Design Roadmapping: Integrating Design Research Into Strategic Planning For New Product Development

By

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Abstract

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While product and technology roadmaps have been well formalized in terms of their structures, methodologies, and frameworks, *design* roadmaps have not been explicitly explored nor studied from either an academic or industry practice standpoint. With increasing uncertainty, rapid change, and complexity in market environments, companies are finding that they can no longer differentiate their products and services by relying on traditional roadmapping processes that focus solely on technologies and product features. Rather, strategies that revolve around the holistic experience provided by a product or service are more likely to be successful in today's market. This dissertation introduces a formalized design roadmapping framework to guide product planning in today's more user-centered marketplace.

Initial exploratory research assessed the current application of roadmapping in industry through observations and semi-structured interviews of product managers, technology managers, and designers from Silicon Valley and East Coast companies. This descriptive study revealed key challenges and opportunities associated with current roadmapping processes, providing a solid foundation on which to create a more effective process.

I introduce and characterize a detailed framework for design roadmapping that focuses on desired outcomes for the user and not just product features nor technologies. It provides a mechanism to explicitly integrate customer/user research into the roadmapping process and use this research to consider appropriate projected technology choices. Similar to traditional product and technology roadmaps, the design roadmapping process presented herein aggregates design experience elements along a timeline by associating key user needs with products, services, or systems.

The design roadmap framework was tested through active research in a large multinational corporation and a small startup, and was applied to new product development curricula at UC Berkeley. In all settings, participants found the new framework beneficial at multiple stages of the new product development process. The activities associated with design roadmapping process were also considered particularly helpful for prioritizing products for commercialization and promoting a shared vision among team members and active communication across organizations.

To my family —
Lovely Yoobin, Yewon, Yedul,
my parents, my brother,
and relatives from both my parents' and my parents-in-law's sides

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1 INTRODUCTION

Chapter Overview

This introduction summarizes the motivation for the research and the organization of the chapters in the dissertation.

1.1 Motivation

Traditional portfolio planning, roadmapping, and product development processes worked well in market environments that were relatively predictable. Technology and product roadmapping have typically been used to align technology development projections with future product platforms and features among internal stakeholders in organizations. However, rapidly evolving technologies (Brynjolfsson & McAfee, 2012) and shifting user expectations are challenging traditional methods. Indeed, in today's rapidly changing market with increasingly complex consumer demands, companies can't differentiate themselves and stay ahead of the competition by simply evolving product features based on new technologies. Thus, even when a company is equipped with a well-developed technology roadmap relevant to its market sector, it can fail by miscalculating the trajectory of consumer adoption of those technologies over time.

New approaches to product development that integrate new customer understanding in near real-time are replacing traditional Stage-Gate and waterfall development processes. These include learning-based innovation approaches (Beckman & Barry, 2007; Voss, 2012) and agile development methods (Cooper R. , 2014). These more adaptive, flexible, and accelerated new product development processes demand new approaches to portfolio planning and roadmapping.

This dissertation research began by analyzing and synthesizing qualitative data from semi-structured interviews – 6 pilot interviews and 40 in-depth interviews – with 46 professionals: product managers, technology managers, and designers from consumer product companies in the San Francisco Bay Area and on the East Coast.

To make roadmapping adaptive and flexible, I developed the design roadmap concept along with an implementation process by incorporating design research into product planning and product development. This design roadmap and implementation process allows a firm to exploit design elements that make up a product concept. This is accomplished in a way that can evolve over time to meet forthcoming user experience expectations. The pace that users adapt to new technologies is not as fast as the pace at which manufactures push their new technologies onto users (Kuniavsky, 2010). Today we need a new way to prepare for the future that integrates technology and product roadmaps, as well as roadmaps driven by evolving user needs. My design roadmap associates key user needs with the products, services and/or systems that the organization aims to develop over time. This design roadmapping process can also be integrated with project selection and prioritization processes to guide how and when design experience elements should be kept or discarded.

1.2 Organization of the Dissertation

This dissertation begins with an introduction to existing roadmapping literature reviews from academic scholars and practitioners. Then, this dissertation delves into current industry roadmapping practices, their challenges and opportunities, and case study implementation. Finally, I explore the application of design roadmapping to new product development curricula. This dissertation concludes with key findings and recommendations for future research.

- **CHAPTER 1. INTRODUCTION**
  This introduction summarizes the motivation for the research and the organization of the chapters in the dissertation.

- **CHAPTER 2. LITERATURE REVIEW**
  This chapter provides a literature review of related work in product planning, and product and technology roadmapping.

- **CHAPTER 3. RESEARCH QUESTIONS AND METHODOLOGIES**
  This chapter presents primary research questions, research methodologies, sources of data, and data validation processes.

- **CHAPTER 4. DESCRIPTIVE STUDY OF CURRENT ROADMAPPING PRACTICE**
  This chapter summarizes the results of descriptive studies and key findings of current roadmapping practices in industry.

- **CHAPTER 5. INTRODUCTION TO DESIGN ROADMAPPING**
  This chapter formalizes a design roadmap by establishing its definition, framework, and steps to be consolidated in product planning and development processes. A design roadmapping template, its components are explained, and a each step of five-step process is described in detail.

- **CHAPTER 6. CASE STUDY IMPLEMENTATION**
  This chapter describes the action research in which the proposed design roadmapping process delineated in Chapter 5 was applied in two industry organizations—a large multinational corporation and a small startup.

- **CHAPTER 7. COMPARISON AND EVALUATION OF TWO ACTION RESEARCH EXAMPLES**
  This chapter evaluates findings from the two action research examples introduced in Chapter 6. Data sources from observations, interviews, and documentation from each case are examined with explicit comparisons.

- **CHAPTER 8. TEACHING DESIGN ROADMAPPING IN PRODUCT DEVELOPMENT CURRICULA**
  This chapter explores the application of design roadmapping in new product development classes as a supplementary project-based learning activity. This chapter examines one in-depth pilot test and in-class case studies with nine student teams in new product development (NPD) courses at UC Berkeley.

- **CHAPTER 9. CONCLUSION AND FUTURE RESEARCH**
  This chapter summarizes the results of the dissertation research and provides overall conclusions and recommendations to both academic scholars and industry practitioners.

2 LITERATURE REVIEW

Chapter Overview

This chapter provides a literature review of related work in product planning and product and technology roadmapping. The review addresses how product roadmaps and technology roadmaps interact with each other, and provides example frameworks from both academic and industry practice. It shows that the historical roadmapping processes, while they fit the times for which they were developed, no longer suit the fast-paced world for which companies are planning today. Thus, new customer-driven approaches to roadmapping that can directly build on customer research are necessary.

2.1 Definition of Roadmaps

The term "roadmap" is typically used to show the roads in a particular area. The Oxford English Dictionary defines it as "a map, especially one designed for motorists, showing the roads of a country or area." In business, the term "roadmap" is defined as "a plan or strategy intended to achieve a particular goal" (OED Online). Several types of roadmaps have been widely defined by practitioners and academic scholars. Since the introduction of the term "technology roadmap" by Sandia National Laboratories (Garcia & Bray, 1997), technology and product roadmapping are now standard procedures in most companies (Ulrich & Eppinger, 2003).

2.1.1 Product roadmaps

Product roadmaps are used to keep a company's product strategies up to date and to predict upcoming market trends through visualization of past, current, and future product lineups over time. It is a useful method for enterprises to keep their product strategies up to date and to show the potential effects of upcoming market trends by illustrating the progression of potential product portfolios over time. Many large companies keep product roadmaps updated regularly and use them as a guideline to decide which technologies should be funded for further development. Cooper and Edgett define the product roadmap as a canvas that lays out the major initiatives and platforms a business will deal with in the future (Cooper & Edgett, 2010). A representative product roadmap example from Ulrich and Eppinger (Figure 1) illustrates a comparison between a corporation's roadmap and those of its competitors (Ulrich & Eppinger, 2003).

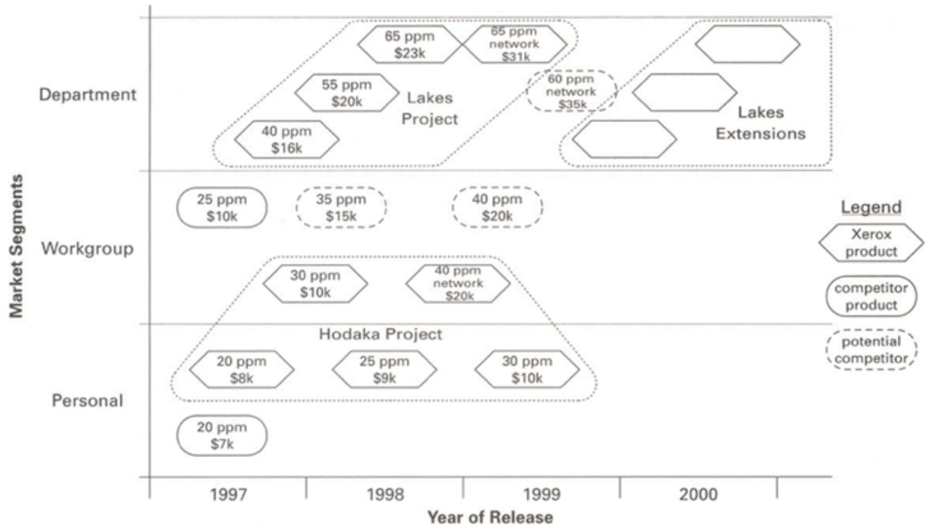


Figure 1. Product roadmap example, adapted from (Ulrich & Eppinger, 2003)

2.1.2 Technology roadmaps

Many researchers define a technology roadmap as a strategic plan for the business's expected technology development or acquisition that is relevant to their existing product lineups (Cooper & Edgett, 2010; Phaal, Farrukh, & Probert, 2004). Ulrich and Eppinger introduced an example technology roadmap, adapted as Figure 2, that illustrates a series of functional elements deployment over a time frame to show progressive evolution of a broad configuration (Ulrich & Eppinger, 2003).

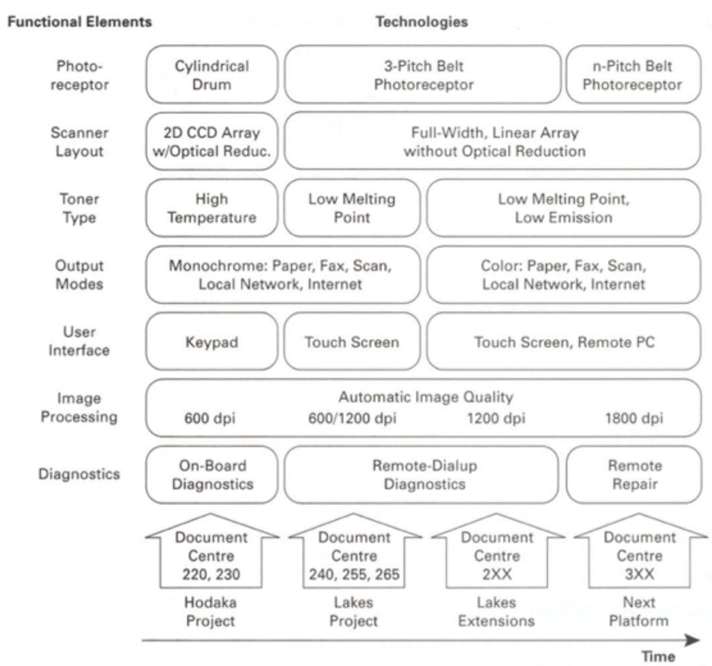


Figure 2. Technology roadmap example, adapted from (Ulrich & Eppinger, 2003)

This is a classic example roadmap that depicts how the quality/performance of functional elements travel linearly over a timeline. For instance, in the "Image Processing" row, the technology roadmap envisions automatic image quality improving from 600 dpi (dots per inch) to 600/1200 dpi, 1200 dpi, and finally 1800 dpi at the end of the time frame. Normally action items for achieving a designated level of technology—in this case, automatic image quality—follow up a technology roadmap. Creax, a consulting firm that supports companies with technological innovation, develops roadmaps for technological trends based on patent innovations over the last several decades (CREAX Corporation, 2014). Mitsubishi Electric is a technology-driven company that manufactures and retails electronic products and systems for a wide range of applications.

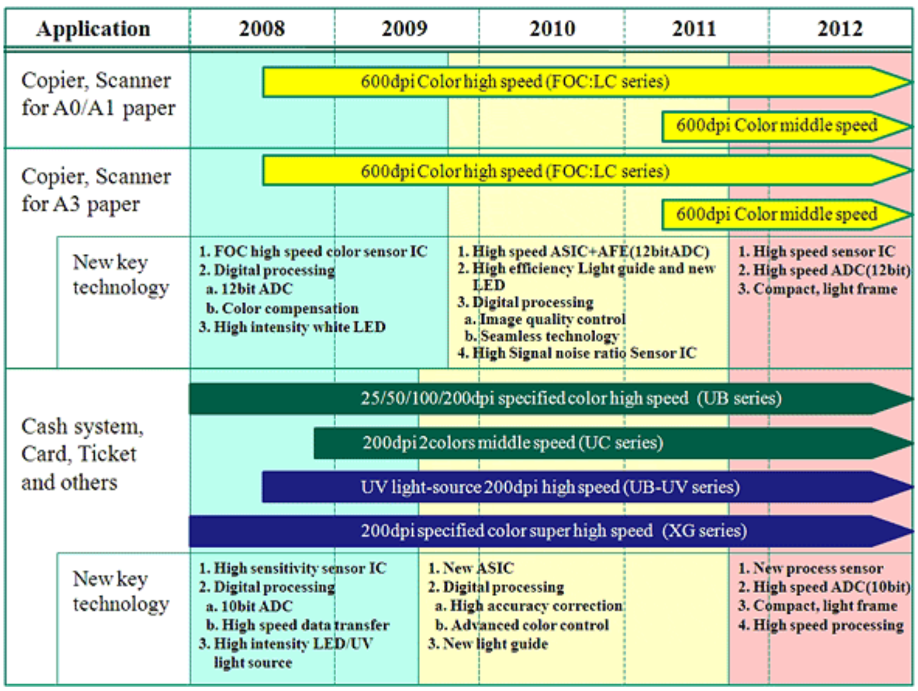


Figure 3. Example technology roadmap, adapted from (Mitsubishi Electric, 2016)

They maintain technology roadmaps illustrating the progressive evolution of image sensors over a 5-year timeline, as shown in Figure 3 (Mitsubishi Electric, 2016). New technologies associated with desired image quality are specified with the anticipated image quality in each application on a product lineup (from A0/A1 paper to A3 paper, and cash system, card, tickets).

Similarly, Meyer and Lehnerd introduced a best-practice product family map that illustrates platform renewals and evolutions (Figure 4) (Meyer & Lehnerd, 1997).

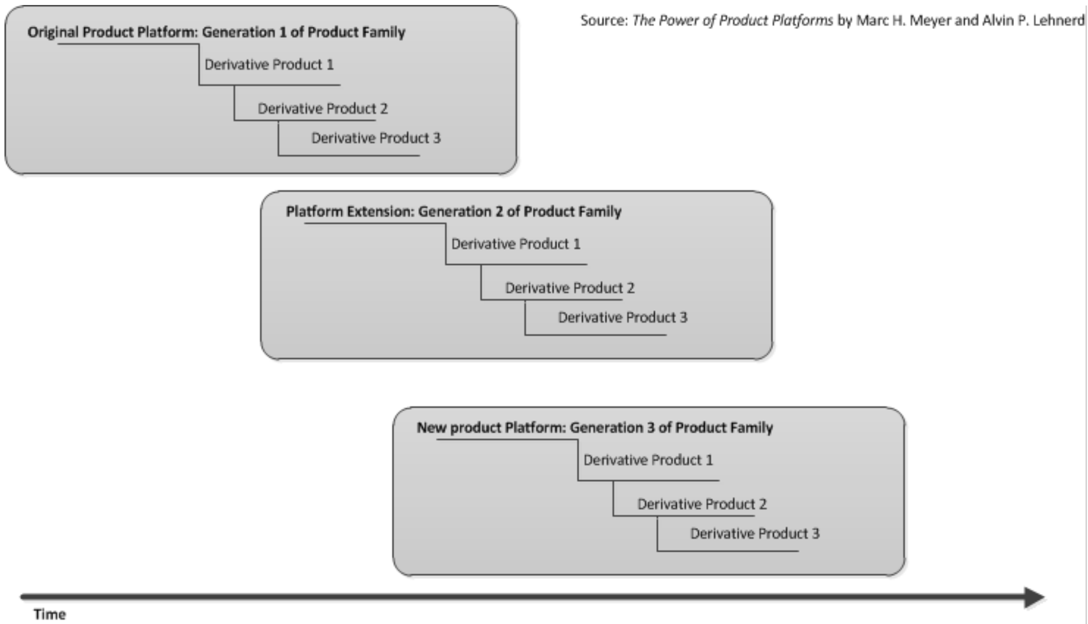


Figure 4. The power of the product platform, adapted from (Meyer & Lehnerd, 1997)

Meyer and Lehnerd argue that companies should illustrate new product development throughout multiple periods—initiating an original product platform, extending it as a renewal, and then creating a new platform. In their model, efficiency, costs, and new features are the main parameters of platform renewal and product development. Discussions of efficiency, cost, and features are already incorporated in several technology roadmapping processes driven by linear development. Petrick and Echols propose a heuristic approach that emphasizes avoiding traditional finance-based thinking, and suggest an integration of technology roadmaps, information technology, and supply chain management (Petrick & Echols, 2004).

More recently, in 2015 the National Science Foundation (NSF) held a workshop to envision upcoming developments in smart-goods manufacturing and to identify opportunity spaces for emerging research. Workshop participants advocated for the importance of having a technology roadmap. They believed that small smart-goods companies are challenged by the lack of resources to keep separate marketing and/or product development teams. Thus, identifying technical challenges to realize the next-generation of goods would be an approachable and accessible way of preparing for future markets.

> "As a small company, key challenges discussed included the need to find investment for exploring advanced manufacturing capabilities and the ability to integrate many disparate engineering disciplines. For these reasons, the speaker advocated the need of a technology roadmap for smart goods which would help smaller companies, absent the marketing and product development capabilities of larger firms, understand the future direction of technology markets and investments."

The resulting report, *NSF Workshop Report: Advanced Manufacturing for Smart Goods* (ASME Manufacturing Engineering Division, 2015) contains an example technology roadmap that predicts the future of autonomous systems (Table 1).

Table 1. A roadmap looking forward at the advancement of robotic systems over time, adapted from *NSF Workshop Report: Advanced Manufacturing for Smart Goods* (ASME Manufacturing Engineering Division, 2015)

	2008	**2018**	**2028**
Human Interaction	Requires Human Operator	Voice Commands	Multi-lingual
Swarm	Single Unit	Within Controlled Environments	Multi Domain Collaboration
Frequency	Restricted RF	Limited Frequency Agility	Multi Band Communications
Functionality	Single Mission Operator Directed	Programmed "Smart" Missions	Autonomous Behaviors
Operating Environment	Restricted Controlled Environments	Expanded Operating Limitations	All Weather Cross Domains
Payload	Single Mission Design	Integrated Sensors	Integrated Systems
Command and Control	Requires Human Operator	Operator Per Command Unit	Operator Per Region
Data Network	Limited by Technology Available	Smart Bandwidth Control	Bandwidth Independent
Endurance	Single Hour	Days	Years
Maintenance	Specialized Skill Maintenance	Remove and Replace	Self Repair
Artificial Intelligence	Sensor Data	Integrated Sensor and Mission Operation	Decision Making

In Table 1, the advancement of a robotics system over time is broken down into the individual system components that make up each row. The progressive development of these system components is described over a loosely defined time frame: past (2008); current/near-term (2018); and long-term (2028). The progression is linear and shows high-level essentials in simple phases. For instance, the "Payload" row begins with "Single Mission Design" which leads to "Integrated Sensors." Finally, "Integrated Systems" are to be built in the last stage. This excerpt from the NSF report provides evidence for Garcia and Bray's argument that technology roadmapping helps organizations make decisions on what technologies should be considered for future investment (Garcia & Bray, 1997). The workshop participants used it to gauge the level of anticipating technologies to be developed over a rough timeframe.

2.2 Integration of Product Roadmaps and Technology Roadmaps

In practice, a majority of companies keep product and technology roadmaps constantly updated and engage them to guide decisions on which products and technologies should be selected and funded for the next phase of product development (Phaal, Farrukh, & Probert, 2001). Thus, there is interplay between product roadmaps and technology roadmaps.

