas); product (the concept or idea that is proposed); and press (the environment) (Rhodes 1961). Recently, Hawthorne et al. (2014) proposed a definition of creativity that addresses the person, process, and product aspects of creativity. They defined creativity as "a state of being and adaptation of personal skill sets that enables an individual to synthesize novel connections and express meaningful outcomes" (Hawthorne et al., p. 67). While traditional definitions focus on the process and product, this definition puts the person in the center. Focusing on the individual allows for better understanding of individual creative capacity and the effects of collaboration.

1.2 Creativity: Measured

Creativity is a multifaceted concept, which can be measured using different approaches. These approaches typically include fluency, flexibility, and originality (Torrance 1988). Fluency refers to the number of non-redundant ideas, solutions or products and is a measure of creative production. Flexibility refers to the use of different cognitive categories and the use of broad and inclusive cognitive categories (Mednick 1962). Originality is one of the defining characteristics of creativity and refers to the uniqueness or infrequency of the ideas, solutions or products generated (Sternberg and Lubart 1999). Traditionally, creativity can be measured using

Fig. 1 Illustration of creative design team

problem-solving tasks that require creative innovation or insight problem solving, or through the process of divergent thinking. Divergent thinking refers to the process of generating many alternate ideas or solutions to an open-ended problem. One example of an extensively used divergent thinking task is the Torrance Tasks for Creative Thinking [TTCT, (Torrance 1968)]. The TTCT involve different tasks both figural and verbal requiring a person to generate many alternate solutions to problems such as completing an incomplete drawing or creating interesting and meaningful illustrations from different shapes. In addition to the TTCT, researchers have expanded the choice of tasks that measure creativity (Kowatari et al. 2009; Saggar et al. 2016). These tasks cover several aspects of creative thinking and range from originality-centered tasks such as designing a pen (Kowatari et al. 2009) to improvisation-centered tasks such as playing Pictionary™ (Saggar et al. 2015a, b, 2016).

2 Team Creativity (Fig. 1): A Literature Review

There has been much research in the field of team creativity. The results of this research shows that while brainstorming in groups is reported to be more enjoyable (Nijstad and Stroebe 2006), groups are not very conducive to the generation of unique novel ideas (Simonton 1988; Walton 2016).

2.1 Wait . . . What Was I Going to Say?

Several reasons have been postulated to explain this effect, the most prominent being the notion of "production blocking" (Diehl and Stroebe 1987). Production blocking refers to the inhibitory effects of groups and can include factors such as turn taking when expressing ideas in the group setting. In particular, research has shown that turn taking can cause people to forget their ideas or decide not to share them (Diehl and Stroebe 1987). Another factor of "production blocking" that can inhibit creative ideation is the added cognitive load of thinking or remembering your idea while at the same time paying attention to others' ideas (Baruah and Paulus 2009; Coskun et al. 2000). Production blocking is exacerbated in larger groups as more individuals share their ideas, and is less pronounced in smaller groups (Nijstad and Stroebe 2006).

2.2 Your Idea Made Me Think Of...

Despite the existence of factors that may inhibit creativity in groups, one of the reasons that groups are thought to be conducive to creativity is that group members can be exposed and stimulated by multiple ideas (Nijstad and Stroebe 2006; Paulus and Brown 2007). Several studies over the years have indeed shown this to be the case, that exposing individuals to others' ideas can stimulate and enhance the creativity of generated ideas (Dugosh and Paulus 2005; Dugosh et al. 2000).

2.3 Larger Groups Can Generate More Ideas Disproportionately

Furthermore, while the potential of this stimulating effect can be masked by the inhibiting factors discussed above (such as "production blocking"), studies have demonstrated that electronic brainstorming, sharing ideas by computers, for instance, can lead to enhanced idea generation compared to nominal groups, especially for larger groups which provide greater numbers of ideas (DeRosa et al. 2007; Paulus et al. 2013). In an interesting study looking at cognitive stimulation and its effect on creativity, Fink et al. (2010) found that exposing individuals to others' ideas not only resulted in more original idea production, but was associated with brain activations (less deactivations compared to free ideation without exposure to ideas) in regions involved in semantic information processing (Binder et al. 2009).

> While large groups can be detrimental to creativity by introducing production-blocking factors, the stimulating effect of being exposed to new ideas from other team members can be an enhancing factor in creative production. This enhancing effect is more prominent when using team environments such as electronic brainstorming where team members interact through electronic devices.

2.4 Free-Riders and the Sucker-Effect

Social factors can have both a hindering and facilitating effect on individual creativity in a group setting. Several social comparison factors have been suggested to account for the reduced ideation of individuals in groups. These factors include "free-riders" and the "sucker effect" (Thompson 2000; Walton 2016). Free-riding describes a situation where an individual reduces effort to avoid the possibility of working harder than fellow group members, while the sucker effect describes a situation in which people think other team members claim credit for ideas, yet leave them to do all the work. These inhibitory effects have been reported to increase as group size increases (Baruah and Paulus 2009; Nijstad and Stroebe 2006). In contrast, facilitating factors can include a cooperative climate and group diversity.

2.5 Diversity Is Good

The use of teams for creative tasks is often based on the notion that teams can increase the range of knowledge and bring new perspectives to the discussion (Hoever et al. 2012). For example, Paulus and Brown (2007) suggested that a diverse group composed of individuals with varying areas of knowledge could produce more creative ideas than a group composed of people with overlapping expertise. Diehl (1992) and Stroebe and Diehl (1994) manipulated group diversity in brainstorming sessions and found that groups with higher diversity exhibited higher group creativity, which was evident by the flexibility of ideas as measured by the number of categories of ideas produced.

2.6 Does Gender Matter?

Though diversity has been argued to increase group creativity, the gender composition of teams seems not to affect the overall creativity of ideas produced unless the task itself is gender activating, such as designing a specific product for men (or women) (Pearsall et al. 2008). Despite this finding, specific instruction to take the others perspective (perspective taking) has been shown to increase creativity in teams (Hoever et al. 2012).

2.7 Fight It Out?

There has been considerable research in the field of team and task conflict and its effect on team performance and team creativity (De Dreu and Weingart 2003; Fairchild and Hunter 2014; Farh et al. 2010). Researchers have suggested that conflict can be beneficial to creativity in certain conditions that include the degree to which team members feel comfortable voicing their opinions and disagreements (De Dreu 2008; Lovelace et al. 2001). Edmondson (2002) emphasized this by stating that task conflict can enhance creativity if it occurs in a safe climate of discussion and productivity.

As opposed to task conflict, team conflict can be detrimental to creativity and innovation (Amason et al. 1995; De Dreu and Weingart 2003; Jehn 1997). In a meta-analysis covering 30 published and unpublished reports, De Drew and Weingart (2003) found that team conflict negatively related to team effectiveness and team member satisfaction. It is important that conflict is kept at the task level and that positive affect be maintained between group members (Isen et al. 1987).

Oxytocin (a hormone and brain neurotransmitter) has been reported to be involved in cooperative exchange within groups (De Dreu et al. 2010). Therefore it has been suggested that collaborative settings may facilitate the release of oxytocin that, in turn, may increase creativity (De Dreu et al. 2015). In agreement with this hypothesis, oxytocin has recently been reported to be related to creative production using both intranasal oxytocin and oxytocin related genes (De Dreu et al. 2013).

Collectively, the literature reviewed here suggests that in order for a group to produce creative, innovative ideas, it is not only necessary for individuals to be able to produce many ideas but the environment must be supportive in order to allow for evaluations that do not promote conflict and reduce negative elements of social comparison. In what follows we will present a summary of our group training protocol, which among others, was set to improve perspective taking, empathy, synthesizing ideas and developing improvisational skills that can lead to higher scores on a standardized test of creativity.

3 Creativity Training: Our Results

Creativity is not a fixed ability; it can be nurtured both through environments that stimulate individual creative potential as well as with training that can promote creative capacity. Creativity is considered the driving force behind innovation and human progress and has benefits to mental health and wellbeing. As such, it is important to examine ways to enhance creativity and investigate the brain networks associated with both natural creativity and the effects of targeted training.

We have previously examined the effect of a targeted design-thinking training in group settings to enhance creative capacity (Bott et al. 2014; Hawthorne et al. 2014; Kienitz et al. 2014; Saggar et al. 2015a, b). We used a 5-week Creative Capacity Building Program (CCBP) to train healthy adults in creative thinking. The CCBP was an abbreviated version of a highly popular class offered at the Stanford Hasso Plattner Institute of Design called ME266 Creative Gym (http://dschool.stanford.edu/classes/#creative-gym-a-design-thinking-skills-studio).

> We designed CCBP as an interactive studio where students can build their creative confidence and sharpen their individual design thinking skills through hands-on experiences, rapid prototyping, and other improvisational exercises (see Saggar et al. 2014, p 31).

Activities in the training program were centered on hands-on projects that varied in constraints of time, materials, objectives, and intention. All projects yielded a constructed or drawn physical artifact. CCBP training was done in group setting focused on improving perspective taking, empathy, synthesizing ideas and improving improvisational skills.

We were particularly interested in determining the effect of CCBP training relative to a (non-creativity targeted) "control" training to see if creativity can be enhanced in just 5 weeks. Using a longitudinal analysis of scores on a standardized test of creativity (TTCT), we showed that with just 5-weeks of targeted training, creative capacity can be enhanced in adults as compared to control (language) training (Kienitz et al. 2014). Furthermore, we also observed enhancements in lower-level executive functioning (i.e., information processing) associated with targeted creativity training (Bott et al. 2014; Thinking Skills and Creativity).

The results of these studies provide evidence that group training, conducted outside of the workplace or scholastic settings, could provide creative capacity enhancement in an adult population. Moreover, improvement in low-level executive functioning suggests that creative training can affect performance on attention tasks that require little cognitive interference, which is related to creativity (Martindale 1999). In summary, these results suggest that creativity and information processing, as measured with standardized, well-accepted measures, can be enhanced through a focused training program.

We were interested in studying the underlying brain mechanism responsible for this boost in creative capacity; therefore we used fMRI (functional magnetic resonance imaging) to look the effects of training on brain mechanisms. A novel game-like fMRI paradigm was designed based on the word-guessing game of Pictionary™ to measure spontaneous improvisation and figural creativity (Saggar et al. 2015a, b). This game-like task was designed to engage participants in spontaneous creativity that would help them reach their creative potential in a non-test-like environment.

At baseline, before training, spontaneous improvisation and creativity were associated with reduced engagement of executive functioning and volitional control, while at the same time associated with increased involvement of implicit processing (via cerebellar–cerebral connectivity).

We also examined the effects of training on brain activations in order to reveal the brain correlates of creative capacity *enhancement* (Fig. 2). Our results, depicted in Fig. 2, suggest reduced engagement of prefrontal regions related to cognitive monitoring and volitional control as well as reduced parietal cortex activation related to the number of hours in the training program. These results suggest

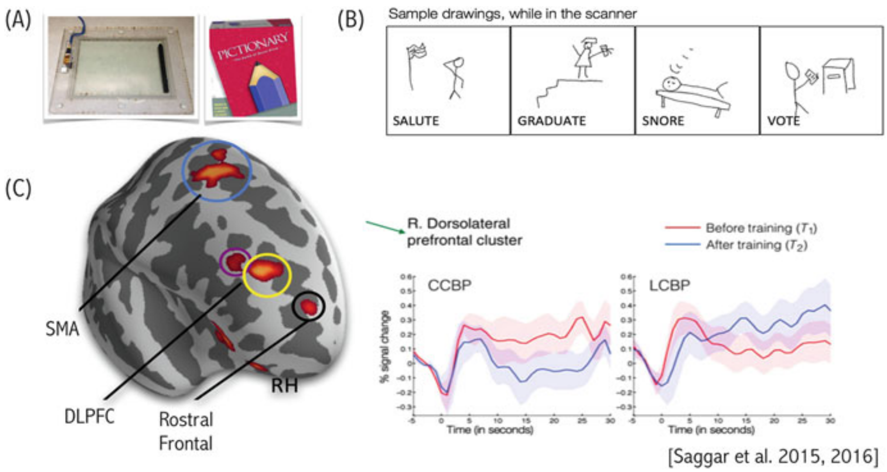

Fig. 2 Effects of training on brain activation. Figure depicts (**a**) MR-safe table and the game of Pictionary™ (**b**) Sample drawings from participants, while performing the task. (**c**) Neural correlates of creative capacity enhancement. After training reduced activity was observed in prefrontal regions in the group that received creativity training as opposed to language training

that training was able to reduce monitoring, evaluating or selecting ideas and help focus more on generating and synthesizing ideas. Furthermore, and similar to results of the baseline analysis, higher cerebellar–cerebral connectivity was associated with improvisation-based creativity training (Saggar et al. 2016). Greater cerebellar-cerebral connectivity has been previously hypothesized to facilitate implicit processing during creative thinking (Ito 2008; Vandervert et al. 2007).

Taken together, our results demonstrate the benefit of a short-term, improvisational group-based training program on creativity. In a 5-week training program, healthy adults were able to boost their creative capacity, improve their lower-level executive functioning and exhibit marked changes in brain activation related to improvements in creative capacity.

4 Conclusion

Taken together, teams and groups can be a nurturing environment for creativity when groups are set in a supportive environment which, on the one hand, allows for evaluation of ideas to take place but on the other hand limits the negative component of social comparison and conflict. Our own study found that training individuals in a group setting to improve perspective taking, empathy, synthesizing ideas and developing improvisational skills can lead to higher scores on a standardized test of creativity (Kienitz et al. 2014) as well as have marked effects on creativity-related neural networks (Saggar et al. 2016).

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Priming Designers Leads to Prime Designs

Jinjuan She, Carolyn Conner Seepersad, Katja Holtta-Otto, and Erin F. MacDonald

Abstract Priming has been used by behavioral psychologists to discover many interesting findings regarding human judgments and decisions. This paper offers two studies and a literature review that highlight how designers use priming to fine-tune their skills. In the past, designers have used priming exercises to help them generate more features, novel features, and uncover latent customer needs during conceptualization. This paper presents two newer design methods that actively prime designers to exhibit or accentuate certain skills during the conceptual design process. They both use primes that require active participation from the subject and sensory/perceptual engagement. Study 1 uses priming to improve designers' product-based communication abilities. Both a low-immersion implicit prime and a high-immersion implicit prime help designers generate more concepts. Additionally, the high-immersion prime leads to better communication of sustainability through the design. Study 2 fosters user-centered originality in design with an explicit priming technique of empathic lead users. This study finds that subjects in the high-immersion priming condition generate design concepts with higher levels of originality and more innovative features targeting product-user interactions, without loss in feasibility. Taken together with findings from other researchers, we conclude that both implicit and explicit priming are promising techniques that can be used to enhance design skills.

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Priming is a psychological technique to affect performance on a task via exposure to a stimulus that activates a particular idea, contextualization, or feeling. The effect is based on the notion that the human mind is organized as networks of associations, such that activating one idea increases the accessibility of associated thoughts, memories, and feelings (Bargh et al. 1996; Cameron et al. 2012). For decades, researchers have used priming to study judgments and decisions (e.g., Mandel and Johnson 2002; Sassenberg and Moskowitz 2005). More recently, priming is being used as a tool to improve skills relevant to creative thinking and problem solving, such as improving creativity (e.g., Friedman et al. 2003) or reasoning skills (e.g., Galinsky and Moskowitz 2000), discussed further below. Researchers in the field of product design have discovered that some approaches historically used in design methods are akin to priming, as will be discussed, and have also created new design methods that specifically harness priming to improve design skills. For example, recent design methods use priming to help designers generate more features, novel features, and uncover latent customer needs in the conceptual design process. This paper presents two such design methods that actively prime designers to exhibit or accentuate certain skills during the conceptual design process. They both use primes that are active, requiring participation from the subject and sensory engagement.

1 Conceptual Design

The product design process proceeds in stages that are generally stated as: (1) defining the design objective or problem statement, (2) gathering information on customers, other stakeholders, and competing products, (3) generating initial design concepts to address the objective, (4) refining a subset of initial concepts to more detailed designs, (5) prototyping and testing these designs, and (6) selecting a subset (typically one or two design solutions) to proceed to full-scale prototyping, analysis, and testing before finalizing the design for manufacturing. The process of generating initial design concepts to address the design objective is known as conceptual design. Many key features of a product, such as function and form, are primarily determined in this stage and exert a crucial influence on the product's entire life cycle (Ulrich and Eppinger 2004). Conceptual design involves challenges such as effective collaboration between multiple disciplines, clear communication of ideas, avoidance of fixation on certain solutions (Jansson and Smith 1991), encouragement of creativity and openness to unexpected solutions, avoidance of "groupthink" tendencies such as premature convergence on an answer, productivity loss in group brainstorming (Mullen et al. 1991), difficulty in aligning user and designer perceptions of a product (Helminen et al. 2010), and many others.

Since other disciplines address similar challenges, conceptual design methods have begun to pull inspiration from fields such as psychology and marketing. With its origins in cognitive psychology, priming is a useful tool to study and influence human cognition and behavior (Custers and Aarts 2010). Priming affects perceptions or behaviors by increasing cognitive accessibility of specific mental content. It resonates well with the conceptual design process in which designers' initial state-of-mind is important as they draw upon their knowledge and experiences to generate ideas.

2 Useful Priming for Designers

Generally, it seems that our behaviors originate from our conscious decisions, but, in fact, subconscious processes influence actions and preferences. Bruner (1957) proposed the concept of “perceptual readiness”, which implies that thoughts and behaviors are driven primarily by what is accessible. He described how current goals and needs might increase the cognitive accessibility of anything that might help to achieve these desired states by priming a certain perspective, and thus, motivation guides perception (Bruner 1957). Kahneman and Tversky (1974) also discussed how the ease with which an event can be brought to mind biases judgment of its probability.

Popular design literature has long included concepts and recommendations related to priming. Examples include the use of stimuli at the beginning of the conceptual design process (e.g., Higgins 2005; Rickards 1974). The stimuli might include related things, such as drawings of competitive products and unscrambling of either neutral or hostile sentences (Marsh et al. 1999), as well as more unrelated things, such as videos of animals performing functions similar to those performed by a mechanism. Researchers have found that exposure to stimuli is very important for effective conceptual design (Daly et al. 2012; Fink et al. 2010; Linsey et al. 2010; Valacich et al. 2006). Other perceptual readiness exercises also guide the design process; for example, sketches improve ideation by interfacing non-visual functional relations and visual features (Suwa and Tversky 1997), even if one is not sketching potential designs.

3 Implicit Priming

Recent research in social psychology studies the implicit and passive influence of priming on social behavior. *Implicit* primes are those primes used subtly in an attempt to prevent people from becoming aware of the influence of the primes. Implicit/passive priming methods (Bargh et al. 2001; Custers and Aarts 2010) are used in a wide variety of studies to affect decision-making and behavior by applying a variety of contextual influences such as stereotypes, expectancies, and environmental changes in behavioral experiments.

Some implicit priming results of interest to conceptual designers are scattered in the literature. For example, a leather briefcase placed on the desk in an office made people behave more competitively (Kay et al. 2004). An outcome that almost did not occur (e.g., John did not win a prize in a lottery because he recently discarded a winning number) led people to be more likely to consider alternative solutions in problem solving (Galinsky and Moskowitz 2000). In online shopping, the background of the website (Mandel and Johnson 2002) or the features included in the recommendation agents (Haubl and Murray 2003) raised the level of importance of related features. For example, a fluffy cloud background emphasized the importance of the comfort of a sofa more than a grey background. Exposing subjects to a target brand prior to a purchase decision made that brand more likely to be retrieved and considered in the later purchase (Nedungadi 1990). Ackerman et al. (2010) reported their findings on how haptic cues, such as weight, texture, and hardness influenced social judgment and decision-making. For example, evaluating a resume on a heavy clipboard increased the importance of a job candidate; handling rough-feeling puzzles raised the difficulty of a subsequent social coordination; and sitting in a hard chair while negotiating increased rigidity in negotiations. Bargh et al. (2001) instructed subjects to work on two seemingly unrelated tasks: a scrambled sentence task, in which subjects constructed four-word sentences from a group of five words, and a fishing game, in which subjects decided how much of the catch to keep for personal benefit versus how much to return to the lake for replenishing the resource. For some subjects, the first task included words related to cooperation (such as "cooperative" or "share"), and for others it included neutral words (such as "umbrella" or "city"). Subjects exposed to cooperation words chose to return more fish to the lake, indicating that the cooperation priming was successful in producing cooperative behavior. Friedman et al. (2003) investigated the effects of attentional priming on creativity. Subjects first completed visual tasks that forced them to focus their attention on a relatively broad or narrow area on a map. In the second stage, the subjects worked on generating unusual uses for an object, e.g., a brick. They found that the broader area focus bolstered creative generation by expanding attention within the semantic network. Rietzschel et al. (2007) activated domain knowledge by priming and found that such primes helped generate ideas with higher quantity and originality in the semantic category of the primes. For example, subjects generate more original and higher-quality ideas about maintaining health via nutrition when the concept of nutrition is primed. Sassenberg and Moskowitz (2005) studied the effects of a creative versus a thoughtful mindset in overcoming automatic associations. They instructed subjects to describe situations in which they had behaved in one of two ways: (a) creatively or (b) thoughtfully (the control condition was no priming mindset). In an ostensibly unrelated second experiment, subjects worked through a lexical decision task to indicate if a given string is a word or a non-word. Subjects responded faster to words that were preceded by a semantically-related word when a no-mindset or a thoughtfulness mindset was activated, whereas those primed with a creativity mindset were not affected by semantic associations. This shows that just working through a simple mental task can help a person to overcome routine associations and think differently, even when the task is seemingly unrelated.

Recently, implicit priming has been introduced into design research experiments. Lewis et al. (2011) tested whether positive affect led to higher creative performance with real-world creativity support tools, such as a simple sketching application (Adobe Ideas) on a tablet (iPad). They manipulated affective primes by instructing subjects to pick one image from the photo library and use that image as a background to practice a drawing. Subjects in the positive, negative, and neutral conditions browsed a library with only positive-inducing, negative-inducing or neutral images, respectively, while those in the control condition were not exposed to any images. The images that subjects were told to select included a laughing baby for positive priming, dead bodies after the 2010 earthquake in Haiti for negative priming, and a hammer for neutral priming. After priming, all subjects worked on a circle task—draw as many sketches as possible using the circles provided in 5 minutes. They found both the positive and neutral primes led people to generate sketches rated as more original, with more elaborations than the negative prime and no prime, and that there was a trend that the positive prime had a stronger effect than the neutral one in terms of the distribution of originality scores.

Design researchers have used explicit, intentional, priming for many years, such as role-playing (e.g., Eden et al. 2002), question technique (e.g., Osborn 1956), and improvisation (e.g., Gerber 2008). Observing customers is recommended as a good precursor/stimuli to ideation (Leonard and Rayport 1997). Such priming is *explicit*, that is designers intentionally perform these pre-design activities to enhance their skills. Below we present summaries of two design methods that employ priming to extend the skills of designers: the first with *implicit* priming, and the second with *explicit* priming. These studies have previously been reported in (She and MacDonald 2014) and (Johnson et al. 2014), and are summarized here for a more general audience, with additional findings in Study 2.

4 Study 1: Priming Designers to Communicate Sustainability Through Product Features

Engineers cannot rely on marketing, advertising, and instruction manuals to communicate the functionality and benefits of the products they create—the products themselves must be designed to be effective communicators. As discussed in *The Design of Everyday Things* and *Emotional Design* by Donald Norman (1998, 2004, 2013), the question of why many engineered products are difficult and frustrating to use, yet necessary and unavoidable (such as a copier), while others are much loved and enjoyable to use (such as a teapot) resonates both with engineers and the popular press. A critical distinction is the communication effort engineered into a product's design: the more thoughtful the communication of information by or through the product, the easier and more enjoyable the product is to use. Unfortunately, in many cases, it may be easier for an engineer to build a machine than to make it communicate effectively to the user.

Sustainable products face a special challenge in the market because many of their best features, such as material selection or manufacturing efforts to lower their environmental impact, are hidden from the customer. Typical marketing strategies, such as sustainability logos, a statement combined with imagery, and third party certification, are not successful due to lack of credibility or that “people are busy, and may not be paying attention” (Brannan et al. 2012). Designers need to communicate sustainability to the customer through product features that the customer intuitively identifies as sustainable.

In this study, we focused on the use of primes to help designers generate design features that communicate sustainability to customers. We employed two *implicit* priming approaches—a low-immersion prime and a high-immersion prime—to activate a mindset of sustainability and perceptions. Most often, people form judgments depending on their perceptions, which are acquired primarily through the five senses: sight, sound, touch, smell, and taste. Therefore, we chose the five senses and sustainability as the combined constructs to use in priming. Both primes involved a focal product—a kitchen sponge. A sponge was selected during the pilot study because it is commonly used in daily life and engages all five senses during use. Additionally, some sponges have visible features that speak to their sustainability, like natural fibers and dye-free production. Both low-immersion and high-immersion priming activities were hypothesized to enhance designer performance in a later conceptual design task in terms of the number of concepts generated by the designer and the extent to which the concepts’ features are beneficial in communicating a product’s sustainability.

The low-immersion prime was a questionnaire in which subjects were asked to write answers to describe: (1) three examples of things that they have done to reduce their environmental impact and (2) the sponge or cloth they use at home to clean dishes using some or all of the five senses (sight, sound, touch, taste, and smell). A pretest revealed that some cultures use a rag instead of a sponge to clean dishes, thus the question was worded to be inclusive of both cleaning implements. It was expected that, by actively thinking about the answers, associated mental content about sustainability and customer perceptions could be more vividly aroused and become highly accessible in a later ideation process.

The high-immersion prime was a collage activity based partially on the work of Guyton (2006), which developed sustainable product semantics and established a set of design recommendations for sustainable designers with collage activities. Subjects were asked to arrange images of sponges and sensory words on a white background with two axes: one tracked preference, from “dislike” to “like”, and the other tracked environmental impact, from “high impact” to “low impact”. Eight images of dish sponges were physically arranged on the two-axis background and matched with 28 sensory descriptors, such as dim, smooth, soft, musty, disgusting, and so forth, as shown in Fig. 1. The collage activity was deemed a high-immersion prime because the subjects physically interacted with a variety of sponge images and sensory words while repeatedly making judgments about perceptions and preferences. When subjects are working on a collage activity, not only specific cognitive orientations but also relevant cognitive procedures become activated. Effects on subsequent design tasks may then be driven by both the orientations and procedures.

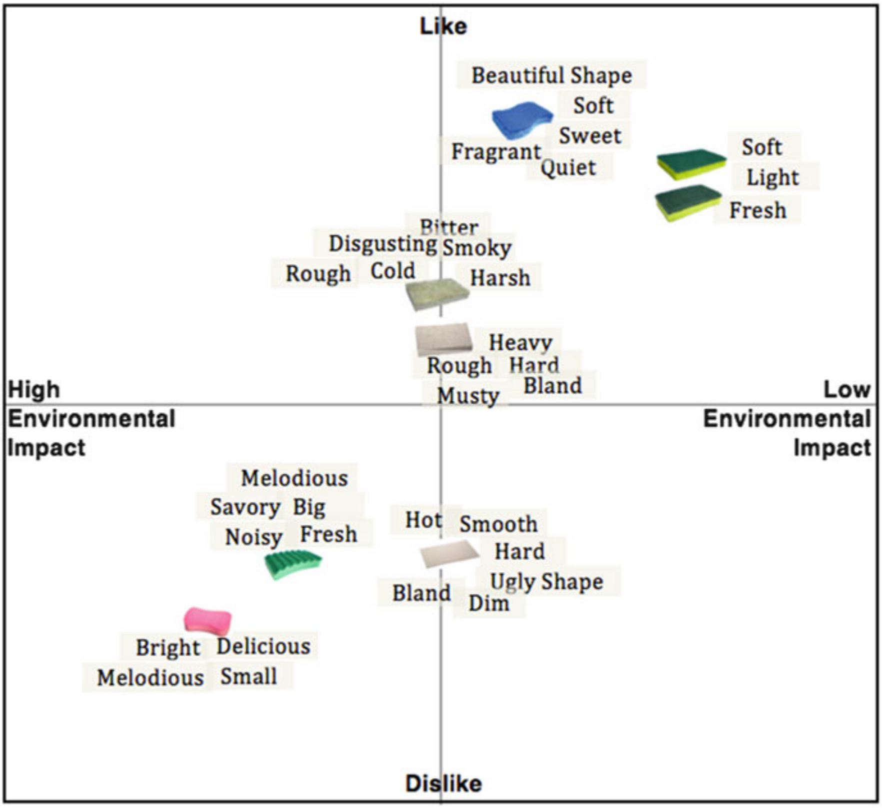


Fig. 1 Demonstration of a collage output (She and MacDonald 2014)

4.1 Method

Subjects Subjects were 30 engineering students (25 male, 5 female; 9 graduate students, 21 undergraduate students), all of whom possessed engineering design background and previously completed at least one engineering design class. They volunteered to participate and received $15 cash if they participated in the summer semester and $10 cash or extra class credit if they participated in the fall semester. The subjects were assigned to the three conditions randomly and evenly.

Experiment Design and Procedure A between-subjects design with three prime conditions was used: a collage prime, a questionnaire prime, and no prime (serving as a control condition). Each subject was scheduled for an individual session of approximately 50 minutes. The purpose of testing the priming effect was not revealed due to the implicit nature of the priming. Subjects were randomly assigned to one of the three conditions to answer questions in written words, make collages physically for 10 minutes, or do nothing. To avoid design fixation and to make the

Table 1 Quantity counting rules summary (Linsey et al. 2005)

1	The same feature (or component) being used in multiple places counts as one feature
2	Each feature counts as only a single feature even if it solves more than one function
3	New combinations of already-counted features are counted in a separate measure
4	Categories of features only count as features when no subordinates are given
5	Features count even if they are not needed or cause the product to not function
6	Features must be shown and not just implied

priming task and design task seem unrelated, we selected a toaster as a focal product for ideation, rather than a sponge, which was used in the priming task. In Design Phase 1, subjects were instructed to create new design features for a next generation toaster in 15 minutes. This task was added to gather data outside the scope of this paper. In Design Phase 2, subjects were directly instructed to generate features that could trigger customers to think about sustainability during an ideation period of 12 minutes. In both of the design phases, subjects were provided both verbal and written instructions. They were encouraged to sketch and/or write as many features as possible, number each different feature, and think aloud. Their sketches, writing, and verbal comments were captured with a digital recording pen. Refer to She and MacDonald (2014) for more detailed materials and results of this study.