Product and technology roadmaps address both technical challenges and customer and industry requirements. It is common to observe efforts to integrate product roadmaps and technology roadmaps (Rinne, 2004; Phaal, Farrukh, & Probert, 2004). Albright and Kappel depict the anatomy of product-technology roadmaps that illustrate how market, product, technology, and summary/action plans are related (Albright & Kappel, 2003). Rinne adds visualization elements to a schematic roadmap by connecting arrows between markets, products, and technologies to illustrate how they are related each other (Rinne, 2004).

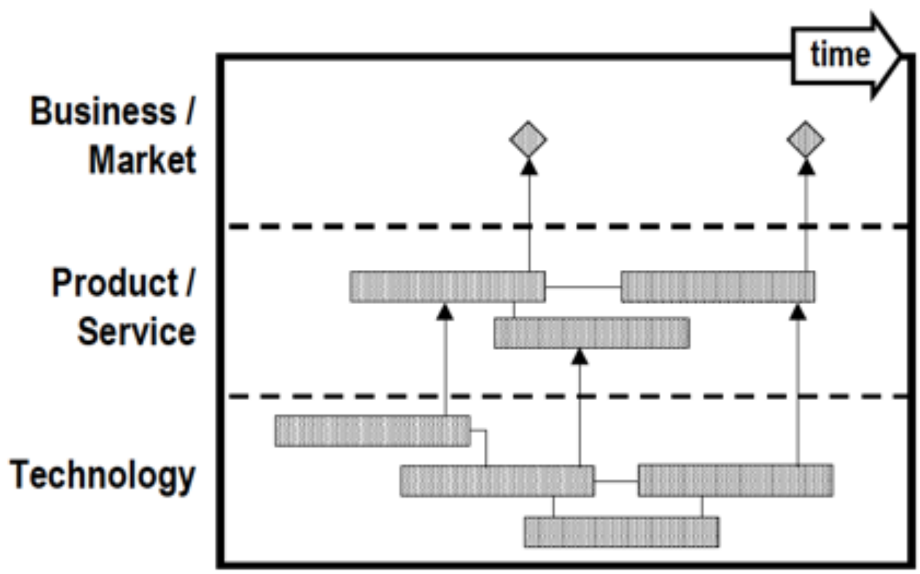


Figure 5. Schematic technology roadmap, adapted from (Phaal, Farrukh, & Probert, 2004)

Based on this generic technology roadmap visualization, markets and technologies are two of the most primary elements that influence the evolution of products. Rinne has attempted to differentiate various roadmapping methods: virtual innovation; innovation factories; and several patterns of co-evolution between technologies, products, and markets, to investigate how technology roadmapping can support a firm's virtual innovation and innovation factories. Phaal et al. illustrate the schematic technology roadmap (Figure 5) that incorporates business/market and product/service into technology progression over a time frame (Phaal, Farrukh, & Probert, 2004).

Recent roadmapping process research attempts to make roadmapping more visual and interactive. Simonse et al. present a conceptual framework that emphasizes visualization of market, product, and technology plans over time (Simonse, Hultink, & Buijs, 2015). Their framework creates a more interactive means of working with roadmaps, by making them visual to teams working together and by providing greater ease for updating them over time. Kerr and Phaal emphasize a design-driven approach and visual representation of roadmaps (Figure 6) for clearer communication among stakeholders (Kerr & Phaal, 2015).

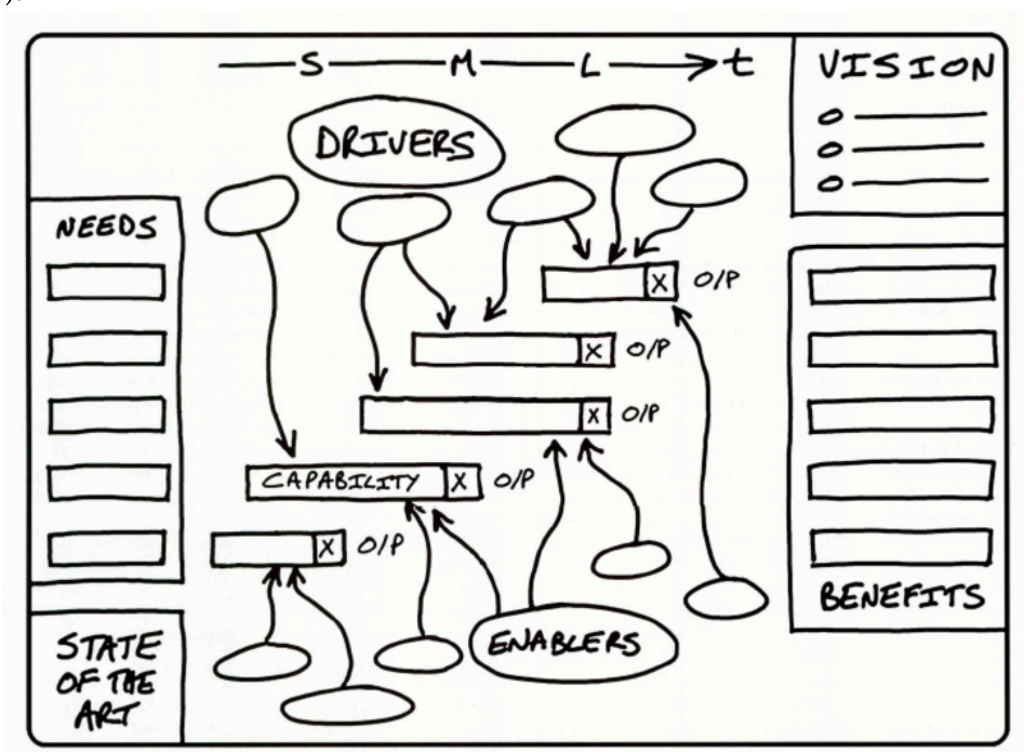


Figure 6. Visualization concept for research initiatives, adapted from (Kerr & Phaal, 2015)

The framework proposed by Oliveira and Fleury addresses the gaps of layer integrations among different information (e.g., technology layers, product layers, and market layers) (Oliveira & Fleury, 2015). They argue for a tool to assess the performance of roadmaps by three different layers.

Another example is Facebook's roadmap (Figure 7). Facebook announced its 10-year roadmap at the F8 Facebook Developer Conference 2016 (Facebook, 2016). At this event, CEO Mark Zuckerberg addressed his vision for Facebook in the next 10 years. He talked about their direction in three main phases: 3 years, 5 years and 10 years (Business Insider, 2016).

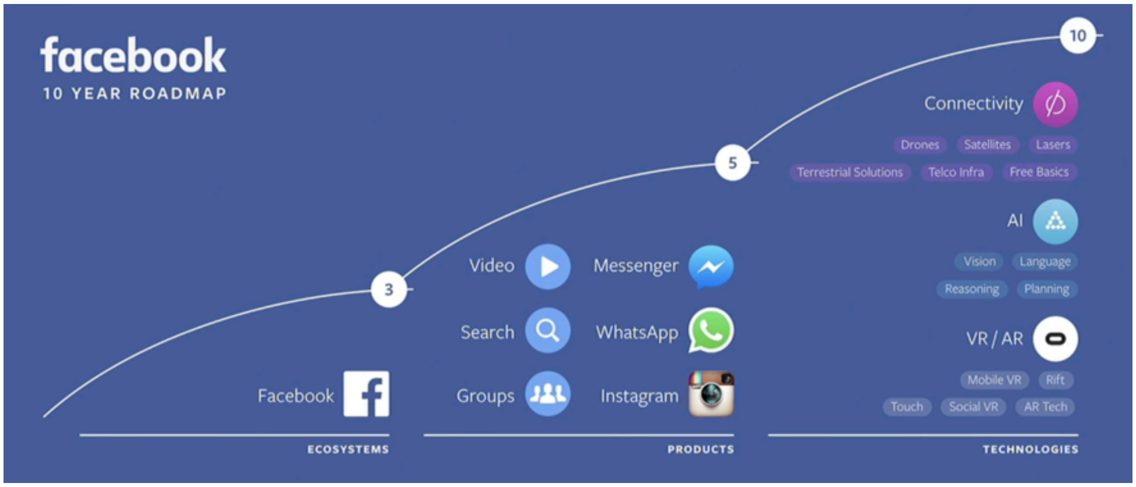


Figure 7. Facebook 10-year roadmap, adapted from (Facebook, 2016)

The purpose of this roadmap is different from traditional product and technology roadmaps in that Facebook aims to engage its "innovation ecosystem" in following the future path that it envisions: eco-systems, products, and technologies. While the content was generic and consisted of things the public already knew, the company explicitly laid out transitional phases to evolve the existing Facebook platform beyond current product levels by incorporating advanced technologies—such as artificial intelligence, virtual reality, Internet access infrastructure—to integrate the notions of ecosystems, products, and technologies as a whole in a single canvas.

2.3 Building Roadmapping Processes

Methods for building product and technology roadmaps have been discussed for several decades in the academic literature for product planning (Phaal, Farrukh, & Probert, 2001; Cooper R. G., 1994; Garcia & Bray, 1997) and to guide the interactive development of products and technologies across an organization (Ulrich & Eppinger, 2003). Garcia and Bray establish three high-level stages of building technology roadmaps: 1) preliminary activity, 2) development of the technology roadmap, and 3) follow-up activity. The establishment of these stages integrates strategic planning and technology planning (Garcia & Bray, 1997). Garcia and Bray emphasize that technology roadmapping helps a firm make decisions on what technologies should be invested in or not. Phaal and Muller describe roadmapping as an iterative process of ideation, divergence, convergence, and synthesis; they introduce a roadmapping architecture involving multiple hierarchical layers (Phaal & Muller, 2009). Vähäniitty et al. suggest steps for creating and updating product roadmaps: define strategic vision, scan the environment, revise and distill the product vision, estimate the product life cycle, and evaluate the planned development efforts (Vähäniitty, Lassenius, & Rautiainen, 2002). Portfolio planning, of which product and technology roadmapping are a part, aims to align the organization's investments to maximize returns, create strategic fit and balance risk (Cooper R. G., 1994). Roadmapping, in turn, lays out those investments over time.

There have been some efforts integrate product families at the project portfolio management level (Voss, 2012). Projects from the portfolio plan or roadmap are fed into new product development processes such as the Stage-Gate process (Cooper & Edgett, 2010; Rinne, 2004) and waterfall development processes (Royce, 1970). Creating product family maps that leverage a series of platforms (product, technology, brand, etc.) over time allows a company to create a series of successive product concepts with new features and enhanced capabilities (Meyer & Lehnerd, 1997). The main focus of these activities is to sustain market leadership over time by leveraging technological advances into products that provide greater efficiency, cost reduction, new features, and so on.

2.4 Market Forces Motivate New Approaches to Roadmapping

Despite the mature application of roadmapping processes in industry, increasing uncertainties, rapid changes, and complexities in market environments are forcing companies to question the validity of strategies that differentiate their products[1] solely by their features, as specified by roadmaps based on linear technology evolutions. Increasingly, the totality of a user's *experience* of a product—the product itself, and how it interacts with other products, systems, and customer supports—ensure market success. Thus, many industrial firms are struggling to find operational methods for implementation of effective roadmapping process and future product planning.

Design/experience-driven approaches have been proposed to connect market forces with product innovations. Human-centered design offers a way forward in this more complex market environment. Human-centered design addresses the tension of balancing a concern for understanding previous and current practices with a concern for anticipating future practices (Steen, 2011). Bertola and Teixeira argue for implementation of design as a knowledge agent in organizations to promote innovation (Bertola & Teixeira, 2003). Shelby et al. present an example of partnership failures due to a technology only–driven approach by arguing that understanding user needs and building customer trust are crucial market success factors (Shelby, Perez, & Agogino, 2012).

[1] In this context, products mean more than physical products, but could include intangible products such as services, software, or other type of solutions that are manufactured or built for commercial purposes.

An et al. introduced integrated product-service roadmaps (Figure 8) along with Quality Functional Deployment (QFD) to push the role of design research in forecasting products and services in the near- and/or long-term future (An, Lee, & Park, 2008).

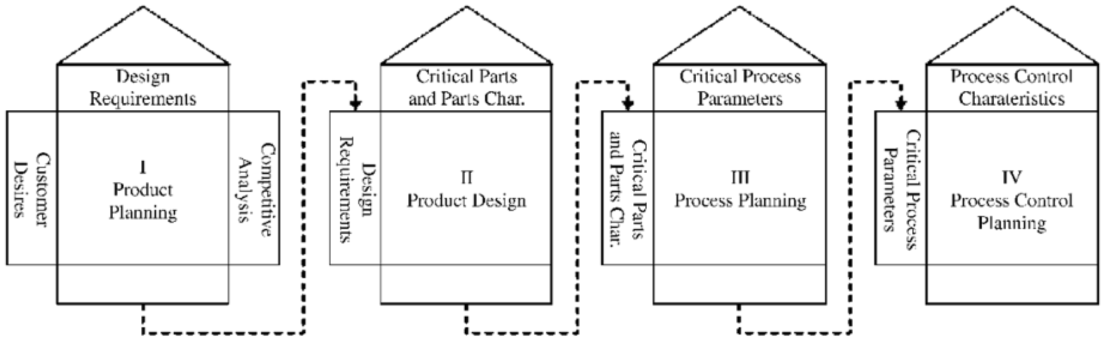


Figure 8. Development of an integrated product-service roadmap with QFD: A case study on mobile communication, adapted from (An, Lee, & Park, 2008)

Geschka and Hahnenwald present a scenario-based technology roadmap (Geschka & Hahnenwald, 2013). They note that a technology roadmap is not influenced merely by technology evolutions, but by external circumstances such as market, societal, and economic factors.

Similarly, "era analysis" is used to plot the flow of information over pertinent timelines to depict a set of activities associated with a given product or service (Beckman & Barry, 2007). An example from Clorox Corporation (Clorox Corp.) is shown to help better understand how sustainability can be integrated into their product lines. In this particular example, the evolution of the definition of cleanliness over time is shown to define an important aspect of sustainability in the context of longer-term general trends (Figure 9). Then, the evolutionary definition of cleanliness in the market is mapped onto product and technology roadmaps.

	ca. 1920s-1945	ca. 1945-1960s	ca. 1970s-1990s	2000s-2020s
Invisible Dangers	Tuberculosis Infections	Polio Mental Illness	**Germs (HIV / e.coli / SARS / Bird Flu)**	**Chemicals, Toxins, Nano-pollutants**
Role and Perception of Germs	Public health initiatives spreads knowledge about the causes and possible prevention of common diseases.	Improvements in sanitation pushes concerns about germs to the background.	Reduced investment in public health and globalization increases concerns about pandemics.	Noncommunicable diseases like cancer and diabetes becomes the main concerns in the Western world.
Role and Perception of Chemicals	Medical use of chemicals lead to great optimism for the potential treatment of many serious illnesses.	Continued progress and development of new "wonderdrugs."	Faith in the health successes of chemicals start to wane. Media fuels suspicion and alienation.	Image of the chemical industry continues to deteriorate while chemists at the same time are responsible for great advances in computer processor technology.
What is "Clean"?	No visible stains	Surface shine Without stains	Disinfected Without stains	Chemical free Different cleaning requirements for different surfaces
Motivations for Purchasing Products	Practical need	Labor saving Leisure Advertising	Instant gratification Expression of identity	Future investment Moral imperative Showing support
Product Life Cycle	Repairs	Industrial durability Planned obsolescence Repairs	Planned obsolescence Partial recycling	Cradle-to-cradle Repurposing Scavenging
Products and Their Purpose	Utility	Labor-saving	Consumption	Restoration Conservation

Figure 9. Era analyses of cleanliness, general trends, adapted from (Beckman & Barry, 2007)

Although platform strategies and previous roadmapping approaches have been useful in conventional product development in the past, current market conditions motivate a more customer-driven approach that can directly build on customer research on desired user experiences, outcomes, and user needs. In the next chapter, I pose research questions and methodologies for better understanding the limitations of current roadmapping methods in order to formulate a new customer-driven approach.

3 RESEARCH QUESTIONS AND METHODOLOGIES

Chapter Overview

This chapter presents primary research questions, research methodologies, sources of data, and data validation processes.

3.1 Research Questions

My research aims to answer the following questions in the field of new product development, design processes, and team collaboration:

1. What are the types of roadmaps used in industry?
2. What is the current roadmapping process, and who has ownership of the roadmapping process?
3. What are the challenges and opportunities for current roadmaps and roadmapping processes?
4. What are the benefits of integrating customers and user needs information into the design roadmapping process earlier?
5. What are the benefits of design roadmapping in new product development education?

To answer the first three questions, I interviewed 46 professionals (six pilot and forty in-depth interviews) at 18 companies in the San Francisco Bay Area and on the East Coast to understand how various types of roadmaps are used and developed within current industry settings. (Chapter 4) and developed a design roadmapping process (Chapter 5). To answer question 4, action research—actual implementation of my proposed design roadmapping process—was used (see Chapter 6 and Chapter 7). Finally, Chapter 8 aims to answer research question 5, by examining a one in-depth pilot test and in-class case studies in new product development courses at UC Berkeley.

3.2 Research Team

In some part of the research (Chapter 4 and Chapter 6 Sproutel action research), I had multiple researchers on my team to collaboratively collect data and validate interpretations of qualitative responses. Researchers were trained to carefully handle data sets. I checked their interpretations against mine to compare data validity. Inter-rater reliability was used to compare scores from each rater.

3.3 Research Methodologies

This research used a wide variety of methods. Early in the process, to explore the current state of roadmapping, I conducted pilot interviews followed by a much larger set of semi-structured interviews. Observations were useful to capture interdisciplinary team dynamics and communication contexts. I conducted action research in two industrial settings.

3.3.1 Pilot interviews

I began with six in-depth pilot interviews to understand how roadmapping is generally used in various industries. Interviewees with at least five years of work experience from business, marketing, design, and research and development were included in the study. Each interview took approximately 1 hour. After each interview, I refined and edited my questions based on comments and feedback. These pilot interviews allowed a more effective script for the ensuing semi-structured interviews applied in Chapter 4.

3.3.2 Semi-structured interviews

Next, I interviewed 40 professionals in a semi-structured format. Semi-structured interviews were useful as they followed more or less the themes outlined but allowed room to explore additional topics that were also relevant to both the interviewee and the interviewer. They gave participants more flexibility in answering the questions in depth, depending on their own organizational structure. The results of semi-structured interviews are discussed in Chapter 4.

Some interview subjects were participants in a one-week-long Executive Product Management Program at UC Berkeley's Haas School of Business; these subjects were interviewed in November 2013 and March 2014. Other subjects were from companies in the San Francisco Bay Area and the East Coast and they were interviewed from August 2013 to May 2016. Thirty-one interviewees were working in a large-size company (employee number > 1,000), two interviewees were from a medium-size company (employee number between 100 and 999), and seven interviewees were from a small company (employee number < 100) Twenty-seven interview subjects were male and thirteen were female. I requested an interview lasting about 15 minutes to 1 hour at a time and locations convenient to the interviewees. Topics included, but were not limited to, questions regarding background, job description, general product development processes and roadmapping, and what's working well and or what's not. Copies of the interview guides are attached in Appendix A and Appendix B.

3.3.3 Observations

Over the course of eight months, I observed 24 professionals in context such as team meetings and conference calls. I observed approximately 45 design meetings, each of which lasted between 30 minutes to two hours, in which multidisciplinary team members discussed their projects. The observers captured key conversations, topics, themes, and controversial arguments in each meeting. With participant permission, these observations were noted and subsequently drawn into reasoned research frameworks. Observations provided insight into how team members collaborate and what types of tangible and intangible deliverables are exchanged during the design process. These observations occurred as part of the design roadmapping implementations (two case studies-Chapter 6). Based on these observations, the roadmapping process was implemented at each company was tailored to the size, culture, and process of each company while keeping the main structure of the five-steps design roadmapping process shown in Chapter 5.

3.3.4 Action research

Action research is a disciplined process of inquiry conducted *by* and *for* those taking the action (Sagor, 2000). It is a flexible and practical approach that is relevant to not only educators but also professionals by assisting the "actors" in improving and/or refining their actions. Action research respects people's knowledge, context, and existing processes, and addresses the issues they are challenged with (Brydon-Miller, Greenwood, & Maguire, 2003). Working collaboratively with participants leads to engaging interaction between researchers and their subjects. This dissertation research tested the design roadmapping process via action research in the practitioner's world in two very different types of organizations—a large multinational corporation and a small startup (Chapter 6).

3.3.5 Online survey

An online survey was created to evaluate design roadmapping workshop participants' satisfaction rate and to receive feedback on the implemented design roadmapping workshop tools. This survey was distributed to participants at Sproutel as well as students in the ME110 class and the Master of Engineering student team. Twenty-three subjects responded (Chapter 6 and Chapter 8) and each was given a unique code (e.g., S-1, S-2, etc.). In addition, 39 more students (S-24, S-25…S-62) answered a separate, open-ended question asking about their satisfaction with the design roadmap workshop as part of an end of semester course evaluation for ME110 New Product Development.

3.4 Data Analysis

Qualitative research is inherently subjective, diverse, complicated, and subtle (Holloway & Todres, 2003). To analyze and synthesize the qualitative interview data, I used both grounded theory and thematic analysis.

3.4.1 Grounded theory

This analysis is used to build an in-depth understanding of the context surrounding communication, internal, and external collaboration. Direct quotes from interviews are coded (line-by-line) and multiple researchers worked together to analyze the data to discover meaningful and indicative patterns to build frameworks (Chapter 4 and Chapter 6).

3.4.2 Thematic analysis

Qualitative research methodologies are used to analyze data gathered from comprehensive observations, in-depth interviews, and workshops. Qualitative research is inherently subjective, diverse, complicated, and subtle (Holloway & Todres, 2003). Thematic analysis is a flexible approach to highlight similarities and differences between gathered data sets. Vivid examples of interpretative thematic analysis implementation have been introduced by a number of academic researchers in the applied psychology field. In my dissertation research, I had verbal data such as interviews and conversation audiotapes that had to be transcribed into written format for further data analysis. Narrative analysis has become the primary methodology to dig into transcription pages for extensive systematic analysis (Riessman, 1993). I implemented the six phases of thematic analysis (Table 2) adapted from Braun and Clarke (Braun & Clarke, 2006).

Table 2. Phases of thematic analysis, adapted from (Braun & Clarke, 2006)

	Phase	Sources of Step
1	Familiarizing yourself with your data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2	Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3	Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4	Reviewing themes:	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5	Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6	Producing the reports:	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

After initial code generation and theme extraction, each theme from the data set was finally connected back to my initial research questions, demonstrating what kind of arguments can be addressed in my dissertation topic. The results of thematic analysis in each chapter are discussed with their respective findings (Chapter 4 and Chapter 6).

3.5 Data Validation/Repeatability

Qualitative researchers have studied the application of inter-rater reliability, i.e., a "two heads are better than one" approach to interpreting qualitative data (Armstrong, Gosling, Weinman, & Marteau, 1997). I used the Inter-rater Reliability Test for data validation (Landis & Koch, 1977; Fleiss, Levin, & Paik, 2013). Inter-rater reliability increases the data reliability by having multiple experienced raters analyze data and compare scores in a systematic approach. In my case study, two researchers (dissertation author and another research assistant) were asked to identify main themes in the interview codes (Chapter 6).

4 DESCRIPTIVE STUDY OF CURRENT ROADMAPPING PRACTICE

Chapter Overview

This chapter summarizes the results of descriptive studies and outlines key findings regarding current roadmapping practices in industry.

It provides answers to the questions:
1) What are the types of roadmaps used in industry? 2) What is the current roadmapping process, and who has ownership of the roadmapping process? and 3) What are the challenges and opportunities for current roadmaps and roadmapping processes? Observations are drawn from the literature as well as from personal interviews with professionals from Silicon Valley, the East Coast, and abroad.

4.1 Research Design

To understand how various types of roadmaps are currently used in industry settings, I interviewed 46 professionals at 18 companies in the San Francisco Bay Area and on the East Coast (6 pilot and 40 semi-structured interviews as described in Chapter 3). Table 3 summarizes the characteristics of the semi-structured interview subjects.

Interview participants were categorized into three distinct job positions, as shown in Table 4. This sorting occurred after the interviews were completed to reflect the interviewee's job duties, not just their arbitrary titles.

Table 3. List of individual interview participants

Job Category	Code	Gender	Company Category	Company Size[2]
Designer	D-1	Male	Software	Large
	D-2	Male	Consumer Electronics	Large
	D-3	Female	Consumer Electronics	Large
	D-4	Male	Consumer Electronics	Large
	D-5	Female	Consumer Electronics	Large
	D-6	Male	Computer S/W & H/W	Large
	D-7	Female	Consumer Electronics	Large
	D-8	Female	Consumer Electronics	Large
	D-9	Male	Glass & Ceramic Materials	Large
	D-10	Male	Consumer Electronics	Large
	D-11	Male	Computer S/W & H/W	Large
	D-12	Female	Computer S/W & H/W	Large
	D-13	Female	Health Care	Small
Product Manager	P-1	Male	Network	Large
	P-2	Male	Communications & Information	Large
	P-3	Male	Internet C2C corporation	Large
	P-4	Female	Network	Large
	P-5	Male	Security Solutions	Large
	P-6	Male	Security Solutions	Large
	P-7	Male	Software	Large
	P-8	Male	Database	Small
	P-9	Female	e-commerce	Large
	P-10	Female	e-commerce	Large
	P-11	Male	Network	Large
	P-12	Male	Security Solutions	Large
	P-13	Male	Financial mgmt solution	Large
	P-14	Male	Online education	Small
	P-15	Female	Internet	Large
	P-16	Male	Home Automation	Medium
	P-17	Male	Health Care	Small
Technology Manager	T-1	Female	Software	Large
	T-2	Male	Software	Large
	T-3	Male	Software	Large
	T-4	Female	Network	Large
	T-5	Male	Camera	Medium
	T-6	Female	Sound Technologies	Large
	T-7	Male	Security Solutions	Large
	T-8	Male	e-commerce	Small
	T-9	Male	Health Care	Small
	T-10	Male	Health Care	Small

[2] Company size defined by # of employees (Large > 1,000, Medium 100 – 999, Small <100)

Table 4. Summary of interview participants

Job category	Product managers	Technology managers	Designers
Number of participants	17	10	13
Description of types of interviewees	Product managers are usually in charge of product roadmaps in their organization. Product managers, marketers, portfolio managers, service managers, & business directors are included in this category.	Technology managers lead or play a major role in a technology development team and usually manage technology roadmaps.	Designers and design researchers lead or play a substantial role in design teams and typically manage the design process in various ways within a firm.
Company categories	Network, communication & information, security solutions, software, E-commerce, financial solutions, online education, internet, home automation, health care	Network, software, camera, sound technologies, security solutions, consumer electronics, health care	Software, consumer electronics, computer software & hardware, glass & ceramic materials, health care

4.2 Interview Results

The results of this descriptive study are summarized in Table 5, which shows the number of participants in each functional category that responded to key primary code sets.[3] Each code set in discussed in greater detail below.

4.2.1 Types of roadmap in use

This section aims to answer the question "what are the types of roadmaps used in industry?" Based on the collected interview data, I defined three types of roadmaps that are most frequently used in the workplace: product roadmaps, technology roadmaps, and design roadmaps. Substantial number of product and technology managers responded that they maintain either a technology or a product roadmap on a regular basis. A few designers answered that they keep design roadmaps, but they tend to be subsets of product/technology roadmaps.

4.2.1.1 Product roadmaps

A product roadmap shows a company's vision and holistic plan, including aspects of business strategy, engineering, marketing, etc. Similar to published definitions of the product segment roadmap (Ulrich & Eppinger, 2003) and the strategic product roadmap (Cooper & Edgett, 2010), the interviewees described their product roadmaps as a

[3] The total number of respondents in the table excludes interviewees who either were not asked or declined to answer specific questions

schematic that illustrates key performance dimensions containing product features, core technologies, marketing, and finance over a timeline. Product managers are the primary owners of product roadmaps.

Table 5. Summary of descriptive research on roadmaps in use

Primary code	Sub-code	Product manager (17)	Technology manager (13)	Designer (10)	Sum (40)
Types of roadmap	Product roadmap	13	7	6	26
	Technology roadmap	6	8	6	20
	Design roadmap	0	0	9	9
Frequency of roadmap updates	Less than a quarter – 6 weeks	2	1	0	3
	Quarterly	5	4	2	11
	Longer than quarterly	1	2	1	4
Purpose of roadmap	Future prediction	7	4	3	14
	Internal collaboration	10	6	3	19
	External communication	10	1	0	11
	Resource allocation	6	4	1	11
Issues on roadmapping process	Lack of feedback loop from users	1	0	3	4
	Ineffectiveness in predicting future	4	2	0	6
	Communication conflict	7	3	0	10
	Plan not followed	1	3	4	8
	Feature driven	3	3	3	9
	Ambiguity and confusion	4	2	0	6
	Lack of agility	1	0	2	3

The interviews revealed that companies generally maintain two types of product roadmaps: one for internal use and another for external use. Internal product roadmaps map out detailed near-term to long-term strategies, illustrate resource allocation to a firm's vision, and are used as a medium to connect internal collaborators, whereas external roadmaps show business partners and customers general directions for the company.

The external roadmaps are popular for software-based companies who need: 1) prompt feedback from key customers on their new product concepts and 2) collaboration with key partners who develop associated products/services. Product roadmaps are sometimes intentionally disclosed for the purpose of appealing to the existing user population with forthcoming products.

4.2.1.2 Technology roadmaps

Technology roadmaps give a detailed plan for engineers to prepare for forthcoming technology development and resource allocation for current and future projects, similar to the definition of technology roadmaps from the literature reviews (Rinne, 2004; Phaal, Farrukh, & Probert, 2004). Usually technology-roadmaps are derived from product roadmaps, but companies whose innovations are heavily technology driven find that their technology roadmaps have a relatively larger influence on product roadmaps than those that are design-driven. Technology roadmaps are unlikely to be shared with outside stakeholders.

4.2.1.3 Design roadmaps

A design roadmap is the last type of roadmap mentioned by the interview participants. While 75% of designers interviewed answered that they kept some sort of design roadmap, the definition of design roadmap was described without common ground. No structured roadmapping for designers was observed; rather, the current design roadmaps in use were mostly described as a map that visualizes design elements of products. They were loosely organized and tended to be subsets of technology/product roadmaps. For instance, one participant answered that her design team is a part of the engineering team. In consequence, the design team owns and maintains the design roadmap only after the technology roadmaps are confirmed beforehand. Another participant described that a design roadmap he owns focuses on developing design elements that make up the key features/functionalities of the current product lineups, not necessarily design initiatives associated with a company's long-term vision.

4.2.2 Purpose of roadmaps

While roadmaps generally aim to portray a particular future state, company goals for roadmapping include various motives, such as forecasting, planning, and administration (Sungjoo & Park, 2005; Phaal, Farrukh, & Probert, 2001). Cooper and Edgett argue that companies with certain types of product innovation strategies, such as product roadmaps, are more likely to perform better (Cooper & Edgett, 2010). They mention that:

> […] On average, only 27.6% of businesses develop a product roadmap, but best performers are about twice as likely to use road- maps as poor performers. […]

In their context, roadmaps are mainly beneficial for resource allocation and deployment. My research captured four primary purposes of roadmaps—future prediction, resource allocation, internal collaboration, and external communication—which are described in detail below.

4.2.2.1 Future prediction

Companies use roadmaps to predict future markets and plan for products in advance so that they can create effective business strategies (Albright & Kappel, 2003; Cooper & Edgett, 2010; Phaal, Farrukh, & Probert, 2004). They use roadmaps to derive actionable items to reach desirable goals in future markets. This purpose is confirmed by the following quotes from my interviews with a technical manager and a product manager:

> "So product roadmapping is important because it gives you two things. First, it tells you the direction in which the company needs to go. So you have a checkpoint and you have a report, you evaluate that and you figure out whether you are on the right track or not." (T-1)

> "The roadmap really is that showing where I'm planning to go in the next year and what I'm hoping to achieve." (P-8)

In many cases, roadmaps enable companies to make business decisions based on the information they obtain. Generally, product managers in my research believed that making any decision was better than no decision. This quote from another product manager captures the general consensus:

> "We can make decisions based on information we have. We may or may not be the right decisions, but any—in my opinion—decision is better than that cycle of indecision." (P-7)

4.2.2.2 Resource allocation

Once executive decision-makers set the company's vision, product and technical managers prioritize plans based on the predicted impact on revenues and customer satisfaction and growth. The key players in the roadmapping process allocate resources based on their priorities. This observation is aligned with the purpose of the strategic product roadmap as part of resource commitment described in Cooper and Edgett's framework for developing a product innovation and technology strategy (Cooper & Edgett, 2010).

I found that 57% of technical managers use their roadmaps primarily for resource allocation while only 38% of product managers do. Since technologies demand time and resources to develop, technical managers need to select and invest in the most appropriate technologies in advance. This result suggests that technology managers may own the resources to be allocated while the product managers do not, particularly in companies in the high-tech industry.

> "For the technology people, that resource allocation is the core problem because they need to develop the core technologies that will eventually make a working prototype happen and [be] compelling." (T-2)

4.2.2.3 Internal collaboration

Eighty percent of our research participants answered that the primary purpose of their roadmaps—a product roadmap, technology roadmap, or design roadmap—was for internal collaboration. They were used to align the product and technology development processes across multiple teams in a company. One technical manager explained that good collaboration with internal stakeholders was necessary to make decisions.

> "You have to talk to a lot of different people. You understand the market, you understand your customer, then you have an idea of what's needed in the product. But then you need to talk to engineers to make sure that there's the technology to help it." (T-7)

Internally, roadmaps were also used to make technological alignments since there are multiple engineering teams in a company, such as software and hardware teams. A technology manager from a hardware company explained it was necessary for the engineers to use roadmaps to collaborate well:

> "For us, there are many independencies, so it [roadmap] helps get alignment. Because they [engineers] have to do a lot of integration or testing, planning, to make sure things align between hardware and software. So its primary purpose is alignment." (T-5)

Also, the internal roadmap provides richer information for communication among collaboration teams that is well aligned with their long-term strategies:

> "We have an internal roadmap, which I think will correspond to traditional product or design roadmaps, but would look much further out. And [it] provides much detail and will actually give [a] glimpse of long-term strategy versus the customer roadmap, which is external." (P-7)

4.2.2.4 External communication

My research found that 56% of product managers use product roadmaps to communicate with external stakeholders whereas only 14% of technology managers do so. Product managers use external product roadmaps to gain feedback about their business plans from key business partners and customers. Another motivation to share product roadmaps with customers is to increase competitiveness. Large companies may lack agility because of their size. One of the product managers at a multinational company explained that they use roadmaps as a marketing strategy to inform customers which features and/or technologies the company is committed to developing in the near future:

> "[A] Roadmap is used as a competitive weapon. Competitors might come up with features that we don't have. Eventually we are doing certain things, but some features may not be covered today. So, the primary purpose of roadmap of our company is to document what we will be doing for the next 18 months…and the customers can make plans and purchase decisions based on that roadmap." (T-4)

Another product manager mentioned that he use roadmaps for communication with their external Business-to-Business customers. Despite the confidentiality of content on the roadmaps, some companies have no other choice but to share them with external collaborators, business partners, and suppliers. This is mainly to build close partnerships.

> "We use roadmaps for the customers to understand where we are placing our bets and help them make decisions based on where we are going and what we see in the future. Roadmapping also helps build [the] company's reputation by showing their bigger plan." (P-1)

4.2.3 Frequency of roadmap updates

Interviewees emphasized the necessity of updating roadmaps on a regular basis to *"keep them alive"* because markets change fast. The majority (66%) of our research participants revised their roadmaps quarterly. I found that the frequency of a company's decision-making process also affected roadmap update frequency. Companies update roadmaps to revise their core product concepts, features, and experience revisions. Also, the update frequency depends largely on a product's lifecycle. Hardware companies are less likely to update their roadmaps frequently because their product lifecycle is relatively long, whereas software companies are likely to update their roadmaps frequently because of short product release cycles. A company may also update its roadmap if there is a change in its fiscal plan that will influence resource allocations (Cooper & Edgett, 2010).

4.3 Challenges and Opportunities

This section aims to answer the question, "What are the challenges and opportunities for current roadmaps and roadmapping processes?" Analysis and synthesis of my qualitative interview data identified three key challenges and three key opportunities.

4.3.1 Challenges

Despite the widespread use and popularity of roadmapping, three major challenges exist: 1) ineffectiveness in predicting the future, 2) lack of a feedback loop from research on end users, and 3) over-dependence on feature-driven roadmapping processes.

4.3.1.1 Ineffectiveness in predicting the future

The primary purpose for roadmaps stated by interviewees was to take future predictions and play them out to identify future opportunity spaces. Previous research also highlights the strength of roadmaps in business forecasting (Kappel, 2001; Cooper & Edgett, 2010). However, due to rapid technological progress as well as swiftly shifting consumer needs, it has become extremely difficult to predict future markets (Beckman & Barry, 2007). Therefore, traditional roadmaps that depend heavily on technological progress have become less and less reliable in predicting changes in recent years.

My research found that inaccuracy in forecasting future market trends was problematic for many key players in the roadmapping process. In practice, business decisions easily deviate from the roadmaps because companies need to react or respond to events that roadmaps failed to predict previously. As one respondent mentioned:

> "Over time, the market dynamics have become even more dynamic. The sine wave is getting tighter and tighter. For me, even predicting what I'm going to produce in six months is very difficult. We invested a tremendous amount of time on roadmapping, but we never ended up producing what we targeted for this [year], even the second year, much less the third year." (T-3)

Roadmaps are expected to present products that will be competitive in the future market so that companies can select appropriate technologies to develop (Phaal, Farrukh, & Probert, 2013). Relying on roadmaps with inaccurate market forecasts poses a high risk to companies because they may not develop products that satisfy rising consumer needs. Effective consumer needs prediction is crucial to developing appealing products. Companies need to direct their engineering departments to develop technologies before they can introduce new products in the market. If the companies invest in technologies for products that will no longer meet upcoming consumer needs, those investments may be wasted.

4.3.1.2 Lack of a feedback loop from research on users

In recent years, there has been a movement for the new product development processes to take into account customer insights to develop products that meet customers' needs (Beckman & Barry, 2007; Kerr & Phaal, 2015). However, my research found that customer feedback is not effectively incorporated into the roadmapping process:

> "There is not a good feedback loop from the consumer side to us. Middle persons overly influence your decisions as a manufacturer regarding what you should create in many cases. But they don't always understand the consumer landscape, what will really sell through." (P-2)

This interviewee explained that there are several intermediaries between the company and its end users. Retailers sometimes overly influence the roadmap and mislead companies into producing what the retailers want to sell instead of what customers want to buy. Although the company may receive access to a full range of market data and customer analyses, customer feedback and insights may be filtered and distorted as the number of stakeholders between the end users and the decision-makers increases. As a result, the key players in the roadmapping process face challenges in capturing latent user needs. Our interviewees highlighted the lack of effective methodologies to extract insights from customers:

> "Although we regularly conduct user tests, there hasn't been user reaction that's strong enough to make a change on our direction; it's more towards incremental changes in features, small pieces." (D-10)

> "It's very hard to figure out the process of how to extract the information I want from my customers and apply [it] to roadmapping." (T-7)

It is difficult to simply take in design researchers' insights from user experience analysis into the business strategy because those researchers often "do not understand [the] business constraints in which the company operates" (T-4). Roschuni et al. define this sort of tension between the designers and business decision makers as *inertia* (Roschuni, Goodman, & Agogino, 2013). Similarly, I found that current roadmapping processes face challenges in key players' inability to define how to make the best use of the design research outcome. I discuss more detailed findings on stakeholder's interactions in section 4.4.

4.3.1.3 Over-dependence on feature-driven roadmapping processes

Nearly every roadmapping process that the interviewees described was technology-driven (Ulrich & Eppinger, 2003). Technology-driven (or feature-driven) roadmaps are relatively straightforward for companies to alter because they can keep adding new or enhanced features to products based on technological progress in any specific time frame. From a marketing perspective, it is easiest to update their new product lineups by simply adding new features to current products. Thus, technology-driven roadmapping may be acceptable as a valid strategy even though those new or enhanced features neither effectively solve customer pain points nor steer a long-term direction. Our respondents described their concerns about the feature-driven roadmapping process:

> "Every year, we need to have different marketing points, which means that we don't have solid good features but keep adding other features into it...because we need to market it differently...so we are not building what's the most important; I think that that's an issue." (D-3)

Even though feature-driven approaches have been effective in the past, industry now requires more radical innovations to respond to shifting consumer preferences (Beckman & Barry, 2007). Moreover, if a company simply adds features based on technological progress, the product may deviate from the most significant user needs. In my interviews, a few respondents answered that their teams are aware of this shortcoming of feature-driven roadmapping:

> "I do think a lot of organizations are feature-driven, and I think it happens a lot with internal tools as well" (P-15)

> "We're trying to shift from feature roadmaps to outcome, customer outcomes. Okay, so we might say we're going to solve these five customer problems in the next six months." (T-3)

4.3.2 Opportunities

By analyzing the major challenges that practitioners have encountered in roadmapping implementation, I identified three opportunities to improve existing roadmapping processes: 1) experience-driven roadmapping opportunities, 2) increasing ownership of designers in planning and roadmapping processes, and 3) preparing for the future using an iterative roadmapping process.