Data Processing Audio data from the recording pen was transcribed to supplement the sketches and writing. Explanations were added to the features that only include sketches or vague descriptions. The explanations were based on their audio record and post-experiment interview. According to the quantity counting rules (Table 1) developed by Linsey et al. (2005), the experimenter checked the number of features. The written features and scanned sketches were entered into a web survey for later rating.

Dependent Variables For the purpose of analysis, our dependent variables were the number of features generated per subject (Measure A, which was processed according to the rules listed in Table 1) and the sustainability trigger rating of each feature (Measure B). To assess the sustainability trigger, two independent raters were asked to separately rate each feature on a Likert scale ("The feature can trigger customers to think about sustainability") anchored at 1 (strongly disagree) and 5 (strongly agree). The inter-rater reliability (Cronbach's alpha) was 0.84 on the initial evaluations and reached 0.9 after discussion of major disagreements. Figure 2 shows a detailed example of features rated at each level.

4.2 Results

In total, 149 features were generated by the 30 subjects in Design Phase 2, with 66 from the collage prime, 50 from the questionnaire, and 33 from those who were not primed. As outlined earlier, subjects in both priming conditions were expected

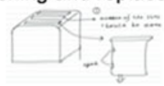
Rating	Example feature
Strongly Disagree (1)	Include a knife holder in the toaster 
Disagree (2)	Keep it small sized to fit in compact spaces Small sized → fit in compact spaces (i.e. smaller kitchen)
Neutral (3)	Make each heating area as a small container, which can be taken out easily for washing and replacement 
Agree (4)	More efficient use of power. Use a reflective cavity - increase reflection of radiant heat with special materials and cavity shape 
Strongly Agree (5)	Include a digital readout of energy use on the toaster MAKE CONSUMER AWARE → have digital readout → requires special components

Fig. 2 Example features at each rating level on sustainability trigger, from strongly disagree (1) to strongly agree (5) that the feature can trigger customers to think about sustainability

to generate more features and more effectively solve the targeted design problem. To compare the performance of subjects who were primed or not, an analysis of variance (ANOVA) approach was selected. ANOVAs were conducted with the total number of features generated by each subject as the response and the priming condition as the independent variable (collage vs. control and questionnaire vs. control). To analyze the priming effect on targeted design problem solving, we used a linear mixed regression model (LMM), with subject as a random factor, and priming condition and rater as fixed factors. Instead of obtaining average sustainability trigger ratings for each subject, LMM treats individual ratings as observations (149 design features * 2 raters = 298 observations). The benefit of LMM is that the variances of the raters and features generated by one subject are modeled as well, rather than hiding them in the average, like ANOVA does.

Measure A ANOVA conducted on the collage prime and no prime revealed that subjects generated more features overall in the collage condition ($M = 6.6$, $SD = 3.2$) than in the control condition ($M = 3.3$, $SD = 1.06$), $F(1,18) = 9.56$, $p < 0.05$. No significant difference was present when comparing the questionnaire prime ($M = 5.0$, $SD = 2.45$) and no prime ($M = 3.3$, $SD = 1.06$), $F(1, 18) = 4.06$, $p > 0.05$. This suggests that the collage prime improves design performance in terms

Fig. 3 An example prototype with two sustainability trigger features: flip-cover that keeps in heat, and two activation levers that enable users to heat each slot independently or as a combination

of quantity, while the effect of the questionnaire prime is unclear, see the discussion for further detail.

Measure B Individual sustainability ratings were analyzed by a linear mixed regression model. Given the large number of observations (298) in our analysis, the t-distribution converged to the standard normal distribution, and a regression coefficient was significant at 0.05 level if its magnitude was at least two standard errors, i.e., absolute t-value exceeds two (Baayen et al. 2008). The estimation from this model showed that the main effect of the questionnaire prime was significant ($t = 2.16$), as well as that of the collage prime ($t = 3.22$). Results indicated that both primes helped subjects solve the target design problem in terms of generating features with higher sustainability trigger ratings.

In a follow-up study (She 2013), a selection of features with high sustainability trigger ratings was designed into realistic toaster prototypes (see Fig. 3 for an example). Subjects participated in a test vs. control purchase experiment, in which some "customers" saw toasters with triggering features during purchasing tasks and some did not. In one task, subjects were asked to rank their desire to know more about attributes that cannot be obtained directly from visual inspection of the prototypes, such as customer rating, energy usage, and shipping method. The results showed that the presence of triggering features increased the ranking of sustainable attributes ($p < 0.05$). Subjects' areas of focus while reviewing stimuli were also captured with an eye-tracking technique. The analysis of gaze data demonstrated that subjects in the test condition paid more attention to sustainable attributes, in terms of percentage fixation time ($p < 0.1$) and percentage fixation count ($p < 0.05$). These findings demonstrate that triggering features cause customers to think about sustainability at the purchasing point and lead them to evaluate related attributes.

4.3 Discussion

Study 1 tested the hypothesis that priming could help designers generate more concepts in general and solve the target problem more effectively. Designers were primed implicitly with the mindset of sensory perceptions and sustainability by answering two simple questions or finishing a collage activity. In line with the prediction, the collage prime helped designers generate more concepts in general. However, the questionnaire prime did not show significant effect on the quantity of concepts generated in total. In addition, both primes helped designers solve the target problem, i.e., generate concepts with higher sustainability trigger ratings. A follow-up study as presented in (She 2013) further corroborates the communication effect of the high-rating features. Together, these findings provide initial support for our priming hypothesis, suggesting that implicit priming induced by tailored content may activate a related mindset to the design problem, thereby improving design performance.

In She and MacDonald (2014), ratings and results based on novice judges are reported along with the expert judges. The novice results are similar and thus not repeated here. However, this study did find that both the questionnaire and collage were effective at improving designers' performance in communicating sustainability, but the collage was more so.

The present research complements and extends the existing literature using primes to enhance designer performance with regard to quantity. Quantity is one dimension that interests design researchers because quantity is often assumed to lead to quality (Osborn 1956; Yang 2009). Lin and Seepersad (2007) demonstrated that using extraordinary sensory primes to explicitly heighten sensory feelings associated with a loss of sight and dexterity can help designers yield a higher breadth of customer needs. However, Lewis et al. (2011) did not find significant effect of positive affective priming on quantity, although it is helpful in promoting novelty. The present study, a sensory and sustainability mindset priming, suggests that for a more targeted design problem, some primes (e.g., the collage prime in this study) can significantly increase the quantity of concepts generated, regardless of quality, while others may not (e.g., the questionnaire prime in this study). It is possible that different primes have different priming strength because rich primes can lead to more "spreading activations" (Bargh and Chartrand 2000). Compared with the questionnaire prime, subjects in the collage condition were not only primed with the mindset of senses and sustainability, but also interacted with images of sponges and sensory words visually, arranged the images and words to form collages kinetically, made more judgments, and spent more time (about 4 minutes more on average). It is possible that subjects in the collage condition were more deeply engaged than those in the questionnaire prime. The level of immersion might also contribute to the prime effect on the quantity measure.

Our study also extends the priming effect to help designers tap their hidden skills, such as communicating with customers through design. Most often, the communication skills of design engineers are not on a par with other obviously needed skills such as creativity or functionality. Lewis et al. (2011) improved novelty by priming positive affect on designers, which is attributed with finding that positive feelings enhanced motivations and broadened associations related to the design problem. We showed that priming designers with the mindset of sensory perceptions and sustainability, in the form of a collage activity or a questionnaire, increased the designers' ability to communicate sustainability with the customer via design, in terms of higher mean sustainability trigger ratings of the features generated. One possible reason is that both primes activated the notion of sustainability, and related associations (e.g., experience, knowledge) became more accessible during ideation. Compared to the questionnaire prime, the collage activity primed the two concepts in a more interactive way, as designers judged both the sustainability and sensory perceptions of each sponge image. Designers might benefit from this procedure when mapping the thinking that occurred during collage arrangement to the later design task. So far, the content of primes in most priming studies has mainly focused on one construct, like creativity (Sassenberg and Moskowitz 2005), alternation (Galinsky and Moskowitz 2000), and cooperation (Bargh et al. 2001). It would be interesting to examine what forms of priming work better when at least two constructs are necessary for the objective of priming; for instance, both sustainability and sensory perceptions are needed for the design problem of communicating sustainability.

5 Study 2: Priming to Help Designers Generate More Unique, User-Centered Concepts

Engineers are tasked with designing products that not only meet specifications for safety, reliability, cost, manufacturability, and many other criteria but also respond to the needs and preferences of their customers. In fact, many of the most successful products not only respond to the needs of customers but anticipate those needs, even when those needs are *latent* or difficult for customers to articulate. Many of the products we enjoy every day, from internet-enabled smartphones to social media websites, were created in anticipation of latent needs, which are associated with high levels of customer satisfaction and delight but are very difficult for customers to articulate *a priori*.

Given the inextricable link between customer needs and product success, engineers employ a wide variety of methods to capture and understand the needs of their customers. Many of the most common techniques, such as customer interviews and focus groups, are most effective for capturing direct needs, such as small changes in size or appearance. Leonard and Rayport (1997) suggest that these traditional methods for gathering customer needs rarely result in novel product concepts. Instead, they suggest empathic design methods in which designers directly observe customers using the product, so that designers can better understand the environment in which the product is used, the circumstances that trigger its use, and any unarticulated needs or problems with the product. Indeed, observing and engaging customers is an important part of most user-centered design and design thinking philosophies (Cagan and Vogel 2002, 2013; Kelley 2001; Preiser and Ostroff 2001; Story et al. 1998). Von Hippel (1986, 2005) takes the concept of observation a step further by arguing that designers should interview lead users who typically have extensive experience with a product, encounter customer needs earlier than the general population, and possess a vested interest in obtaining a solution to those needs. These lead users are better positioned than typical users to provide a richer understanding of customer needs and more likely to offer suggestions for innovative product concepts (Urban and Hippel 1988). As documented by Hannukainen and Holtta-Otto (2006), lead users can also involve disabled persons, including not only those with genuine physical disabilities (impaired sight, hearing, mobility), but also those with situational disabilities, defined as ordinary users operating in extraordinary environments (e.g., a person using a cell phone in a noisy public place). Lead users can also involve extended user groups, such as users older than age 65, when identifying needs for product design for a general population (Raviselvam et al. 2014).

The difficulty with all of these empathy tools is that designers are limited by their powers of observation and sometimes find it difficult to deeply internalize all of their customers' needs. To address this challenge, some recent design tools and techniques advocate immersion of designers in their target usage contexts. Examples include acting out scenarios in body storming (Kelly 2001), wearing age suits that help the designer experience the physical limitations of aging (Ford Motor Company 2007; Singer 2011), or using disability goggles to experience a particular visual impairment (Thomas and McDonagh 2013). In this study, we focus on the use of these types of immersion activities as primes to help designers generate more unique, user-centered concepts.

We asked designers to generate concepts for a next-generation alarm. Prior to the conceptual design task, designers were exposed to one of two types of primes: a minimally immersive prime and a highly immersive prime. The objective was to understand how the highly immersive primes impacted the designers' performance in the concept generation task, in terms of the novelty of the concepts generated and the extent to which the novel features enhanced the product's interactions with the user.

The low-immersion prime provided a control condition for the experiments. Participants were instructed to interact with representative alarm clocks for a short period of time. The alarm clocks were standard, off-the-shelf models, representing both digital and analog displays. Participants were instructed to progress through all the steps of setting up and using the clock, including setting the current time and the alarm time and turning off the alarm.

The high-immersion prime was an empathic lead user activity, similar to those investigated by Lin and Seepersad (2007) and Hannukainen and Holtta-Otto (2006). Participants were instructed to interact with the off-the-shelf alarm clocks while experiencing situational disabilities. Each participant used the alarm clock while wearing a blindfold, earmuffs, and oven mitts, and each participant watched other participants engaging in the same activities. The blindfold and ear muffs were intended to limit the participants' ability to see or hear the clock, similar to the challenges faced by a person with impaired vision or hearing or by an ordinary person in a deep sleep who finds it difficult to respond to the physical alarm. The oven mitts were intended to limit the participants' dexterity, similar to the challenges faced by someone with a condition like arthritis or by an ordinary person suffering from sleep-induced grogginess or unusually large fingers. All of these conditions were intended to challenge the participants' sensory and physical interactions with the clocks and to accentuate any associated challenges. The intent was to activate the participants' cognitive orientations towards the way the user interacts with the device.

Approximately half of the participants engaged only in the low-immersion prime, while the other half engaged only in the high-immersion prime. With this strategy, all participants generated concepts for the same design problem and interacted with the same prototypes. The only difference was the situational disabilities experienced by the high-immersion group. More details on the experimental design are available in Johnson et al. (2014), and the study is summarized here.

5.1 Method

Participants The participants were 111 undergraduate mechanical engineering students at The University of Texas at Austin. All of the participants were senior-level students nearing the completion of a mechanical design methodology course. They volunteered to participate in exchange for extra credit in the course. All students were also offered an alternative extra credit opportunity to avoid unintended coercion. The participants were randomly assigned to the two conditions.

Experiment Design and Procedure A between-subjects design was conducted with 54 participants randomly assigned to the high-immersion prime, which served as the experimental condition, and 57 participants to the low-immersion prime, which served as the control condition. Participants were grouped into teams of four to seven students per team. Each team of participants interacted with the representative alarm clocks for 15 minutes. Then, each participant was instructed to individually sketch at least three concepts for a next generation alarm. After an initial sketching period of 15 minutes, each participant rotated their sketches to another person in their team to expand and comment on the ideas. Every 5 minutes, the sketches were rotated to another unique participant until they returned to their original owners. Uniquely colored pens identified the originator of the sketches and comments. This technique is a hybrid of 6-3-5 and C-Sketch, as described by Otto and Wood (2000). It was implemented because the exchange of written sketches has been shown to be a very effective ideation technique for engineering design problems.

Dependent Variables The dependent variables were the level of originality and the level of feasibility of the resulting concepts. The two variables were chosen to investigate whether the high-immersion primes lead to more creative concept generation and whether there is an accompanying change in the likely realizability of the concepts. All creative features were also classified into one or more categories of innovation to investigate whether the high-immersion primes lead to improvements in product-user interactions at a greater rate than other categories of innovation, such as additional functionality.

All metrics were evaluated at the feature-level because we have found feature-level analysis to be more repeatable (Srivathsavai et al. 2010). Alarm clock features were classified in the following categories: mode of alarm, display type, information shown, user input, energy source, snooze, music player, shape/layout, and any additional uses (cf. Johnson et al. (2014) for detailed descriptions of each feature category).

Originality was assessed at the feature level based on a five-point scale, with ratings of 0, 2.5, 5, 7.5, and 10 representing common, somewhat interesting, interesting, very interesting, and exceptional designs, respectively. The scale is derived from an eleven-point scale used by Charyton et al. (2008), and it is similar to a novelty metric proposed by Shah et al. (2003) Prior to evaluating the concepts, a list of standard implementations of each feature was compiled by reviewing commonly available alarm clocks available at popular retail and online stores. For each feature of each concept, originality was evaluated relative to those standard lists; any feature that appeared in commonly available products automatically received a zero originality score. After all features were evaluated for a concept, the concept-level originality score was recorded as the maximum feature-level originality score for that concept.

Technical feasibility was assessed at the feature level according to the four-point scale illustrated in Fig. 4 and based on a metric developed by Shah et al. (2003) and modified by Linsey (2007). To receive a technical feasibility score of ten, the feature must be similar to a solution available in the marketplace, even if that solution is embodied in a different type of product. For example, an alarm that requires a user to stand on a scale to deactivate it may not exist in the world of alarm clocks, but similar functionality exists in various products ranging from digital scales to automatic doors, such that the technology could be repurposed straightforwardly.

Finally, if a feature earned a non-zero originality metric, it was also evaluated with respect to the five categories of mechanical innovation defined by Saunders et al. (2011):

- functionality (whether the feature enabled the concept to offer a significant new function relevant to the goal of waking the user)
- cost (whether the feature significantly lowered the operating or purchase cost of the product)
- architecture (whether the feature leads to a significantly improved architectural layout including a more attractive size or layout)
- external interactions (whether the feature leads to more convenient or more efficient use of material, energy, or information and whether it interacts with existing infrastructure in a beneficial way)

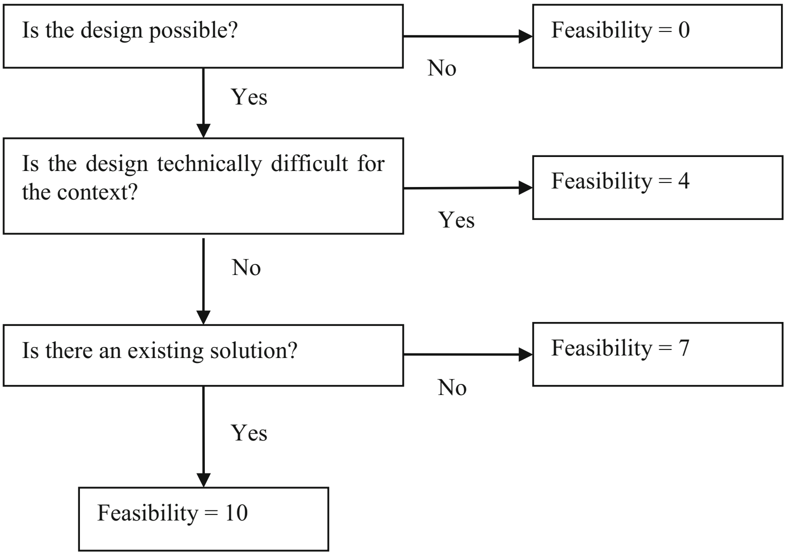


Fig. 4 Flow chart for feasibility metric (Johnson et al. 2014)

- user interactions (whether the feature makes the concept easier to use physically, cognitively, or from a sensory perspective)

Whereas the originality metric measures the uniqueness of a feature relative to existing solutions, the innovation categories differentiate between different types of unique features.

Data Analysis Two researchers independently evaluated all of the concepts and then discussed any discrepancies and agreed upon a merged set of originality and feasibility scores and innovation characteristics for each concept. Interrater reliability was assessed with a weighted version of Cohen's Kappa (1968) for the interval judgments in the originality metric, Cohen's Kappa (unweighted) (Cohen 1960) for the binary judgments in the innovation characteristics, and percent agreement for the feasibility metric. Based on a subset of 47 concepts, substantial agreement was achieved between the raters, with a weighted Kappa value of 0.9 for originality, a Kappa value of 0.8 for the innovation characteristics, and 85% agreement for feasibility.

5.2 *Results*

The participants generated a total of 173 concepts for the low-immersion prime and 172 concepts for the high-immersion prime. The high-immersion participants generated concepts that were more original (M = 3.63, Std Error = 0.22) than the low-immersion participants (M = 2.72, Std Error = 0.21). A Mann-Whitney test indicated a statistically significant difference between the two groups ($p < 0.01$). There was no statistically significant difference in the feasibility of the concepts from the two groups (M = 9.79, Std Error = 0.08 for the low-immersion group; M = 9.91, Std Error = 0.04 for the high-immersion group; p-value = 0.39 for the Mann-Whitney U test). The concepts generated by the high-immersion participants exhibited several categories of innovation at a higher rate than those generated by the low-immersion participants. Innovative architectural, external interaction and user interaction features were exhibited at higher rates by the high-immersion participants, but only the increase in user interaction features was statistically significant. A total of 55% of the concepts generated by the low-immersion participants exhibited innovative features that made the concept easier to use, versus 76% of concepts from the high-immersion participants ($p < 0.05$ from a Mann-Whitney U test).

5.3 Discussion

The results indicate that the high-immersion prime helped designers generate concepts that were more original than those of the low-immersion participants, without sacrificing technical feasibility. On average, the concepts from the high-immersion primes solve the original design problem with solutions that are more unique than those from the low-immersion primes, but almost all of the concepts are still realizable (with a mean feasibility score of 9.79 on a scale of 1 to 10) with currently existing technology. The prevalence of user-interaction related characteristics among the high-immersion concepts can be traced back to many of the unique features in those concepts. Many of the high-immersion concepts offered unique means of waking the user, in contrast to the typical auditory signal and response. For example, solutions included eye masks that vibrate or expose the eyes to bright light, gently vibrating bed frames or mattresses, or alarms that fire soft projectiles at the user. Other solutions focused on the ineffectiveness of the auditory alarm and accompanying snooze for waking the user. Examples include sensor mats at the foot of the bed that turn off the alarm when the user stands, electronic toothbrushes with built-in sensors that turn off the alarm when the user brushes his/her teeth, or puzzles or brainteasers that must be completed to activate a snooze.

The evidence indicates that the high-immersion primes are serving as a de-fixation tool for redesign problems like this one. Ongoing research indicates that designers are particularly prone to fixate on products or solutions to which they have been exposed in the past (Jansson and Smith 1991; Purcell and Gero 1996; Purcell et al. 1993; Nijstad et al. 2002; Perttula and Sipila 2007; Kohn and Smith 2011; Chrysikou and Weisberg 2005). All participants in these studies had a very high level of familiarity with alarms, and they had interacted with representative alarm clocks prior to ideation, making participants particularly susceptible to design fixation for this problem. In order to earn non-zero originality scores for their concepts, they needed to generate features that were not embodied in commonly available alarm clocks, which occurred at a much higher rate for the high-immersion prime. Although the results are not reported here, similar experiments have been repeated on different products, including a hand-held litter grabber (cf Johnson et al. (2014) for more information). These experiments indicate that the high-immersion prime does not lead to a much higher level of originality for the litter grabber problem, possibly because the product is much less familiar, the design space is much less crowded, and there are more opportunities for unique solutions that are unavailable in the marketplace. Hence, there is less need for the high-immersion prime to defixate the participants.

6 General Discussion

The present research provides a further step in investigating the potential of using implicit and explicit priming to improve designers' performance in two separate studies. Study 1 targets improving communication through the design itself, which is less emphasized in engineering design education but increasingly more important in getting to a successful product. The results are promising. Both a low-immersion prime and a high-immersion prime help designers generate more concepts, and the high-immersion prime leads to better communication of sustainability considerations through the design itself. Study 2 fosters user-centered originality in design with an explicit priming technique of empathic lead users. This study directly compares the effect of a high-immersion prime and a low-immersion prime, and finds that subjects in the high-immersion priming condition generate concepts with higher levels of originality and more innovative features targeting product-user interactions, without any loss in feasibility.

There are several limitations to Study 1, and these limitations suggest avenues for future research. While the purpose of this study is to investigate whether primes could be used to help designers tap their hidden skills, such as communicating with customers through design, and the results are indeed supportive, further research is needed to discover the mechanism behind this effect and recommend principles for designing better primes. Wheeler and DeMarree (2009), for example, reviewed prime-to-behavior mechanisms, covering multiple mechanisms such as direct activation of behavioral representations, goal activation, biases in person perception, biases in situation perception, and biases in self-perception. In addition, some potential factors may limit the extent to which the present research generalizes. First, the subject sample was small and all of them were engineering students. It should be noted that the priming effect on designers' performance might be mediated by designers' expertise. Second, the toaster is a familiar product to most designers, and thus it is unclear how the prime works on the design of more unfamiliar products. To corroborate our conclusion, a broader variety of designers and products should be tested.

Similar to Study 1, Study 2 also used engineering students as subjects and the results may thus not be generalized to more experienced engineers, for example. Further, the study focused on a limited set of situational disabilities suggesting that an investigation of other possible situations is needed, as well as a deeper understanding of what types of situational disabilities, immersion techniques or primes are most effective and under what conditions or for what types of problems. In addition, originality might be weakened due to fixation in both high- and low-immersion prime conditions, and it is possible that subjects who do not interact with any example products might have higher originality scores than the low-immersion primed subjects. Without a baseline condition, the effect of the empathic lead user prime (high-immersion) on originality cannot be determined definitively.

Priming has been used across a variety of domains in an attempt to change people's thinking or behavior. In judging the effectiveness of a prime, the predominant belief is that a prime works better if subjects are not aware of the influence of the priming task on the target task. Most psychology experiments have revealed strong implicit priming effects by using unrelated studies set up without subjects being aware of the association between the two tasks. In the design community, a number of ideation techniques are also based on the priming principles, but they are conducted more explicitly, such as stimuli (Higgins 2005; Rickards 1974), role-playing (Eden et al. 2002), question technique (Osborn 1956), empathic lead user technique (Lin and Seepersad 2007), and WordTree design-by-analogy method (Linsey et al. 2008). These two studies add to this body of literature with evidence that both implicit and explicit priming have benefits in design. The findings encourage the usage of priming technique to address more challenges in the design process, such as aligning the perceptions of a product from designers' and users' perspectives and improving collaborations in inter-disciplinary teams. However, we do not know when to use implicit priming and when to use explicit priming. Future research can explore if implicit and explicit priming direct attention and information processing similarly, or if they have unique benefits in directing attention, influencing saliency, and improving ideation.

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From Place to Space: How to Conceptualize Places for Design Thinking

Martin Schwemmle, Claudia Nicolai, Marie Klooker, and Ulrich Weinberg

Abstract More companies have begun to leverage the unused potential of place. By re-designing the work place or introducing new spaces that are dedicated to innovation projects, they are attempting to increase employee motivation, team performance, innovation management, and the overall innovativeness of the whole organization. However, companies often struggle with the proper conceptualization of the place. As a result, they copy spatial setups from other organizations. However, such copied places are often not linked to the corporate culture, do not match their users' needs, and neglect the existing spatial structures; consequently, their effects remain below their actual potential. One reason for this problem may stem from a lack of knowledge regarding how to conceptualize places for innovation processes in general or Design Thinking in particular. This lack of knowledge also holds true for research because research on the place and its effects in both the organizational and managerial contexts is rather scarce. In this chapter, we address the question of how to conceptualize places for Design Thinking. We first provide relevant theoretical foundations and then explain the conceptualization of a Design Thinking place by using the example of HPI D-School Potsdam. This theoretically founded and practically experienced approach will provide the reader with basic knowledge of how to conceptualize places for Design Thinking and addresses both researchers and practitioners.

1 Introduction

Whereas bean bags, couches, table football, chill-out areas with amazing coffee makers and movable furniture have long become the icons and symbols of a hipster start-up culture, particularly in young technology companies, big corporations

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in traditional industries today also realize the potential and power of place[1]. Consequently, companies create innovation centers, innovation labs, collaboration areas or even design thinking floors to provide spatial settings for creative and innovative tasks (CB Insights 2016) and therefore experiment with, test, and foster an innovative working culture. Some companies even take 'place' to a strategic level and redesign entire office buildings to support collaboration and increase company performance (The Commission for Architecture & the Built Environment 2005; Bacevice et al. 2016).

At the HPI D-School Potsdam, the role of place in the context of the Design Thinking approach is highly important. The importance of place is reflected in the three fundamental aspects of Design Thinking, which we refer to as the three Ps: process, people, and place. The Design Thinking *Process* is an iterative innovation process that builds up its momentum around collaborative creativity while being grounded in a processual designerly work-mode with different stages. The *People* are represented by cross-functional, multidisciplinary teams that are built by matching a group of people with different expertise and backgrounds and relying on shared and transformational leadership. The *Place* refers to a variable space that invites and allows for creative team work and can be easily adapted to different work-modes.

Places for Design Thinking are important for three reasons. First, research has demonstrated that space has a positive influence on team performance and creativity (e.g., Amabile et al. 1996; Ceylan et al. 2008). Because both are important success factors of innovation management, the place must be considered to have a strong influence on innovation outcomes, including productivity in new product development. This influence has also been shown the other way around: Place was found to be one of the factors that explained why implementing Design Thinking as an approach to initiate and foster change in the organizational culture failed (Schmiedgen et al. 2015). One reason for such a failure is that the spatial design was not able to appropriately express the intended organizational culture change (Elsbach and Bechky 2007). Another concept underlying the Design Thinking approach is to evoke and foster creative mindsets that are open to receiving inspiration from both outside and inside the innovation team, the organization, and the predefined problem and solution space. When used as an intervention, the application of the Design Thinking process model forces people to let go of their well-established problem solving techniques and project management patterns and thereby gain new perspectives. A 'new' place that is different from the everyday (individual) workplace is such an intervention and is thus a good representation of the new perspectives to gain and the new insights and ideas to discover. Entering a design thinking place tells the user to leave ritualized work-modes behind (e.g., "leave your ego out of the door"). In contrast, when Design Thinking is an everyday work mode (that represents the experience of participants who are enrolled in Design Thinking programs at the HPI D-School), the variability and flexibility of

[1]We distinguish the terms 'place' and 'space' and provide definitions in Sect. 2.1.

the place allow new spatial experiences, although the room, floor, or building itself wears out its 'newness factor' over time and is therefore no longer surprising. Third, Design Thinking is not merely a collection of methods that includes instruments and tools to be applied in different process stages but is a mindset that seeks cultural changes in organizations (Kelley and Kelley 2013). Edgar Schein (1984) stated that organizational culture has three levels: basic assumptions, values, and artifacts. The basic underlying assumptions are not always readily apparent; they are represented by the artifacts that are the visible aspects of a culture. Transferred to Design Thinking, Schein's model implies that although basic assumptions (e.g., "everybody can be creative" and "build on the collaborative creativity of teams") are not visible, a Design Thinking place that fosters creativity and innovation can be regarded as an artifact that symbolizes the underlying innovation culture within an organization. Similar to an iceberg model, place represents the visible portion that sits above the water surface. However, this visible section can only be seen because of the (larger) part that sits below the water's surface (i.e., the underlying culture and mindset). Further, the visible portion is perceived as meaningful because of its embodiment in ritualized behavioral patterns and situated actions (Harquail and Wilcox King 2010; Beltagui et al. 2015). Thus, a change in the innovation culture only works if both parts of the iceberg—above and below the water surface—are considered. Simply adding a fancy place does not automatically change the underlying culture.

Owing to the importance of place for innovation, many companies aim to provide adequate places for their employees, particularly for knowledge workers. To do so, the companies often seek good examples so they can copy the places. However, living room-like loft offices with carpets, colored walls, and movable whiteboards are not the blueprint of an innovation place that will work for any company. Rather, and as examples have shown, solely copying concepts from other organizations without adapting them to the own organization may even backfire (Waber et al. 2014). The reason for the need of adaption is rather simple: Places serve organizations that have specific processes and purposes and users who have specific needs[2]. Because these processes, purposes, and user needs vary significantly between organizations, innovation places must reflect these differences. The urge of reflection also relates to the abovementioned model of corporate culture. Without understanding and considering the underlying basic assumptions and values (i.e., the organization culture), a place would be similar to the peak of an iceberg that does not have a foundation. To clarify, simply placing colorful sticky notes, sharpies and a Time Timer in a meeting room does not transform that room into a place for Design Thinking.