4.3.2.1 Experience-driven roadmapping opportunities

Purchasing decisions for consumer products are no longer driven entirely by product or service features. Rather, the holistic experience around the product or service is becoming more dominant in today's market (Pine & Gilmore, 1998; Pine & Gilmore, 2011; Beckman & Barry, 2007). Many participants in our research addressed this point in similar ways. They described several usages of design implementations in their organizations, particularly during the roadmapping process. One example is a software company who credits *design DNA* as a key driver of innovation for the entire organization. In this company, they develop a roadmap based on outcomes rather than features.

> "We try to be very vague in terms of how at first, and we don't try feature-driven roadmaps, but outcomes of features." (T-2)

Recent efforts (Kerr & Phaal, 2015; Simonse, Hultink, & Buijs, 2015) to bring experience design in as an essential part of the roadmapping process, either beforehand or concurrently, demonstrate the potential to improve the traditional feature-driven technology or product roadmapping processes.

4.3.2.2 Increasing ownership of designers in planning and roadmapping processes

Although a majority of interviewees argued that they wanted to bring more design aspects into the roadmapping process, they did not have detailed execution plans to do so. While designers answered that they already used or were aware of product, technology and design roadmaps in their work, the number of product and technology managers who were aware of these design roadmaps was relatively low (see Table 5). None of the product managers or technology managers said they used a design roadmap, whereas 90% of designers responded they have a design roadmap. Such contradiction of responses across technology/product managers and designers reveals an opportunity for increasing the presence of design-driven roadmaps and improving the direct application of design into the roadmapping process. Many interview participants addressed the necessity of including designers early in the planning and roadmapping process:

> "This is like a customer experience group or a user design experience group, but they are not, they are not part of the product team or haven't been part of our product team traditionally. I think, probably their engagement would help us better solve the right problem." (T-6)

4.3.2.3 Preparing for the future using an iterative roadmapping process

More agile and iterative roadmapping processes can be used to incorporate rapid changing market conditions. A lack of agility was one of issues that practitioners have struggled with in their roadmapping. One interviewee stated that roadmapping is not really about predicting the future, but preparing for it:

> "We can prepare for it, but we can't predict future. We don't know what's going to happen next." (T-9)

Another interviewee explicitly emphasized the need for an iterative design roadmapping process. Due to increasingly more complicated and unpredictable market conditions, his company has decided not to initiate roadmaps until a certain level of feasibility has been met and market acceptance achieved. This interviewee commented:

> "After iteration of parallel prototyping processes, we select the most compelling one among many to put on our roadmap." (T-3)

Designers point out that the *"plan not followed"* can be the highest missed opportunity in the existing process (33%). They would like roadmapping to be more flexible and iterative so that it can react better to market changes. Also, they wanted to include key overarching experiences into new product/service roadmaps using a highly iterative, design-oriented internal process for new concepts. Respondents commented:

> "Leverage that expertise, build a hypothesis and test it. Don't sit down and do a bunch of research unless you don't know what the question is. If you know what the question is and you don't know the answer, then start with an answer. And work it back, much faster. Much faster process." (T-4)

> "I think our biggest problem has been ambiguity. It's more about communicating clearly on that roadmap really what we're doing. Which can sometimes be hard when you're dealing with multiple, multiple items. We could say, okay we're going to focus on a specific industry. And that's one level of kind of more vision for it, but then what are you actually going to do to deliver on that?" (P-8)

4.4 Stakeholder Interaction in Roadmapping Practices

This section examines the context of stakeholder collaboration across job descriptions—designers, engineers, and managers who work collaboratively in high-tech companies. The in-depth interviews with professionals who work on highly interdisciplinary collaborative projects form the basis for the findings.

Specifically, this section answers the following two questions: 1) How do design researchers, engineers, and designers collaborate on the product development process? and 2) What kind of attributes should a firm bring into its product and technology roadmapping processes? The goal of the research in this section is to better understand current roadmapping processes and design attributes for running design projects. My aim was to extract the most common themes and keywords to identify challenges and opportunities within stakeholder interactions.

4.4.1 Prior related work

While interdisciplinary collaboration is highly encouraged, communication between members in a team, group, or company is often quite fragile (Roschuni, Goodman, & Agogino, 2013). The invisible tension, or inertia[4], among team members tends to cause communication issues (Figure 10). Kuniavsky argues that observing the user experience would help reduce the gap between designers and engineers (Kuniavsky, 2003). A prototype plays a crucial role as a medium to demonstrate an unexplored concept to other stakeholders within an organization (Zimmerman, Forlizzi, & Evenson, 2007). Despite the strategic importance of design to the firm, the diffuseness of design makes it difficult to use strategically (Dumas & Whitfield, 1989). Inertia between human-centered design researchers, the product development team, and other stakeholders causes communication problems, which result in silos around these internal organization structures (Roschuni, Goodman, & Agogino, 2013).

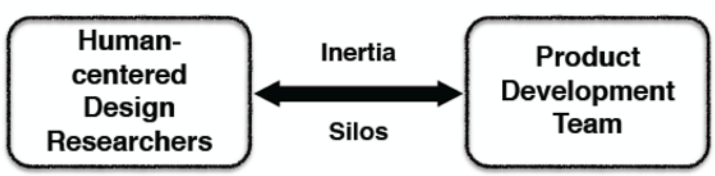


Figure 10. Relationship between human-centered designers and the product development team (Roschuni, Goodman, & Agogino, 2013)

In practice, the past twenty years have seen a codification and formalization of the innovation process—particularly in new product development, where the creation of

[4] Inertia, a group of individuals' reluctance or inability to alter their thought world, compounds the inherent difficulty of creating shared frames across boundaries.

"stage-gate" processes and their execution by cross-disciplinary teams has become well-established in many organizations. However, companies today are struggling with increasingly broad and complex innovation challenges as they seek to provide a package of complete solutions—not just discrete products—to their customers in a rapidly changing technological environment. This is causing many firms to seek on understanding of the more fundamental principles underlying core user needs and innovation opportunities (Beckman & Barry, 2007).

Zimmerman et al. illustrate the pathways and deliverables between interaction designer researchers and other HCI (human-computer interaction) researchers (Zimmerman, Forlizzi, & Evenson, 2007). In this context, research artifacts such as tangible prototypes encourage better communication between two groups of stakeholders—researchers and practitioners in HCI community (Figure 11).

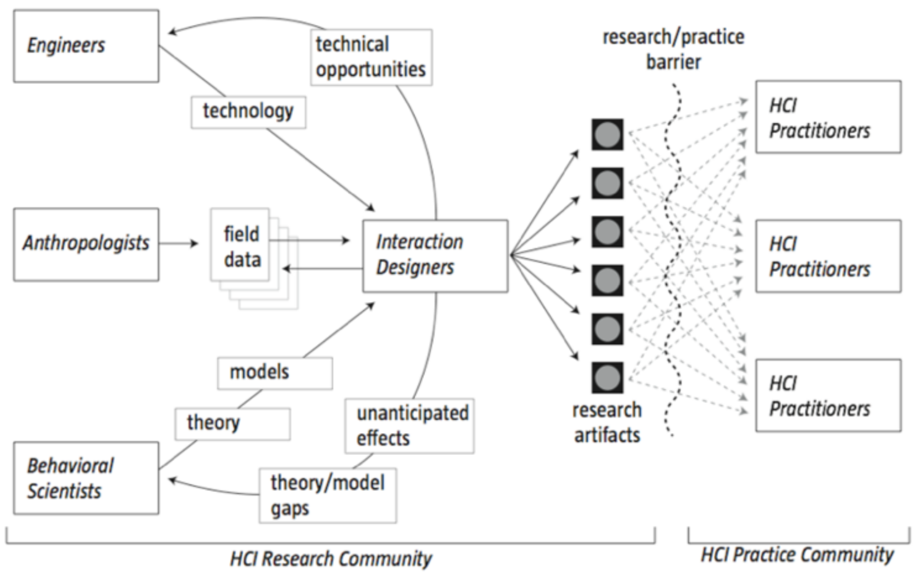


Figure 11. An illustration of the pathways and deliverables between and among interaction design researchers and other HCI researchers.[5] (Zimmerman, Forlizzi, & Evenson, 2007)

4.4.2 Lessons learned about stakeholder interaction in roadmapping Practices

After iterations of thematic analysis (Braun & Clarke, 2006) on the interview scripts, three main keywords stood out—*collaborative, user experience,* and *constructive* roadmapping processes. This section presents interpretations, representative quotes, and sub-

[5] The illustration emphasizes how the production of artifacts, including prototypes, positively influences the interaction between the research and practitioner HCI communities.

keywords, followed by additional highlighted keywords. The discussion also draws from an in-depth literature review.

4.4.2.1 Importance of prototypes in internal and external collaborations

Internal collaborations include interplay between several groups/teams in an organization to achieve a shared business goal and output. Such collaboration entails aligning detailed design processes, outcome expectations, deliverables, and formats throughout the product development process, in addition to sharing a series of prototypes for knowledge exchange. It employs continuous efforts of decision-making at each stage of the product development processes to move forward to the next step. External collaborations consist of processes such as sharing stakeholders' current status, envisioning and creating ideal scenarios for customers, and aligning expectations and outcomes for collaborative efforts.

Prototyping plays a vital role in both internal and external collaborations. While the prototyping process enhances communication among team members (Zimmerman, Forlizzi, & Evenson, 2007), expectations regarding 'prototype' differ greatly between designers and engineers. The designers I interviewed believe that prototyping is a supplementary process, whereas the engineers believe it is crucial. Conflicts occurred when these two collaborators came together and had to compromise their perspectives. While designers tend to use a prototype to explore futuristic concepts, engineers are more likely to use a prototype to focus on solving current technical challenges. A design interviewee stated:

> "The technology people are driving the prototype realm of things and the designers have been focused more on the long term, what is the vision of this thing. Sometimes, prototypes only cover small parts of a whole." (D-5)

Furthermore, a prototype is not the only sharable deliverable between internal collaborators. Sometimes, counterparts expect more from collaborating internal partners beside final prototypes. One respondent mentioned that:

> "[A main result of] this group [internal collaborator] is not just a final prototype. We expect them to provide us feasible resources to investigate and a project direction as well as…a realistic product concept that gives users a new experience and fulfills user needs." (D-3)

Sharing intangible outcomes such as an overarching vision, direction, and associated experiences with a physical working prototype helps stakeholders to exchange ideas and knowledge in a clear and comprehensible manner.

4.4.2.2 How early user experience is considered in the product development process

I interpreted interview responses as an indication of technology-driven approaches, where technology is considered first, followed by user-experience factors. Beckman and Barry state that:

> […] Many engineering-driven organizations start with solutions and then in classic technology push fashion, place those solutions in the market to see whether or not there is a need […] (Beckman & Barry, 2007)

User experience is merely a tool for justifying concepts in an internal development process. The more convincing the user scenario is, the more likely it is to be selected as a project. Practitioners prefer a variety of user research methods, but tend to prefer similar types depending on their job responsibilities. Designers tend to do more internal analysis, while engineers rely more heavily on prototype testing. Engineers are very reluctant to allow users to give feedback on a WIP (Work in Progress). They require a finished prototype before they are comfortable with users testing it. The evidence can be found in my in-depth interviews. One engineer argued that:

> "We're approaching it from a very technical side of things and obviously technology can drive new user experiences." (T-5)

Whereas a designer stated an opposite perspective that:

> "[What] we should have done is to find a big theme for the project before we find out the right project. We have not done that yet." (D-6)

4.4.2.3 Constructive roadmapping in an appropriate balance between concreteness and abstraction

Although activity outputs are exchanged among internal stakeholders in an organization, different teams hold different perspectives on what these outputs mean. This gap happens in the roadmapping process as well. To minimize conflicts, firms require a middle person to bring several stakeholders together, communicating their ideas into the other party's roadmap, influencing the other party's long-term product planning, and fundamentally allowing for coherent transitions between the pieces of high-level roadmaps. While roadmaps are useful for planning (Cooper & Edgett, 2010; Ulrich & Eppinger, 2003), roadmapping preferences can vary dramatically across an organization. While executing a process, some find it more useful to continually update a loose, short-term plan as they go, whereas others find that a near-term focus can limit creativity or the development of unique concepts.

For short-term plans, dates and concrete next steps decrease conflict and improve communication within the team. Short-term plans do not necessarily only cover incremental evolutions, but also often drive radical evolutions in experience and shifts in product meaning (Verganti, 2013). It is encouraging to achieve a shared agreement on roadmapping without limiting its ability to innovate. Here is representative quote from an interview participant:

> "Our headquarters set up their roadmap based on ours. The innovative ideas from this group inspire headquarters [to come to greater] consensus based on them. Headquarters still wants to hear more from the [internal innovation] lab regardless [of whether] it is right or wrong. […] We have some kind of plan and next steps are more detailed than the last step. I know what the next steps are after, in a form more abstract and fuzzy. This is kind of my approach." (D-2)

Regardless of the degree of concreteness or abstractness, my interviewees found that creating a roadmap in the planning phase is preferable to not doing so.

> "I think that the problem is that our innovative ideas aren't on the roadmap. I think someone needs to put it on the roadmap and that is either through another group or through the committee." (P-5)

4.5 Chapter Conclusion

My interviews, in conjunction with published results from other studies, reveal key findings regarding current roadmapping practices in industry. Three major challenges include: 1) ineffectiveness in predicting the future, 2) lack of a feedback loop from research on end users, and 3) over-dependence on feature-driven roadmapping processes. Three major opportunities include: 1) experience-driven roadmapping, 2) increasing the ownership of designers in planning and roadmapping processes, and 3) preparing for the future using an iterative roadmapping process.

The results of this descriptive interview study helped lay a fruitful foundation for establishing the design roadmapping process. Successful product and service designers need to effectively communicate their ideas, concepts, and findings with internal stakeholders including designers, engineers, marketers, managers, etc. Sharing intangible outcomes such as an overarching vision, direction, and associated experiences along with a physical working prototype helps stakeholders to exchange ideas and knowledge in a clear and comprehensible manner. Based on the findings from the descriptive study in this chapter, the following chapter introduces my concept of the design roadmap and its associated frameworks, processes, and steps.

5 INTRODUCTION TO DESIGN ROADMAPPING

Chapter Overview

As shown in the last chapter, there is no agreed upon definition of usage of a design roadmap. Therefore, this chapter formalizes a design roadmap by establishing its definition, framework, and steps to be consolidated in product planning and development processes. A design roadmapping template, its components are explained, and an each step of five-step process is described in detail.

5.1 Beyond Traditional Roadmapping

While product and technology roadmaps have been well-formalized in terms of their structures, methodologies, and frameworks, design roadmaps have not been explicitly explored nor studied from either an academic or industry practice standpoint. My research questions arise from the discovery that design has not been effectively incorporated into roadmapping processes. Through the interviews summarized in the preceding chapter, I have found that quite a few leading companies keep some form of a design roadmap within their organization. However, their design roadmaps appear to be mostly subsets of product and technology roadmaps that have not been fully implemented in a way to achieve strategic business goals on a long-term basis.

Dumas & Whitfield address the strategic importance of design to the firm's organization even as they concede that the diffuseness of design makes it difficult to use strategically (Dumas & Whitfield, 1989). By their own definition, design is delineated as a course of action for developing an artifact or system. Various types of design processes and methodologies have been introduced by designers, engineers, and practitioners and have been implemented widely as a way to develop new product concepts driven by users/customers (d.school, 2016; Brown T. , 2008; Beckman & Barry, 2007). Collected user data in the early stage of new product development plays a crucial role as input for shaping both design frameworks and the creation of a compelling product concept. Zimmerman et al. define design research as an intended activity to produce knowledge that is not necessarily aimed at immediate commercial application (Zimmerman, Forlizzi, & Evenson, 2007).

While a general design process commonly focuses on several steps within a single product development cycle, a general design roadmapping process includes time across multiple development cycles. Thus, rather than a single product development cycle, design roadmaps depict progressive phases of product evolutions. Whereas the results of one product development cycle ultimately end in a single generation's design concept, the design roadmapping process depicts progressive design outcomes across distinct product generations. The inclusion of time frame is an essential part of a roadmapping process that includes past, current, and future perspectives (Phaal & Muller, 2009). The comparison between these two processes is illustrated in Figure 12.

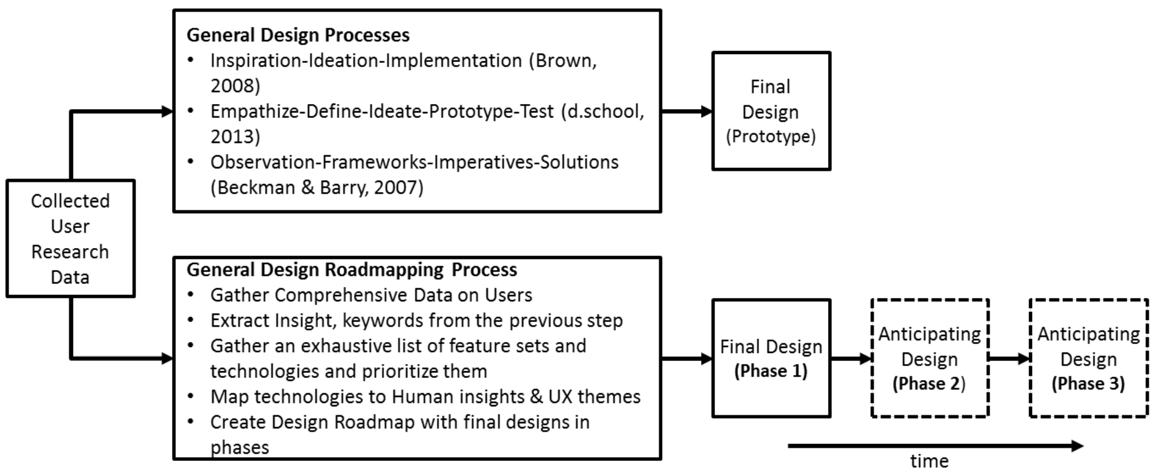


Figure 12. Comparison between the general design process and the general design roadmapping process

The need to address various types of roadmaps and roadmapping approaches shows up repeatedly in previous research (Garcia & Bray, 1997; Cooper & Edgett, 2010; Phaal & Muller, 2009; Phaal, Farrukh, & Probert, 2001). The design roadmapping process adheres to three principles derived from a combination of my literature reviews (Chapter 2) and descriptive study results (Chapter 4): 1) to focus on development of customer and user experiences, not just on features; 2) to increase engagement of designers early in the planning process; and 3) to provide a means for rapidly responding to changes in the environment.

5.2 Design Roadmap: Putting User Experience First

Design roadmapping is a way to embed user experience goals into the earliest stages of conceptual design. This new approach is the result of primary feedback from the semi-structured interviews (40 interviews with 18 Silicon Valley firms and 1 the East Coast firm) referenced in Chapter 4, where attempts to bring user experience into roadmapping have been observed as a reaction to today's market conditions. Design-related activities largely focus on identifying the right frame and problem to solve as part of planning (Beckman & Barry, 2012). The design roadmap concept presented in this dissertation supports the initial planning activities of the product development process.

5.2.1 Definition of design roadmap

I define a design roadmap as a canvas that positions expected core user experience and design elements along a timeline and then associates them with products, services, and/or systems an organization wishes to deliver. Similar to conventional product and technology roadmap templates (Ulrich & Eppinger, 2003; Cooper & Edgett, 2010), my design roadmap uses the x-axis to represent the timeline from present to future and the y-axis to represent design elements. The design roadmap aims to integrate information from a traditional technology roadmap, which shows the progression of technologies over time, and a product roadmap, which shows product characteristics over time.

Chapter 4 demonstrated that roadmapping participants aspire to include subjective elements, such as user experiences, desired outcomes, and user needs that are not covered in conventional technology and product roadmapping processes. Here is an example quote from one of my interviewees:

> "What we do and where we are going is determined by the market, something we call market inflections. So, if we then define some certain trend in the market, in technology, and if it's something [of a] game changer, we definitely want to be in. Then, the company sets that vision, which is say 5-7 years out. Then a strategy is built, a strategy anything between 3-5 years. Strategy is the action that materializes that vision. In this case, we are going to developing, whenever we are putting together code, we need to have a mutual…mindset [among our] engineering teams. And execution is next. You have vision, strategy, and then execution goes in the next 18 months to 2 years [and budget is set]. When [this] vision and strategy are set, we will show at a high level where we are going without disclosing too much detail." (P-1)

I formulated the design roadmap concept and its processes to respond to these interests, focusing on user experiences and form factors, as they were the most frequently requested design elements (Chapter 4). Thus, the elements of the y-axis comprise several layers of user experiences and different form factors. The layers of experience levels—from overall user experience to detailed experience—on the y-axis are developed to help participants clearly articulate the relationships among experiences and to facilitate making complementary choices.

The 3 x 3 blocks in Figure 13 below illustrate two levels of user experience (in two layers) and one level of derivable form factors (in the third layer) across time periods.

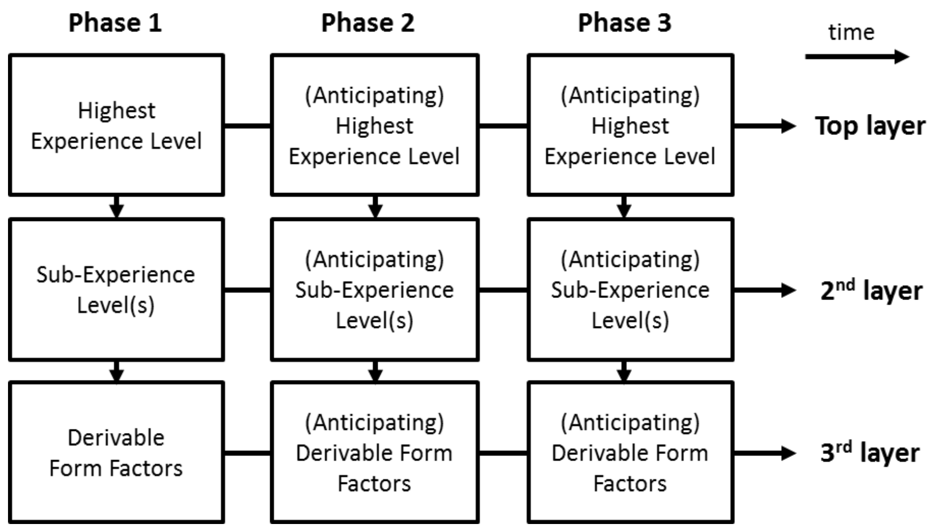


Figure 13. Schematic of design roadmapping—illustrating distinct experience levels from highest (top layer) to sub level (2nd layer), and derivable form factors (3rd layer) by each project aligned to time phases

The top layer portrays a short description of the overarching experience. The second layer details the sub-experiences that form the highest experience level. The different experience level is depicted along with derivable form factors: product, service, or system in the third layer. These derivable form factors are chosen as layer attributes because the professionals interviewed in Chapter 4 were inclined to bring experience attributes associated with not only a product but also intangible properties. These layers are designated to be filled in by team members, taking into account new information from design research results, user trends, technical feasibility, etc. to show the progressive evolution of design attributes. The way future product concepts are envisioned in this design roadmap is different than previous approach such as (Meyer & Lehnerd, 1997), as the key drivers that trigger the next phases in my model come from outside the corporation—namely, from the user's perspective.

5.2.2 Example design roadmap template

An example template is shown in Figure 14. Most importantly, the design roadmapping template is created to make its process flexible and responsive to changes that might be required as the design team works through product development after the initial design roadmapping exercise. This allows the design roadmapping process to be iterative and to reflect emerging market needs and user inputs as new data accumulates, in contrast to traditional roadmapping approaches, which tend to be completed at a defined point in time (Cooper & Edgett, 2010). The value of building a design roadmap comes not only from the initial design roadmap itself, but also from the conversations involved in the process.

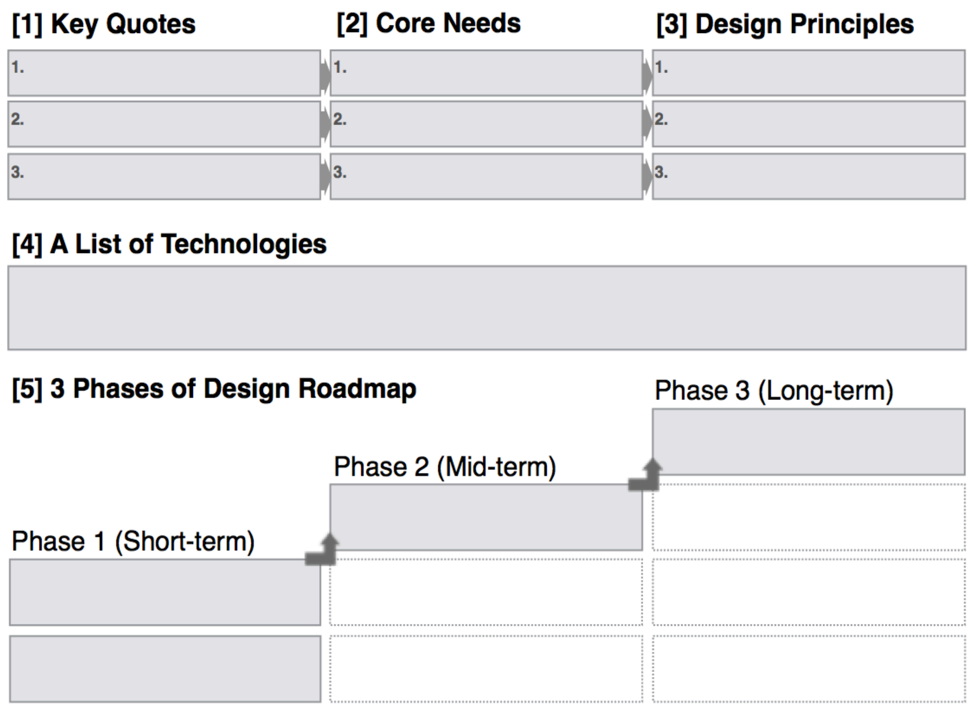


Figure 14. Example design roadmapping template produced by the author

5.3 Framing the Design Roadmapping Process: Objective, Steps, and Elements

My aim is to create a design roadmap framework based on understanding how multidisciplinary teams collaborate, communicate, and frame problems and opportunities—incorporated in the roadmapping processes—which was defined in Chapter 4. Product development teams made up of individuals from different educational and functional backgrounds may encounter difficulty exchanging ideas and knowledge with each other (Dougherty D. J., 1987). Understanding how product development teams learn is essential due to the high level of uncertainty and a need for expertise integration (Edmondson & Nembhard, 2009). Product development teams often do not collaborate across departments to connect technical issues and market issues, and information sharing is limited (Dougherty D. J., 1987). Hey et al. examined interdisciplinary new product development teams at UC Berkeley and found that more structured guidelines, tools, and frameworks are required to assist student product development teams (Hey, Van Pelt, Agogino, & Beckman, 2007).

My action research (Chapters 6 and 7) focuses on how teams engage in portfolio planning and roadmapping to establish their goals, visions, and processes, and how they make decisions around the allocation of resources to projects driven by user experience criteria.

The teams I examine are not only multidisciplinary, but also work across organizational boundaries (between corporate and remote entities, or between a firm and its external stakeholders).

Based on my understanding of the use of roadmapping today, I constructed a design roadmapping framework and steps for implementing it. When applying it to industry organizations, I aim to improve product development and roadmap processes by promoting engaging team collaboration and augmenting their existing processes and systems. This model, shown in Table 6, was initially developed and subsequently refined as it was tested in action research case studies (Chapter 6).

Table 6. Five steps of the design roadmapping process

	Title	Description
1	Gather comprehensive data on users, users' experience, and trends	Conduct selective in-depth interviews, behavioral observations for unexplored needs and opportunity spaces for innovation, comprehensive online surveys, expert interviews, and trend report reviews.
2	Extract core design principles from user needs, experiences, and trends	Synthesize data to create common themes and insights and extract core design principles. Narrow user group focus. Find pain points. Create primary and secondary personas and use scenarios. Record key observations and data from these personas and use scenarios.
3	Gather an exhaustive list of technologies containing core feature sets of the design concept and prioritize them	Research existing technologies and functionalities. Brainstorm potential new features. Prioritize the technologies that best support core feature sets of the design concept. Select which technologies would be beneficial and useful for the target personas.
4	Map projects to design principles	Prioritize technologies based on design principles that stem from themes and insights, and examine how technologies can be applied to address opportunity spaces and pain points of target user groups. Rate projects relative to design principles.
5	Create design roadmap	Combine elements from user research and technology analysis to map out a plan that integrates human-centered solutions with targeted technologies of core feature sets for a design concept. Create a cohesive, collective shared vision for a design team.

Different levels of roadmapping can be deployed depending on the depth and context of conversation among stakeholders. I thus ended up with two types of design roadmaps for different needs: a simplified version and a detailed version. The simplified version consists of the core, high-level agreements on the roadmapping elements, primarily promoting executive-level conversation associated with the roadmap construction. The detailed version includes specific elements of each phase in addition to the high-level agreement associated with the simplified version, eliciting deeper conversation over established high-level roadmaps. This dichotomy is reflected in the following quote from an interviewee:

> "Roadmapping happens on a lot of different levels. I think there's executive-level roadmapping, where they're looking at the whole organization and what the whole organization is doing and what, you know, what will we be? Then we do it, I think very much on a divisional basis. In some ways, some of our roadmaps are talking about strategy and where we're going, but then there is the tactical, like, How do I actually get this thing built?" (P-8)

As a part of the roadmapping process, a vision statement is included to connect the results of the design research and design roadmap creation among participants. While not all visions succeed (Lipton, 1996), effective visions are associated with higher-performance outcomes (Kantabutra & Avery, 2010). Quigley states that the vision of the company must indicate where the company is today and where it will be in the future based on the roadmap (Quigley, 1994). One interviewee responded that:

> "So the roadmapping for me, for me as a product manager, is—on one hand I do have to report up to executives, and so, is to tell the executives (we do it on a yearly basis, you know)—there's kind of a three-year vision at any given time. But what we do at the product manager level is, really, I would say it's a one-year, maybe two-year plan at the most. The roadmap really is that: Here's where I'm planning to go in the next year and what I'm hoping to achieve." (P-8)

5.4 Chapter Conclusion

In this chapter, I proposed the formalized concept of design roadmap, including its components and process. The design-driven roadmapping approach was motivated by three opportunities that include: 1) making roadmaps experience-driven, 2) increasing ownership of designers in roadmapping, and 3) making roadmaps visually simple and clear. The proposed design roadmapping process in this chapter is implemented in action research case studies in the following chapters. The detail results and findings will be discussed in Chapter 6 and Chapter 7.

6 ACTION RESEARCH IMPLEMENATION

Chapter Overview

This chapter describes the action research in which the proposed design roadmapping process delineated in Chapter 5 was applied in two industry organizations—a large multinational corporation and a small startup. Prior to the industry implementation, a pilot test was conducted beforehand on a company-sponsored graduate student design team. Findings of the two implementations are presented in this chapter, while these results are compared and discussed in Chapter 7.

6.1 Introduction

The proposed design roadmapping process in the previous chapter was devised to assist project prioritization and selection, team collaboration, and design-driven roadmap development. The process aggregates design experience elements along a timeline that associates key user needs with the products, services and/or systems the organization wishes to deliver. To test the design roadmapping process and illustrate its benefits, I conducted action research via case studies at two different types of organizations—a large multinational corporation and a small East Coast startup. The design roadmapping process was applied, with my facilitation, to existing ongoing design projects undertaken by these companies. The goal of these case studies was to introduce the design roadmapping process and demonstrate how it could be incorporated in planning the evolution of a product concept in response to anticipating future market/user trends.

6.2 Pilot Test

Preparatory to action research implementation in a real industry situation, I conducted a pilot test with a product development team of five graduate students. As part of a one-year Capstone Project curriculum (Capstone Experience, 2016), these graduate students at UC Berkeley were using a human-centered design approach to explore untapped user needs and wants in the Internet of Things market. These students were already doing a company-sponsored capstone project on this topic, and they agreed to apply and test the proposed design roadmapping process. I chose this particular team because it had similar characteristics—goals, product development flows, team dynamics, and cultures—to the large-company selected for my case study.

The design roadmapping intervention occurred at the point at which the team had completed customer research observations, interviews, user needs extraction, and the first round of concept generation. The design roadmapping interventions that the team participated in included a series of activities made up of five core elements illustrated in the previous chapter (Table 6). Throughout the pilot test, the team provided feedback on the framework (Figure 14) presented in Chapter 5.

Iterating over two separate workshop sessions, the graduate student team ended up with several types of design roadmaps. The team members first came up with five sub-level design principles extracted from observations and interviews as part of their individual design research (see Appendix C). The team's findings were then merged into an integrated design roadmap that incorporates design elements, product features, and technology evolution, as depicted in the integrated roadmap in Appendix D.

Although this pilot test involved only one small multidisciplinary design team and was thus a limited trial run, it provided constructive feedback for modifying the roadmap framework for full-scale action research.

6.3 Action Research Example 1: Asian-Silicon Valley Corporation

6.3.1 Summary

In this case study, the design roadmapping process was applied to projects undertaken by a large corporation's innovation lab located in research centers in San Francisco and Mountain View, California, in partnership with corporate stakeholders located in Asia. The five-step design roadmapping procedure was provided along with detailed implementation information and direct facilitation. The decisions from the design roadmapping process have been incorporated into the company's commercial plans. Key findings in this corporate case study bolster the positive impact of design roadmapping in moving strategic thinking from a technology/feature-driven process to one that is design/experience-driven. It shows how firms might weigh choices between user needs, design principles and technological innovation.

6.3.2 Research methodology

The design roadmap framework was tested with individuals and with groups through design roadmapping workshops. As facilitator, I provided close guidance during one entire product planning cycle (the five steps in Table 6). Actual implementation occurred in Phase 1, from August 2014 to February 2015. Post-interviews and wrap-up interviews occurred in Phase 2, from March to May 2015. Due to confidentiality agreements with the company, specific findings are presented as general insights; I was required to omit descriptions of the specific technologies and design features under consideration.

6.3.3 Launching the action research

After the eight months of observation to understand the existing processes employed by the company, I implemented the design roadmapping process to augment the processes already in use. The company graciously allowed three different design teams, of three-four members each, to participate in the case study. Each team was working on a different product concept. The case study was flexible to minimize time-delays in the company's ongoing product development process (Sagor, 2000; Brydon-Miller, Greenwood, & Maguire, 2003); thus, I sought to assist participants by enhancing each team's performance.

At the beginning, I made an oral introduction of the proposed process to team members who were still at the early stage of design concept development. The first steps of this process involve collecting a large amount of data about possible product users and then extracting insights on human desires from this data. Technologies that create feature sets of the product are then identified, and these technologies are mapped to human desires. Finally, a design roadmap is created as the final step of an approach that allows for a shared vision to be distributed across the entire design team.

The five steps of design roadmapping shown in Table 6 were introduced through an additional three workshops per each team. During the workshops, a facilitator (dissertation author) introduced the design roadmapping concept, frameworks, and steps used to identify anticipated product concepts through a human-centered design approach. In addition, design roadmapping templates (Figure 14) were shared with each team. The facilitator spent approximately 10 hours with each team, examining each team's progress in using the design roadmapping process and conducting post-interviews to reflect on the suggested framework.

6.3.4 Data analysis

One hundred and seven pages of full interview scripts and 12 pages of observation notes were collected over eight months. Using Grounded Theory (Charmaz, 2014; Strauss & Corbin, 1998; Glaser, 1992) to analyze our observation and interview data and refine our analyses, transcriptions were extracted, from which I highlighted, interpreted, and extracted keywords and key quotes. Two researchers (the dissertation author and a manager in the company no on any of the case teams) worked in parallel; the results and insights of their individual analyses were then merged into one consolidated Excel spreadsheet.[6]

Project deliverables and other artifacts were subsequently examined to further comprehend the context of meetings. This process allowed us to fully document the new design roadmapping framework and the changes it made to the existing product development process and team collaboration practices. Findings from the case study are presented herein.

6.3.5 Existing corporation design process

The group we collaborated with to apply our design roadmapping process consisted of employees who were assigned to three independent design projects. The main function of the group was to create innovative early concepts that would ultimately be scaled for mass commercialization. Each of the three design projects was launched three months prior to our arrival.

In this company, the scope/goal of each design project is set every year by mutual agreement between the corporation headquarters and the innovation group of which the three case study projects are a part. Each project was concurrently working towards the same objective: design a new consumer display concept for three-five years in the future. The teams aimed to create an ideal, yet realizable, user experience irrespective of cost. Each project team was multidisciplinary, including at least one user interaction/user experience designer, one engineer/prototyper, and one design researcher who was responsible for the user research over all three projects. The goals of the three projects—P, W, and M—are shown in Table 7.

Table 7. Goals of the three projects in the case study

Project Name	Description
Project P	Reflect on the flowing stream of everyday life to strengthen family connections and shared identity.
Project W	Explore various forms of (tele) presence, leveraging the screen's facility to mediate casual long-duration engagements between remote people and distant places.
Project M	Explore how full-body interactions, augmented reality, and faceted media manipulation can unlock realms of fantasy, storytelling, and imaginative play.

[6] Due to confidentiality agreements with the company, I exclude the raw Excel spreadsheet, but only provide general results and findings.

The roadmapping intervention augmented the three stages of the company's existing design process, outlined in Table 8: project scoping, prototyping/testing and refining/documentation. The first step of the company's existing process is to define the project scope. Then user experiences and scenarios are developed and evaluated by internal members through rapid prototyping. Finally, refinements of these concepts are integrated into both tangible (e.g., sketches, mock-ups, and prototypes) and intangible (e.g., code and interaction architectures) deliverables, and a full package of documents (e.g., specifications, presentation slides, written documents, and videos) is delivered to internal collaborators. Our interventions were applied across all three stages.

Once these three steps are completed, the ideas, concepts and insights obtained from the company's innovation centers in Silicon Valley are shared with personnel at corporate headquarters in Asia who are responsible for development through concept feasibility and commercialization.

Table 8. The pre-existing three-stage design process in action research #1

Design Process	Descriptions
Project scoping	Research user cases and scenarios in the real world to find high-value opportunities/applications. Identify user experience principles to guide explorations.
Prototyping and testing	Evaluate scenarios to identify core user experiences and features that are required for designing new products and services. Build short-sprint MVPs (Minimum Viable Products) and test them with target user segments.
Refining and documentation	Iteratively refine the seed products that demonstrate value and scale up to achieve a broader vision of the project. Prepare demonstrations and documentation to assure successful knowledge transfer.

6.3.6 Applying design roadmapping in the action research

This was the first time the company participants had performed design roadmapping, so the design roadmapping framework and process were introduced gradually—first to the three project leads and then through team workshops and individual sessions. The following sections detail the processes used in each of the five steps of the design roadmapping process.

6.3.6.1 Step 1: Gather comprehensive data on users, users' experiences, and trends

Data from various user studies by both this group and the headquarters' groups were collected. As part of the pre-existing design processes, expert interviews were conducted by internal employees in a company with market leaders to give the project teams insight about mega-trends and how these might affect user lifestyles in the near future. Each design team also reviewed reports from external channels, such as Intel's Trend Report 2014, Gartner's Hype Cycle Reports 2013 and 2014, IEEE's 2022 CS Report, Goldman

Sachs' IoT reports, and the like. Qualitative user research data collected by a skilled internal design researcher at the corporation became a valuable source for further analysis as well. This research was synthesized by embedded employees—a lead researcher, a skilled internal design researcher, and three design project leads into fifty user experience themes with primary keywords that represented user trends.