With the relevance of places for innovation in general and for Design Thinking in particular and with the existing pitfall of solely copying a place without linking it to the organization's culture, it is remarkable that—to the best of our knowledge—research has yet not tackled the conceptualization of innovation and, thus, Design

[2]Users' needs refer to more than simply 'having enough space' or 'colorful walls', as discussed in Sect. 3.2.

Thinking places. The existing literature either covers place (and space) rather generally without providing specific links to Design Thinking or covering its conceptualization and cultural issues (e.g., Dul et al. 2011) or it simply describes the best practices and gives shopping lists for Design Thinking places without reflecting these best practices and adapting them to the specific conditions.

Thus, the aim of this chapter is twofold: We first want to provide theoretical foundations of space and place and go beyond simply describing spatial structures by providing a reflection that links the space-as-it-is to the conceptual and underlying basics of Design Thinking, the Design Thinking process, the users, and the context within the organization. We also want to share our experiences of conceptualizing the Design Thinking place at the HPI School of Design Thinking in Potsdam and describe our Design Thinking place and how it is used. In sum, the theoretically based practical experiences provide the reader with a basic understanding of how to conceptualize Design Thinking places based on specific organizational contexts.

The structure of this chapter is as follows: First, in Sect. 2, we provide relevant definitions and clarify how place-making, users, spatial structures, and organizational context are related. We further introduce the requirements for the place linked to Design Thinking as mindset, work modes, and process. Second, by using the HPI D-School Potsdam as an example, Sect. 3 describes how these concepts are applied and presents the 'resulting' Design Thinking place. Additionally, we discuss how the experiences at the Design Thinking place at D-School as an educational place can be transferred to places in non-educational organizations. This chapter closes with a discussion in Sect. 4.

2 Conceptual Understandings of Places, Spaces, and Design Thinking

2.1 Place and Space: A Clarification

In practice, the terms 'place' and 'space' are often used interchangeably ('work places' and 'innovation spaces'). However, they must be carefully distinguished since they represent two highly interrelated but different concepts. In his seminal work "The Practice of Everyday Life", Michel de Certeau describes space as a "practiced place", or "In relation to place, space is like the word when it is spoken" (De Certeau 1984, p. 117). Thus, for him, places as non-spoken words are dead, whereas spaces have been turned into life (or "produced") by users interacting in and with the place. Additionally, the roles in this place making process are defined: Urban planning (urban planners) defines the street (the place), which walkers using this street transform into a space (De Certeau 1984). The space "comes to life as a social construct which shapes empirical reality and is simultaneously shaped by it" (Soja 1989, p. 25). In the context of Design Thinking, this differentiation between place and space means that—similar to urban planners—we can conceptualize

Design Thinking *places*, which are then transformed—during the Design Thinking process by multidisciplinary teams—into Design Thinking *spaces*. Against this background, both terms—Design Thinking places and spaces—may be used, depending on the focus of the conceptual (place) or used (space) part. Because this chapter focuses on the conceptualization of these places, we primarily use 'Design Thinking places'.

2.2 Space as a Relational Concept

Managers often create Design Thinking places for a specific purpose, e.g., enhancing the organizational creativity and innovation potential of individuals and organizations. Furthermore, places are used as tools to change an organization's culture and establish a Design Thinking mindset (e.g., an appreciation of the collaborative and creative power of teams versus individuals or the value of constructive feedback and failure as opportunities to learn and improve). Existing Design Thinking places such as those at the HPI School of Design Thinking in Potsdam or d.school at Stanford University have become models that promote a common understanding for a generalized Design Thinking culture. However, the exemplary places mentioned above are regularly reduced to physical aspects. Often, only fragments of their spatial concept are copied, detached from actual context- and process-related requirements and neglecting hidden structures of innovation places. Building on the previous paragraph, then, only the places are created, and they are not considered spaces-in-use. This reduction may result in the misuse and unfulfilled potential of the established Design Thinking place. To prevent valuable resources from being wasted, a thorough understanding of the concept of Design Thinking places and spaces is necessary.

Explaining our conceptual understanding of place and space will provide a basis to further define the concept of Design Thinking places. Often, a space is reduced to a place—being a physical container that is fixed and steady with boundaries in which people can move around. In line with sociologists such as Henri Lefebvre (1974) and Martina Löw (2000), we apply a relational view and regard space as something that is relational, dynamic, and socially constructed. Accordingly, and in alignment with the thoughts on place and space presented in the previous section, a place is transformed into a space by acts, interactions, and constellations and is therefore constantly evolving (Lefebvre 1974; Löw 2000). Spaces are defined by the interactions of users with inherent structures (of the place) based on their need for interaction and are embedded within the organization to create an organizational context. As shown in Fig. 1, the spatial structures (of the place) and users (with specific needs) reciprocally affect each other. Place making occurs within the organizational context and defines the space (e.g., workspace, innovation space). We next elaborate on these components in more detail.

The *organizational context* includes physical and non-physical factors that are outside or inside an organization. However, factors inside the organization lie

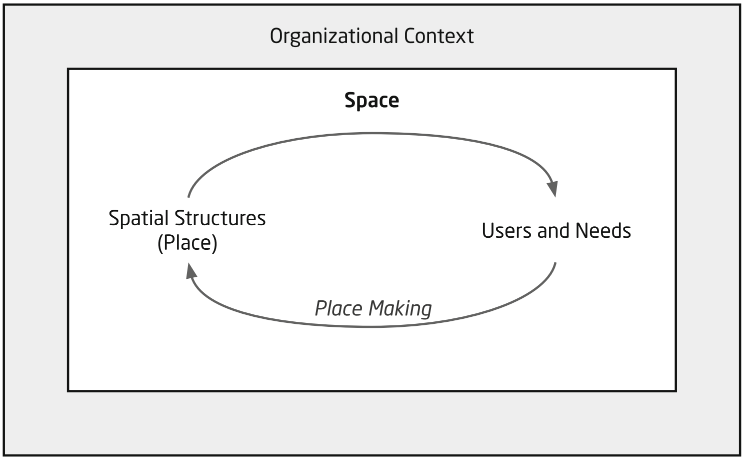

Fig. 1 Place making as relational constitution of interactions (based on Lefebvre 1974; Löw 2000)

outside the place; otherwise, they are spatial structures (see below). Physical contextual factors outside the organization include its geographic location (and, thus, the climate), the infrastructure, and its surroundings (e.g., other buildings in the neighborhood). Non-physical factors outside the organization include legal regulations (e.g., minimum room sizes), the culture in which the organization operates (e.g., cubicles and offices without windows are common in the U.S. but not in Europe), and the customers or other stakeholders. Non-physical factors inside the organization include the organizational culture (values and norms), the organizational nature (a well-established company or a start-up), inherent characteristics (large vs. small company; profit-oriented vs. non-profit; data-driven vs. people-driven business designs), and the organizational purpose, vision, and mission. There may also be certain processes, such as knowledge or project management (Doolen et al. 2003).

Spatial structures of organizational (work) spaces can be either physical or non-physical. Physical structures may include the layout of the space, the floor plan, and equipment, such as furniture and material. Non-physical structures may include rules and rituals, programmed events, or a curriculum. Architects and facility managers generally co-design physical structures (i.e., the place). In contrast, non-physical structures are generally designed by managers or shaped by the organizational culture.

Users of a workspace (i.e., employees who work on innovation team projects) interact with spatial structures and transform the place into a space. By implication, structures generate actions. From a managerial perspective, this indicates that a spatial structure can be designed as a trigger and support for certain activities and modes of working. With a focus on creativity and innovation, this chapter focuses on incorporating *users' needs* with regard to information and knowledge exchange, collaboration and integration as well as communication and teamwork.

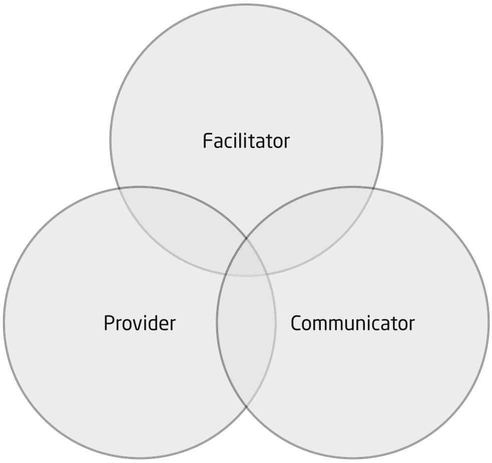

Fig. 2 Three dimensions of designed structural interactions (Klooker et al. 2016, p. 70)

As a consequence, it is necessary for the conceptualization of the place to consider the used space, with the users revealing their needs while they interact. However, this consequence also implies that users may use the designed structures differently than intended, resulting in what we call ‘misuses’ or workarounds.

If place making is considered a relational constitution of interaction in which space “derives from the interaction of structure and action” (Löw 2000, p. 53), it is worth considering the relational arrays between spatial structures and their users to better understand how to constantly generate momentum. We studied a large variety of designed (best-practice) innovative workspaces and identified three dimensions of designed structural interactions (displayed in Fig. 2; Klooker et al. 2016). We differentiate between spatial structures that are designed to facilitate specific interaction patterns and work processes, provide resources in terms of materials and tools, and communicate a mindset and corporate culture.

The applied conceptual understanding of organizational innovation spaces shows that there is no single general concept for establishing a Design Thinking place. The organizational context, users with their specific needs, and the spatial structures must be considered and the spatial concept designed accordingly. Thus, there cannot be a perfect innovation place in general; it always depends on the specific organizational context.

2.3 Design Thinking: Mindset, Work Modes, and Process-Related Activities

The theoretical foundations previously discussed apply to spaces or innovation spaces in general. This section specifically discusses conceptualizing Design Thinking places and closely analyzes Design Thinking and consequences of a place. Place making occurs in pre-structured conditions (Löw 2000). It makes a huge difference if we consider the repetitive day-to-day-activities of an individual employee at the corporate workplace or in the context of temporal teamwork in innovation projects. In the following and based on the above-mentioned role of multidisciplinary teams for Design Thinking, we would like to explore and systematize the latter, i.e. innovation places for project based teamwork.

Design Thinking is often reduced to a creative method that individuals use to generate solutions for a specific (design) problem. Consequently, a common goal for designing spatial structures for Design Thinking is to foster idea generation. We challenge this limited perspective of Design Thinking and Design Thinking places by differentiating between mindset, work-modes and process-related activities as different layers of Design Thinking and discussing the implications of conceptualizing Design Thinking places.

Aiming to institutionalize Design Thinking as a *mindset* in an organization (and not only as an idea generation technique) moves us beyond creativity and towards innovation: Innovation—understood as ideas shifting from one context to another—requires a mindset of openness and inclusion (Groys 2014). Therefore, Design Thinking places are designed as generative spaces that allow users to become 'unofficial' architects by adjusting and changing spatial structures, using structures differently from what they were designed for or creating new structures according to their needs (Kornberger and Clegg 2004). The general concept that Design Thinking incorporates a mindset of openness is reflected in the concept of a 'generative building' that emergently organizes the flow of communication, knowledge, and movement (Hatch and Cunliffe 2013, p. 222). Consequently, Design Thinking places are extremely flexible. The ability to move furniture, artifacts, and objects around freely to adjust the space according to both the current and changing needs also generates action and allows employees to remain in flow, which is considered a crucial support in creative processes (Csikszentmihalyi 1990). However, the duality of structural ordering and interaction has its limitation if space is limited and a scarce resource. Because innovation spaces have multiple users at the same time, some might be excluded from using the same resources (e.g., if there is only one prototyping area that is occupied by another team). Therefore, the generative building concept is also linked to a social, participatory design and construction of space (Fayard and Weeks 2007).

Throughout the Design Thinking process, different *modes of working* are applied and overall, divergent and convergent thinking alternate throughout the process. To facilitate different styles of interaction, the place must provide different spatial settings or the ability to transform the space: Divergent thinking generates multiple solutions to a problem and requires different directions and an open spatial structure; convergent thinking seeks a unique solution to a problem and needs closed environments (cf. Guilford 1957; De Bono 1970). The distinction between these different spatial setups as a consequence of the underlying work modes becomes even more clear if we consider the difference between creativity and innovation. Creativity means generating a wide variety of ideas that are new and surprising to an organization, whereas innovation refers to the implementation of these ideas (Amabile 1988; George and Zhou 2001; Tierney and Farmer 2002; Anderson et al.

2014). Accordingly, Design Thinking places must be designed in a manner that not only allows the generation of new and useful ideas but also focuses on and supports the implementation of these ideas. This broader perspective requires a ‘hands-on’ atmosphere (e.g., through a work bench), resources to build prototypes for testing, and processes to create business models. Therefore, Design Thinking places are generally used as project places that support (team) creativity and are workplaces that foster innovation and a fruitful innovation culture within organizations.

According to our third layer, a Design Thinking space fosters not only different work modes but also enhances interaction patterns during the iterative *process*. We at the HPI D-School Potsdam follow a process blueprint that distinguishes between six phases: Understand, Empathize (Observe and Immerse), Define, Ideate, Prototype and Test. For us, the iterative Design Thinking process is itself part of the larger and iterative model of Strategic Innovation Design (Liedtka and Ogilvie 2011). During the first iterative loop, the strategic fields of opportunity are identified and represented by innovative human-centered problem-solutions and the subsequent iterative loops focus on transforming this new problem-solution-fit into a compelling solution-product-fit, which then becomes an implementable product-market-fit. Therefore, different process stages and several iteration loops determine the necessary resources to be provided. These resources could be material and tools for, e.g., prototyping low-resolution ideas, working prototypes, and high-resolution solutions and could thus range from paper, glue, scissors and pencils to DTP software, video equipment and video editing software up to 3D printers or small computers, such as Arduino.

In the following section, the HPI School of Design Thinking will serve as an example of a Design Thinking place. Identifying spatial structures, contextual factors, and user needs will help clarify why a Design Thinking place was conceptualized in that specific way. This knowledge may help other organizations better conceptualize their Design Thinking places in the future.

3 The Design Thinking Place at HPI D-School Potsdam

3.1 Overview

The previous section outlined the importance of the organizational context, users and their needs, spatial structures, and the relational constitutional processes of place making for innovation and Design Thinking places. In this section, we analyze a real-world example, the HPI School of Design Thinking in Potsdam. In addition, we introduce our academic program, its participants, and the specific organizational context. Then, we present the Design Thinking place at HPI D-School. Figure 3 provides an overview of this structure.

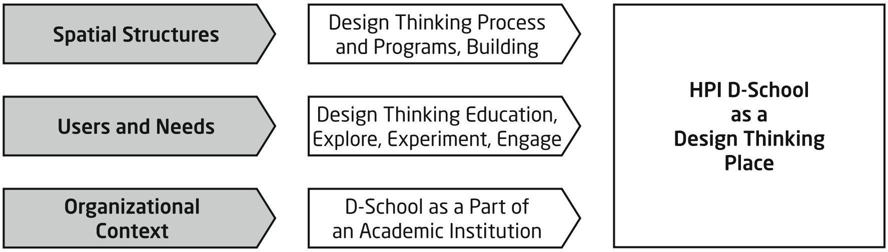

Fig. 3 Conceptualizing the Design Thinking place at the HPI D-School

3.2 Organizational Context

The organizational context of HPI D-School is given through the Hasso-Plattner-Institute (HPI), which focuses primarily on IT research and education, and the D-School is part of it. In a physical sense, the D-School building is part of the HPI campus, and the HPI campus is part of the campus of the University of Potsdam. The campus is located near a lake ('Griebnitzsee') and is surrounded by trees and residential areas. A nearby train station connects HPI to Berlin (approximately 30 minutes to Berlin's central station) and Potsdam (approximately 10 minutes to Potsdam's central station). Most students and coaches commute from Berlin. From a non-physical perspective, the organizational context is represented by the primary goal of the HPI: to provide research and teaching with a highly practical and innovation orientation. Therefore, the D-School is clearly an innovation space where not only innovation itself occurs but people are also taught to understand Design Thinking and incorporate the Design Thinking mindset. The D-School educates more than 320 students per year in Design Thinking; this includes 80 Students in the First Track, 160 students in the Basic Track and 80 in the Advanced Track. Against the background of problem-based learning and HPI's practical orientation, the D-School offers an educational setting that incorporates multiple stakeholder groups such as students, alumni, faculty members, external coaches, experts, mentees, and project partners from large and small corporations and non-profit organizations. Therefore, the D-School operates as a platform or fluid and networked organization. During semester breaks and during the semester, the D-School hosts various activities, such as conferences, boot camps, master classes, or workshops in Design Thinking, innovation, entrepreneurship, social innovation and related fields.

3.3 Spatial Structures

The physical spatial structure is primarily determined by the existing building, the floor plans, and the furniture. The D-School building was not planned as a Design

Thinking place but was originally designed to be a three-story office building that hosts three different IT-faculty departments (one on each floor). When the interior of the building was redesigned to include several studio spaces for team work (space as facilitator), work spaces for building analog and digital, low- and high-resolution prototypes (space as provider and communicator of a bias towards action), sharing and communication spaces, reminders of its original intent were intentionally kept (e.g., dark stripes on the carpet indicate the old office structures; carpet and wooden floors indicate the old separations between offices and hallways). These reminders are also visible in other D-Schools around the world; e.g., the genovasi d-school in Malaysia uses a former newspaper printing facility and kept some of the original interior. The HPI D-School at the University of Cape Town uses an old café on campus and kept the cashier area, which now serves as a communication hub. However, in Potsdam, we removed some walls to adjust the interior of the building to its new purposes, and some of the flooring was replaced. In addition, most of the furniture at the HPI D-School cannot be found in any other lecture hall or seminar room at a typical university. The collaboration furniture that we use (particularly the high tables and whiteboards on wheels) was co-designed together with the D-School. In addition to the furniture, the place offers writable surfaces on every wall.

However, there are still some elements that retain the "old fashioned" educational experience (e.g., office chairs and desks). When—due to the change of the non-physical structure from hosting offices to facilitating Design Thinking—we changed the office building to the D-School, the strategic intent was to remain a(n academic) learning place but in a completely new manner. Hereby, our strategic intent followed the MAYA-principle: most advanced, yet acceptable. The space would have to be 'advanced' in that it fosters a subculture of innovative learning, but at the same time, this new sub-culture should still be 'acceptable', i.e., related to the overall organizational context.[3] On an aesthetic level, this link to the HPI as the D-School's organizational context is also reflected in the look-and-feel of the studio spaces, which are similar to an IT institute: colors are white, gray, and silver; textures are primarily glass and metal; and the high tables and flexible whiteboards are rectangular shapes with clear and sleek designs.

The non-physical spatial structures of the HPI D-School primarily include the curriculum and Design Thinking as the process and mindset to be facilitated. Since we have already discussed Design Thinking on several layers in the previous section, we now focus on the curriculum. The academic program of the D-School offers three different formats: the First Track (5 days), the Basic Track (1 semester), and the Advanced Track (1 semester). Students attend D-School twice a week for an entire day (Tuesday and Friday for the Basic Track, Monday and Thursday for the Advanced Track; and the First Track is a 5-day compact course). In addition, the HPI

[3]This is why the HPI D-School retained one traditional seminar room in its building. This room is regularly used to showcase the transformation of a typical room into a space that fosters innovation teamwork by rearranging (and not replacing) the furniture and "hacking the space" (e.g., by using Duct Tape).

D-School offers program activities in the fields of innovation, entrepreneurship and startups. The program is conducted in English. Approximately 30% of the students have a background in STEM (IT & engineering), 20% have experience in business, 20% have experience in creative disciplines, and 20% have experience in social science and humanities. Two-thirds of the students are German, and the remaining students have international backgrounds.

3.4 Users and Needs

As previously mentioned, the user structure is diverse and includes students, alumni, faculty members, external coaches, experts, mentees, project partners, and other guests. We do not describe their demographical background, but identify their common needs based on four principles underlying Design Thinking (Empathy, Explore, Experiment, and Engage). We further explain how these common needs include aesthetic, instrumental, and symbolic functions of the place. Aesthetic functions "affect sensory experiences" of the users that cause cognitive and emotional responses; instrumental functions "improve the performance (...) and satisfaction" and are strongly linked to the place as facilitator and provider; and symbolic functions "affect cultures and identities of organizations" and are linked to the place as a communicator (Elsbach and Bechky 2007, p. 91).

At the HPI D-School, we identified four general principles that are the basis for Design Thinking: Empathy, Explore, Experiment, and Engage. Because *Empathy* is more related to the Design Thinking process and individuals (mindset) and does not so much focus on the place, we focus on the remaining three principles. These principles (Explore, Experiment, and Engage) reflect work modes during the Design Thinking process and therefore represent the needs of participants in a Design Thinking format that are relevant for place making. These principles and the users' needs hold true for a participant of a 2-day introductory workshop to Design Thinking, an experienced program-designer, a faculty member, a Design Thinking coach with more than eight years of experience, or a project partner coming in contact with Design Thinking for 6 months.

The principle *Explore* refers to seeking innovative solutions that are not obvious. The Design Thinking process means to understand first whether the 'right' problem is addressed before starting to generate ideas ("Are we doing the right things?" vs. "Are we doing things right?"). It also means to seek out different strategic directions and fields of opportunity. Spatial structures that enhance teams' creativity and innovation potential in an Explore context are reflected in an open spatial layout with semi-open team spaces. From an aesthetic perspective, these semi-open team spaces create zones of transition between the workspaces of teams and their environment and allow privacy, communication, and inspiration. At the HPI D-School, team spaces are limited by movable whiteboards and equipped with high tables on wheels and high chairs (Fig. 4). Thus, from an instrumental level, this

Fig. 4 Team spaces at HPI D-School

flexible furniture allows the team space to change and interactions with the external environment, including other individuals, teams, and coaches to be easily altered. On a symbolic level, team spaces look identical and are empty at the beginning of the process (referring to an empty canvas and the white cube; O'Doherty 1986), which invites teams to inscribe their personal and relational patterns into the space. The visually emptied zones that are used for teamwork contrast with material supplies, inspirational objects, and visual signs in other areas of the Design Thinking place (please refer to Fig. 5). These juxtapositions of white and colorful, emptied and equipped, clear and chaotic should trigger the continuous enhancement of an ongoing relational constitution of interaction patterns between the team space and its surrounding space and thereby inspire exploration.

The second principle is *Experiment*, which refers to creative problem-solving capacity building. In regards to the Design Thinking process, experimentation is linked to 'thinking with your hands', 'trial and error', and 'learning from failure'. Conceptual ideas that result from Design Thinking processes not only exist as a drawing on a sticky note but materialize in low- and high-resolution prototypes. Triggering a maker's attitude on an aesthetic level involves creating different work zones for building prototypes that stimulate a 'feeling of doing' (Fig. 6). From a functional perspective, prototyping spaces must be equipped with the appropriate materials, tools, and instruments. Such a space also conveys the symbolic message that "we are moving our innovation project to another stage" by advancing a concept into a materialized prototype. In addition, equipped maker spaces communicate the

Fig. 5 Material supplies

Fig. 6 Prototyping pop-up space

Fig. 7 Make space (3D printer, DTP software)

types of prototypes that are expected to be created. Therefore, dedicated areas for prototyping that are equipped with different materials (e.g., playful material and cardboards for low-resolution prototypes or fancy tech-spaces with a 3D printer and software for high-resolution digital prototypes) serve as sources of inspiration and indicate specific making modes (Figs. 7 and 8).

The third principle, *Engage*, refers to establishing external and internal relationships outside and within innovation teams. Intense teamwork within an innovation team space must be counter-balanced through the sharing of findings, insights, ideas, concepts, and business designs with others, particularly coaches, co-teams, project owners, experts, and mentees. From an aesthetical standpoint, the spatial structure should convey the message that the space is meant to be an auditorium for giving and receiving critical feedback, not for showcasing highly polished presentations. At the HPI D-School, all presentations occur within the D-School building; only the final presentation at the end of the semester is conducted in a lecture hall on campus. From an instrumental perspective, sharing spaces must be large enough and offer comfortable seating for all participants. The symbolic notion of these shared spaces is fostered when these spaces are close to the teamwork spaces and are easily accessible because they continuously symbolize that these spaces and people can be shared outside the team space.

Fig. 8 Make space (work bench)

In addition to opportunities for sharing, the Engage principle highlights another counter-balance: spaces to communicate, hang out, relax, and cool-down. These spaces are typically lounges or 'silent rooms' (e.g., a library; Figs. 9 and 10). It is notable that the act of engaging can take on different forms based on the organizational context and spatial structure that is constrained by climate, building structures, and interior designs. The layout of the HPI D-School and its surrounding nature invites changes in the environment for communication purposes. Outside the building is a lawn with a small pavilion that has been redesigned into a temporary Design Thinking space (Fig. 11). Teams often change their perspective by engaging with nature. Because of the hot and humid climate in Kuala Lumpur, going outside is not an option for the students at the d.school genovasi. Instead, they designed a large communal area in the center of a studio space for innovation teamwork. The floor is covered with the layout of a playing field, which is a symbolic message of playfulness and random encounters (Fig. 12).

3.5 The Design Thinking Place at the HPI D-School

The HPI D-School building includes three floors and a basement; each floor includes approximately 475 square meters of space. In addition to the spaces for

Fig. 9 Lounge area

Fig. 10 Silent space (library)

Fig. 11 Pavilion outside

Fig. 12 Communal area at d.school genovasi

Design Thinking education (Basic and Advanced Track), the building has one seminar room, (shared) offices for the program lead, program managers, program assistance, and researchers and other rooms for storage and technical equipment. The building has a glass front and all rooms (except bathrooms, kitchens, and

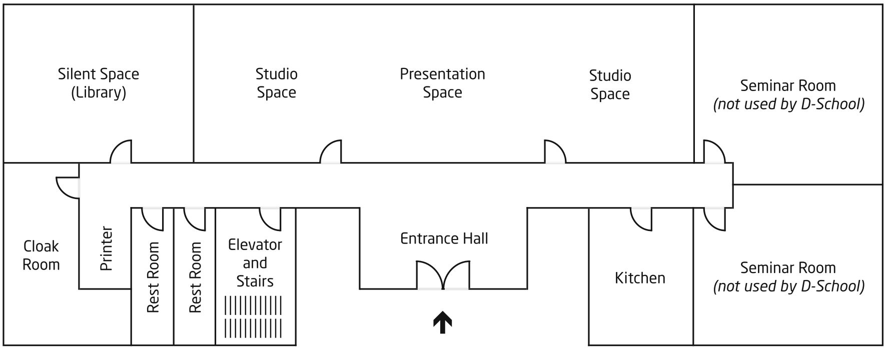

Fig. 13 Floor plan, ground floor, HPI D-School Potsdam (schematic)

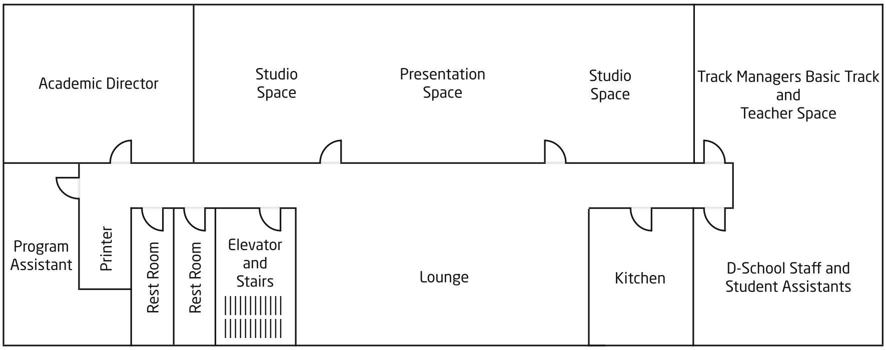

Fig. 14 Floor plan, 1st floor, HPI D-School Potsdam (schematic)

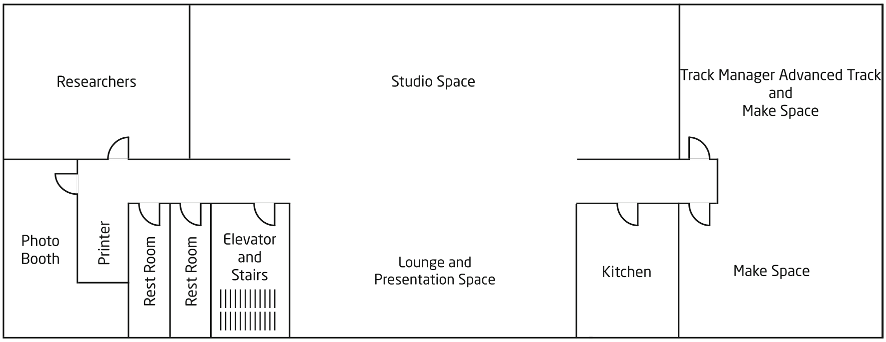

Fig. 15 Floor plan, 2nd floor, HPI D-School Potsdam (schematic)

rooms for technical equipment) are naturally lighted. The floor plans are provided in Figs. 13, 14, and 15.

We conclude with a discussion regarding space-in-use. During a Design Thinking project, many places fulfil various tasks that highlight the high need for flexibility.

For example, the *Lounge* hosts the warm-up activity at the beginning of each day; is used as an alternative team space (e.g., for check-outs or team reflection); offers sufficient space for ideation or prototyping; serves, particularly in winter, as a chill out zone during breaks; can be used for practicing presentations; hosts a buffet with coffee, tea, and drinks; and after presentations, can be used to host a festive buffet dinner for the participants. The *Studio Space* is primarily used for work in the team spaces; however, it allows cross-sharing with smaller or larger groups and can be used as an extended presentation space (particularly for conferences) and even serves as a dancefloor after the final presentations. The *Silent Space* (library) is used as a knowledge resource and offers a variety of books. This space is also used for silent desk research, for coaches meetings, to relax (some participants even use this space to take short naps), to make phone calls, or for D-School staff if other areas are too noisy or busy. The *kitchens* are primarily used to prepare coffee and tea; however, these spaces are also informal meeting places for coaches and D-School staff and are used by external caterers during events.