6.3.6.2 Step 2: Extract core design principles from user needs, experiences, and trends

From the fifty user experience themes and market trends identified in Step 1, twelve design principles were extracted as key drivers for the design work. These twelve design principles were defined by internal team members. The extracted design principles were prioritized by frequency of occurrence (measured as a percentage of data points). Labels for the twelve core design principles, listed below, are evocative of common characteristics:

- Empowered Data: Streamlined/distilled data usage enriches a person's life (22%)
- Technology-Empowered Experience: Technology can be developed to enhance human life experience (e.g., Oculus Lift, Google Glass, etc.) (15%)
- Authenticity: Over-exposure to reproduced data triggers appreciation of the original (11%)
- Co-existence/Mixture/Transition: Two different worlds live together (e.g., analog/digital, inside/outside, input/output and internal/external) (9%)
- Communication Network: Human-to-human, device-to-device communication for co-activities, collaboration, co-watching, co-media consumption, or simply being connected in a close loop (9%)
- Physical Representation: Long history of analog experience (e.g., paper) triggers analog-like digital interaction (7%)
- Mobile Experience: Seamless "on-the-go" experience extended from stationary experience (7%)
- Anticipatory Computing: Data collected from multiple sensors and devices provide appropriate recommendations regarding future needs and user behaviors (6%)
- Software-Based Device Control: Control over device based on intangible interaction (4%)
- Minimal/Ambient Interaction: Having more features and experience on top of previous experience motivates users to admire simplicity (4%)
- Data Storage Paradigm Shift: Confidential data storage from device to cloud (4%)
- Privacy/Security: Nonintrusive means of technology integration maintains a secure feeling of privacy (2%)

6.3.6.3 *Step 3: Gather an exhaustive list of technologies containing core feature sets of the design concept and prioritize them*

While the prior two steps focus on capturing customer and user needs, particularly as projected into the future, this step examines the technologies that are available to deliver those experiences. Across the three design projects—P, W, and M—the project leads, who had full knowledge and expertise on each project, identified and documented 83 sub-technologies that contained the core feature sets of the three design concepts.

Table 9. Number of technologies identified for each project concept by each project lead

	Project P	Project W	Project M	Sum (%)
Short-term	19	8	8	35 (42)
Mid-term	15	8	11	34 (41)
Long-term	5	5	4	14 (17)
Sum	39	21	23	83 (100)

These 83 sub-technologies were derived based on the experience they wanted to develop. The combination of these technologies defined the desired experiences of each design project. The project leads then categorized them by the development time that they would require: short-term (1-2 years), mid-term (3-5 years) and long-term (more than 5 years). Short-term technologies accounted for 42% of the total, mid-term for 41%, and long-term for 17% (Table 9). Various factors affected how each project team determined which technologies were short-, medium- or long-term: the priority placed on the user experiences to be developed, technology feasibility, bill of material costs, and completeness of user scenarios at that moment.

Table 9 shows that the percentages of technologies in both the short- and mid-term are similar. Although the first priority for the project lead was to create the most compelling concept for the short term, a significant number of concepts, experiences, and features that could not be implemented in the first phase were kept in a repository for further development in following phases. This step identifies times when the sub-technologies immediately needed may not be available and how availability of necessary technologies may influence creating the desired user experiences for different phases.

6.3.6.4 *Step 4: Map projects to design principles*

The three projects (shown in Table 7) were evaluated against the list of twelve design principles by the team members using a six-point Likert scale (0: not at all related, 1: barely related, 2: somewhat related, 3: related, 4: closely related, 5: highly related). The resulting scores were multiplied by the weight assigned to each design principle from the user and trend research and summed to create the scores shown in Table 10. Ratings were analyzed to compare differences and similarities among ongoing design projects, so as to figure out possible directions, whether to include the projects or not, and how to depict key design principles of the three projects in insightful roadmaps. While all three projects had similar profiles, the magnitudes of their scores differed. Project P outscored Project W, and both significantly outscored Project M.

6.3.6.5 Step 5: Create design roadmap

This step combines design elements from the user research completed in Steps 1 and 2 and the technology analysis described in Steps 3 and 4. Throughout this final step of design roadmapping implementation, participants mapped out a plan that integrated human-centered solutions with targeted technologies in order to create a cohesive, collective shared vision and experience for a design team to follow over time.

Table 10. Project rating by design principle
(full-list of rating comparisons can be found in Appendix E)

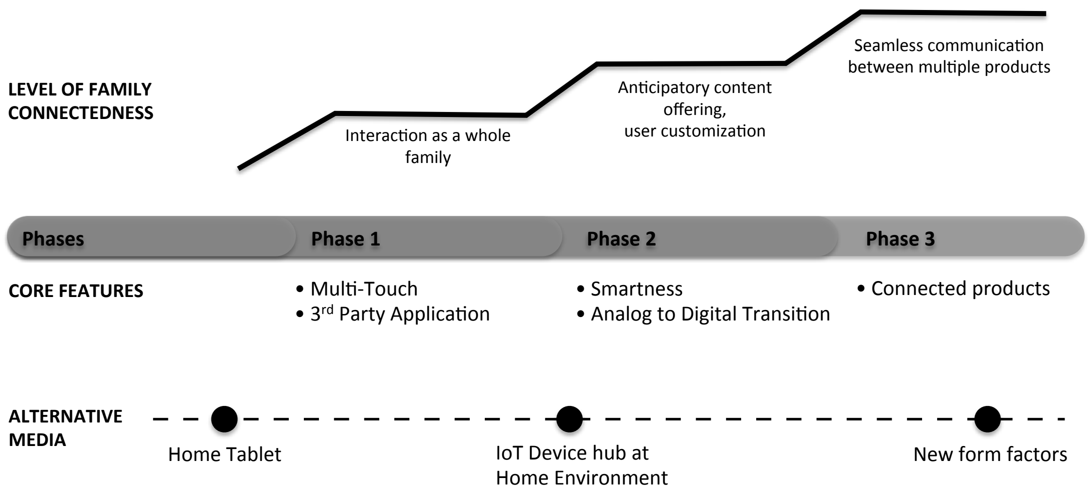
	Project P	Project W	Project M
Empowered Data	51	39	15
Technology-Empowered Experience	31	23	19
Communication Network	20	15	14
Co-Existence/Mixture/Transition	16	13	7
Physical Representation	7	10	3
Anticipatory Computing	14	13	3
Minimal Interaction	10	9	6
Authenticity	13	10	9
S/W based Device Control	7	7	4
Privacy/Security	2	4	0
Mobile Experience	11	9	6
Data-Storing Experience Shift	8	5	4
Sum	190	157	90

The design concepts can be evolved to expand their experiences in various types of form factors. Table 11 depicts the progressive level of experience defined by each project and its description. Sample roadmaps from Projects P, W, and M are depicted in Figure 15, Figure 16, and Figure 17, respectively.

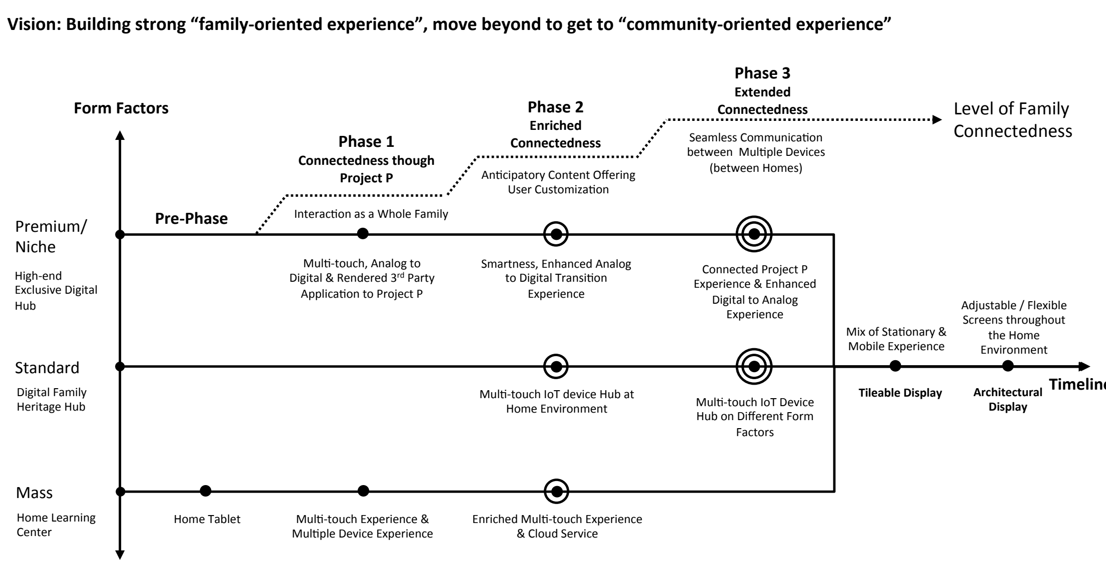
The final roadmaps created by project leads were refined several times as each project moved forward. Two different types of design roadmaps—simplified and detailed—were created in parallel to support different levels of conversations under a collective shared project vision. The simplified design roadmaps were beneficial for glancing at high-level experience themes and core features (depicted on the y-axis), and anticipating design concepts over time (x-axis). The detailed design roadmaps allowed practitioners to have richer communication, as they included detailed project descriptions such as lower-level experience themes and the types of form factors (y-axis) that represent those themes over the long-term span of the project (x-axis).

Table 11. The level of experience to be accomplished is defined prior to a phase of technology exploration

Experience level	Project P	Project W	Project M
Short-term	Family Reflections	Open Connections	Content Generation
Mid-term	Understand Family & Individuals; Anticipatory Customization	Enriched Connections	Add-on Evolution Kit Bundling Stand-alone
Long-term	Technology Improved Connectedness	Seamless Connections	Sharing Generated Content
Description	Project P's short-term goal is to provide a digital artifact that enables frequent reflections on family identity, heritage, and well-being. This concept evolves in the next phase with enhanced experiences for better family understanding. Finally the long-term goal is reflected in technology-driven experiences that can be customized to anticipate individual family needs.	Project W's short term goal is to remotely connect people who are apart through displays. The experience was enhanced by enriched technologies for emotional connections and the fundamental goal is to aim for making a seamless connections.	Project M's short-term goal is to engage users in content generation via a technology-driven tool. The design concept has evolved to expand it to various types of form-factors. The fundamental goal of this project is to make a platform that allows users to share the contents with other connected users via the online space.

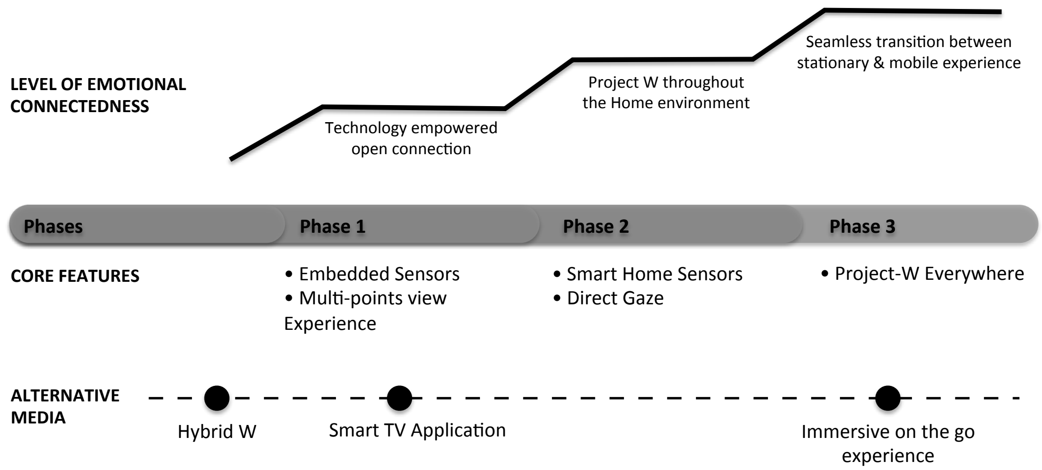


(Top)

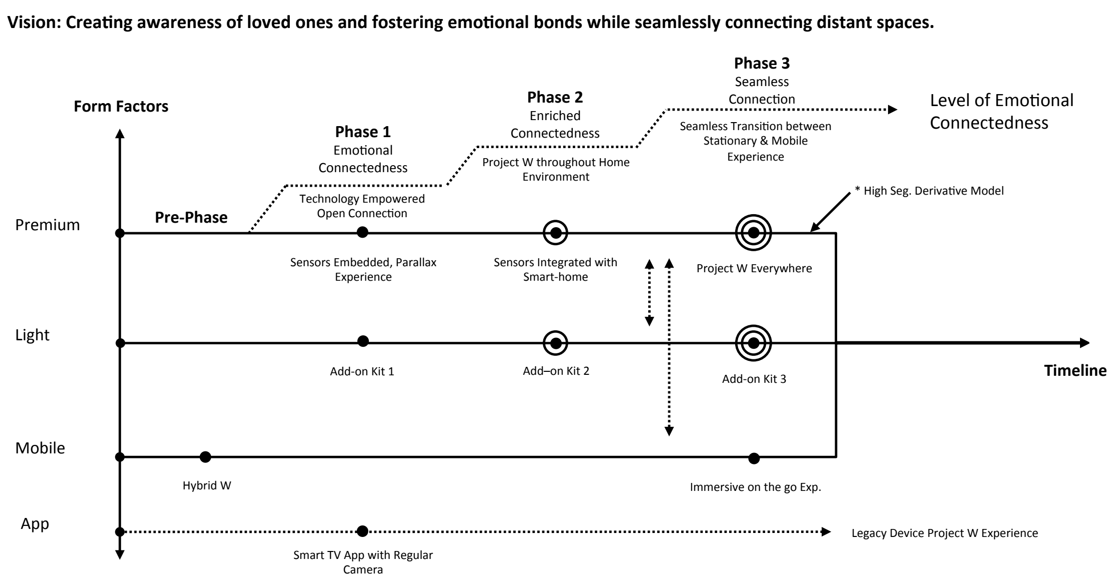


(Bottom)

Figure 15. Project-P design roadmaps: the simplified version (top) and the detailed version (bottom)

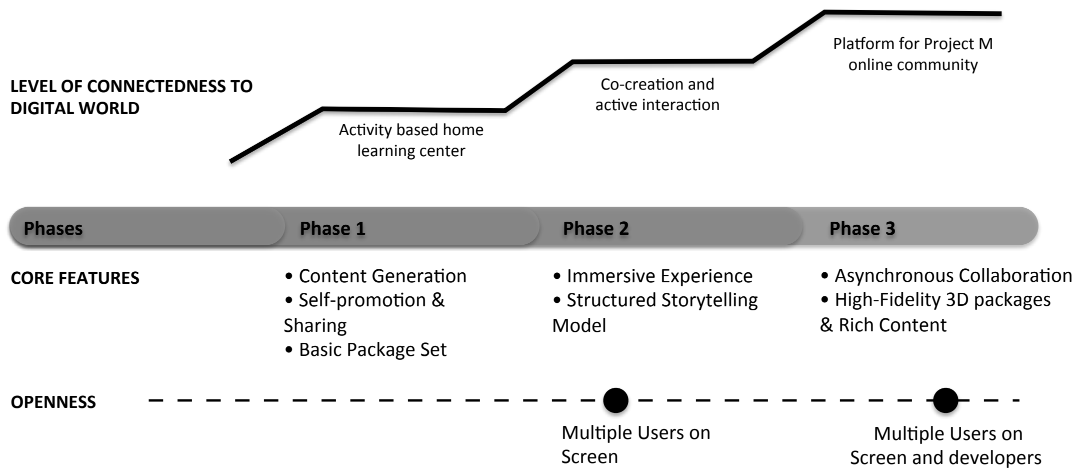


(Top)



(Bottom)

Figure 16. Project-W design roadmaps: the simplified version (top) and the detailed version (bottom)



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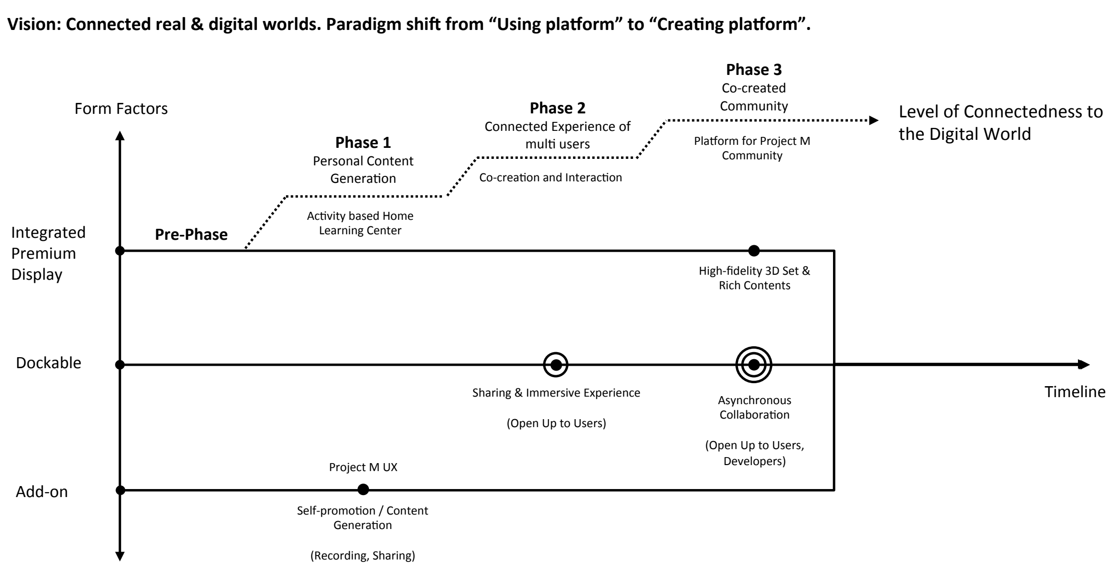


(Bottom)

Figure 17. Project-M design roadmaps: the simplified version (top) and the detailed version (bottom)

6.3.7 Post interviews with design project leads

After completion of the design roadmapping process and transfer of the tangible and intangible deliverables from the Silicon Valley innovation team to corporate headquarters, follow-up interviews with each of the three project leads were conducted to discuss the benefits and drawbacks of the design roadmapping implementation. One benefit frequently mentioned by the project leads was having a wide-open roadmap layout that enabled them to explore without imposing technical constraints early in the planning stages—a stark contrast to how technology roadmaps were created and maintained. One participant commented:

> "It really worked well. I mean the way [the template of] the design roadmap was loosely defined at the beginning, then incorporated frameworks and concepts from our users' perspectives, and then guided us to apply new technologies to help us achieve user experiences [that we aim to create in the future] worked great."

This highlights the challenge of traditional roadmapping, often described as "a plan not followed," in which the traditional technology- and/or product-driven roadmaps typically consist of attributes that are linearly deployed over a timeline. In some cases, the participants appreciated a way to explore arbitrary technologies and features that were not on their original plans to achieve an admirable user experience. Thus, one of the opportunities of design roadmapping is to make the process more agile and iterative without requiring concrete linear future predictions (Cooper R. , 2014) by loosely defining the initial phase. Another participant commented:

> "As [I am] a project lead [and a user experience designer], it was my first experience of [creating] a design roadmap during my decade-long career. It was useful as we started with a design perspective, [iterated on] key opportunity spaces, then looked into [associating] different technologies at micro levels."

Throughout the phases, the high-level experiences were kept the same and the associated sub-experiences evolved gradually, whereas the technologies and features were not considered until these specific experiences were clearly defined. These results were reassuring as they appeared to achieve the experience-driven design goals of the design roadmapping process.

6.3.8 Findings

This action research in a large Asian‑Silicon Valley Corporation provides insight into the important transition that companies are making as they move from being largely technology-driven to being more customer- or design-driven. It shows how a company can lay out a plan to develop user experiences over time, not just focus on a single experience in the present. It shows how the company might weigh choices between user needs (and associated design principles) and technological innovation—picking up the project with higher scores based on the design principle criteria, not technological innovation. The next sections highlight some key findings from this cation research.

6.3.8.1 The effort to move from a technology-driven to a design-driven approach

An analysis of the choice of technologies in the projects represented here suggests that there is still room for more customer-focused design work. Of the total number of technologies identified by the project leads on the three projects examined, a majority (58%) were technologies concerned with input sensing—that is, they support data gathering from users or other devices to the display without user interventions. Only 24% of technologies were targeted towards benefits that directly support the users' tangible/intangible experience resulting from the display (see Table 12).