3.6 Similarities and Differences of Design Thinking Places in Educational Institutions and Other Organizations

The space that we describe in this chapter and that also serves as the source of our experiences is an innovation space in an educational setting. However, we are convinced that the conclusions we draw for the proper conceptualization of innovation spaces are valid for innovation spaces in non-educational organizations and can be used to conceptualize innovation spaces in companies. Next, we discuss similarities and differences between educational and organizational learning spaces, implications for spatial settings and the three Ps of Design Thinking: People, Process, and Place.

Whereas innovation spaces in companies are primarily used by employees, educational spaces are generally used by students, coaches, faculty members, and project partners. There are four primary differences between these user groups. First, students and young professionals are a rather homogenous group in terms of age; they are generally between 20 and 35 years old, whereas employees may range between 20 and 65 years. However, this difference should not have an impact on the usage of space (unless there are physical disabilities). The perception of interior design may differ between these two user groups. Younger generations might prefer a colorful design combined with steel and glass (as in start-up offices), and older generations might prefer other colors and materials. Second, students and young professionals are also a rather heterogeneous group and apply for the Design Thinking programs for many good reasons: to gain creative confidence, to experience collaboration and team work, to learn how to use new innovation tools, to engage with like-minded individuals, or to become an entrepreneur. Employees that use innovation spaces at their companies are also driven by these motivations, but are more focused on innovation outcomes. Third, students use innovation spaces in a more intense manner or at least over longer periods of time. At HPI D-School Potsdam, for instance, they use the space 2 days a week for a whole project that can last between 8 and 16 weeks. This high usage frequency allows them to get to know the spatial setup in a more detailed way, to better adapt it to their needs and to be more experimental in trying out new spaces or spatial setups. In companies, participants use the spaces for some workshop days. Therefore, they might need more guidance to actively make use of the space. Fourth, students have to apply for Design Thinking education, whereas participants in company workshops might not have had a free choice to join. Whereas this free vs. forced choice can impact the (initial) motivation, again, it does not impact the requirements for the space. Because students may anticipate what an innovation space might look like, participants who have not prepared themselves could be irritated by a space that looks very different from their usual office environment. This first ‘shock’ might be mitigated by explaining why the space is important for innovative tasks and the reasons for its distinctive design.

The Design Thinking process is not entirely different between educational and company settings. However, two other differences might occur. First, the type and scope of design challenges may differ. At D-School, students engage in all types of innovation projects (product development, service design, experience design, business design, designing strategic future, all for different industries); these projects might be more focused in companies. Consequently, companies do not necessarily need advanced prototyping spaces, such as a workshop or a 3D printer, but may instead need material that is more suited for their innovation projects. Second, the group sizes of participants might differ. At HPI D-School Potsdam, eight teams that include five students each, work in one studio space and regularly share their findings, ideas, and experiences. In a company setting, the number of innovation teams and their size may be smaller and/or larger; therefore, studio and sharing spaces can be smaller or bigger.

Another difference might be the location of the innovation space. For many HPI D-School students who live and study in Berlin, commuting to Potsdam involves physically leaving their comfort zone. The same holds true if companies have their innovation spaces off site. However, there might be organizations or universities where the innovation space is located on campus and participants or students take the same route every day but simply enter another building. In these cases, the contrast between normal surroundings and an innovation space may be fostered by the look and feel of the space. For example, a more technically oriented company with clean offices might consider wooden furniture, carpets, and colorful walls to provide a contrast for their innovation space. In summary, the differences between innovation spaces in companies and educational settings are rather insignificant and may be instinctively considered if the specific context is analyzed thoroughly prior to conceptualizing the space.

4 Discussion

This chapter discussed conceptualizing places for Design Thinking. We first introduced the relevance of place in regard to Design Thinking and described pitfalls for companies introducing innovation places. We then provided the relevant theoretical background for studying and conceptualizing places for Design Thinking. We distinguished the terms 'place' and 'space' and clarified their relationship: 'spaces are lived places'. Second, we introduced space as a relational concept and introduced relevant factors including spatial structures, users and their needs, their interaction (place making), and the organizational context. As the third component of the theoretical foundations, we introduced Design Thinking and three layers that include: mindset, work mode, and process-related activities. The following section described and explained how these theoretical concepts are transferred to an actual place. The HPI D-School Potsdam served as an example. Following the provided theoretical structure, we described in detail what relevant organizational context factors are, which needs the D-School users have in common and how the (existing) spatial structure influences the place. The resulting place was finally illustrated with pictures, floor plans, and a short description of the space-in-use.

This chapter provides valuable for researchers and practitioners. First, we provide a sound theoretical basis for research in the context of work or innovation space and place that embraces central theories of philosophy and sociology. Second, we examine places in the context of corporate culture and—in combination with the pitfalls outlined—describe a field for potential future research. Third, we describe a framework of space which researchers might want to theoretically extend or empirically analyze. Practitioners benefit from our chapter in several ways. First, we describe the potential of space and the pitfalls of solely copying existing spaces. Second, we provide practitioners with actionable theory-based components to consider when conceptualizing a Design Thinking space. Third, we use a real-world example to describe how these theoretical components can be practically 'filled' and fourth, what the result of a conceptualization of a Design Thinking place might look like.

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Part IV
Design Thinking in Practice

Mapping and Measuring Design Thinking in Organizational Environments

Adam Royalty and Sheri Shepard

Abstract Dozens of for profit and not for profit organizations across a wide range of sectors explicitly employ Design Thinking as a core innovation methodology. This demonstrates how versatile the tools and frameworks are. It also presents an opportunity to better understand how the organizational environment impacts how design thinking is applied. This chapter covers two studies that explore organizational environments. The first study is the development of a mapping technique called a Design Thinking Ecology that highlights a number of organizational variables and how they interact with design thinking. The second is a case study of a community of design thinking practitioners across four separate companies. Their collaboration highlights the role each organizational context has on the individuals and the group as a whole.

1 Introduction

This chapter outlines the development of tools that describe the real world context in which design thinking is being applied. This is important because design practice is heavily influenced by the context in which it exists. We cannot fully understand the impact design thinking has without taking into account the environment that surrounds it.

Over 100 organizations have official design thinking efforts (Köppen et al. 2016). Clearly this methodology is more than just a fringe movement. At the same time, design thinking is a relatively new way of working. It still represents a new investment that companies are making. As this investment increases, so to does the call for returns.

Our ability as researchers to measure the impact of design thinking affects the viability of the overall movement in two ways. The first way is the ability to demonstrate value. If organizations cannot see the value, they will stop investing in it. Even if advocates personally believe in this methodology, the old adage still

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rings true, "what gets measured, gets done." Eventually every leader of innovation in an organization has to show the value. The second way is that measuring helps improve how design thinking is applied; it is essentially a robust form of feedback that people can use to enhance practice.

Multiple HPDTRP projects have focused on measuring design thinking (Hawthorne et al. 2014; Royalty et al. 2012, 2014, 2015; Royalty and Roth 2016; Saggar et al. 2016). This has led to a host of new measures including the Design Thinking Creativity Test (DTCT), the Creative Agency Scale, a Creative Growth Mindset Scale, and Design Thinking Snapshots. It is important to note that each of these measures focuses on an individual or team. Furthermore, many of them are being used beyond the laboratory in real settings. This creates an opportunity to compare and contrast impact between different companies. However, different organizations provide different settings for creative innovation. To have meaningful comparisons it is crucial to understand what role environmental factors play.

Mapping environmental conditions that support strong design thinking practice is essential because many organizations bring design thinking in as a driving force of their greater innovation efforts. Yet there is no shared knowledge of successful or unsuccessful practices. Fortunately there are many organizations using design thinking and a reasonably large subset of those that have been using it for multiple years (Courage 2013). This means that we can use their experiences to begin to map out more precisely how design thinking has been and can be used.

This research project seeks to develop useful maps and measures that can both describe organizational environment and demonstrate impact. This leads to three primary research questions:

What variables are most necessary in creating a useful descriptive mapping of how design thinking is applied across organizations?

What design thinking behaviors are exhibiting in pursuit of innovation?

Do differences in team design thinking behaviors correlate with differences in creative output?

The sections below describe how we have addressed each research question.

2 Design Thinking Ecologies

2.1 Background

Design thinking ecologies were created in a previous year (Royalty and Roth 2016). The goal was to describe what design actions organizations engage in and how they are implemented. Because these mappings are dynamic, it is possible to see a change over time. Practically this will help innovation leaders better understand how they can choose to implement—or iterate—design thinking.

Our initial version described the creative environments of 4 different organizations each of which used design thinking as part of their innovation strategy.

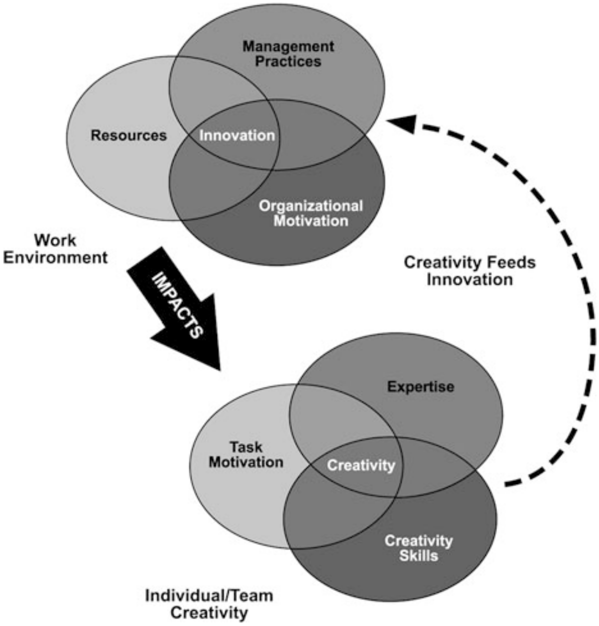

Fig. 1 Amabile's model of creativity and innovation in organizations

The ecology is based on a theoretical model of creativity and innovation in organizations (Amabile 1996a, b). In her cyclical model work environment impacts team creativity, while team creativity drive innovation. The work environment is made up three components: organizational motivation, management practices, and resources. Organizational motivation represent the strategic goals for innovation. Management practices capture how the leaders support the creative work of employees. Resources is a broader category that includes initiatives, human capital, and more. These environmental components provide a great lens to look at our organizations' ecologies with. Therefore, any mapping framework should include them (Fig. 1).

The theoretical model lead to a 3-part ecology. The Innovation Target 2×2 (Fig. 2a) shows where the design thinking efforts fall relative to a general innovation framework. Incremental or breakthrough innovations that focus on cost savings or revenue generation. This relates to Amabile's organizational motivations. We plot known design thinking projects and programs that exist in any given year for each organization.

The Design Activities Diagram (Fig. 2b) captures how much of each activity an organization is doing. This relates to Amabile's resources. There are four distinct axes, resulting in a spider diagram of each organization. What will be important is the general shape of the resulting diagram. For this iteration we chose axes of: experts (number of), empoyees trained (percentage of total workforce), training (number of events per year), and projects (number of projects per year).

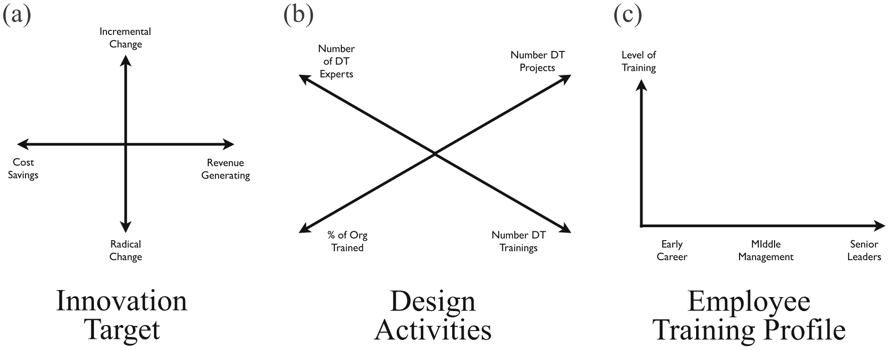

Fig. 2 Ecology mapping framework. (**a**) reflecting organizational (**b**) reflecting resources (**c**) reflecting man-motivation agement practices

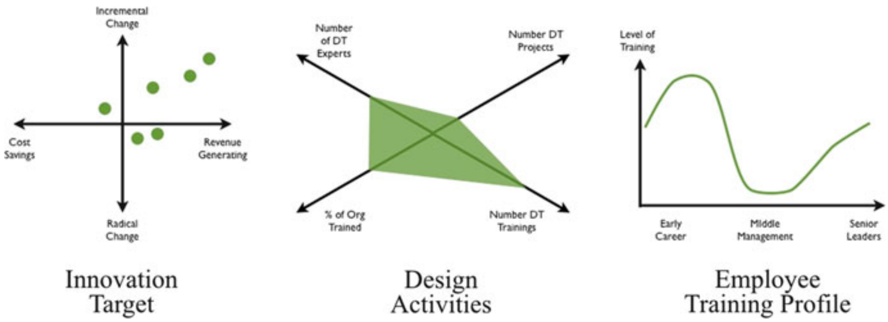

Fig. 3 Ecology map of a large financial services firm

Finally the Employee Training Profile (Fig. 2c) represents the depth of design thinking capacity in a workforce and where that capacity is located along a leadership spectrum. This relates to Amabile's management practices. This chart captures the distribution of activity. Design activity is a combination of practicing, leading, and teaching designing thinking. The horizontal axis shows how much design activity exists in different leadership levels.

Figure 3 is an example of an ecology mapping for a financial services firm that uses design thinking to drive their innovation efforts.

2.2 *Methods*

After developing the initial ecologies we shared them in two separate forums. The first forum was at the 2016 DTX (Design Thinking Exchange) meet-up. This community is a mixture of researchers and practitioners focused on design thinking. There were approximately 40 attendees representing around 20 companies and 5 universities. We presented the ecologies and underlying theoretical framework to the entire community. As part of a 30 minute "breakout session" we received feedback from approximately 10 people from different companies. They shared what ecology components were more and less relevant to their environment. They also shared what types of activities they would want to see in future iterations.

The second forum was a series of semi-structured, in-depth interviews with 6 members of the design thinking collaboration we researched (see Sect. 2 of this report). The interviews lasted between 30 minutes and 45 minutes. We interview protocol focused on the different components of the ecology as well as how they would use the information in practice.

The responses from both forums were pooled. We examined the responses using an open coding methodology—specifically looking for major patterns. A series of common themes arose. These themes fell two general categories. The first category was the value of the current model and components. The second category was what important design activities were not included.

2.3 Initial Results

The respondents expressed enthusiasm for the ecologies as a whole. Nearly all of them noted that this would help them compare the design thinking efforts between organizations, which could inspire their own practice. Surprisingly a majority suggested that this would be a good tool to capture internal design thinking efforts and share within their own organization. This revealed that many innovators responsible for driving design thinking do not currently aggregate their efforts in a descriptive manner.

There were, however, clear areas that could be improved. The themes we synthesized from the feedback are listed below by category;

Suggested Modifications to the Original Ecology

The innovation target was too narrowly defined. The initial innovation target was a 2×2 with a cost savings/revenue generating horizontal axis and an incremental change/radical change vertical axis. This was based in large part on how one organization framed their design projects. However, a number of other companies did not view their innovation goals through a similar lens. A more general model is needed.

The training profile, while intuitive, was difficult to generate. Nearly all respondents thought it was valuable to plot out how much design thinking education different levels of management in an organization have. Notably it highlights gaps in training which suggest a gap in practice. The way this was generated was to count the number of design thinking trainings employees in three levels of management had. The main issue was that the levels of management were too broad. Three levels are not enough. A categorization that lines up more a larger, more standard management model is needed.

Historical data was too difficult to obtain. Many organizations do not have records of the total number of design thinking trainings and/or projects they've run. This is partly due to the fact most organizations experimented with design thinking in a rough, less organized way in the beginning. The initial activities were scattered and not counted. As the activities became more commonplace, they became easier to record. Another issue with record keeping is that the innovation teams responsible for running design thinking don't know about every design-based project or learning experience. For example, a designer at a large financial services company told us that they have trouble tracking the actions of employees they train. Often news of a design-based project comes back to them through a chance encounter in the elevator. This suggests that we should seek recent activities over total activities.

Suggested Additions to the Original Ecology

Where design thinking is practiced in the organization. Several respondents noticed that the ecology does not make any distinction between the different divisions or groups of an organization. A company that has a little design thinking in all business units is a very different context from one that has a lot of design thinking in one business unit and none in the others. The original ecology would not necessary be able to distinguish those two cases.

Capturing strategic intent. The innovation target is designed to reflect the innovation intent of an organization. The types of activities a company engages in does reflect intent to some degree. However, nearly all organizations have stated goals for innovation. Furthermore, there are often stated goals for the use of design thinking. They might not be as high profile as the overall innovation goals, but they often exist as part of leaders' strategic intent. These goals need to be included.

Assessment plan. Simply put, everyone wants to know how others assess the success of design thinking. This is typically done through sharing successful examples but more robust—and quantitative—methods are desired. The demand for assessment plans is so high that it must be part of the ecology.

After reviewing the themes we revisited the relevance of the theoretical framework. None of the major issues stemmed from a fundamental conflict the purpose of the initial ecology and it's components. Rather participants struggled with some of the details. In fact, feedback on the three component categories was very positive. Therefore, we believe the theoretical framework is still a useful underpinning for the ecology.

What we did do is to create a survey with a set of new questions on it based on the feedback. The survey is longer and more detailed than before. See the table below for a summary of the changes (Table 1).

By the end of summer we anticipate completing 2.0 ecologies for 6 to 8 companies. Figure 4 shows three of the updated visuals for the new ecology with initial data inputted. The Innovation Target captures project duration as well as the new innovation categories. The Employee Training profile has 6 categories, up from 3. This provides more detailed resolution on what levels of people have been trained. A completely new graphic is the Business Unit Distribution chat. This lists where the approximate percentage of design thinking activities occur in the organization.

Table 1 Updated design ecology items

Theoretical component	Ecology 1.0 items	Ecology 2.0 items	2.0 response type
Innovation target	Projects plotted on cost savings/revenue generating Incremental/break-through 2×2	Stated innovation goals	Short answer
		Stated DT goals	Short answer
		Org value of design aspects	1–10 rating
		Number of projects by innovation type (core, adjacent, transforming)	Numeric
Design activities	Total percent of employees trained	Number of DT projects by duration	Numeric
	Total number of trainings	Number of DT trainings by duration	Numeric
	Total number of DT experts	Distribution of DT activates through organization	Percentage
	Number of total DT projects run	Current assessment techniques	Short answer
Training profile	Number of trainings attended by DT trained employees across 3 management levels	Number of people by DT expertise	Numeric
		Percentage of employees with DT training across 6 management levels	Percentage

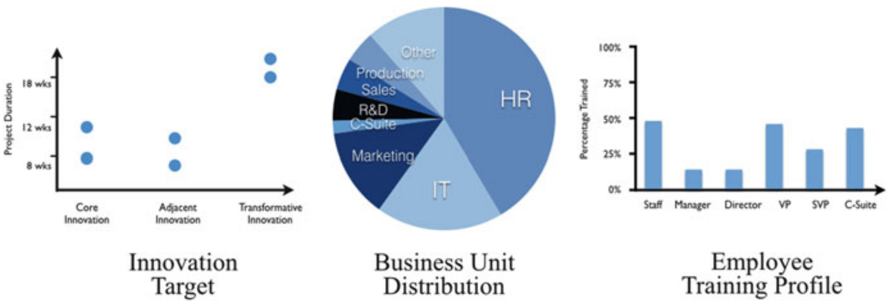

Fig. 4 New design ecology visuals

3 Study 2: Design Thinking Communities of Practice

3.1 Background

Two year ago a collaboration formed amongst creative innovators in four different organizations: Fidelity, JetBlue, Citrix, and Nordstrom. They came together with 4 common goals.

- To conduct joint design thinking trainings for novices in their respective companies.
- To develop design thinking capacities beyond those taught in introductory workshops.
- To learn and be inspired from other organizations that apply design thinking.
- To explore collaborating on joint business problems.

We have been following the group since they formed. This year marked the completion of their initial prototype—each company had an opportunity to host an event. The primary gathering this past year was a virtual writing retreat hosted by Citrix. As stated in the accompanying proposal for 2016–2017, the collaboration will begin a second prototype and bring in new members from new companies.

There were essentially 8 core members of the initial collaboration. These people coached the joint workshops and attended biweekly video call. Every core member but one received the majority of their design thinking training through the Stanford d.school or Product Design Program. For each one teaching or leading design thinking is an official aspect of his or her job.

This is an ideal setting to generate case studies describing how design teams from different companies can work together to create something new. In the past year, the HPDTRP induced a notion borrowed from a twenty-first century military term called team of teams. In essence, this describes a shift away from a siloed command and control system to a decentralized network. We believe the members of this collaboration exhibited behaviors in line with a team of teams. But unlike the military or other examples they used design thinking to facilitate their collaboration.

They operated without getting explicit approval from supervisors in their own organizations. The teams reformed periodically when needed. For example, a JetBlue core member flew out to Seattle to join the Nordstrom team for a weekend in preparation for their event. The team of team members found themselves working an extremely different—and more effective—manner through the collaboration than in their official job.

3.2 Methods

We were participant observers during the duration of the collaboration. We attended the video calls and captured field notes. We attended all four events, taking fields notes and facilitating various global debriefing sessions through reflection tools such as "I like, I wish" and journey mapping (Royalty et al. 2015).

We conducted two rounds of semi-structured, in-depth interviews with the members of the collaboration. The first round occurred in summer of 2014. The second round concluded this past spring.

The final large gathering hosted by Citrix was unique in that it was not a joint training session. Rather it was an opportunity for members of the collaboration to share what they learned over the past 2 years. The teams met virtually 1 hour each day for a week. Seven core members participated plus two outside guests—designers from Kaiser Permanente's Innovation Lab. They were invited to participate because they could give more objective feedback on our work.

The first two days were paired interviews. Two members of the collaboration from different organizations connected via phone and interviewed each other. One person was the subject on Monday; the other person was the subject Tuesday. The general topics of the interview were memorable experiences with the collaborative, salient learning, and things you would have done differently. The interviewer was responsible for taking notes and posting them to a shared google drive.

All the participants came together (virtually) on the third day. Their assignment prior to meeting was to read through notes of two interviews they were not a part of. The participants spent the hour generating several themes and reducing them down to 8 core themes that they believed ran through the collaboration's nearly two years of work.

Day 4 was an individual writing day. We (the researchers) captured the themes from day 3 and created a series of 8 writing prompts—one for each theme. The participants were asked to respond to some or all of the prompts. The format and structure of their writing was left up to them. They added their output to the shared google doc.

On the final day, we spent time reading the output. The week concluded with a discussion of next steps in terms of sharing what we created.

3.3 Results

Below are the 8 themes—with brief descriptions—that emerged from the writing retreat. These represent the activities and behaviors that were most core to the collaboration.

Personal Relationships Impacted Mindset and Motivation The interactions between collaboration members while designing learning experiences and coaching formed a personal bond. These encounters facilitated an open dialog around how individuals practice design thinking.

Tools and Technique Sharing The collaboration members spent much of their time together teaching novices design tools through the various workshops. However, members of the collaboration also shared more advanced tools with each other. The sharing included how to successfully communicate design thinking results with upper management. This includes examples of how applying a tool—like journey mapping—actually led to an insight or innovation.

How Organizations Value Design Thinking Each of the 4 organizations valued design thinking in different ways. Nordstrom used it to help their employees become better creative problem solvers. Fidelity, on the other hand, focused more on inserting a design process into the product development efforts.

Overcoming Barriers Everyone mentioned the importance of overcoming internal and external barriers. Driving innovation is a large organization has many emotional ups and downs. Celebrating—or at the very least acknowledging—these victories is essential to keeping a positive attitude.

Sharing the Story with Leaders and Stakeholders People responsible for driving design thinking have to demonstrate success to their leaders. How this is done was the subject of a number of video calls. In fact, part of the purpose of inviting senior leaders to the workshops is to share the success stories of other companies. In effect they pooled their successes to better justify the use of design thinking.

View of Design Thinking Trainings The purpose of conducting design thinking arose a lot. Specifically the collaboration members in each organization wrestled with guidelines for deciding who to train and who not to train.

Unexpected Evolution of Design Thinking This refers to design thinking having a role in an organization that was not planned for. This could be positive, negative, or neutral. For example, the connection between design thinking and incubator projects was not planned for but allowed for interesting new opportunities.

Human Centered Environments On a more abstract level the collaboration members described their efforts as making elements of their organization more human centered. This can happen through programing, coaching, or an actual physical redesign of the space.

The next step is to apply these 8 codes to the spring interviews and the 54-page Google doc created during the virtual writing retreat. We will look for patterns and examples that will help us further describe how these teams worked with each other. This will help us understand the core principles behind how design thinking can facilitate a team of teams.

One promising case study coming out of this work is the story of how the teams helped each other establish incubator programs. As more and more large organization turn to intrepreneurship—replicating entrepreneurial activities within a company—programs like corporate incubators for internal teams are on the rise (Antoncic & Hisrich 2003; Parker 2011).

Citrix created an incubator program called SparkPark that used design thinking as the primary working method for their internal startup teams. Two of the SparkPark leaders were members of the collaboration. They ultimately invited a Fidelity team to participate in SparkPark with the Fidelity collaboration members included as coaches. The structure and procedures Citrix developed ultimately informed a new Fidelity incubator program. Not long after, two JetBlue collaboration members asked Fidelity to help them launch their own incubator program. In fact, the first event was a joint project between JetBlue and Fidelity. The most remarkable thing about this outcome is that the teams work almost completely independently from the centralized corporate structure. There were no contracts or MOU signed. They simply didn't ask permission from their superiors. Instead the different teams worked swiftly together because they had a shared language—design thinking—and a shared history of working together. This is a great example documenting the unique power design thinking has in facilitating a team of teams.

4 Conclusion

Continuing to develop measures is crucial as design thinking matures into a ubiquitous methodology. Organizations need to know how effective this way of working actually is. Furthermore, the more the application of design thinking is measured, the easier it will be to increase efficacy.

The primary challenge is that because design thinking is so often contextually dependent, the measures may become contextual dependent as well. Taken to the extreme this suggests that every organization using design thinking needs to develop custom measures for that only work inside their unique environment. This is problematic as it could pose a barrier to collaborations in both industry and academia—people might become too siloed in their own context.

The goal of this work is to give industry leaders and researchers frameworks for comparing organizations across a range of environmental variables. In a way, it bridges the gaps between contextual silos. Fortunately there are enough early adopters of design thinking to develop robust maps. This ultimately should increase the spread of design thinking as an organization looking to take on this methodology can more easily learn and be inspired from a range of others organizations who have already done so, even if they have a very different environment.

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Human Technology Teamwork: Enhancing the Communication of Pain Between Patients and Providers

Lauren Aquino Shluzas and David Pickham

Abstract There is an urgent need within hospitals to reduce the amount of time that clinicians spend interacting with computers, in order to increase direct patient engagement, complex problem solving abilities, and overall patient satisfaction. This research explores the application of design thinking in health IT systems engineering. It is motivated by a need to: (i) enable clinicians to capture data from patients in a more natural and intuitive way, (ii) increase the amount of time for face-to-face patient interaction, and (iii) increase the speed and accuracy of tasks requiring acute critical thinking skills for complex medical scenarios. Specially, through need-finding with patients and providers at Stanford Health Care, we narrowed the research focus to center on the application of technology to improve the communication of pain between patients and providers during post-operative care. We present must-have and nice-to-have features of an interactive pain management and assessment system, based on input from patients and providers; and illustrate early conceptual prototypes aimed at enhancing the social transaction between patients and caregivers in the communication of pain.

From a design thinking perspective, this research (i) examines the use of technology to capture "a digital story" of patient needs during the course of care; (ii) studies the impact of human augmentation on healthcare team performance; and (iii) explores the ways in which the seamless integration of technology into patients' and providers' lives can influence behavior change and health outcomes for situations requiring acute point-of-care interactions, particularly for pain management and assessment. We conclude this book chapter with insights into future work aimed at enhancing the communication of the pain experience between patients and clinicians.

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1 Introduction

This research aims to preserve the “human” aspect of healthcare through enabling clinicians to focus on direct patient engagement, critical thinking skills, and complex problem solving—while relying on computers to perform repetitive tasks that are time consuming or prone to human error. This research is motivated by an urgent need within hospitals to reduce the amount of time that clinicians spend interacting with computers performing manual data entry tasks, which is estimated to comprise approximately 40% of nurse’s daily activities; in order to increase time for direct patient engagement and critical thinking. The negative impact of this technology, predominately electronic health records (EHR), is increasingly being documented. For example, nurses from a recent study commented: “Some providers don’t even make eye contact with a patient because they are focused on the computer. It takes some of the good bedside manner away from the encounter” (Kohle-Ersher et al. 2012).

From a clinical perspective, despite the many advantages that EHR systems provide over traditional pen and paper charting (Poissant et al. 2005), the use of electronic systems has led to an increasingly impersonal transformation in clinical practice that we aim to address. This change is largely attributed to: the extensive amount of time required for documentation, check-box charting without narrative reporting, and the lack of point-of-care and real-time documentation processes (Stokowski 2013). From a financial perspective, over $74.1 Billion USD is spent per year for nurses (RNs alone) to perform computer data entry tasks (based on median salary estimates), rather than the medical procedures for which they were trained—an alarmingly high figure that hospitals throughout the U.S. are striving to reduce (US News and World Report 2013; National Center for Health Workforce Analysis 2013).

1.1 Increased Documentation Time

The introduction of EHRs has placed a tremendous burden on clinicians. A recent study reported that EHRs have added 3 h of work-load to a typical 12-h shift (25%), due to the amount of time required for “logging in and out; paging through unnecessary screens; duplicate entries; trying to find where to chart something; slow, cumbersome systems; and increased mandatory documentation” (Stokowski 2013; Ward et al. 2011). Similarly, the use of copy-and-paste features in EHRs has been shown to perpetuate errors, as clinicians instinctively begin to operate in an “auto pilot” mode. Worryingly, clinicians have indicated that they do not consider documentation time as time spent providing patient care (Keenan et al. 2008). One nurse comments: “***In reality, we don’t need to do anything at all for the patient, as long as we document that we did***.”

1.2 Check-Box Charting Without Narrative Reporting

Many nurses express dismay at the loss of space in the patient record to write narratives—***to tell a story*** about what is happening to the patient and what occurred over the course of care. The 'art' of medicine, the human interactions contributing to care, are being lost. Such narratives (and the ability to read a patient's "story") were once integral to pen and paper charting, yet are now considered to be essential elements missing from communication among healthcare providers (Struck 2013). Prior to EHR implementation, a typical written nursing progress note would be tailored and focused, using frameworks such as SBAR: the pertinent *S*ituation, *B*ackground, *A*ssessment, and *R*ecommendations for clinical care. However due to the ease of 'click' button documentation, as well as mandatory institutional and regulatory documentation requirements, clinical documentation has expanded exponentially and become less pertinent to the patient's care.

In a recent study, one nurse commented: "***We are nursing the chart rather than the patient***. I never thought I would see the day when a machine would need to be cared for more than my patient" (Stokowski 2013). Many nurses express the sentiment that "check boxes" and menu items do not sufficiently capture elements of patient care. Importantly, picking items from a menu, rather than using critical thinking to determine what is important to a particular patient's care, is thought to potentially impair the development of nurses' higher-level skills. Likewise, only selecting items from a menu, limits the full description of a patient's clinical status (Kelley et al. 2011). The voice of the nurse and other clinicians is being lost.

A nurse from a recent study commented: "My patients are highly variable human beings. I want to document as a professional, ***not as a robot checking boxes*** . . . It is hard to get a good picture of the information that is there, because it is scattered over multiple screens, and it takes a long time to gather" (Kossman and Scheidenheim 2008; Stokowski 2013).

1.3 Lack of Point-of-Care and Real-Time Documentation

Lining up at workstations-on-wheels (known colloquially as 'WOW' carts), after a shift has ended has become common practice within most hospitals. Nurses in a recent study indicate that failure to chart in the moment is one of the biggest barriers to providing adequate patient care, and that human behavior change is badly needed. The study indicated that 72% of respondents had stayed after their shift to finish charting, since there was insufficient time to do so while delivering patient care (Keenan et al. 2008; Stokowski 2013). One nurse commented: "I need a stenographer to follow me around during my work and record everything I see, discover, think, evaluate, and do." Another said: "I got a nursing degree, but I'm ***really just a data-entry clerk***." The apparent ease of electronic documentation has inadvertently led to its expansion.

This phenomenon is not restricted to nursing. In the fast-paced environment of the Emergency Department ‘clinical scribes,’ often would-be medical school students employed on a part-time basis, are being hired by hospitals to shadow physicians and document their patient interactions, physical assessments, and plan of care. What previously took a glance and a swipe of a pen, now entails a log-in procedure, hundreds of mouse-clicks, menu selections, and click-boxes. When a scribe is not employed, it is not uncommon for a clinician to document in real-time on a piece of paper (sticky note) while leaning on a WOW cart, only to re-enter the information into an electronic record after the emergency encounter is completed (Ward et al. 2011). Besides the wasted time spent double charting, there is also an incredible risk for documentation error and loss of sensitive data.

1.4 Existing Technology

In light of several of these challenges, previously HPDTRP-funded research examined the use of the Google Glass head mounted display as a hands-free method of measuring, annotating, and tagging chronic wounds, and transferring data to/from a patient’s EHR (Aldaz et al. 2015). This project was well received at Stanford Health Care for the specific task of wound care assessment, which tends to require less face-to-face patient/provider interaction.

Existing research has also examined the use of dashboards to optimize how clinicians document, in an effort to minimize the check-box approach and increase the focus on telling a patient’s story. A pilot study showed that it is “possible for the EHR to pull relevant data from the history, key problems, diagnostic results, and events during the hospitalization, into a dashboard that allows providers to see the patient story at a glance when they open the record” (Struck 2013). Clinicians involved in this study noted that the dashboard approach could solve the narrative problem of “what has happened to this patient?” But, the dashboard fails to address the question of “what has happened during *my* shift?”—which nurses using pen and paper used to document through detailed narratives.

To address the problems discussed above, we conducted an in-depth needs finding effort at Stanford Health Care to select a target application that could particularly benefit from a reduction in time-consuming documentation tasks in routine clinical care.

2 From Provider-Centered to Patient-Centered Focus

Early in the need-finding phase we focused improvement on reducing time-intensive tasks, like the process of administrating and documenting medications and admitting a new patient to an inpatient unit. These scenarios were selected as they have relatively standard work processes and the associated documentation is quite burdensome. We hypothesized that if we could develop an interface that reduces manual documentation, this would increase the productivity of the nurse when admitting a patient to an inpatient unit or while administrating medications, and improve the overall patient-provider experience.

During need-finding however, three significant barriers to success were quickly identified. First, clinical documentation is performed using a proprietary software platform. In the United States a limited number of providers account for the majority of EHR systems in use. Any EHR change requiring implementation and testing would require a high degree of technical integration and therefore cooperation and collaboration from institutional and corporate partners; a scenario thought unlikely by the clinical leaders interviewed. Second, early system conceptualizations were based on a wrist-worn device similar to that worn by some NFL quarterbacks—in an effort minimize the physical distance created by the WOW carts between the patient and nurse. However, as documentation is solely completed using WOWs, subjecting different elements of care to various documentation capture systems, like a wrist-worn device, would be impractical. For any potential documentation system to be successfully developed and deployed, it would need to encompass the entire continuum of clinical care, and not require nurses to change documentation systems for each task. Finally, keeping wrists bare is an important consideration in clinical practice, as it aids in handwashing and the prevention of infection. Clinical leaders felt strongly that any such wrist-worn device would therefore be impractical, and may contribute to infections if worn by nurses performing patient care. Based on these barriers, we sought to interview senior leadership at Stanford Health Care to gather their insights into the organization's EHR needs.

Based on these interviews, an important idea was posed by a clinical leader—"... I think it would be really helpful if you could help us understand and improve our *pain scores.*" In this context, a pain score is a term used to describe a survey that attempts to gauge a patient's recent inpatient experience as it relates to pain. The surveys (conducted by an independent organization, *Press-Ganey*), ask patients to describe their care after discharge from a health care facility. Related to pain, questions are asked such as 'did hospital staff do everything they could to help you with your pain?' Responses are then compiled and used to develop a metric that is used to benchmark across like-organizations. The adequate management of patients experiencing pain is a compelling problem, and one faced by institutions across the United States.

In our early work, we set out to improve the interface of the EHR through developing new technology and reducing burdensome workflows for nurses. However, there were significant barriers to this work. Furthermore, organizational priorities were more narrowly focused on improving pain management and its documentation. As pain is a highly individual and dynamic experience, efforts to improve its management could benefit from design thinking principles. Therefore, based on user-insights, we reframed our effort to improve human technology teamwork to focus on how we could improve the experience of patients who have pain during hospitalization, by specifically attempting to improve the communication of pain between patients and providers.

3 Need Finding: Observation and Interviews

With a reframed focus on pain management, we conducted interviews with former patients from Stanford Health Care (SHC) to gain a better understanding of their recent hospitalizations and pain management experiences. The patients included three women and one man. Three of the patients had undergone heart transplant surgeries and one patient underwent two surgeries for a labor and delivery case involving placenta percreta. The research team also shadowed a pain specialist nurse at SHC to capture the process of assessing and managing post-operative pain from a clinician's perspective.

A summary of need-finding data from a patient- and clinician-centered perspective is schematically shown in Fig. 1a–c. The patients described feelings of anxiety due to a lack of mobility during hospitalizations and having to stare at the clock

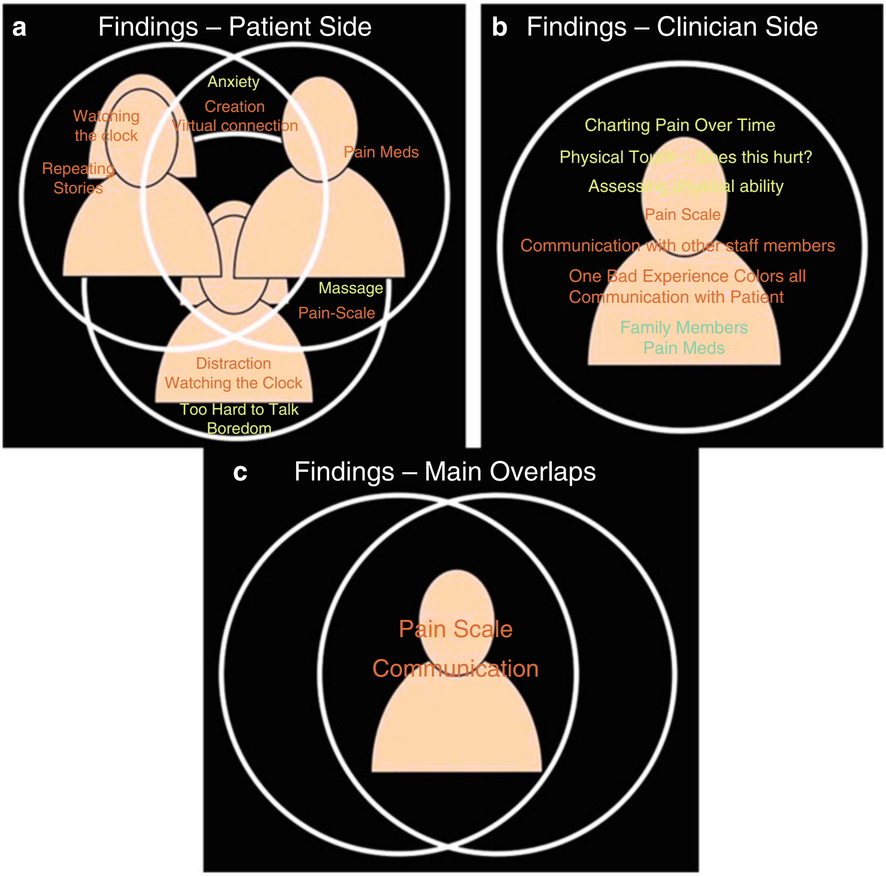

Fig. 1 Needs finding based on patient need (**a**), clinician needs (**b**), and overlapping needs (**c**)

in their hospital room for several hours at a time. They emphasized the importance of creating a virtual connection with friends and family members to provide health updates on a regular basis as a way to cope with pain; and one patient described the benefits he obtained from creating stories of his daily routines—as a way to bring levity to an otherwise difficult experience. The patients also discussed the confusion they often experienced with respect to the standard 1–10 pain scales. One patient mentioned that she would always assign a maximum score of "5" to her pain level, since she could not psychologically accept that the pain could be worse then what she was currently experiencing. Due to a lack of prior reference, another patient would select an arbitrary value to describe her pain, not knowing if the pain could be significantly better or worse at a later time.

The clinicians we shadowed discussed the importance of charting pain over time, and the need to communicate pain accurately with other staff members. Accurate pain assessment was particularly important during the first hour after medication administration, to ensure that the prescribed medications were effective in alleviating a patient's pain. One clinician mentioned that one "bad pain experience" can color all future interactions with a patient, and thus emphasized the importance of proper management and communication.

Two overlapping themes based on inputs from patients and providers were: (1) the need to improve the standard 1–10 pain scales beyond a uni-dimensional construct, and (2) the need to enhance the communication of pain between patients and providers—particularly in terms of understanding one's pain experiences as a multi-dimensional social transaction between patients and providers that recognizes the behavioral, psychosocial, and environmental aspects of pain.

The nice-to-have and must-have features of an improved pain management system (based on patients' and providers' perspectives) is captured in Table 1.

Table 1 Features in an improved pain management system

Must-Have Features	Nice-to-Have Features
• Improve communication between patient and provider (real time communication alerts). • Assist clinicians in making decisions about pharmacological pain relief. • Provide an easy and intuitive to use system for all patients, regardless of mobility limitations. • Recognize the complex, socio-behavioral aspects of pain.	• Provide distraction from pain (through social interaction, gaming, higher level cognitive function, etc.) • Facilitate data sharing, gathering and retrieval for patients and providers. • Provide non-pharmacological therapeutic relief through a pleasant touch and feel for patients, or way to reduce anxiety and restlessness.

4 Early Stage Prototype Development

Early stage prototypes focused on user (patient) technologies (Fig. 2). The first was a device that could be squeezed by a patient when s/he is in pain, and the second was a wearable sensing device. As pain is highly individual, these prototypes focused on capturing the pain episode, its onset and the duration. We envisioned capturing pain episode's as a continuous measure and identifying peaks of intensity that could inform nurses and improve clinical practice related to pain management.

Subsequent physical prototypes built on the concept of sensing and capturing episodes of pain and extended these by exploring how a patient might physically communicate the experience of pain non-verbally. Two methods came forward: a push-button device that could be used to measure pain by interaction frequency (Fig. 3), and a squeeze ball that could be used to measure pain by applied force—grip strength (Fig. 4). Light Emitting Diodes (LEDs) were added to provide visual feedback to the user.

Each physical prototype had different limitations. The use of a push-button device could possibly capture the onset of pain at the time of occurrence, independent to nursing assessment, but would not provide details as to the type, location, intensity, or duration of the pain episode. The device could be repeatedly pushed to indicate increased pain, but this would be difficult to assign meaning and to standardize across a wide population.

Conceivably a squeeze ball would provide nurses with more information on a patient's pain than a push-button device. Squeezing the ball would provide details as to the onset and intensity of the pain episode, but could not capture information

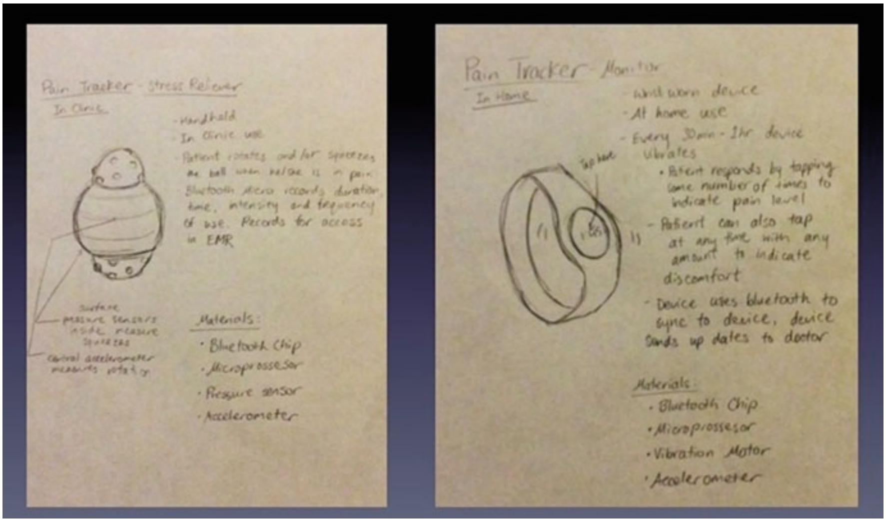

Fig. 2 Initial concepts for pain management prototypes

Fig. 3 Push-button pain tracking prototype

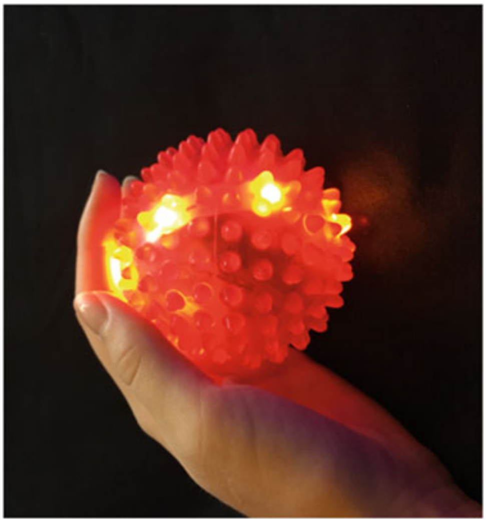

Fig. 4 Squeeze-ball prototype

on the pain's type, location, or duration. Furthermore, it was evident through the squeeze ball prototype that the experience of pain is very different amongst patients. Our insights had been captured primarily from patients who interacted with their environment intensely during a pain episode, through squeezing, shaking, rubbing hands etc. Whereas others in pain may lay still, without the energy or desire to interact with their environment. Therefore despite some advantages to both the push button and squeeze ball prototype over existing verbal assessment of pain, further conceptual development was needed.

5 Summary of Pain Management Pilot Study

From sharing the early conceptual prototypes with providers, we learned (as earlier work has shown), that in order for a new technology, process or intervention to be widely adopted in a health care setting, it must benefit not only the patient, but also the hospital and provider (Shluzas and Leifer 2014). As such, a human-centric, non-pharmacological pain management system with features aimed at enhancing a patient's experience and wellbeing must likewise provide data that enables hospitals to quantitatively track pain levels and to make proper medication dosing decisions. Since expressing pain by grip strength (cross-modality matching) is a more intuitive task than the cognitive process of assigning a numerical value (Gracely 1988), we conducted a pilot study with eight healthy subjects in the Human Pain Experimental Laboratory at Stanford Health Care to determine if the magnitude of pain reported by a hand-squeezing action correlates with numerical pain reports using the standard pain rating scales. The TSA-II NeuroSensory Analyzer (Medoc Inc.) provided graded heat stimuli (up to 52° C) to each subject's forearm. In each session, subjects quantified experienced pain on a numerical pain rating scale or by hand squeeze (dynamometer connected to a wireless data link (Vernier Systems). The pilot data showed a correlation between these two inputs for pain reporting. This preliminary work highlights the possibility of using a physical squeeze interaction as an alternate to nurse's manually recording 1–10 values from standard pain scales, in a patient's EHR—and aims to make the process of communicating pain more direct and intuitive for patients.

6 Discussion and Future Work

To address the problems discussed above and to build on our preliminary pilot study, we aim to conduct future research to refine and test a pain assessment tool that moves beyond the unidimensional pain scale, in an effort to improve communication between patients and providers. Using a design thinking approach, we intend to reframe the problem of pain management to consider strategies that recognize the behavioral, psychosocial, and environmental aspects of pain.

It is recognized that the richness and complexity of the pain experience is inadequately reduced and oversimplified when rated on a unidimensional scale (Williams et al. 2000; Knotkova et al. 2004). Although methodologically convenient, self-reporting pain on unidimensional scales requires the patient to integrate qualities of the experience in unknown ways, leaving important distinctions, such as "differences between sensory-discriminative qualities, intensities, and affective discomfort confounding" (Goodenough et al. 1999).

A glaring problem with self-reported pain on a 1–10 scale is that it excludes a large number of patients because of the cognitive and communicative burden it requires (Hadjistavropoulos et al. 2007). Self-report requires the linguistic comprehension, and social skills necessary to provide a coherent expression of pain; therefore, the strategy is problematic with some of our most vulnerable populations, the cognitively impaired (Abbey et al. 2004), the critically ill, infants, and young children (Walker and Howard 2002).

Even for people who are communicatively and cognitively competent, self-reporting pain using today's standard methods leaves a large potential for bias and interpretive error. An inherent assumption in pain assessment is that the patient wants to minimize his or her pain and that the clinician wants to treat it or alleviate it. This is referred to as the "assumption of mutuality (AoM)" and unfortunately, is far from reality. Patients are often reluctant to self-report pain, and typically assume that clinicians will know they are in pain; yet, clinicians assume that patients will report pain as necessary despite this reluctance (Watt-Watson et al. 2001).

6.1 Communication Problems Between Patients and Providers

Patients provide many reasons for suppressing or masking their report of pain, including a fear of negative consequences. Patients often express concern about inconveniencing clinicians, seeming to be complaining, or having fears of tolerance or addiction to medications; and a belief that pain cannot be relieved (Ameringer et al. 2006; Cleeland et al. 1994). At the other extreme, patients might exaggerate, purposely or unwittingly, their report of pain. Reasons for exaggeration may include efforts to obtain opioids, the so-called drug seeking behaviors (Vukmir 2004), and avoiding responsibilities, or seeking compensation (Mendelson and Mendelson 2004; Mittenberg et al. 2002). A myriad of personal factors have been shown to influence or bias a clinician's response to self-reported pain. These include patients' demographics, such as age, sex, and ethnicity, as well as factors such as *level of empathy, past exposure to pain, and personal beliefs about pain* (Dalton et al. 1998).

6.2 Need for a Conceptual Shift

The American Pain Society introduced "pain as the 5th vital sign" and numerical or visual pain scales currently represent the gold-standard for assessing pain (Claassen 2005). However, to conceptualize pain as "a vital sign" implicitly assumes that it is comparable to the traditional four vital signs pulse, temperature, respiration, and blood pressure. These signs are objectively assessed, physiologically based, and easily obtained in the clinical environment. While the conceptualization of pain as a fifth vital sign highlights its importance, it is also misleading because pain is not easily measurable, nor is it an objective parameter. Pain is a subjective, multidimensional, and interactive experience that may evolve over time.

As such, future research aims to *capture and communicate pain as a dynamic process, a transaction*, between patients and providers. Through a design thinking approach, this work aims to influence behavior change in situations involving shared medical decision-making between patients and providers, for both acute and chronic care situations. Furthermore, future work aims to further develop research collaborations between Stanford's Center for Design Research and the medical community, both at Stanford Health Care and neighboring health care facilities.

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Learning from Success and Failure in Healthcare Innovation: The Story of Tele-Board MED

Anja Perlich, Julia von von Thienen, Matthias Wenzel, and Christoph Meinel

Abstract Tele-Board MED is a digital documentation system for medical encounters. It is used as an adjunct to talk-based mental health interventions. Having reported study results on Tele-Board MED a number of times—which always reflected the favorable aspects of the system—audiences have also been interested in any failures along the way. Indeed, there are two good reasons why such occasional failures are more than an entertaining footnote to a project. First, design thinking holds that they are critical for learning. Second, innovations in the healthcare sector are known to be particularly challenging. In this chapter, we thus reanalyze the Tele-Board MED project, focusing on both successes and failures along the way and tracing their role for the development of the project.

1 Introduction

The Tele-Board MED concept of cooperative medical treatment documentation involving both doctor and patient has progressed in the last four years from a budding idea to a usable prototype. Tele-Board MED (TBM) allows for digital note taking, visual presentations of patient cases and multiple usage of collected information—from patient handouts to early drafts of official clinical documents. Figure 1 shows a system overview including use cases and feature descriptions. Throughout the development and testing steps, we published a collection of TBM study findings that were all favorable. In dialogue with the design thinking research and medical informatics community there was one type of question raised by the audiences over and again: What about failures? What barriers are you facing? Are there contrary positions or opposite effects? These questions are likely to be raised, because an open dialogue on failures is strongly promoted in the design thinking community. Furthermore, creating and diffusing innovations in healthcare services is especially challenging.

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Fig. 1 Tele-Board MED system overview

This chapter draws a comprehensive picture of the Tele-Board MED project flow and illustrates the transition of different prototypes to attempts at real-life implementations in clinical routines. In the evaluation we pay special attention to pitfalls and boosters, thus illuminating how the process moves towards the *bring home* phase (cf. von Thienen and Meinel 2014), and showing how ideas are advanced to make an impact in the real world. We start with a theoretic introduction regarding the notions of "failure" and "success" in approaching complex problems as they typically occur in design challenges. Furthermore, we briefly describe what makes innovation in healthcare especially challenging. In the main part of this chapter, we set out to tell the story of TBM and thereby reconsider the design process (see Fig. 4 for a visual overview). Intermittently, we carry out Success-Failure Analyses, visualizing how different prototypes were able to address certain user needs, and how test results informed subsequent work.

1.1 Analyzing Failure and Success

The subject of learning from both failure and success is deeply engrained in design thinking traditions. Already John Arnold, who planted the seeds of a design thinking culture at Stanford's Mechanical Engineering department in the 1950s, noted that "the fear of making a mistake is a very devastating emotional block to creative activity. People should realize that progress is made through failure as well as through success" (Arnold 1959/2016, p. 86).

Far beyond design thinking, successful prototype tests are recognized as positive results that help innovation projects move ahead. The same does not hold for failing prototypes, though, and this discrepancy warrants an especially careful treatment of failures. Design thinking has a rich tradition in addressing this challenging subject. Writing about the *Gift of Failure*, Roth (2015) observes that "if you are mindful about what you have done, failure is a teacher" (p. 121). Kelley and Kelley (2013) highlight the importance and difficulties of handling negative test results: "While much has been said about fear of failure, it still is the single biggest obstacle people face to creative success" (p. 40). "We give students a chance to fail as soon as possible, in order to maximize the learning time that follows" (p. 44). Hawthorne offers classes on how to *Fail Faster* (e.g., 2015). Royalty et al. (2012) find that design thinking trainings help students handle failures even years after graduation; in self-reports, alumni describe "comfort with seemingly negative states [...] such as failure" (p. 87).

Building on design thinking practices and creativity research, von Thienen et al. (2017a) suggest a *Failure Theory* to support and better understand learning processes that failing prototypes can initiate. This theory holds that failures are an excellent means to advance key domain knowledge. Failures indicate that something in the domain of interest is badly understood by the project team. Examining failed tests can help to pinpoint insufficient ideas and identify directions for the search of intriguing—surprising and effective—solutions (Fig. 2).

Based on *Failure Theory*, von Thienen et al. (2017b) have developed the *Success-Failure Analysis*, a tool for advancing domain knowledge—design thinking style—by means of reflecting on prototype tests. One tool that we will also deploy in

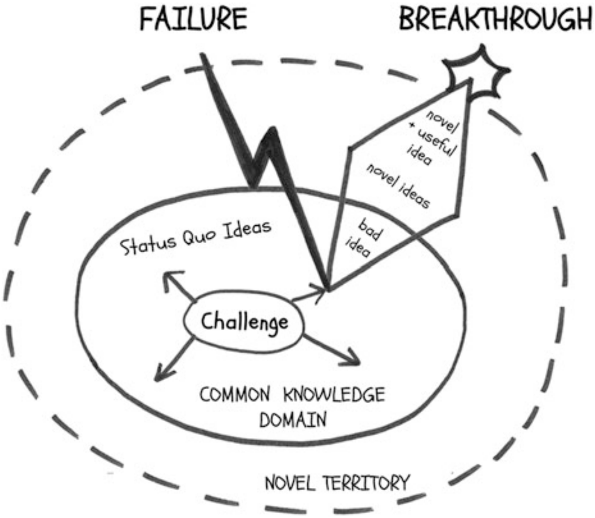

Fig. 2 A failure can be turned into a breakthrough when it is used to identify bad ideas, or questionable beliefs in the Common Knowledge Domain (which contains already existing problem views and solutions in the domain of interest). Then, a divergent search for novel ideas can follow, until the process converges on a novel and useful solution. (Figure reprinted from von Thienen et al. 2017a)

the following is the *Success-Failure Matrix (SF-Matrix)*, which helps teams prepare and analyze prototype tests (Fig. 3). To better understand how prototype tests aid learning, the team is asked to express their domain understanding before they start testing. What needs does the project team focus on, and how important are they presumably? How well does the team think they address user needs with their present prototype? After the test, results are compared to initial expectations. To the degree that findings diverge from expectations, learning can occur. The team can advance their domain understanding.

Building on *Failure Theory*, we differentiate between different types of failures.

Type-1 Failures occur when a team does not yet tackle the “right problem.” Such failures are typically grounded in one or two misapprehensions: (1) A presumed need turned out not to have been worth tackling and/or (2) A critical need has been overlooked and is under-addressed by the prototype. Thus, the team may have to return to the *empathize* or *define* mode (cf. d.school 2010) to learn more about their domain.

Type-2 Failures occur when a team tackles the “right problem,” but does not yet have a good solution. In that case, the team will have to return to *ideation* and *prototyping*.

Mini Failures mean that the team expects their prototype to perform badly, and so it does. Such a result can occur both in the case of known or unknown needs.

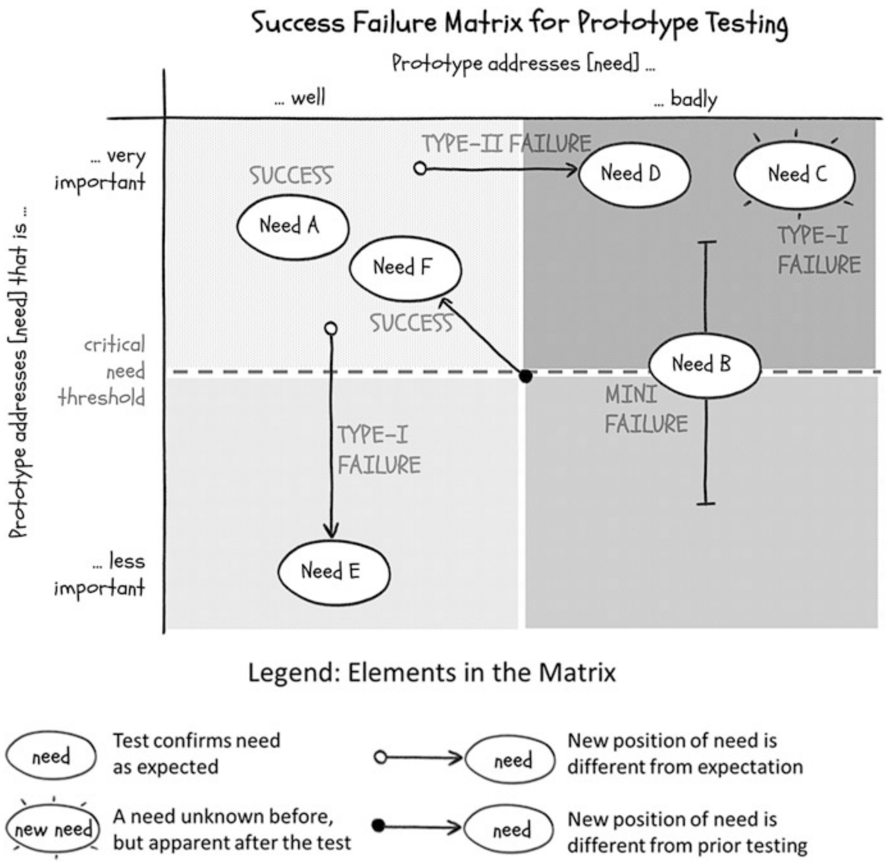

Fig. 3 The success failure matrix reflects how well a team already understands their domain, as evidenced by prototype tests. In line with design thinking values, this analysis focuses on user needs when asking for the domain knowledge of a team. When a prototype addresses all important needs well (i.e., test users are fully convinced of its qualities and want to adopt the novel solution), the test is successful and the innovation project can proceed without further iterations. When a prototype fails to address one or more critical needs well, or addresses the wrong needs, the team has the opportunity to advance their domain understanding. Unaddressed needs may be clear or unclear after the test. Understanding them better likely becomes a major goal of subsequent work

The prototype turns out to be as ineffective and inefficient as it was expected to be. Empirical evidence suggests that mini-failing prototypes benefit creative work more than testing no prototypes (cf. von Thienen et al. 2017a). Mini failures are tools for learning by clarifying the problem and solution space.