Table 12. Breakdown of technologies chosen by project leads by application area (the example of the illustration between input and output of technology flow can be found in Appendix F)

	Project P	Project W	Project M	Sum (%)
Input	24	17	7	48 (58)
Transition	2	0	2	4 (5)
Output	10	2	8	20 (24)
Artifact	1	1	0	2 (2)
Storage	1	0	3	4 (5)
Unique Sale Point	1	1	3	5 (6)
Sum (%)	39 (47)	21 (25)	23 (28)	83 (100)

The definition of each term in Table 12 is listed below:

- Input: Technologies that support data gathering from users or other devices to the display
- Transition: Technologies that support information transition between Input and Output in either direction
- Output: Technologies that support users receiving intangible/tangible benefits from the display
- Display: Technologies that are solely related to display
- Storage: Technologies related to data storage either on the device or the cloud
- Unique Sales Point: A marketing term not related to any of categories above that refers to a compelling feature that attract users to adopt a product

Beckman and Barry argue that high-tech companies tend to be driven by technology rather than by user needs (Beckman & Barry, 2007). By our observation, while teams in our action research aspired to be "experience-driven," they tended to become more "technology-driven" when they started making critical decisions on the project. Instead, they became overly focused on how to use the technologies on hand to create design concepts without considering what benefit the technology might provide for customers.

6.3.8.2 Planning user experiences over time

Among the three design projects analyzed in our case study, we found a clear pattern in how the level of experience evolved through each phase of the design roadmap. When it came to envisioning the next user experience, we observed a common pattern of taking the new experience to a level above the previous phase. The most common terminologies used among project members included verbs such as *enhanced, improved, enriched, or increased* to articulate the level of experience they wished to create in the next development phase. For instance, for Project W (Table 11), the level of experience in the context of the connection theme evolved from open connections (short-term) to enriched connections (mid-term), and then to seamless connections in the long-term.

Once the desired level of experience was clearly defined, technologies were then identified to support that experience. A description of each technology was defined in project-specific language to extract core user experience levels for short-, medium-, and long-terms. I observed that the design roadmapping process encouraged teams to change their convention for considering possible technologies. Technological feasibility was not even considered until desired levels of user experience were fully defined. In Project W, core features were discussed as embedded sensors (short-term), direct gaze (mid-term), and connected mobile sensors (long-term) only after their respective levels of experience were defined (Figure 16). This provided a means to actively define the experience levels to be achieved in future product releases.

6.3.8.3 Weighing conflicts between design principles and technology innovation

The mapping of design principles against a list of technologies was crucial, and many contradictions were found. Knowledge of the feasibility of a technology considerably influenced decisions about the level of experience planned in each phase. For instance, even though the project teams identified strong, compelling new concepts to develop, some of the required technologies would not be available in the short- or mid-term phases. As it was critical to decide in which phases (short-, medium-, long-term) the technologies under consideration should be placed, team members prioritized which technologies should be evaluated first. These processes entailed our intervention to guide intensive discussions to align defined design principles with appropriate technologies. In many cases, a project that scored high against technology innovation criteria would score low on design principles, and vice versa. The three design projects in Table 13 illustrate the levels of technological innovation in each project as measured by project members.

Table 13. Level of technical innovation required for development (low, medium, and high)

	Project P	Project W	Project M
3D parallax display-display technology	-	High	-
Image capturing technology	-	High	High
Multiscreen synchronization	Low	Medium	-
User face detection	-	Medium	Medium
Multi screen UI	Medium	Low	-
Touch gestures interaction	Medium	Medium	-
Air gestures recognition	-	Low	Low
Object recognition	Medium	Medium	Medium
Human Buddy Skeleton Extraction and Motion Tracking	-	-	High

From this comparison table, Project P had the lowest technological innovation levels compared to the other two projects, while its score on design principles (Table 10) was the highest. For Project P, most of the necessary technologies were available off-the-shelf and thus could be implemented in existing devices. However, Project W and Project M required extensive development of innovative technologies such as depth cameras and advanced image-capturing techniques that haven't been examined yet.

In making tradeoffs between technology choice and user experience design, two criteria arose as particularly important in our case study: acuteness of pain points and the expected frequency of defined user experience:

1. Acuteness of pain points

A concept will not be well received by users unless it can solve acute pain points, regardless of the level of technology innovation. If there are effective available solutions, users will choose them; only extreme or lead users are willing to risk purchasing and learning to use innovative technologies (Von Hippel, 1986). For example, Project M was considered an interesting concept with high scores for technology innovation, but not one that solved crucial pain points for users. Thus, Project M received low scores against the design principle criteria.

2. Expected frequency of defined user experience

All teams considered the frequency of the target user experience to be important. Google (Google, 2016) calls it the "Tooth Brush Test," which they use to determine which company is worth buying (Business Insider, 2014). Based on their criteria, they consider whether a product is something that users will use often as opposed to once or twice a day. Similarly, in this case study, two primary methods were used to measure the frequency of target user experience. The first method is to create a journey of users in their daily life cycle to see how frequently potential users can be expected to interact with a certain user experience across user-devices' touch points. Actual user testing on concept prototypes was also used to evaluate the most frequently used interactions. The teams concluded that the motivation to use a solution as part of their daily routine provided evidence of the most frequently used and engaging user experiences. One respondent noted:

> "How often the product will be used is very important. Think about the toothbrush test. What is the point to create a product people would use less than twice a day?" (D-9)

6.3.8.4 Lessons learned from the application of design roadmapping in a large organization

In an organization where two distinct groups collaborate—a headquarters in Asia and its innovation lab in Silicon Valley—the design roadmapping process facilitated better communication and decision-making processes between them. Early product concepts initiated in Silicon Valley were delivered to headquarters in Asia to be considered for product lineups and roadmaps in commercialization strategies. Deliverables from Silicon Valley were sent in various formats, e.g., oral presentations, reports, videos, prototypes, and in-person demos. Interviews with internal stakeholders revealed that improvements in internal communications were crucial to the success that was the result of the design roadmapping process implementation. Employees had different perspectives and expectations of their projects and often deliverables were unclear in the past.

There were occasionally significant gaps between the two parties in defining the final goals of the projects and the level of final prototype completeness. These communication gaps were similar to those found between interaction designers and human-computer interaction practitioners in the HCI research field (Zimmerman, Forlizzi, & Evenson, 2007).

Another interesting observation was that prototype demonstrations were inefficient, as the two parties did not share a clear idea of the product concept within the limited range of remote communications deployed. Often the technology-driven thinking preferred by headquarters limited innovation team members' perspectives and creativity. Building design roadmaps increased the engagement of representatives from both sides early in the planning process. This observation demonstrates that a key benefit of roadmapping is improving internal communication among diverse stakeholders within a company as well as external communication with outside collaborators such as suppliers, partners, and vendors.

In many contexts, the design roadmaps promoted better communication by conveying a design concept as not only a form of the physical prototype but also as an intangible visual canvas that showed both current and anticipated designs, developed core experiences, and selected associated technologies for future lineups. In addition, the design team's prioritization of key projects via the design roadmapping process greatly influenced corporate-level decisions for strategic design concepts, which drove funding for future evaluation.

As a result of the design roadmap-based decisions, the company further developed the Project P concept, which had the highest score on design principles. The design roadmapping process led to the launch of a common household product the following year (Spring 2016) with enhanced functionality to improve family connection and engagement experiences (Brown R. , 2016). The main goal of this project—"Reflecting the flowing stream of everyday life to strengthen family connections and shared identity"—remained the same as it was defined in their design roadmap. This example illustrates the benefits for design roadmapping in strategic planning for high-tech products.

6.3.9 Limitations

The main focus of this research was to complete a concrete case study over a long period of time where a multidisciplinary team collaborates with internal stakeholders in a remote region. An obvious limitation of our industry example is that design roadmaps by nature work with sensitive intellectual property; thus, confidentiality agreements deter me from presenting more specific results.

Specific results, however, would not be exactly replicable across organizations, as the nature of the experiences and technologies involved would, by definition, differ. The details on any given design roadmap will vary based on a company's organizational conditions, interests, goals, objectives, and available resources. However, I expect that organizations with similar structures (e.g., remote strategic planning, design, and product development functions) can derive benefits similar to those documented here. The contents generated by participants would differ by their different backgrounds, knowledge, and experiences while the design roadmapping process would be alike.

6.3.10 Action research implementation #1 conclusion

This case study illustrates the use of our design roadmapping framework as a method to enhance early-stage design and project selection processes driven by "design principles" criteria—that is, by the end user's experience. The design roadmapping process augmented the existing design process of a global high-tech company's innovation centers located in Silicon Valley, with corporate stakeholders located in Asia. Using in-depth interviews and long-term observations of a global company that develops high-tech consumer products, this case study encompassed the five-step process of design roadmapping, providing useful illustrations and examples.

The design roadmapping process assisted project prioritization and selection. Mapping the design elements to technologies—as an effort to integrate customer and user needs with technology choices—was a crucial part of the process that led to in-depth discussions of trade-offs among participating team members.

Finally, our action research encouraged the teams to focus on experience-driven planning early in the design process, thereby increasing the likelihood of creating a product desired by customers. It increased the engagement of designers early in the planning process so that they could take more ownership in decision-making. Lastly, the design roadmaps initiated in this case study promoted active communication among stakeholders—exchanging design ideas about not only the current concept and its physical prototype but about future design concepts as well.

6.4 Action Research Example 2: Sproutel and Jerry the Bear

6.4.1 Summary

In this second action research implementation, we applied the design roadmapping process to a project undertaken by Sproutel, a startup company located in Providence, RI, which designs healthcare products following a human-centered design strategy. The proposed design roadmapping process in the previous chapter (Chapter 5) assisted the company's internal collaboration processes in prioritization and selection of core experience elements and technologies. The process aggregates design experience elements along a timeline that associates key user needs with the products, services and/or systems the organization wishes to deliver. To illustrate the design roadmapping process, the five-step design roadmapping procedure (Table 6) was provided along with detailed examples (e.g., industry project and academic research practices). The outcomes of the design roadmapping process were incorporated into the firm's strategic visioning and future market preparation. Key findings in this startup company case study bolster the positive impact of the design roadmapping process in moving strategic thinking from a technology/feature-driven process to one that is design/experience-driven.

6.4.2 Research methodology

The action research at Sproutel (Sproutel, 2016) is the result of an exploratory study, documents analysis, participant observations, and in-depth interviews. Direct quotes from in-depth interviews and participatory observations were collected and analyzed using grounded theory (Charmaz, 2014; Strauss & Corbin, 1998; Glaser, 1992) and thematic analysis (Braun & Clarke, 2006) to extract insights and to refine design roadmapping frameworks.

The research goals were to:

1. Understand the unique concept design processes driven by human-centered design and design thinking approaches within the context of a startup company.
2. Understand how inter-disciplinary team members collaborate together.
3. Implementing action research: create integrated design roadmaps by the end of the workshop.

We tested the roadmapping process through an action research case study with Sproutel, a small-scale startup company developing commercial products in the health care industry (Mecial Marketing & Media, 2016). Sproutel is a relatively new startup whose mission is to improve the healthcare of children with chronic diseases by promoting healthy lifestyles early in life. They are passionate about achieving innovation through a human-centered design approach. Their first product is *Jerry the Bear* (see Figure 18), a cuddly bear that serves as a “best friend” who measures glucose levels and gives advice to kids with type 1 diabetes.

Figure 18. Jerry the Bear with a backpack, an insulin pen, interactive storybooks, injection sites, and tickle spots, adapted from (Sproutel, 2016)

Two-phase action research incorporated preliminary interviews and roadmap developments (Phase 1 in May 2013) as well as in-depth interviews, observations, and roadmap refinements (Phase 2 in April 2016). As in the first case study, due to confidentiality agreements, I present a part of the specific findings as general insights, but am required to omit descriptions of the specific technologies and design features under consideration.

6.4.2.1 Preliminary interviews

On-site interviews, each of 30-45 minutes’ duration, were conducted with all four team members—design, engineering and management employees—at Sproutel’s office in Providence, RI. The interviewees, identified by job category in Table 14, were key players in the ongoing Jerry the Bear project who were able to provide mature perspectives on their experience with Sproutel’s complete design process.

Table 14. Summary of case study participants

	Designers	Engineers	Managers
Number of interviews	1	2	1
Job responsibility	Human-Centered Design User Interface/User Experience/Industrial Design, and Design Research	Mechanical Engineering, Software Engineering, Prototyping	Management, Product Design, Prototyping

While participants in the previous case study example have their own distinct job descriptions and responsibilities, the participants in this case study have comparatively flexible job descriptions and overlapping duties for collective team collaboration. At the time of these interviews, Sproutel consisted of only four people; thus, each employee had to be highly versatile.

6.4.2.2 Observations

I actively engaged with Sproutel staff throughout design and prototyping iterations (Figure 19) until the first Jerry the Bear product was commercialized. I held several informal meetings with team members through Skype, Google Hangout remote-meetings, and in-person conversations. I made a four-day visit to their office in 2016 to closely engage with their regular working environment. The on-site visit was extremely useful as it allowed me to better observe their interactions, communication, brainstorming, and design processes. It aimed to capture key conversations, topics, themes, and controversial arguments in the team's natural working environment. With participant permission, these observations were noted and captured in photos for further data analysis and synthesis. The observations helped me understand how team members collaborated and what types of tangible and intangible deliverables such as sketches on a whiteboard, verbal communication, prototype reviews, etc. were exchanged during brainstorming processes.

Figure 19. A series of Jerry the Bear prototypes display at the office entrance

6.4.2.3 Action research implementation

After a few years of a close collaborative participation through both informal and formal interactions such as observations, interviews, and conference calls to understand the existing processes employed by the company, we implemented the design roadmapping process twice over three years (in 2013 and 2016) to augment the design processes they already had in place. We made both verbal and written introductions of the proposed processes gradually to four core team members who were still at the early stage of the design concept development for the next version to be launched to the market place.

The five steps of design roadmapping shown in Table 6 (Chapter 5) were introduced through several Skype conference calls and phone calls before the on-site workshop was held in April 2016. Research goals, background information, and examples were shared and discussed with one of the co-founders. During the on-site workshop, I introduced the design roadmapping concept, frameworks, and steps to be used to identify anticipated product concepts through a human-centered design approach. In addition, I shared design roadmapping templates with the four employees I had interviewed earlier.

The case study was made up of three sub-sessions that lasted approximately seven hours in total with the team: 1) examining individuals' progress using the design roadmapping template, 2) integrating individual roadmaps into the team's shared roadmap, and 3) conducting post-team interviews to reflect on the suggested framework thereafter.

6.4.3 Existing company design process

At Sproutel, the scope/goal of each design project is set every year by mutual agreement between team members. During the interviews, the firm was working towards the high-level objective of designing a new product concept that improves the healthcare of children with chronic diseases (Innovating health through kid-centered design, 2016). Their design approach is patient-centered and empathy-driven (Sproutel process, 2016). Sproutel's business model positions the company in the middle of expert medical treatment and families and seeks to connect them (Figure 20).

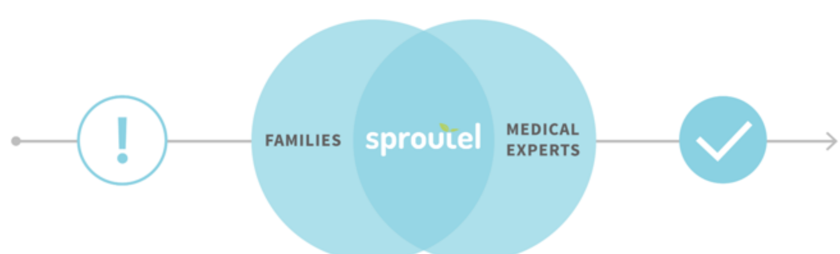
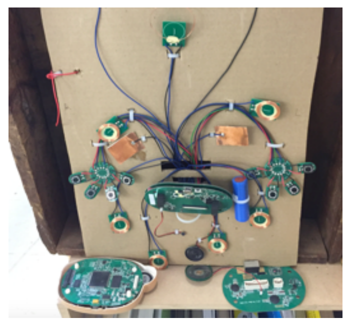
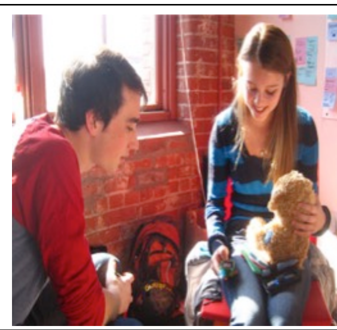


Figure 20. Schematic illustration of Sproutel design process, adapted from (Sproutel, 2016)

The team is multidisciplinary, including engineers, designers, and researchers. The members define themselves as digital storytellers, engineers, artists, tinkerers, troublemakers, and doers (Sproutel, 2016). The roadmapping intervention described herein aimed to augment the three stages of the company's existing design process, outlined in Table 15: Identify, Immerse, and Impact.

Table 15. Three stages of design processes in case study, adapted from (Sproutel, 2016)

Design Process	Descriptions	
Identify	This step starts with needs finding by talking to children, families, medical experts, and companies to find opportunities for creating an impact.	
Immerse	We dive in. We work with families to understand how health is managed at home, directly with kids to understand what they perceive, and collaborate with medical experts to synthesize best practices in care. This spawns an iterative prototyping and testing process, refining our design with each turn of the crank.	
Impact	After successful testing, products are released into the world, often with the help of the champions we've worked with to initially identify a need. We aim for measurable impact and work with clinical partners to conduct outcomes research after product launch.	

6.4.4 Applying design roadmapping in the case study

Sproutel is a distinctly design-driven startup company that heavily relies on child-centered design methods, using storytelling and empathy as tools to develop their new product concepts (Innovating health through kid-centered design, 2016). Their unique design process—Identify, Immerse, and Impact—has been progressively evolved over time without losing their team's high-level vision and philosophy. They keep a rule of "40% prototyping and 60% user feedback": i.e., they use an efficient process to get to 40% prototype completion and test out, and then complete the remaining 60% of the design based on user feedback.

[…] I think our current process does a great job at getting us to forty percent prototype completion. We can pick a need. We can create and test the prototype. That's what the process does. It is the process that pushes those things further. And I think it is partly conflated by other things because that forty percent is what you need to get market evaluation and feedback. […]

While preserving their existing design process, we implemented two iterations of my design roadmapping process (2013 and 2016) at times when the team needed to work on planning for the next anchored project schedules.

6.4.4.1 First iteration—creating the 1st version of the design roadmap

The first iteration of Sproutel's design roadmap addressed a new product development effort focused on exploration of product concepts that ranged from current form factors to extended form factors for the future marketplace. In Sproutel's initial 2013 design roadmap (Figure 21), the top layer represents the evolution of core experiences in each phase of the anticipated product development. The middle layer contains primary user needs extracted from design research based on observations, interviews, and ethnographic research. The contents were intended to let the team to capture high-level general needs, not secondary needs (Ulrich & Eppinger, 2003). This is because establishing overarching user needs was more crucial in a planning phase to initiate middle layers on the design roadmap template, whereas specific user needs (e.g., secondary user needs and tertiary user needs) could be developed later. The lowest layer represents the anticipated core outcomes, including a specific user's benefit from using their product/service.