Success means that a prototype addresses a central need well. Already existing beliefs about problem and solution space are reinforced (e.g., a hunch becomes a conviction) and some novel beliefs, knowledge or ideas may be added. When all central user needs are well addressed, the project moves into the *bring home* phase where the solution is advanced to impact the world.

1.2 Innovation Challenges in the Healthcare Sector

Many design thinking projects end with prototype testing, and only a few project teams succeed in enhancing and refining their final idea to an innovation that impacts real life by entering existing structures and organizations. Creating and diffusing innovations in healthcare services is especially challenging. Healthcare personal is relatively unprepared to take risks, and their professional work is subject to legal duties and regulations. Any available time they have is most likely to be assigned to patient care rather than to dealing with new things.

Greenhalgh et al. (2004) define innovation in health service delivery and organization as "a novel set of behaviors, routines, and ways of working that are directed at improving health outcomes, administrative efficiency, cost effectiveness, or users' experience and that are implemented by planned and coordinated actions" (p. 582). They list a number of key innovation attributes that influence the adoption of something new: relative advantage, compatibility with users' values, complexity, possibilities to experiment, observability of benefits, potential for individual reinvention, boundaries where innovation and organizational structures meet, uncertainty of outcome and its perception as risky, relevance for users' tasks, knowledge required to use it, and user support. These attributes, however, are neither stable features of the innovation nor secure determinants of adoption. Instead, it is the interaction of the innovation, the intended users, and their specific context that determines whether and how an innovation is implemented. We will come back to these attributes in our conclusion.

There are various kinds of innovations in health care (Herzlinger 2006). Business model innovation may reshape the organization and delivery of medical care. Innovations building on a patient-centered approach can change the ways patients, or consumers, use health care. Technological innovations can lead to novel diagnostic and treatment methods, new drugs, medical devices, monitoring sensors, body parts produced by 3D printers assembling cells, and so forth.

Tele-Board MED is a health information technology innovation. Thompson and Brailer (2004) define health information technology as "the application of information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of health care information, data, and knowledge for communication and decision making" (p. 38). There are numerous attempts to understand the creation and diffusion of innovation in healthcare. The *Technology Acceptance Model* and its variations aim for predicting and explaining end user reactions towards technology (Holden and Karsh 2010).

2 The Tele-Board MED Story

In this section we tell the story of the Tele-Board MED project in a holistic way touching upon both successes and failures of different prototypes. We summarize and reflect upon our practical experiences using the SF-Matrix (Fig. 3). A visual overview of our project story is shown in Fig. 4.

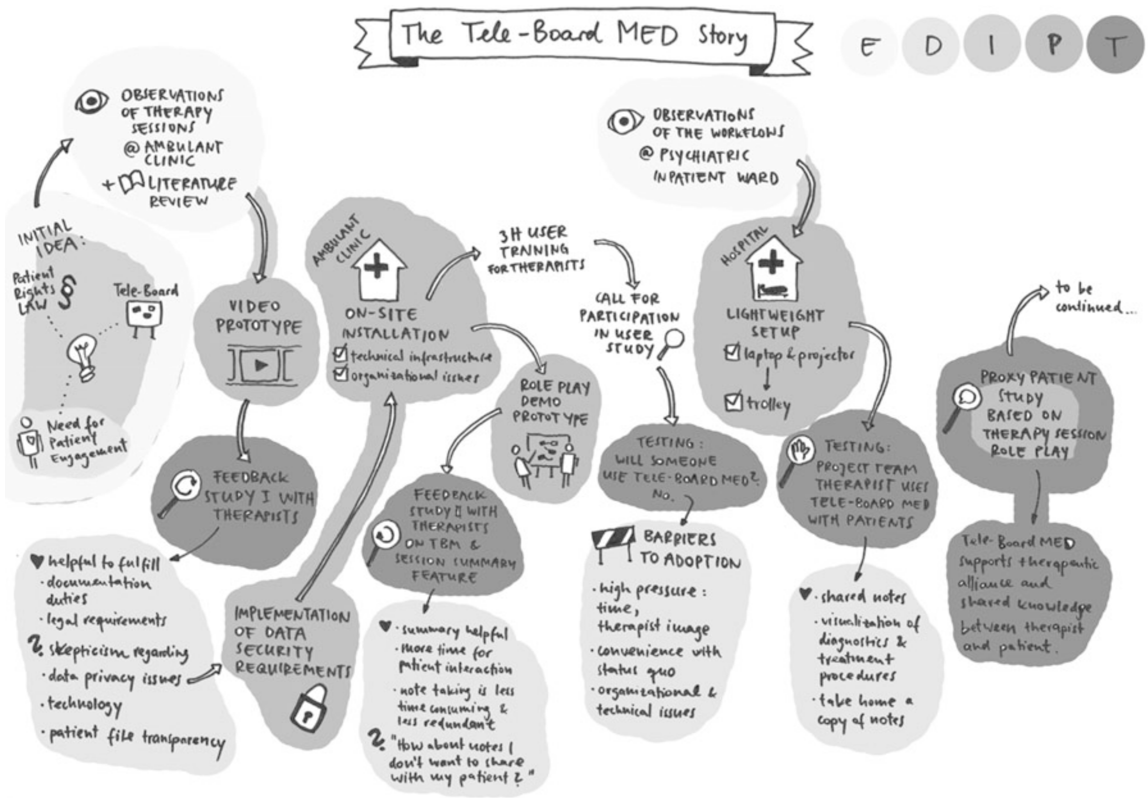

Fig. 4 A visual overview of the Tele-Board MED project story. The steps we took can be related to the design thinking process phases: **E**mpathize, **D**efine, **I**deate, **P**rototype, **T**est (d.school 2010)

2.1 The Idea Is Born

The initial idea was born when Germany passed a new law to consolidate patient rights in medical encounters (Bundesgesetz 2013). Among other regulations, it calls for complete record transparency and grants patients the right to obtain electronic copies of their files any time. For psychotherapists, fulfilling these requirements seemed almost impossible. The common documentation approach was handwriting, yielding files that were neither well readable for patients nor easily available in an electronic format. As an additional concern, handwritten piles of paper appeared increasingly outdated as treatment documentation. Moreover, therapists had to create official case documents regularly, where they ended up retyping handwritten treatment notes into a computer. These were more than enough reasons to think about a change.

In an ambulant psychotherapeutic clinic, the two clinic directors and a therapist who also worked as a design thinking researcher sat together and wondered how a better solution could be found for the future. That was when Tele-Board came into play. Tele-Board is a software tool that simulates a whiteboard and allows digital note taking and visualizing with a tip of the finger (Gumienny et al. 2011; Gericke et al. 2012; Wenzel et al. 2013). What if the documentation of treatment sessions could be done jointly with the patient through simple and quick gestures? Could this be a feasible way of creating digital notes during treatment sessions? These ideas were just the start of our journey.

The clinic directors decided to give it a try, and a research agreement was signed to develop “Tele-Board MED” and use the system in the clinic. In the meantime, the therapist studied prevailing documentation routines in detail. The writing of case reports after a certain number of therapy sessions is a crucial part. In order to obtain funding for treatments from the social health insurance, therapists have to write reports which describe the patient case, analyze the problem, and propose a treatment plan. Practically, this involves browsing through session memos, questionnaires, and work sheets, and deciphering handwriting. Information is oftentimes captured multiple times and searching for information in piles of handwritten notes can be a time-intensive task.

2.2 Dry Run with Psychotherapists

In order to introduce Tele-Board MED (TBM) to the group of therapists at the ambulant clinic, we created a short video of 15 min that illustrates the new requirements on medical case documentation and the concept of TBM in use cases, setup, interaction, features, and hardware options (cf. Fig. 5b). With our

Fig. 5 A history of prototypes, from conveying the idea to working prototypes of Tele-Board MED (TBM). (**a**) Picture prototype: the general idea of interacting with TBM. (**b**) Video prototype: 15 min explanation of therapist's needs in fulfilling the new legal requirements and the challenges around creating case reports, as well as a demonstration on how TBM works and addresses user needs. (**c**) Role play to demonstrate the TBM real-world prototype in an ambulant clinic–Part I: 30 min rehearsed role play by the project team, Part II: 20 min improvised role play with the therapist from the project team and a participant as a patient. (**d**) Working prototype in a psychiatric ward. TBM is used with a laptop, a projector, and a wireless keyboard. In order to improve mobility, we stored the devices, including a printer, in a trolley

video prototype at hand we were able to present the idea to potential users. We conducted a survey and sent out emails to the therapists working at the ambulant clinic that included a link to the video and a questionnaire. The latter was designed to investigate their attitude towards and use of technology, as well as their perception of the usefulness of TBM. It contained a wide range of quantitative and qualitative items. What participants liked most about TBM was how it supported them in administrative documentation tasks and in fulfilling legal requirements. The evaluation of responses regarding documentation tasks showed that therapists could save one third of their normal working time when assembling case reports based on the digital notes taken with Tele-Board MED (von Thienen et al. 2015; Perlich et al. 2014). Skepticism was found regarding several issues; the evaluation revealed the following crucial questions:

- Will the therapeutic relationship between therapist and patient be impeded when they operate a computer system and look at a screen during their therapeutic dialogue?
- How difficult or easy will it be for therapist and patient to learn the usage of the system? How time-consuming will it be?
- Is the full transparency of patient files requested by law favorable for therapy success at all?
- Is digital note taking worth the risk of unauthorized patient data access?

These questions set the course for further developments. The possible effects of TBM on the therapeutic relationship should be tested in practice with a usable system. In practical trainings, therapists should learn how to use the system. The full transparency required by law would be a prerequisite for our work. High standards in patient data security should be of top priority in the design of TBM for the real world.

2.3 Early Internal Testing

Parallel to the establishment of contacts at clinical institutions, we conducted user tests within the research team and our academic environment. As early, non-clinical evaluations, we role-played psychotherapy sessions with therapist, patient, and TBM on a digital whiteboard. Real-to-life anamnesis sessions were led by our therapist team member. Several colleagues were asked to tell their own or invent a story, and act out a conversation in their first meeting with the therapist. This way, the therapist team member was able to practice the use of TBM with a "patient." The application's graphical interface was better adapted to medical encounters. Documentation panel templates for specific use cases were created and tested.

2.4 The First Real-World Tele-Board MED Prototype

The project team including the directors of the ambulant clinic considered the implementation of data security measures to be of the highest priority. Here, we followed the recommendations of the German Medical Association that are based on the European Data Protection Directive. A dedicated server running the web-based TBM application, including the database, was set up and integrated in the clinic's local network, but disconnected from the public internet (Perlich et al. 2015). The server's hard disk was encrypted, and mechanisms were put in place to create secure backups on a daily basis. Once the setup was finished, TBM was accessible on clinic desktop computers and laptops connected to the network. Most notably, one room in their premises was equipped with a dedicated digital whiteboard and other supplementary hardware devices, such as wireless keyboards and tablet computers—two of each for both patient and therapist. The furniture, which typically consists of two chairs and a small table, was extended to include a standing desk on wheels.

The setup involved close collaboration with the system administrators of the clinic on infrastructural and technical issues. We encountered manifold challenges ranging from drilling holes for laying network cables to coordinating the occupancy of the TBM room for system installation and introduction sessions. Hence, the investment of time and resources for the preparation of TBM's first real-world application was fairly high. By the time the system was set up and introduced, the intended clinical training period of the therapist as a member of our research team had unfortunately come to an end. The consequences of the absence of our therapist team member as a "super user" advocate for TBM would soon be visible.

2.5 Wet Run at the Ambulant Clinic (Which Fizzled Out Before It Had Hardly Begun)

Once the system was set up, after about four months we invited the therapists working at the ambulant psychotherapeutic clinic to several events to spread the word on TBM. In the first introductory event we presented a role play of an individual psychotherapeutic treatment session with TBM (cf. Fig. 5c). This turned into an improvisational play where several participants one after the other took on the therapist's role. Thereby they got an impression of how it feels to have TBM as a "third player" in the patient encounter.

As part of this introductory event we conducted a survey to collect feedback from the therapists. The questionnaire addressed their note taking habits, their attitude towards technology-supported documentation, and their opinion on TBM including its session summary feature (Perlich and Meinel 2015; von Thienen et al. 2016). We learned that therapists need to find a good balance between giving their full attention to the patient and capturing important contents immediately, so as not to forget it. The wish of reducing time for administrative documentation tasks was as boldly stated as in the first feedback study. A crucial point was also raised on the sensitive nature of patient notes. What if the therapist wants to write down a personal thought that could potentially offend the patient? This might not only hurt the patient's feelings; it could ruin the therapeutic relationship and even end the treatment.

Furthermore, we conducted two 3-h schooling events with therapists at the ambulant clinic where the TBM system with its basic software features and the available hardware equipment were presented. The participants who brought laptops were able to log in with individual credentials and try it on their own devices. There was positive feedback by the therapists (e.g., one therapist who tried the system herself said that its use was intuitive). Another therapist was eager to start using it in treatments. However, this person was seeing patients in an office of the clinic where TBM was not available due to computer network issues.

We ended the introductory training sessions with an invitation to participate in our planned TBM user study. Information sheets describing the goals and conditions of the study were handed out. The planned study was aiming at clarifying whether TBM improves the patient-therapist relationship and whether its usage can lead to a better, faster documentation of higher quality with less errors. The study was designed for six therapists treating four patients each over a total of 15 sessions. Two study conditions were intended in order to compare therapy sessions with and without TBM. All study participants should receive financial compensation. Interested participants had the option of receiving additional training on using TBM.

After the described schooling events, which we ran twice, we waited for responses. We waited a couple of days. We waited for a couple of weeks. Nobody signaled interest for either study participation or system usage. The log files on the server indicated only very little usage activity during and shortly after the introductory events.

2.6 Inquiry About Barriers

After all the effort we had put into the setup and introduction of TBM in the ambulant clinic we were at a loss to explain why we had not been able to convince a single user. We had failed.

Slowly but steadily we tried to make sense of what went wrong. The clinic clearly faced challenges of providing rooms for every therapist and treatment. Therapists had to make room booking weeks or even months in advance of meeting with a patient. We had hoped to create an incentive for TBM use by prioritizing therapists who actually wanted to use the system in the room with the interactive whiteboard. However, booking the room in advance in order to become familiar with the whiteboard device was still complicated and thus would have required a very high motivation. We further asked ourselves whether the study conditions were incompatible with therapists' opinions. While one therapist stated that she would make the use of TBM depending on the respective patient, the proposed study design suggested fixed distributions of sessions with and without TBM. Oral feedback statements during the introductory events had pointed at the perceived complexity of the system. One person said: "I would only use the system when I feel confident about it. It seems demanding to use the system—I would have to learn how to operate the devices and how to use the software". Another person asked: "How much time do I have to plan to get used to working with Tele-Board MED?"

About 5 months later and after consultation with the clinic directors, we sent out an email to all participants of the introductory events with a questionnaire regarding potential barriers to the usage of TBM. Out of 21 recipients only two people (male and female) sent the completed questionnaire back to us. Both stated that they were not interested in using TBM for several reasons. The technical preparations at the beginning of the therapy session would take too much time. They did not feel confident enough in operating the system together with patients. They neither saw an added value for themselves as therapist nor for their patients. They thought it would harm their therapeutic relationship.

We analyzed the user reactions to our first real-world prototype with the SF-Matrix shown in Fig. 6. All therapists in the ambulant clinic acknowledge that they can create thorough documentation with TBM, where there may likely be fewer errors due to the double-check procedure that now includes doctor and patient. This

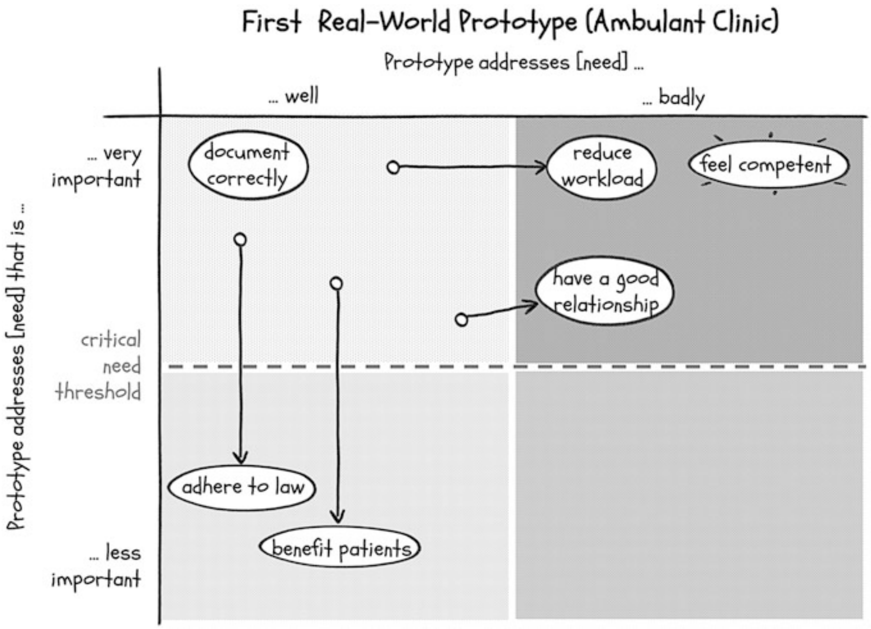

Fig. 6 Success-Failure Analysis of the first real-world prototype (cf. Fig. 5c)

is a success. However, the test shows that therapists rather use their handwritten documentation strategy than TBM, well-aware that they fail to adhere to new legal requirements with handwritten notes. Adhering to the law just doesn't seem so important. Offering patients additional benefits such as print-outs after the session seems even less important as an incentive for using TBM. Both adherence to law and additional benefits are granted by TBM, but seem to be of minor importance. Here, we face type-1 failures. However, we decided not to disregard these needs in the future as they are crucial for health care, even if they are not decisive aspects of system usage. Furthermore, therapists are expected to experience a reduced workload with TBM due to the creation of digital notes that are immediately available for official case documents. However, therapists obviously experience an increased workload instead. They have to learn how to handle the novel technology; they have to start the system ahead of therapy sessions; they need to book the specially equipped treatment room etc. This is a type-2 failure: An important need is badly addressed. Also, that therapists express doubts as to whether the technology would really aid therapist-patient relationships reflects another type-2 failure. Finally, there appears to be a completely unaddressed need that the team did not anticipate to such an extent. Therapists want to feel competent in front of their patients. Unfamiliar technology (both software and hardware) bears great risks in this regard—another type-1 failure.

2.7 New Start with a Second Real-World Tele-Board MED Prototype

While we were still waiting for reactions to our call for testing TBM in the ambulant clinic, new chances opened up in a hospital. Our therapist team member started to work at a psychiatric inpatient ward. We came to the agreement with the ward's director that our therapist team member would document treatment sessions with TBM. In the beginning, she closely observed the daily routines on site, saw patients and talked to staff members. The workflows at the hospital were, in contrast to the ambulant clinic, determined by around-the-clock patient care in day and night shifts. Hence, several health professionals were responsible for one patient and handovers of patient information among staff took place on a daily basis. Moreover, therapists had to be very flexible in the rooms they would use for treatment sessions. Therefore, the stationary setup of TBM with an interactive whiteboard situated in one room was not suitable in this context. We changed the setup to a more basic and flexible one, consisting of a laptop, a projector and a wireless keyboard with touchpad. In order to improve the mobility, we stored the devices including a printer in a trolley on wheels (see Fig. 5d). This way, the therapist was able to prepare documentation panels before the session in any available room. When it was time to see the patient, the trolley was moved, some cables were plugged and the session could start. The dismantling after the session could be realized as quickly. Thus, it took up only very little of the precious treatment time. This mobile setup had more parallels to the analogue way of handling records right before and after the treatment session. Usually, therapists get ready to meet the patient by looking up notes of previous sessions and by preparing some material. When the time has come, notes are folded and taken in the treatment room, and the patient can be invited in.

Our therapist experienced the usage of TBM with about 20 patients in diagnostics and treatment sessions. The joint note taking activity and the visual presentation of therapeutic content in simple language led to an increased acceptance of diagnoses and to patient-therapist bonding (Perlich and Meinel 2016). The print-outs of the notes served as more than just memory aids for patients to take home with them. It also eased the information handover to staff members. But even though therapist colleagues were able to notice the benefits of the system, they were not seriously interested in using it. We realized that risk aversion is very high: when something is unknown it is avoided. Besides that, the time and performance pressure on the ward staff is immense. However, the patient feedback was clearly positive. They were thankful for the transparent and cooperative treatment approach. Patients were also able to better understand their problems and appreciated the print-outs to take with them for self-reflection and sharing with others (Perlich et al. 2017a).

The user test with our second real-world prototype at the hospital was again analyzed with the SF-Matrix (see Fig. 7). As the prototype before (cf. Fig. 6), TBM in its novel setup helps with correct documentation. The following aspects

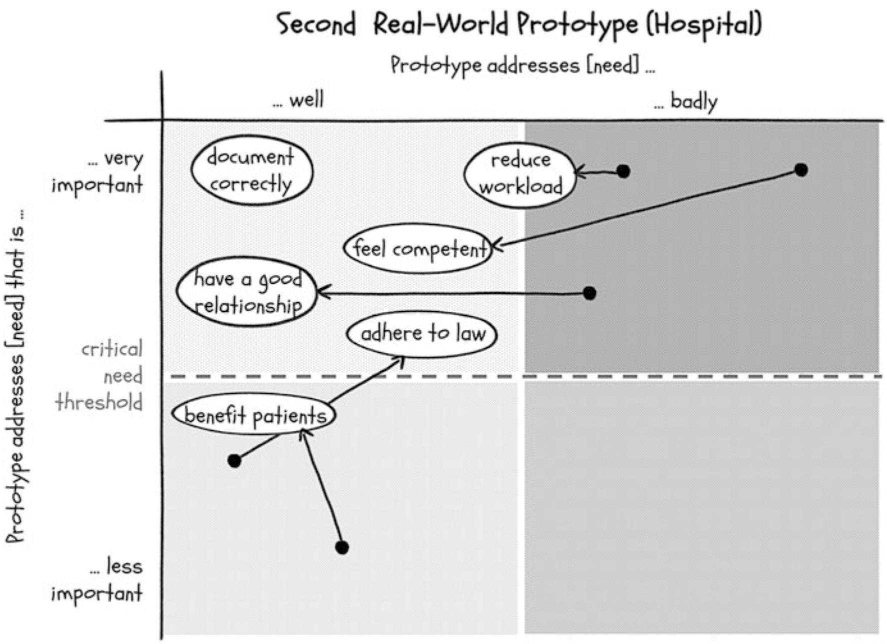

Fig. 7 Success-Failure Analysis of the second real-world prototype (cf. Fig. 5d)

represent improvements and thus move towards success. Feedback from patients and observations in the hospital show that using TBM affects interactions and relationships positively. By means of in-advance training, the therapist acquires a feeling of security and technology competence, allowing for a non-hesitant usage of the system. With the novel prototype, the workload is reduced. However, setting up the system ahead of each session and removing it afterwards still remains a challenge since it takes a minute or two, but, ideally, should only take a few seconds. In the hospital environment, adherence to laws is considered very important. The novel prototype fulfils basic requirements but is not as sophisticated as the complex system that was created for the ambulant setting. As patients express their appreciation for some TBM features, such as obtaining print-outs after the session, these benefits tend to be valued more than in the first prototype testing. However, the possibility of providing these benefits with TBM would, at the same time, not increase the number of therapists who use the system. Thus the corresponding needs do not appear central; they remain below the critical need threshold.

2.8 Learning from Proxy Patients in a Non-Clinical Context

Our latest studies were designed in a way to test the effects of TBM independent of a clinical institution. We presented TBM in the form of an impromptu role play that showcased a therapeutic dialogue to a multidisciplinary audience. The role of the psychotherapist was played by our therapist team member. The patient role was played by a person from the audience who spontaneously volunteered to share a personal problem. The role play contained two parts (with and without TBM), each of which was followed by data collection. Both the audience and the volunteer "proxy patient" filled out questionnaires. The participants observed positive effects of TBM on the creation of shared knowledge and therapeutic alliance between patient and care provider. The latter aspect indicates that TBM strengthens therapeutic communication, integration, collaboration, and patient empowerment (Perlich et al. 2017b). This study setup allowed us to test the effects of TBM independent of therapists' time and professional image pressure that comes with the workload in clinics. The investigation delivered valid answers to the repeatedly raised issue about the effects of technology use on the therapeutic relationship.

3 Conclusion

The quintessence of the evaluation of our design process is that understanding and addressing failures has been vital to advance the project—sometimes in the sense of overcoming obstacles and sometimes in the sense of gaining new inspirations. Failures along the way helped us gain a better understanding and differentiation of the complex nature of user needs in mental health care. When designing technology interventions for psychotherapy sessions, both perspectives of therapists and patients call for particular consideration, as well as the dynamics in their encounter. While patients readily accepted the new way of documentation in therapy sessions and even thanked our therapist team member for advancing their understanding of therapeutic procedures, our potential therapist users on the other hand were anything but easy to convince about including the system in their patient care routines. Their refusal provided impetus for us in striving towards expanding our knowledge about the therapists' day-to-day practices and their context-specific needs.

Our practical experiences regarding beneficial and deleterious factors on Tele-Board MED's way to clinical practice can be related to the innovation key attributes that we described earlier in this chapter (cf. Greenhalgh et al. 2004). The first real-world prototype (the TBM setup in the ambulant clinic) has not been adopted by therapists at this point for several reasons. In our introduction we placed great emphasis on TBM's relative advantages of fulfilling legal requirements and of documenting digitally. We highlighted that the performances of the therapists' documentation tasks will be improved as digital notes can be taken directly and reused for clinical documents. However, the presumed reduction of workload was diluted by the perceived burden of learning and integrating a new technological system. We were confident and optimistic that many therapists would use the system, as it was compatible with the patients' rights law and its call for patient-therapist cooperation at eye level. However, this law did not necessarily reflect the therapists' values and needs. In addition to that, our prototype at the ambulant clinic was perceived as too complex, since it was presented as an ensemble of novel hardware devices, such as the digital whiteboard, and plenty of software features. We paid too little attention to how therapists would smoothly integrate the system in their work practices and ways to provide them with the knowledge they would have required to use the system. While we gave the therapists the chance to try the software application on their own by providing them with login credentials for TBM, we realized that the barriers for experimenting with the whiteboard device were too high. It was not easy to book the specific room for individual trials of the system. Our call for study participation in the introduction certainly added to the perceived complexity. Furthermore, we underestimated the perceived personal risks of therapists. Even though the directors of the ambulant clinic had a favorable position towards TBM, they did not provide any incentives for therapists and the usage was an optional choice. This meant that therapists would have had to bear the full responsibility for the resulting effects. Seemingly the balance between risks and benefits was not appropriate.

The second real-world prototype in the hospital ward was characterized by its lightweight hardware setup including laptop, projector, and printer in a trolley.

Since we reduced the "hard core" to the software application and adopted the hardware to conditions in the clinic, it was more flexible to fit in the ward procedures and more convenient to use in any available room. The major factor for successful practical usage was the commitment of our therapist team member. While she used

TBM at the hospital ward, staff members could observe the benefits of legible and visible notes when information handovers and staff meetings took place.

In sum, it remains a demanding task to address personal therapist needs comprehensively, including the need to feel at ease with handling technology in treatment sessions. However, we can say that TBM addresses key challenges that mental healthcare services are facing: "The need to improve the outcomes of interventions by improving the effectiveness of treatments and increasing the levels to which clients successfully engage with treatments" (Doherty et al. 2010, p. 244).

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The Design Thinking Methodology at Work: Semi-Automated Interactive Recovery

Joachim Hänsel and Holger Giese

Abstract The methodology of Design Thinking (DT) suggests a repertoire of methods and techniques that lead to different forms of the DT methodology in practice. Which methods and techniques have been employed is of special interest to stakeholders, such as project managers and researchers. However, the repertoire of these methods and techniques does not convey much concerning the order of employed methods and techniques in practice. Capturing the employed DT methodology is difficult, because the subjectively perceived and objectively employed DT methodology may differ. In our former work, we implemented recovery rules that successfully reconstructed the DT methodology from captured DT project documentation. Our qualitative evaluation shows that the methodology could be reconstructed without human intervention with a confidence of approx. 50–80%. However, in order to draw valid conclusions about DT methodologies use a higher level of confidence must be achieved. Therefore, to proceed from a qualitative to quantitative analysis of employed DT methodologies we extended our recovery approach to a semi-automated recovery approach to (a) increase the completeness and accuracy of the reconstructed methodology and (b) use insights gained during the semi-automated recovery to enhance the recovery rules.

In this chapter, we report on our extended semi-automated recovery approach. As a preliminary result of our experiments, we conclude that our semi-automated interactive recovery approach can be employed to increase the completeness and accuracy of the reconstructed methodology. By using insights gained during the semi-automated recovery to enhance the recovery rules and therefore allow to proceed from a qualitative to quantitative analysis of used DT methodologies.

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1 Introduction

When applying the methodology of Design Thinking (DT) (Meinel and Leifer 2011; Plattner and Meinel 2009) a repertoire of different methods and techniques can be employed and therefore the application of the DT methodology can lead to very different forms in practice. For stakeholders such as students, teachers, project managers, or researchers it is of particular interest which concrete methods and techniques have been implemented for a given project. For example, from an educational perspective, DT students want to look back and reflect about their employed methodology, while DT teachers are interested in getting an overview of the students' project. From a business perspective, project managers want to know whether the project finishes on time with an innovative outcome. From a researcher's perspective, it is fundamental to understand which flow of phases, methods, techniques, and artifacts was employed to enable valid conclusions about creativity and innovation.

It is therefore very crucial to understand the actual implementation of the DT methodology in order to fulfill the individual needs of the mentioned stakeholders. However, the repertoire of methods and techniques does not convey much concerning the order of applying methods and techniques in practice. Furthermore, capturing the employed DT methodology in practice is a difficult task, because the subjectively perceived and objectively employed DT methodology may differ.

In our former work (Beyhl and Giese 2015b), we successfully recovered the structured flow of phases, methods, techniques, and artifacts to reconstruct the employed DT methodology of several educational DT projects. We did this by exploiting that the design artifacts are manifestations of the methodology at work as depicted by Fig. 1.

The recovery of the structured flow of phases, methods, techniques, and artifacts as outlined in Beyhl and Giese (2015b) is achieved by (a) capturing created DT

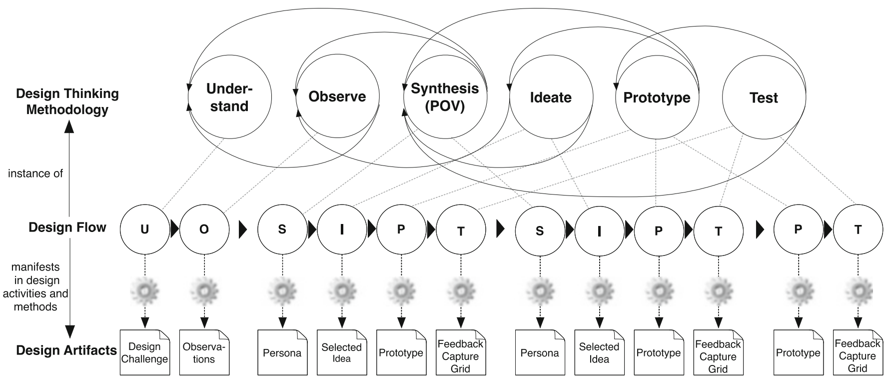

Fig. 1 Relation between the design thinking methodology, the design thinking methodology at work, and the design artifact for a design thinking project (Beyhl and Giese 2016b)

artifacts and (b) analyzing these DT artifacts, with the help of recovery rules to recover the employed DT methodology as depicted by Fig. 2. Our approach consists of an active repository that stores captured DT project documentation (A), an ontology (B) that describes which kinds of information need to be recovered, and a search index (F) that stores the recovery results. The recovery results are created by recovery modules (C) that are composed as a recovery model (D) made up of dependent recovery modules. The recovery model is executed by the recovery engine (E) that reuses already recovered lower-level information to infer higher-level information as described by the recovery model. The user can access this information and state its specific queries via the query engine (G).

Our qualitative evaluation (Beyhl and Giese 2015b) shows that the employed methodology could be reconstructed without human intervention with a confidence rating of approx. 50–80%, depending on the kinds of information that are recovered. However, to be able to draw valid conclusions about employed DT methodologies in practice, a higher confidence needs to be achieved. Therefore, in this chapter we extended our recovery approach to a semi-automated interactive recovery approach for three reasons. First, we would like to increase the completeness and accuracy of the recovered DT methodology. Second, we plan to use the insights gained during the semi-automated recovery to enhance the recovery rules themselves. Third, by doing so we proceed from a qualitative to a semi-automated quantitative analysis of employed DT methodologies, when the recovery rules yield results that are complete and accurate enough.

Current DT research shows that creating documentation in DT projects, which also should include information about the employed DT methods and techniques, is perceived as obstructive by Design Thinkers (Beyhl et al. 2013a). The consensus of the DT research community shows that asking Design Thinkers to document their projects for the sole purpose of search is not appropriate. Furthermore immediate benefits are necessary to motivate Design Thinkers to document their projects (Beyhl and Giese 2015a).

While current research has focused on capturing the artifacts and design rationales created by Design Thinkers [e.g., Tele-Board (Gumienny et al. 2012), Project-Zoom (Beyhl et al. 2013b; Beyhl and Giese 2015a), LogCal (Menning et al. 2014)], it has neglected to capture in detail the methods and techniques employed. Our automated recovery approach (Beyhl and Giese 2015a, 2015b, 2016a) permits automatically recovering the design journey of innovators. However, the approach is not interactive and tailored to take additional manual annotations into account.

Current research activities investigate and measure team interaction (see Sect. 2.2), focus on the internal structure of design steps, or provide different Design Thinking process models. These activities aim to explain the nature of Design Thinking instead of reflecting real design flows. The existing work has thus a *microscopic view* on design flows, because it focuses on certain aspects of the overall design flow. In contrast to the existing work, our approach investigates the whole design flow including design phases, activities, and techniques. Therefore,

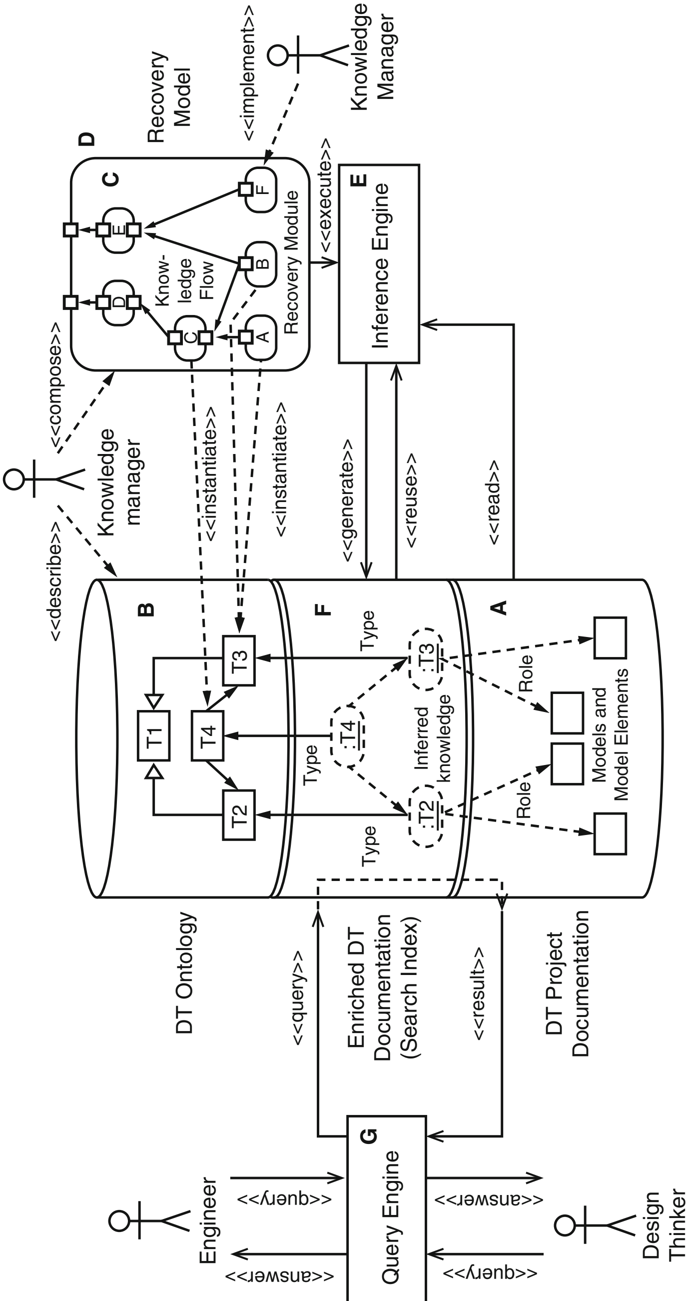

Fig. 2 Inference engine and its elements [from Beyhl and Giese (2016c)]

our approach has a *macroscopic view* of design flows. We are especially interested in the order of design phases, activities, and techniques and the rationales for the transitions between these design steps.

First we report on related work concerning already existing innovation process models and theories by summarizing these in Sect. 2. In Sect. 3, we motivate the suggested approach for a semi-automated recovery of design thinking methodology at work. Afterwards in Sect. 4, we describe how our approach supports the interactive enrichment of the artifacts and how the inference engine interactively improves its findings based on the enrichment. We summarize our research results in Sect. 5.

2 State of the Art

There are several process models and theories concerning innovation and research covering how to capture, recover, and trace the design flow in innovation projects. An additional area of study is how design team behavior and design decisions may influence the resulting overall design flow. However, currently no approach to interactively recover the innovation process at work appears to exist. Therefore, we will first describe the main existing innovation process models and theories in Sect. 2.1. Then, we review approaches covering design team behavior in relation to design decisions and their impact on the overall design flow in Sect. 2.2. Finally, we discuss related research how to capture, recover, and trace the design flow of innovation projects including our own research in Sect. 2.3 and discuss the relation to the interactive recovery approached in this chapter.

2.1 Innovation Process Models and Theories

Different innovation process models and theories exist in the scientific literature.

According to Meinel and Leifer (2011) the Design Thinking methodology is a rather chaotic model that emphasizes “learning through rapid conceptual prototyping” and consists of five major steps: (re)defining the problem, need finding and benchmarking, ideate, prototype, and test. Similarly, the didactic model outlined in Plattner and Meinel (2009) suggests six quite similar design phases: understand, observe, define point of view, ideate, prototype and test. The didactic model sketched in Institute of Design at Stanford (2010) suggests five design phases the main difference being that the empathize phase is a combination of the understand and observe phases of Plattner and Meinel (2009). In Lindberg et al. (2008, 2011) the Design Thinking methodology is consequently described as “a broad problem solving methodology that is as such no process, but shapes processes” criticizing that didactic models (e.g., Meinel and Leifer 2011; Plattner and Meinel 2009; Institute of Design at Stanford 2010) “entail a certain danger of misinterpretation when they are interpreted too orthodoxly". Therefore, an alternative conceptualization is suggested that employs the terms "working modes" and "working rules" instead of traditional process terminology.

The situation concerning the more general topic of innovation processes is quite similar. In Brown (2009) innovation is described as a "system of overlapping spaces rather than a sequence of orderly steps." These considered spaces are inspiration, ideation, and implementation. It is emphasized that "Design Thinking is an exploratory process" where the phases are passed several times. In Skogstad and Leifer (2011) the "Unified Innovation Process Model for Engineering Designers and Managers" is proposed. It is stated that "designers have limited ability to plan for insight discovery" and that the activities plan, execute, and synthesize are combined into a process model where several interruption points allow the necessary interaction between designers and managers. Finally, in Edelman and Leifer (2012) designing is considered to determine a path by way of finding and dealing with "making significant changes to an object" and navigation dealing with "making incremental changes to an object" as parts of the design flow.

2.2 Design Team Behavior

Design team behavior analysis in the literature either observes the design teams in real-time or analyzes the behavior of the design teams retrospectively.

TeamSense described in Kress and Sadler (2014) falls into the first class that aims at accelerating the collaborative design flow using unobtrusive sensors in the design workspaces in order to detect patterns of team activity and provide related feedback to design teams based on the detected pattern. TeamSense further evolved to provide more insights about design team performances to the design team, design team coaches, and team managers (Sadler and Leifer 2015).

The Interaction Dynamics Notation (IDN) (Sonalkar et al. 2016) supports in analyzing design team behaviors and interaction as a diagnostic instrument that isolate interaction behaviors of design teams that influence design outcomes. Its goal is to improve the performance of a design team and thus indirectly also the design outcomes.

All of these approaches provide a microscopic view of design flows, because they focus on certain aspects of the overall design flow. In contrast to the existing research, our research investigates the whole design flow including design phases, activities, and techniques and therefore has a *macroscopic view* of design flows.

2.3 Capturing, Recovering, and Tracing Innovation

LogCal (Menning et al. 2014) is an analog paper tool for capturing and tracing information in the context of design thinking projects. It enables the template-based documentation of design thinking projects employing Plan-Do-Check-Act (PDCA) cycles. In these cycles the students document their design project and thereby also create and retrieve design rationales and reflect on their design flow. However, the tool LogCal only provides a means of capturing the employed design flow, but no way of recovering knowledge which was not provided explicitly.

A digital tool ProjectZoom (Beyhl et al. 2013b), which we developed in cooperation with the HPI School of Design Thinking, supports students while documenting their design projects by providing a virtual whiteboard. ProjectZoom permits aggregating design artifacts stored in multiple digital repositories and thus enables students to cluster and interrelate these artifacts on the whiteboard. They can draw circles around artifacts and lines between artifacts and create clusters. Furthermore it allows adding textual annotations to artifacts, lines, and circles.

In practice, process mining is used to capture and visualize the flow of employed methods and techniques as well as created artifacts for structured processes (van der Aalst and Giinther 2007). Thereby, process mining enables process discovery, monitoring, and improvement. However, process mining research is based on processing structured data, such as event logs provided by process engines. In DT such structured process data does not exist and, therefore, existing process mining approaches cannot be employed.

Based on our past research that supports traceability for innovation processes (Beyhl et al. 2013a, 2013c), we also developed an automated recovery approach (Beyhl and Giese 2015a, 2015b, 2016a). It is based on the considerations of the links between the artifacts and the design activities (see Fig. 1), permits search in the documentation of design thinking projects to recover the design journey and capturing it by adding traceability links between design artifacts. However, the approach was neither interactive nor tailored to take additional manual annotations into account.

3 Semi-Automated Interactive Recovery Approach

In our paper (Beyhl and Giese 2015b) about traceability recovery for innovation processes, we present our recovery approach for DT methodologies (see also Sect. 1 and Fig. 2). The general algorithm implemented with the help of the recovery modules is to first exploit metadata, such as creation dates. These creation dates enable recovering a chronological order of artifacts, which in turn enables the identification of clusters of artifacts that represent design phases. When metadata such as file names, file hierarchies, and file content (if available) is exploited the design phase name can be associated with the identified design phases. With these design phases at hand, transitions between design phases and continuations of design phases can be recovered. Furthermore, the first and last artifacts created in design phases can be considered as milestones that may embody design rationales for future design activities. Moreover, milestones in certain design phases are often represented by a certain kind of process artifact. For example, the last artifact in the point-of-view design phase is often a persona artifact that summarizes the outcome of the design phase in terms of a milestone, while the last artifact in the test design phase is often a feedback grid that captures the feedback of prospective end-users, for example their likes and dislikes concerning the tested prototype and, therefore, embodies the rationale for next design phases such as ideation or prototyping.

The evaluation results presented in our paper (Beyhl and Giese 2015b) are promising. For example, the evaluation results show that we can recover DT methodology information with a mean confidence of approx. 50–80% depending on the DT project. By extending our approach towards a semi-automated approach where inference and manual annotations enrich the outcome, we aim at improving the recovery results by providing an interactive visualization to inspect and revise recovery results to enable a better understanding and comparison of the employed methodology from different stakeholder perspectives.

In previous work, we employed a recovery approach to recover the employed design flows from design documentation. For example, the approach extracts metadata such as creation dates or keywords from captured design artifacts to order the design artifacts chronologically. Afterwards, the approach reasons about employed design phases, activities, and techniques using the extracted metadata. Then, the approach can argue about the transitions between these design steps and may extract the rationales for these transitions.

However, the whole recovery process consists of different challenges. First, the design documentation is very often unstructured and contains a lot of non-machine readable artifacts such as photographs of whiteboards. Second, the recovery of the design steps from these design artifacts is fuzzy and different people may extract different design steps from these design artifacts. Third, the rationales for the transitions between design steps are often hidden and difficult to extract for people who did not participate in the design project.

These issues lead to the case that the recovered design flows are incomplete or incorrect. For that reason, we extended our recovery approach in a manner that enables analysts to revise the recovered design flows manually. For example, analysts can extract additional metadata from design artifacts manually or correct the recovered design flow. Then, our approach is able to take the additional input and the corrections into account and continues the recovery process incrementally.

In summary, we extended our recovery approach from one that is automatic to one that is semi-automatic. This semi-automatic interactive recovery approach enables analysts to increase the completeness and correctness of the recovered design flows. With this semi-automatic recovery approach, we are now able to conduct more fine-grained analyses of employed design flows. Thus, the recovered processes now also include information about employed design techniques and activities that were missing before. Furthermore, this information can be used to justify the rationales between design steps.

Therefore, we explore, as depicted in Fig. 3, how an interactive view can be employed to achieve a higher completeness as well as a higher accuracy. Accordingly, it is possible to gain a better understanding and comparison of the DT methodologies employed. This interactive view provides a visualization of

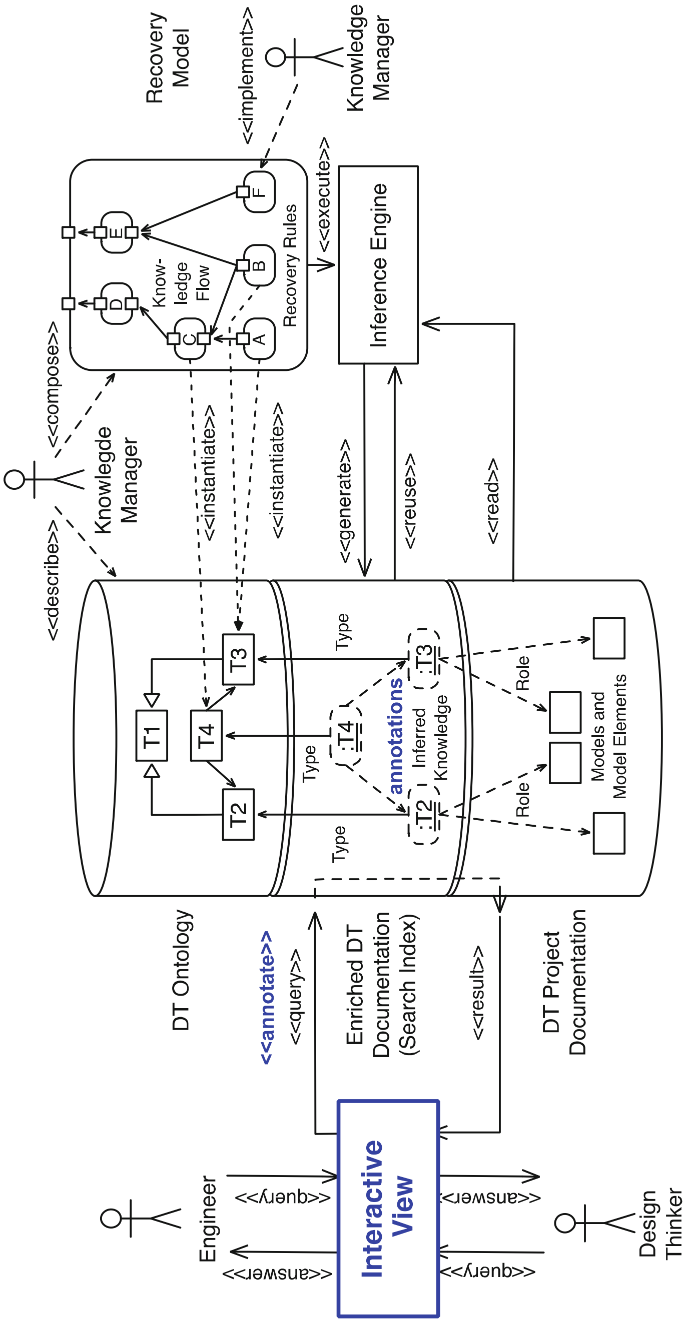

Fig. 3 Extended inference engine and its elements (new elements in *blue*)

the DT methodologies at work (see Fig. 4) and allows interactively enriching findings by means of manual annotations (<<annotate>>). Based on the enriched knowledge, the inference engine then generates additional findings. Due to the resulting interplay of enriching the findings and reasoning by the inference engine, a semi-automatic recovery of more complete and accurate results can then be achieved.

For the *interactive view,* we developed a prototypical visualization for the recovery results that permits adding interactive manual annotations by domain experts to enrich the visualized recovery results. By manually adding and removing information about certain kinds of methodology information or modifying the belief values of recovery results, domain experts can—during their recovery adjustments—browse, discover, and recover information about employed DT methodologies. Additionally they can interactively evaluate the completeness and accuracy of the recovery results achieved so far.

By gathering more accurate information about the DT methodology at work, practitioners can employ the DT methodology more effectively and researchers can better identify which aspects of the DT methodology need a more detailed consideration. Some of the stakeholders will benefit from the visualization by having a better orientation and by "learning from failures." Other stakeholders may be able to make better decisions about how to apply the DT methodology or better judge a concrete project as to how much progress has been made and whether there are any risks. Finally, by combining the data from multiple projects the understanding of the interplay of methods and techniques of the DT methodology will be improved and typical process fragments as well as their positive or negative impact on the projects will become visible.

4 Application Example

Based on our former prototypes concerning the traceability of innovation processes (Beyhl and Giese 2015b), we developed a prototype for the semi-automated interactive recovery that permits automatically finding process knowledge within design documentation and, afterwards enables analysts to revise the recovered process knowledge. Then, the revised process knowledge is considered by the approach to revise the automatically recovered process knowledge.

Figure 4 shows the graphical user interface for the results of the inference engine provided by the approach. It depicts design artifacts, such as images with solid circles and recovered design process knowledge with dashed circles and lines. The dashed lines mark which design artifacts are used to justify the recovered process knowledge. In some cases the approach can make conclusions for artifacts based on their naming, but sometimes the naming does not permit such conclusions and an interactive enrichment via annotations is required to help the inference engine. This approach automatically takes this additional information into account to make additional conclusions.

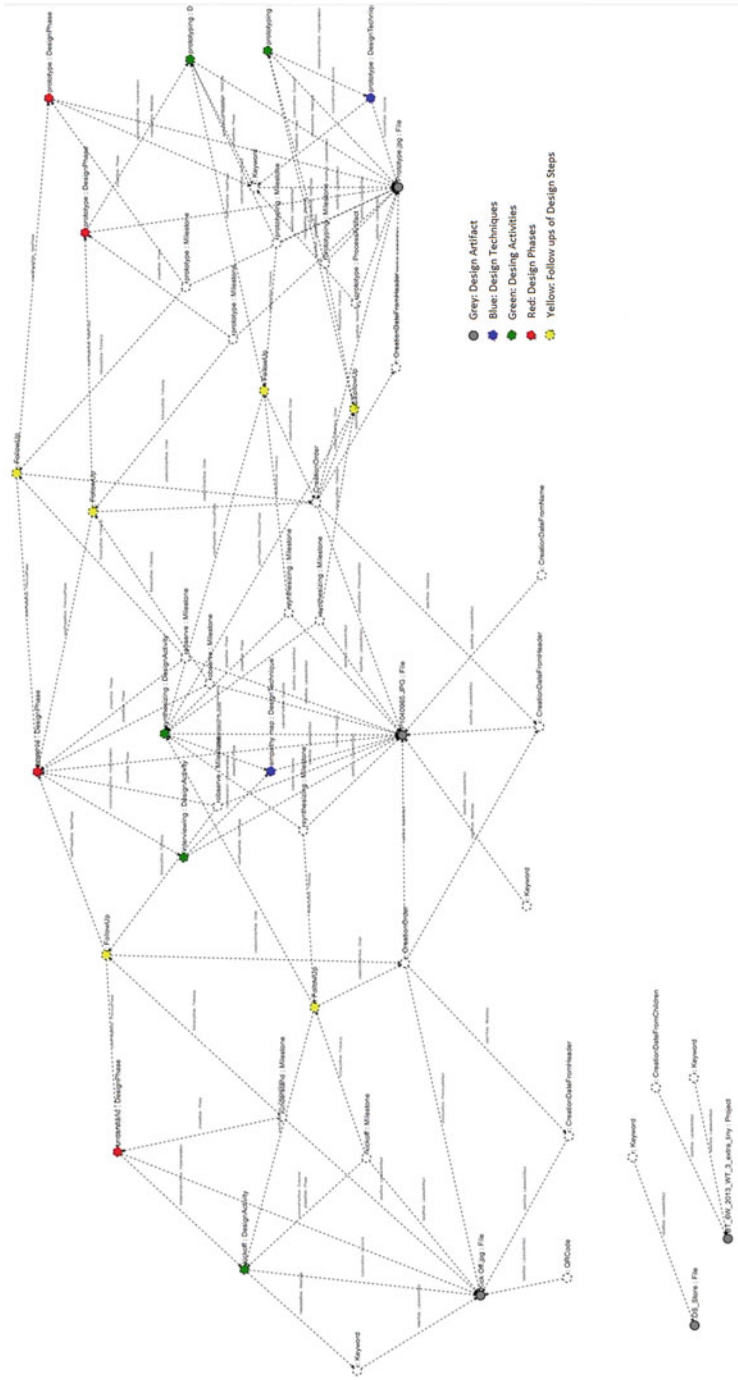

Fig. 4 Graphical user interface for the results of the inference engine

The dashed circles further denote the kind of recovered process information by their colors. Design artefacts are denoted by circles in grey. Furthermore, the approach concludes automatically that one design activity is a follow-up activity of another design activity denoted by a node with a yellow circle. Moreover, the approach automatically detects that a continuation activity exists as denoted by a purple circle.

With this semi-automated approach, analysts can enhance the knowledge base that is used by the approach to automatically derive design process knowledge. To demonstrate the approach, we will use in the following a simplified small project example, depicted already in Fig. 4, to explain the employed notation that consists of three main design artifacts (grey circles), which are images capturing whiteboards that have been employed in a design thinking project. The initial analysis result of the inference engine is depicted in Fig. 5.

Some first ordering as depicted in Fig. 5 can be based on creation dates. As the first artefact is called "Kick Off.jpg", the inference engine can also conclude that it belongs to a kickoff activity. Also in case of the third artefact, the name "Prototype.jpg" reveals to the inference rules that this artefact refers to a prototype activity. However, the second activity has no meaningful name and thus the inference cannot conclude anything concerning the related activity based on its naming.

We then can navigate to the artifact in the middle to see what it is about (see Fig. 6). It is easy to see that it is in fact an empathy map. In a manual step we can then annotate that the JPG file in the middle captures an application of the empathy map design techniques and thus is an empathy map.

If this one manual annotation has been added, the inference engine can continue the reason process and concludes in our case that the artifact is related to a synthesis design activity. Therefore, the inference has detected overall that the design process includes a sequence of design activities, namely kick off, synthesis, and prototype as depicted in Fig. 8.

A second look at the image of the artifact in the middle reveals that a QR-code documents that the empathy map was created as a result of an interview (see Fig. 7). Consequently, we can also annotate manually that the empathy map was in fact employed to implement an interview design activity.

Based on this additional manual input, the inference engine can then continue the reasoning process and conclude that we have a sequence of understand, observe and prototype design phases that characterize the employed design thinking process as visualized in Fig. 9.

In summary, (as shown in Figs. 4–9) the inference engine is able to properly identify the design thinking methodology at work, supported by the interactively added annotations. Starting from the three design artifacts in gray, the approach first concludes without the need for manual annotations that the left artifact with name "Kick Off.jpg" belongs to the Kick Off design activity. Furthermore, the approach concludes, also automatically, that the right artifact with name "Prototype.jpg"

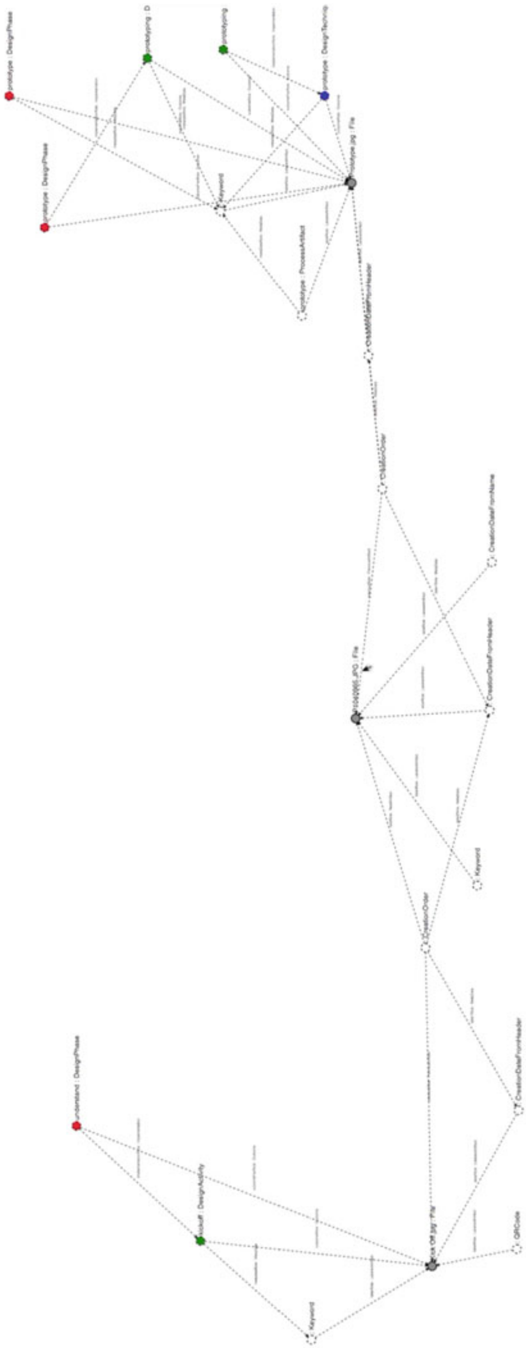

Fig. 5 Initial analysis result presented via the graphical user interface

Fig. 6 Artifact in the middle navigated via the graphical user interface

Fig. 7 An important detail of the middle artifact navigated via the graphical user interface

belongs to the Prototype design activity. But, the approach is not able to extract automatically a design activity for the artifact in the middle. For that purpose, the analyst opens the design artifact and concludes that it embeds an empathy map. Thus, the analyst labels the design artifact in the middle with the keyword “empathy map”. Then, the approach automatically takes this additional information into account to conclude that this artifact belongs to the Prototype design activity. Furthermore, the approach concludes automatically that this Prototype design activity is a follow-up activity to the Kick Off design activity as denoted by the yellow circle. Moreover, the approach automatically detects that a continuation of the Prototype activity exists as denoted by the purple circles.

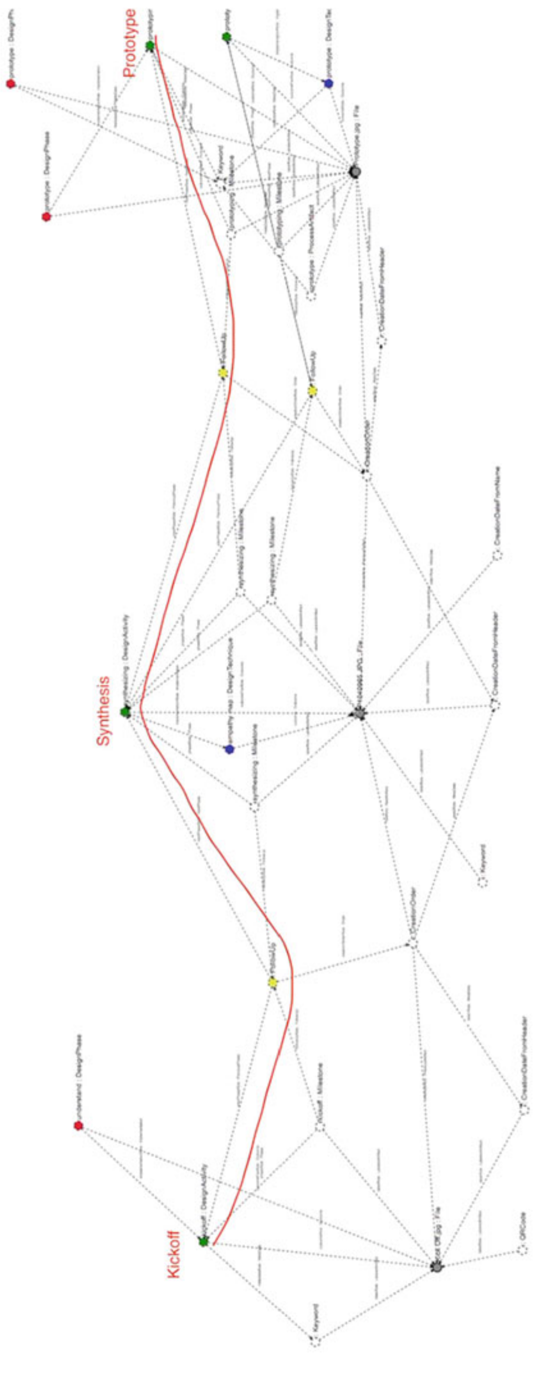

Fig. 8 Analysis results from the inference engine in the graphical user interface after annotations of the employed design technique have been added

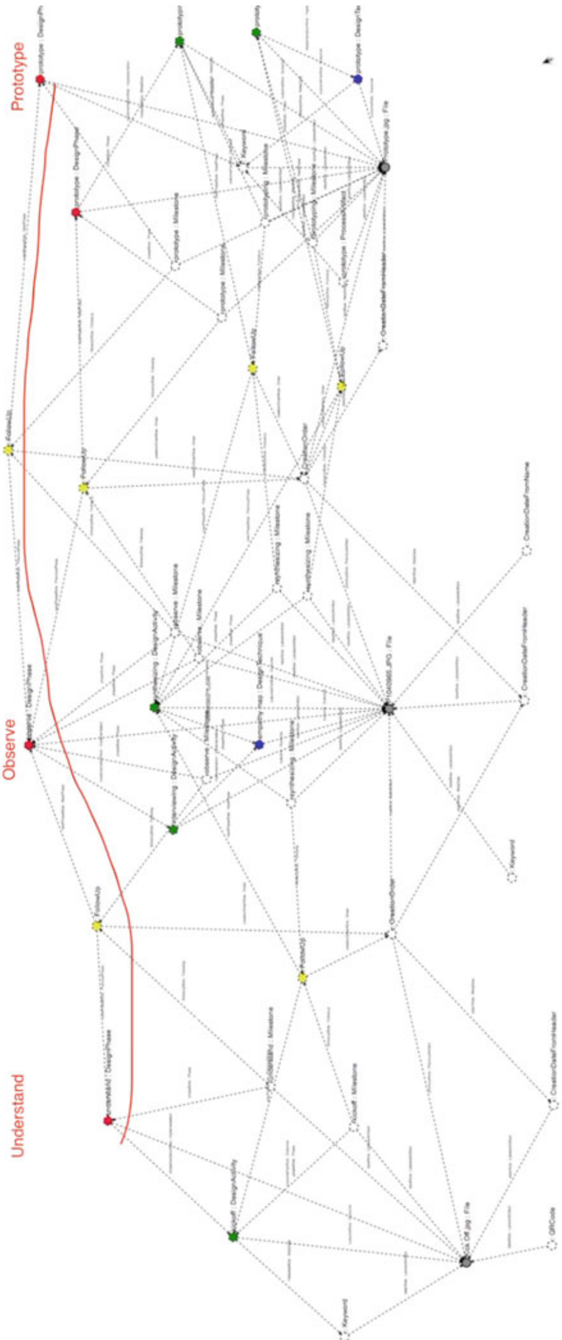

Fig. 9 Analysis results from the inference engine in the graphical user interface after annotations of the implemented design activity have been added

5 Conclusion

In this chapter, we have shown that valid conclusions about employed DT methodologies in practice could be achieved with higher confidence by extending our recovery approach towards a semi-automated interactive recovery approach where the inference engine can exploit interactively added annotations to improve its results.

Our experiments indicate that we can increase the completeness and accuracy of the recovered DT methodology and that we can use the insights gained during the semi-automated recovery to enhance the recovery rules themselves. Consequently, we established a first step to proceed from a qualitative to a quantitative analysis of employed DT methodologies. The recovery rules together with the interactive annotations by domain experts can result in recovery results that are so complete and accurate that a quantitative analysis becomes possible and helpful.

However, there remains a lot to be done to make the approach more easily applicable in practice. In particular, the approach must be made more scalable. On the one hand, the tool needs to know what knowledge concerning the design thinking methodology at work is actually targeted. Then, the tool would have to guide the design thinker to those specific artifacts that need annotations to come up with the still lacking conclusions. Otherwise, if the tool would not guide the user to the relevant artifacts, the effort to add manual annotation would likely be too high due to the high number of artifacts involved.

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Abracadabra: Imagining Access to Creative Computing Tools for Everyone

Joel Sadler, Lauren Aquino Shluzas, and Paulo Blikstein

Abstract How might we empower anyone to create anything? Designers may dream of whimsical ideas, and then turn these ideas into physical prototypes. Armed with duct-tape, cardboard and illusion, "Wizard of Oz" prototypes may communicate the essence of an idea using only raw materials found in every household. However, for electronic prototyping, the tools needed to create functional devices may not be accessible to technical novices. *Physical Computing* tools with electronics, sensors, actuators, programmable microcontrollers and microcomputers, are increasing in their affordability, but the tools and knowledge needed to combine these parts may not be readily accessible to the average citizen. Here we examine prototyping through the lens of *Creative Computing,* and propose that *accessibility* is the cornerstone of electronic prototyping tools. We explore accessibility through an observational case study of a designer prototyping a smart electronic device. We show that typical electronics prototyping tools have significant accessibility barriers to the everyday novice. This work underscores the need to find new ways of designing Creative Computing tools to be more accessible to the everyday dreamer.

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1 Motivation: Closing the Gap Between Idea and Prototype

Abracadabra, based on the Aramaic phrase avarak'davara "I create as I speak" (*Kushner* 1993).

1.1 Accessibility: There When You Need It

What does accessibility mean for novice electronics prototyping? Accessibility is one of three key usability factors in the proposed Create Computing Framework (Sadler 2016), where we desire tools to be "usable to the greatest extent possible by people of all ages and abilities" (Mace 1997). Therefore a universally accessible electronics toolkit is one in which anyone, regardless of their technical knowledge, physical resources, or financial status, is able to express their ideas. Industrial designers, such as Henry Dreyfuss, expressed the idea of accessibility more precisely by specifying his designs to accommodate "98% of the population" (Dreyfuss et al. 1993). By designing broadly ergonomic physical products, Dreyfuss demonstrated a key insight: that we can design for the statistical variations of the average user by considering the extremes in a population bell curve (e.g. height, weight, visual impairment, etc.). Designing for the worst-case physical or cognitive abilities, helps to ensure more universally accessible products.

For our work in Creative Computing, we have adopted Dreyfuss' benchmark of designing for the 98% of the population, and extended this usability constraint to the design of electronics prototyping systems. This chapter aims to dissect dimensions of accessibility by (i) highlighting common accessibility barriers with electronic prototyping tools and (ii) presenting an ethnographic case study of a user attempting to prototype a smart shoe device. We show that electronics prototyping, for the 98% percentile, is difficult because many special tools are required to make a working smart device (Fig. 1).

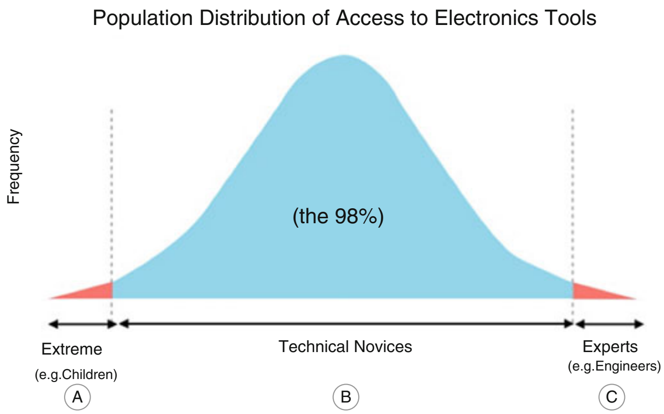

Fig. 1 Accessibility and designing for novices, 98% of the population

2 Barriers to Novice Electronics Prototyping

Our goal is to enable technical novices (the 98% percentile of the population) to prototype smart devices. But what are the existing barriers that might get in the way of prototyping and reduce accessibility? Smart devices typically consist of three common building blocks:

A. **Sensors** (or inputs): which transform physical phenomenon (e.g. pressure, movement, light, etc.) into electrical signals.
B. **Actuators** (or outputs): which produce some physical phenomenon such as actuated movement, sound or light.
C. **Processors**: that act as the intelligent intermediary between sensors and actuators, transforming incoming sensor signals into modulated outputs. These processors can be simple logical circuits ("if-this-then-that"), or more advanced fully programmable computers or microcontrollers see Sadler (2016).

The combination of sensors, actuators and processors is what makes up most novice toolkits. For novices, working with these smart systems can be especially challenging due to the following common issues discussed by Sadler and Leifer (2015):

(1) **Usability of the tools**: Since the different toolkits are designed for different audiences, toolkits vary widely in how easy they are for novices to use. Some toolkits are designed specifically for novice users, such as children, while others may be designed for technically savvy hobbyists or engineers.
(2) **Knowledge gap in both hardware and software**: Interfacing with smart systems requires both software and electrical hardware familiarity. The user may have to author code to specify the behavior of the system, as well as creating and debugging electrical circuits. When working with sensors and actuators, supporting circuitry may be needed (e.g. with resistors, diodes and capacitors) in order to transform signals, protect components, and ensure electrical compatibility. The more electronics or software knowledge that is needed, the harder it is for novices to participate.
(3) **Cost**: While the cost of sensors, actuators and processors continue to decline, the summation of physical parts can present a significant financial barrier for novices. While common electronic components, such as resistors and LEDs, can be purchased for pennies, fabricating a single custom printed circuit board (PCB) can cost hundreds of dollars. Toolkits that are more specialized for novices, tend to be more expensive due to the additional investment into usability features.
(4) **Computational Resource Constraints**: Depending on the cost and what the novice is prototyping, a given toolkit may not have sufficient computational power to achieve the prototype's goal. For example working with high bandwidth sensors such as cameras or inertial measurement units (IMU) may require computational resources of a full computer, rather than microcontrollers which are an order of magnitude cheaper, but are more computationally constrained.

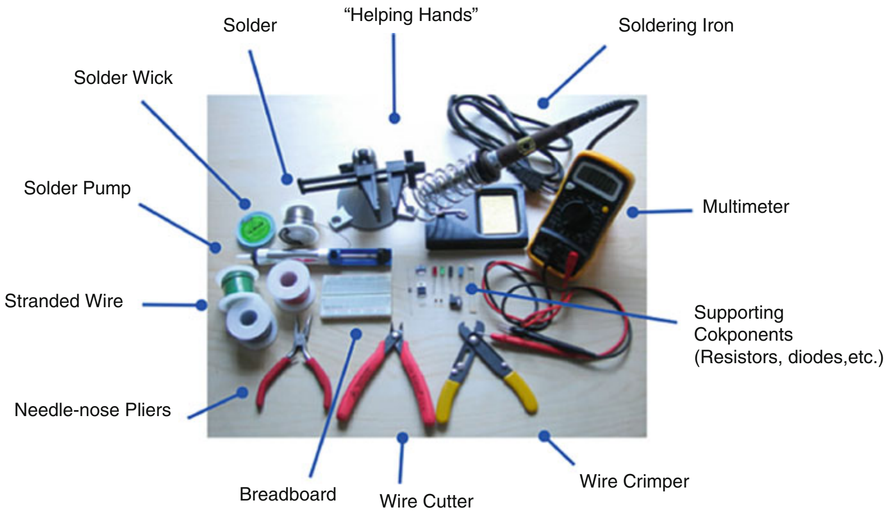

Fig. 2 Example of typical tools needed for electronics prototyping

(5) **Requiring special tools**: In working with electrical hardware, physical, digital and electrical tools may be necessary to create even a basic sensor system. For example, the use of soldering irons, breadboards, and wiring cutters are often needed. Without the necessary tools, progress may be stalled or halted. Figure 2 shows an example of twelve different tools typically needed with microcontroller toolkits such as Arduino (Mellis et al. 2007).

(6) **Component availability**: Without physically having the components on hand there is often some time needed to identify and acquire the necessary parts. The lack of having "parts on hand" is frequent for less experienced users. Delays of hours, or days, are likely if components need to be ordered and shipped. In the context of rough and rapid prototyping, where a prototyping session might be on the order of an hour, these sourcing delays are significant time barrier.

3 Methods: "First-Person" Prototyping a Smart Shoe

What do the barriers to electronics look like in from a first-person point of view? In this exploratory case study we use two ethnographic methods to looks at the prototyping process:

i. **First-Person Ethnography**: Using a wearable camera to follow a prototyper through their steps to make a working smart shoe. In this way we can see prototyping from the viewpoint of the actual builder.

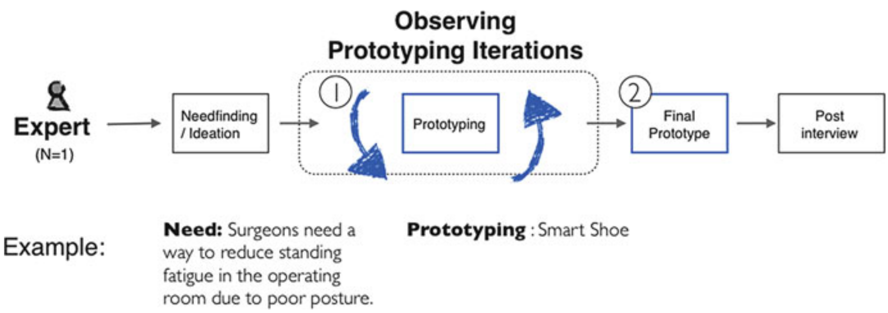

Fig. 3 First person prototyping case study for the smart shoe

ii. **Expert Usability Case Analysis**: Using experts, rather than novices, as a way to consider the best-case usability scenario. The rationale behind using an expert for this case study is to first see how the tools are used when the knowledge requirements are not a limiting factor (Barrier #2 in Sect. 2). We can then observe the remaining usability issues under the assumption that novices will also struggle with similar issues, but in greater magnitude than experts.

Our goal was to follow an experienced builder, who had formal training in electronics device prototyping (e.g. a graduate university class in mechatronics), using whatever tools felt most natural to solve a real world problem. We recruited an expert who had completed a 9-month graduate engineering course on smart product design. The subject was given a wearable camera (chest-mounted GoPro Hero 4), and they were asked to journal their prototyping process while solving a design challenge. We observed the video footage and conducted post-interviews (Fig. 3).

3.1 The Smart Shoe Design Challenge

The design challenge was based on a previously conducted clinical observation where we found that surgeons in the operating room spent long hours standing in un-ergonomic positions, with weight on one leg. The participant translated the clinical observations into an idea to create a smart shoe that would detect standing postures, and then give feedback to change position "if the surgeon was standing on one leg for more than ten seconds" (Fig. 4). This idea represents a typical smart device that has a (i) single sensing goal (e.g. a way to detect standing pressure), (ii) a single output (e.g. a vibration buzzer), and (iii) a way to connect the two over conditional logic (e.g. if standing for more than X seconds, then buzz).

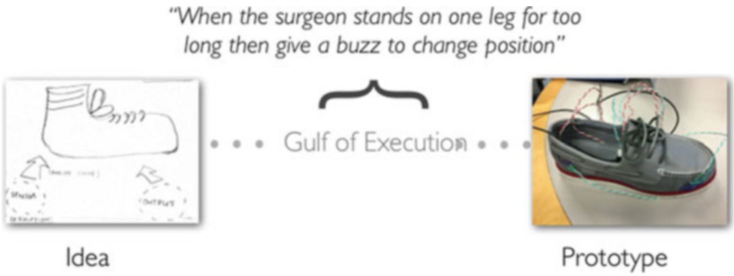

Fig. 4 The smart shoe prototyping challenge

4 Results and Observations

An analysis of the participant video, for time and tool usage, included the following:

1. **Time to prototype:** >15 hours. The participant took approximately 15 hours to make a working prototype of the smart shoe.
2. **Tools count:** 30+ different tools. They used over 30 different resources and tools in the making the prototype including: the Arduino microcontroller toolkit, discrete electronic components (resistors, LEDS, diodes etc.), hand tools, soldering tools, online knowledge resources, the local electronics store and parts from three different local maker spaces.
3. **Cost:** The participant purchased $100 worth of parts.

Snapshots of the participant's prototyping process are shown in Fig. 5. From the videos and post-interviews we synthesized the following key observations:

A. Sourcing Time: Significant Time Is Needed to Get All the Parts
Surprisingly, significant time is spent getting the physical parts in the first place. In some cases, parts were not on-hand, and the participant had to drive to a local electronics store to find an appropriate vibration motor. After not finding the part that they needed, they ordered a compatible component online which took several days to arrive. In total, we estimated that it took 5 hours (a third of the total time) to select, locate, order, and receive, the components needed for the smart shoe prototype (Figs. 5a–c). This mirrors what we heard in informal interviews with local product designers, where we found that a time lag in getting parts was a common prototyping barrier. Stocking common parts in an electronics workspace is a possible solution, but we do not always know in advance what components will be needed. Prototypes take time to build, regardless of expertise, and gathering parts represents a significant amount of this time.

B. Time and Tools: Even Simple Prototypes Take a Lot of Time for Experts
Our participant took over 15 hours to go from a sketch to a functioning version of a single-sensor, single-output device. While prototyping time will vary largely

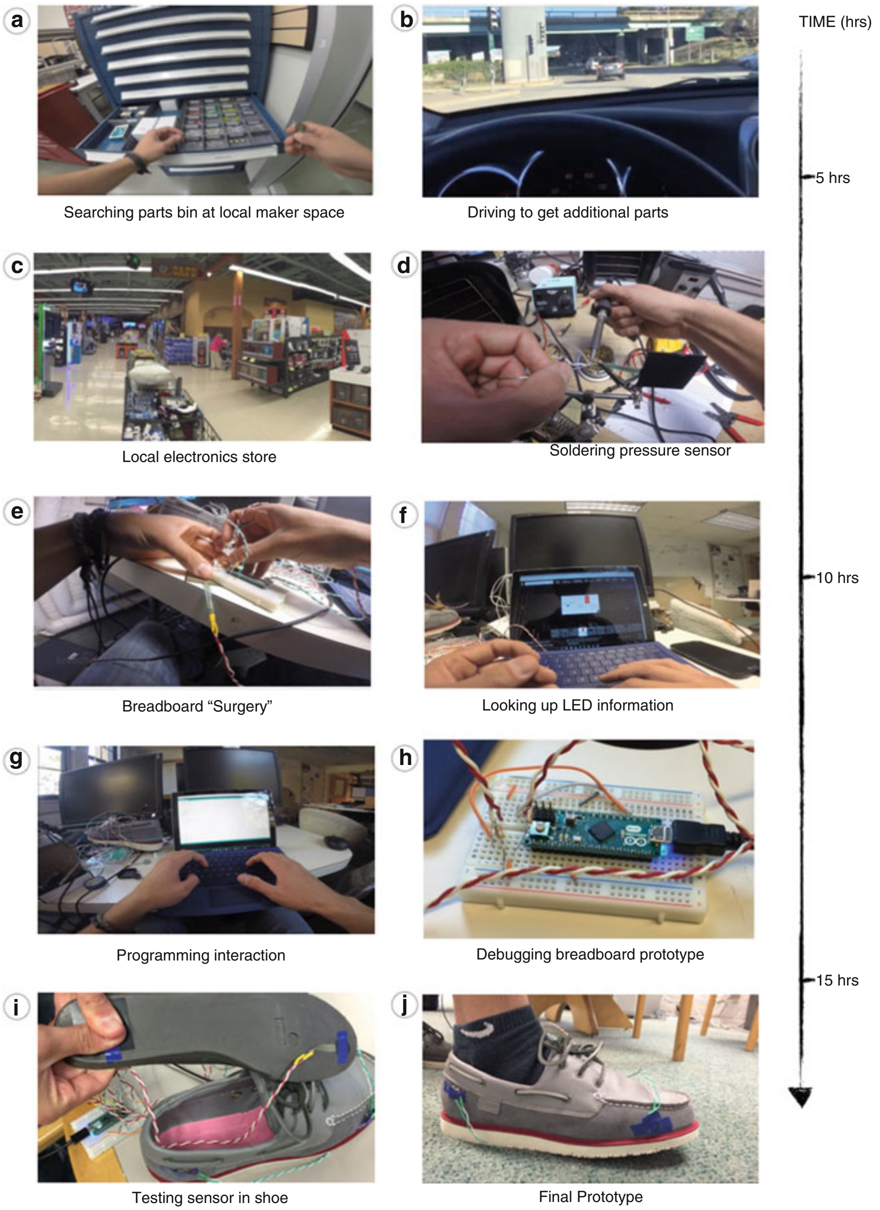

Fig. 5 Prototyping steps in the making the smart shoe

by person and prototype, this multiple-hour time frame signals that there are many ways to become blocked while prototyping. The sourcing time, as mentioned above, is a significant potential delay, but once all the parts are physically aggregated, a number of tools are needed to shape components into working smart devices. The participant used the common Arduino microcontroller platform with typical tools for working with electronics (Fig. 2) including soldering equipment, an assortment of physical hand tools and electronic debugging. Novices may not have direct access to these tools, and this adds further financial, and time barriers. In order to achieve 1-hour prototyping time frames, we must find ways to reduce the dependence on specialized tools.

C. Space: The Use of Multiple Maker Spaces

Our participant used several “maker” spaces to get to the final working prototype. The shoe used in the prototype was found in one location as a free item from a previous design project (J in Fig. 5). This maker space however did not have adequate soldering and ventilation for combining the electrical components, so the participant went to an alternate location to work on the circuitry (D in Fig. 5). In the process of soldering a small pager motor for vibration feedback, the participant accidently destroyed the delicate electrical leads, but did not have replacement parts. They were able to find a replacement component from the “parts bin” at third maker space located on the university campus. This third space was only available to students who had paid a yearly access fee ($100), and had completed 2 hours of safety training beforehand. While maker spaces are becoming more common, the average novices may be unaware of local fabrication resources, or they may not be able to afford the access fees. Fabrication facilities were a significant part of our participant’s prototyping process, but this not yet a universally accessible resource.

D. Costs: Significant But Not Prohibitive

The participant was reimbursed for $100 worth of purchases. While this represents a significant cost, it is not prohibitive for a student project. The trend towards continuously lowering component costs helps to make electronics prototyping financially more accessible, and we expect that this trend will continue to aid novices. The bulk of the cost was the purchase of multiple Arduino microcontroller boards ($25), and flexible force sensing resistors ($10, FSRs SEN-09376). The participants first used an Arduino Uno board, which is a physically larger, “brick” form factor of the Arduino toolkit. The participant mentioned that the larger size was helpful to more quickly create the electronic circuitry without worrying about fitting the device into a small volume. A second type of Arduino (Arduino Nano), roughly the size of a stick of gum, was used as an embeddable form once the circuit was completed. As the costs continue to lower, we expect to see multiple microcontrollers and microcomputers used as a regular part of prototyping, particularly in space constrained domains such as wearable computing.

E. Debugging Is a Significant Friction Point—But Feedback “Hacks” Help

The participant stated that debugging the functionality of the system was the most time consuming part of the process (roughly one third of the time). This mirrors findings in other prototyping case studies (Analytis, et al. 2015). In particular, the prototype did not function as initially expected, and it was unclear whether there was a mistake in the electrical design, or software programming. Because there are

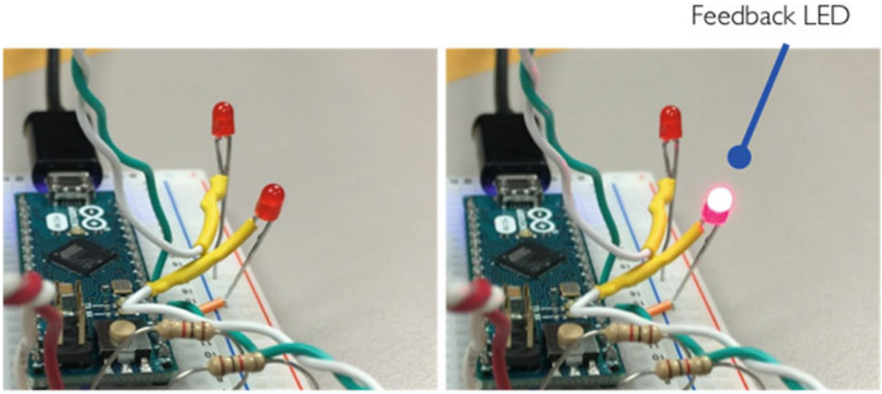

Fig. 6 Example feedback "hack": an added LED to give increased debugging feedback

physical, electrical, and logical domains that can all have points of failure, it can be difficult to find the source of a malfunction. These malfunctions could be cause of simple errors, or a more complex interplay between electronics and software. The aggregation of these kind of interruptive errors can sum up to significant cognitive loads that may hamper creative performance (Sadler and Shluzas et al. 2016).

At one point in the recorded video we observed the participant attempting to upload new code to the microcontroller board without success. After 5 minutes the participant realized that the board was not plugged in. Sometimes the solution is simple, such as plugging in a forgotten wire, but other times the "mystery" goes unsolved. At another time point, the participant was puzzled as to why a particular vibration motor was not turning on. After an hour they threw the component away, deciding to try a new component. In post-interviews the participant hypothesized that the component was designed for a different voltage range, or that the part had possibly been previously destroyed, but the source of the original malfunction was never understood. Simply starting over with a new component was one way to solve the problem. Later, when the participant tried again with a different motor, they added an LED light component to the circuit to give some visual feedback that current was indeed flowing through the new motor (Fig. 6).

A key observation is that: quickly debugging a prototype depends on the feedback channels that indicate which domain is the cause of a problem. If the LED is on, it means that the component is electrically connected, and the problem may lie elsewhere in software. Adding feedback channels increases accessibility, and previous work has shown how this insight can be applied to visual feedback in the novice Bloctopus system (Sadler et al. 2015).

F. Programming Simple Interactions Takes many Lines of Code

The participant described programming interactions as a significant challenge for the prototype. The final smart shoe was intended to work logically as: "if standing for more than 10 seconds, then buzz a motor". The interaction can be summarized in

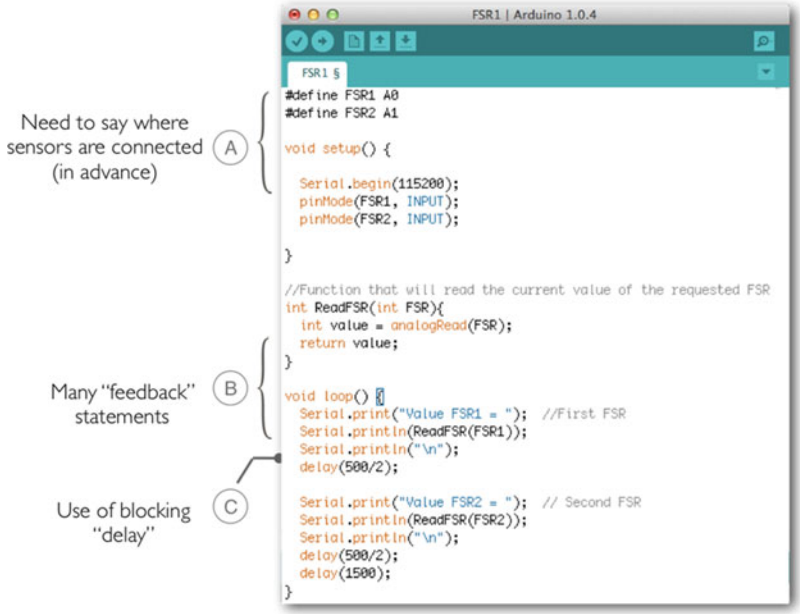

Fig. 7 The participant's initial code to read if a person is standing on the sensor

one sentence, yet the participant wrote 165 lines of code for the final prototype. The description of the interaction may be simple, but the implementation can be verbose and challenging even for expert programmers. For example, Fig. 7 shows 21 lines of code the participant initially wrote to check if the force sensors were working.

We can see (A in Fig. 7) that the participant wrote several lines of code to declare in advance, what sensors are connected, and where they were electrically connected. As the program grew, they connected additional components but had to continuously update the code to maintain synchronization between the code and the electrical domain. Additionally, later in the program we can see frequent use of statements to "print" the state of the system to the screen (B in Fig. 7). The bulk of the program was therefore boilerplate code to (i) declare what components were plugged in to the microcontroller and (ii) to gain feedback on the operation of the system (similar to the use of feedback LEDs in the electrical domain).

When asked about the large volume of code in the final prototype, the participant explained that programming "time-based" interactions was particularly challenging. The code required keeping track of "standing for more than 10 seconds," while continuously reading sensors. However, in the early program (C in Fig. 7) we see the use of a delay function, which puts the system to sleep for some period of time. This is problematic for programming smart devices, since they need to respond dynamically to user input and avoid going to sleep. Later the participant modified the program to remove the use of delay, but this resulted in increased complexity of the code.

These observations highlight important accessibility shortcomings of programming smart devices with systems like Arduino: i.e. the need to find ways to (i) more fluently express concurrent interactions, (ii) reduce the programming burden for common tasks, such as adding new sensors, and (iii) increase feedback channels in the software and hardware, without requiring many lines of code and expert knowledge.

5 Conclusions

Accessibility, the ability for anyone to use the tools, is a core component of the Creative Computing Framework. We defined an accessibility benchmark of designing for the 98% of the population, inspired from the early accessibility work of Henry Dreyfuss. Accessibility barriers to novice electronics prototyping include: tool usability, knowledge requirements, cost constraints, computing power, specialized tools, and sourcing components. We explored some of these accessibility factors through a case study of a designer creating a smart shoe prototype for a clinical problem. We found that the participant was able to make a functioning prototype in 15 hours, and used many tools that novices would not commonly have access to. We discussed strategies to improve accessibility by: reducing dependence on expert tools, increasing feedback mechanisms, and exploring alternative programming techniques. By continuing to find ways to improve accessibility we hope to see electronics prototyping become as easy as uttering the words abracadabra.

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