Sproutel's design roadmap, coupled with a technology and product roadmap, shows the progression from the beta version to the final version, and finally to the Jerry the Bear platform. It shows the integrated roadmapping process where design iterations begin with the design roadmap: identifying underlying vision based on desired *core experiences*, *primary user needs*, and *outcomes*, which are in accordance with technologies associated with Sproutel's functions/features on technology and product roadmaps. Here is a quote from one of Sproutel's employees:

"We've had roadmaps for how we think about taking Jerry the Bear as a case study and example in type 1 diabetes, and extrapolating that into a platform, and then adding across childhood diseases/disorders/illnesses into the technology and how that might got across bigger categories and grow bigger." (P-17)

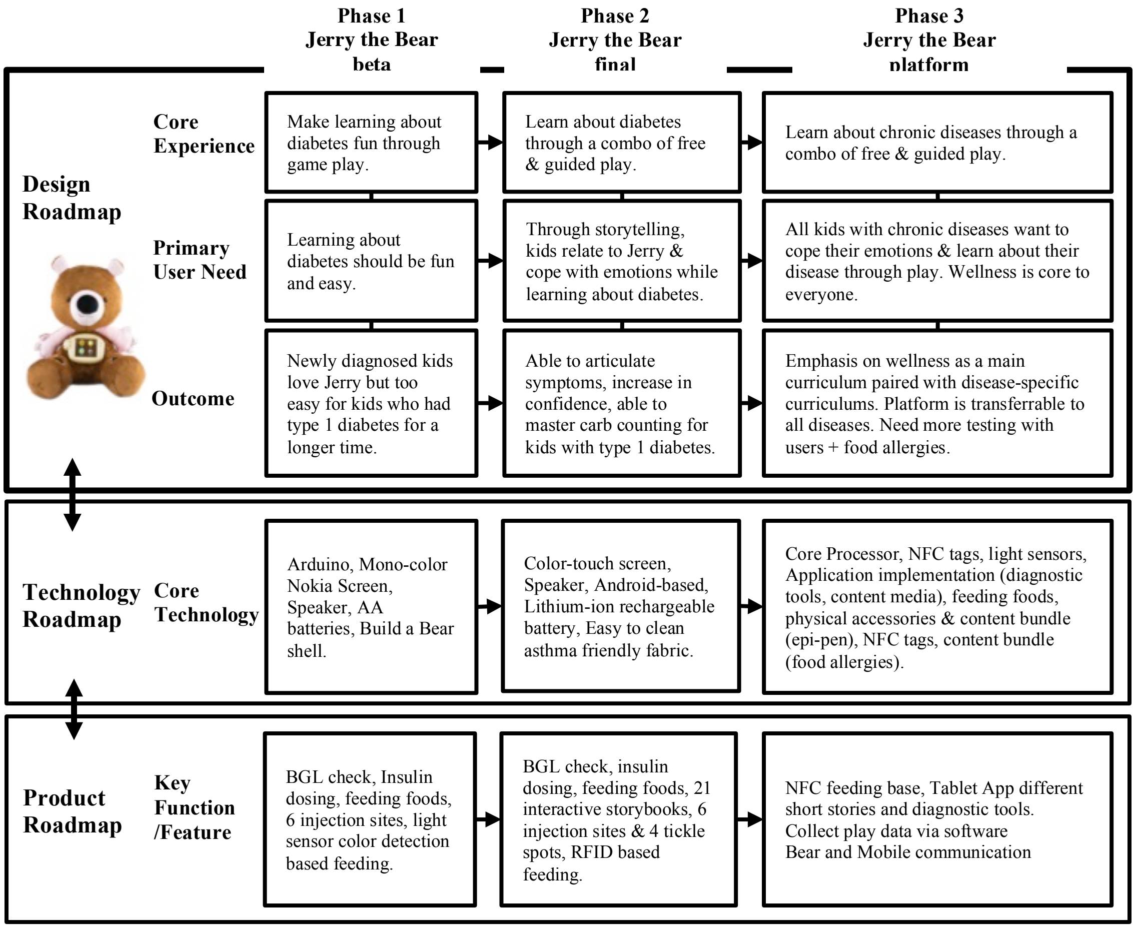


Figure 21. A preliminary simplified schematic example of an integrated design, technology, and product roadmaps: Sproutel's Jerry the Bear

6.4.4.2 Second iteration—creating the second version of the design roadmap

Another iteration reproducing the second version of the design roadmap occurred when we conducted an on-site visit to Sproutel's office in 2016 (see Figure 22). The workshop was held in their meeting room with the following agenda: introduction, individual roadmapping, team roadmapping, and post-interviews/discussion.

Figure 22. Individual design roadmapping practices: two pages of the worksheets are distributed (Apr. 2016)

In the second iteration, we distributed updated design roadmap templates as a two-page worksheet that participants could fill out individually. This version of design roadmap template keeps the initial structure of the template in introduced in Figure 14 (Chapter 5) but provides detail guidance. The framework in Figure 14 consists of five phases—extracting key quotes, developing core user needs, defining design insights (principles), defining a vision statement, and creating design roadmap in three phases. We aimed to make this version more explicit and comprehensive (Figure 23). The definition of each phase and examples were added to the template. Figure 24 and Figure 25 exhibit a copy of the example design roadmap filled out by one workshop participant. Three individual roadmaps—by the Chief Executive Officer, Chief Operations Officer, and Chief Creative Officer—were later consolidated into one shared version in a subsequent discussion section of the workshop. Here is one comment from a participant:

> "I'm excited to see that I think the roadmapping when the fact that that individual roadmapping activities bringing people together helps company culture. I think it is a really powerful tool." (D-13)

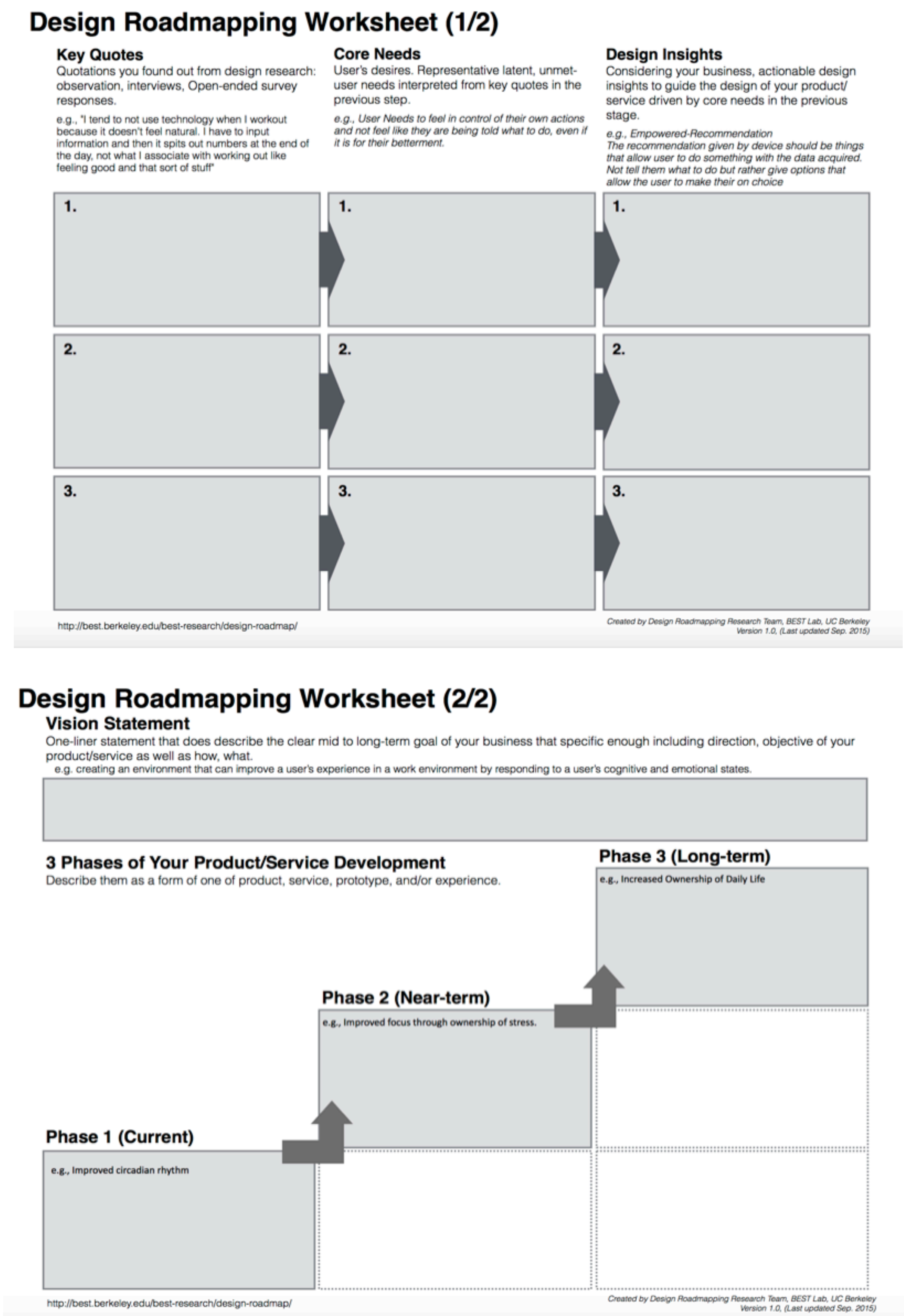


Figure 23. Design roadmap template 2-page worksheets

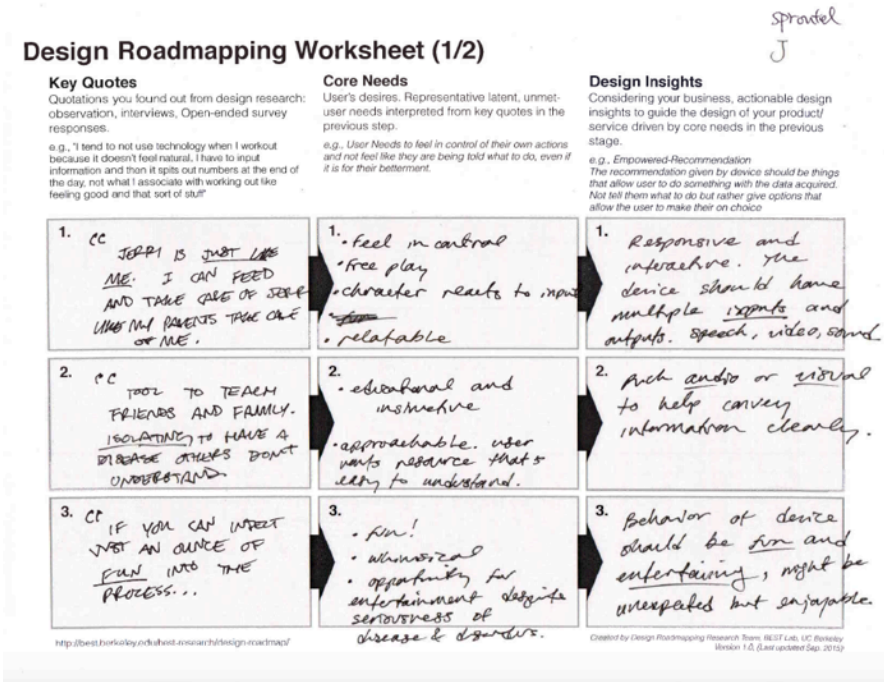


Figure 24. A copy of the design roadmapping workshop worksheet – individual (1/2)

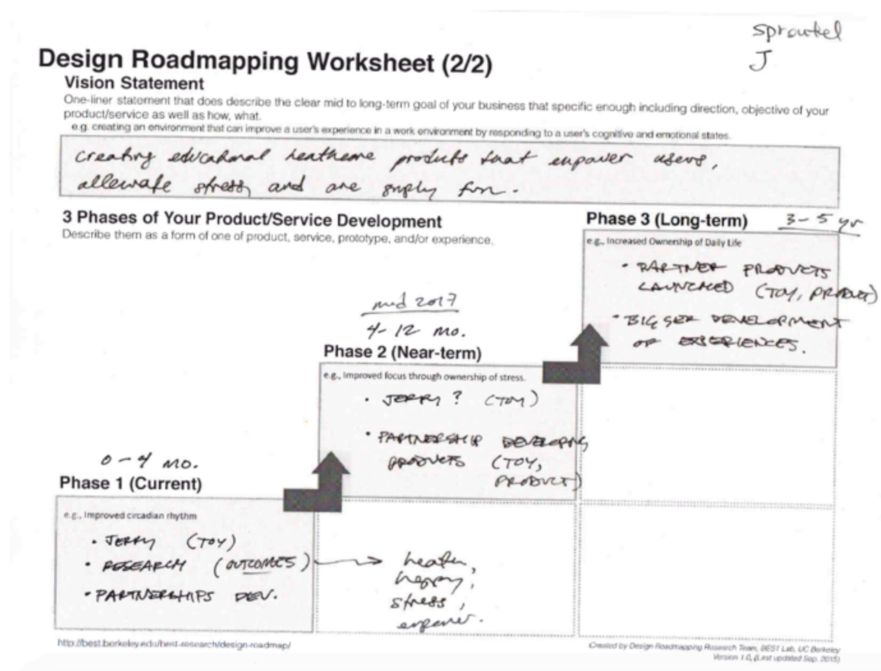


Figure 25. A copy of the design roadmapping workshop worksheet – individual (2/2)

6.4.5 Data validation/repeatability

I used inter-rater reliability test for data validation for coding the Sproutel qualitative data. In total, 143 line-by-line codes were created and discussed. The results of the inter-rater reliability showed similar interpretations of the same codes and close agreement on what theme extraction—Similar (1: very similar, 0: somewhat similar) and dissimilar (-1). Average percent agreements in the inter-rater reliability fell into 83% agreement—which comprises both the very similar (66%) and somewhat similar (15%) responses—and 17% disagreement on the codes. We selected themes from the codes that fell into agreements in "very similar" for further data synthesis. The calculated Cohen's kapper value is 0.95, where Cohen's kapper values greater than 0.75 are considered as "excellent" agreement beyond chance; values below 0.40 represent "poor" agreement beyond chance; and values between 0.4 and 0.75 considered as "fair and moderate" agreement beyond chance (Fleiss, Levin, & Paik, 2013). Of those in the very similar categories, insightful arguments were extracted and the results of them are presented herein as four distinct patterns found.

6.4.6 Results

I collected 43 pages of interview scripts and three pages of observation notes, and dozens of pictures over both project phases, mostly from on-site visits in April 2016. Using Grounded Theory (Charmaz, 2014; Strauss & Corbin, 1998; Glaser, 1992) to analyze the observation and interview data and refine the analyses, transcriptions from which keywords and key quotes were highlighted, interpreted. Two researchers worked in parallel; the interpretation, results, and insights of their individual analyses were then merged into one consolidated document to draw the conclusion.

Twenty-three photos captured Sproutel's working environment. Project deliverables and other artifacts such as a series of Jerry the Bear prototypes were captured. A commercial Jerry the Bear was purchased for close examination of the product's components. It allowed subsequent examination of the context of how the Jerry the Bear's current form factor, tangibility, and interaction models were shaped. The resulting contents of design roadmap worksheets from workshop participants, using quotes and insights from their design research, are summarized in Table 16. Although four individuals took part in the workshop, one couldn't make the first section due to prior commitments. Three individual design roadmap workshop worksheets were collected from the three senior executives who took part. The observations, as well as results of implementing, the roadmapping framework, are presented below. The four key results are summarized in the following sections.

Table 16. Summary of consolidated individual design roadmap worksheets (Sproutel)

	CTO	CEO	CCO
Quote 1	Jerry is "just like me." I can feed and take care of Jerry like my parents take care of me.	A diagnosis is such a stressful time, I wish we had Jerry sooner.	Helping/taking care of Jerry helps me understand why my parents help me
Quote 2	Tool to teach friends and family. Isolation to have a disease others doesn't understand.	Jerry has t1D, just like me.	My superpower is type I diabetes & it's the best thing in the world.
Quote 3	If you can inject just an ounce of fun into the process…	Feeling emotionally supportable and container is critical to all children, not just there with ADHD.	I like that Jerry is just like me.
Need 1	Feel in control Free play Character reacts to input Relatable	Education Support Connection/Community	Help understand diabetes in context of a relationship I easier to learn
Need 2	Educationable and instructive Approachable. User needs resource that is easy to understand	Children need to feel emotionally comfortable to support to not feel alone when they contract a chance illness.	Self-esteem (Up) Building confidence
Need 3	Fun! Whimsical Opportunity for entertainment despite seriousness of disease & disorders	All children need support to have confidence	Something to relate to -- so that user doesn't feel isolated.
Design Principle 1	Responsive and interactive. Your device should have multiple inputs and outputs. Speech, videos, sound	Recommend to help parents gain knowledge, confidence, to support in disease from as close to point of diagnosis as possible	Physical interaction call-based approach/curriculum that helps understanding/learning about diabetes in an easier way.
Design Principle 2	Pick audio or visual to help convey information clearly.	Recommended that children with chronic illness receive emotional comfort through using the device.	Positive language + empowering story
Design Principle 3	Behavior of device should be fun and entertaining, might be unexpected but enjoyable	Recommended that children receive confidence through use of device	Product should have traits that are unique to the user (personality/design characteristics)
Vision Statement	Creating educational healthcare products that empower users, alleviate stress, and are simply fun.	We will empower children with confidence + self esteem, to overcome whatever obstacles (disease, etc.) stand in their way to live happy + healthy lives	Creating experiences/products that makes health an empowering fun experience
Phase 1 (Current) 0-4months	Jerry (Toy) Research (Outcomes: health, happy, stress, empower) Partnership Dev.	Improve behaviors, toy, ease of use Building relationships	- Jerry the bear (old, camp) - Methodologies to abstract curriculum - pre-impact /white paper material - expertise validation
Phase 2 (Near-term) 4-12months	Jerry (Toy) Partnership developments Products (Toy, Products)	Improve internal process for IP creation to partnership Improve independent tech creation Expanded collaboration	Partnership Improved/validated curriculum Stronger brand Clear product dev. process Validated outcomes Word? Collaborative network

Phase 3 (Long-tem) 3-5years	Partner Products launched (toy, products) Bigger development of experiences	Match making space of ideas of tech to which space to pursue? ==> Stable cash flow	Sustainability - Variety of curriculum - Network of experts - More form factors/experiences - Maybe integrated experience with medical levels? - Trusted company with trusted products

6.4.6.1 Two paths of product development processes

While the company has one single commercial product lineup available in the marketplace, they have been seeking two types of product development paths—one path for current model improvement, and the other path for coming up with a completely new market concept.

> "There are two parts of our current product development: One, we're improving our existing product platform. The other one is coming up with new concepts and different markets, so existing product development, we'll gather insights from existing customers, how can we improve Jerry better, what's the UI flow, so using those insights we try to improve our UI, improve the software process, so that's kind of like we ask our customers to get insights. The newer one is, as I mentioned before, it's the two types of research we do, so it's a weeklong sprint, so we try to do 3 days of really intensive research, so currently we will write all the research questions and we'll divide and conquer, and we'll do research like synthesis, like share insights everyday, and then using those, we'll map out all the opportunities and where we can tackle the most, because we know it's kids, we know it's health education, it kind of gives us a scope of how we want to focus, so remaining of the week on Thursday and Friday we'll brainstorm and have a concrete idea with the goal of, we don't have to come up with the form, but enough [of a] clear concept that we can make a one-pager and move on. And hopefully at a later date we can use those ideas to prototype later, but at this point, our focus has been more on generating a lot of ideas that we can hone later." (D-13)

These two different tracks of concept development allow Sproutel flexibility in developing new concepts. They call this agile process the "sprint" method. It entails one-week-long participation—three days of research and two days of brainstorming".

6.4.6.2 Conventional human-centered design lacks mapping market opportunity and customer development

Human-centered design (HCD) is a design approach that emphasizes understanding of the needs, attributes, behaviours, and goals of the users (Gasson, 2003). HCD's systematic user research methodologies have been broadly adopted in new product/service development processes to make new offerings more useful and attractive to customers/users as well as in usability test (Maguire, 2001). HCD helps designers better understand human behavior and how people engage with products and services

(Krippendorff, 2004; Giacomin, 2014; Kim, Kocsik, & Agogino, 2013). However, our participants address the main backdrops of adapting human-centered design in their practices. They argued that the human-centered design approach lacks mapping market opportunities and customer development.

> "The piece that is missing from the human-centered design process is mapping market opportunity and mapping customer development, because all those things need to happen in conjunction. We face this issue that we develop the cool product but we did never know who the customer was." (P-17)

Prior to using our design roadmap framework, Sproutel had difficulty connecting their HCD design research with their strategic planning for new product development. As a startup, they need agile processes that can be performed simultaneously. Our design roadmap allows startups to situate HCD research and strategic product planning into one place together.

6.4.6.3 Prototyping and testing for/with investors, not real users

While an ideal scenario of user testing is to test their prototypes with real users (Gasson, 2003; Innovating health through kid-centered design, 2016) and lead users (Urban & Von Hippel, 1988) (see Table 15), Sproutel found that they inadvertently spent significant time testing their concepts with stakeholders such as investors and potential partners in a way that had a direct influence on their decisions.

> "Instead of testing those prototypes with users, they are tested with investors to see whether they are attractive enough to raise money to continue the process, which is not right." (P-17)

Product development based on what investors wanted instead of what users need often resulted in a failure for the firm to set concrete long-term plans for the future and resulted in faulty decision making.

> "In the past, there was an investor who had a really strong opinion about something. We might go certain way with a flow we were developing, making our own [decisions]. Trying to appease them so we could have money to survive as company often resulted in us…changing…direction more often and not driving [the] process…from the needs of users or our own research." (T-10)

A similar problem was observed in our descriptive studies (Chapter 4) in which several intermediaries between end users and companies could lead to a wrong decision.

6.4.6.4 Business-oriented goal setting

Although they didn't call it a roadmap, Sproutel does have a framework to plot out short-term to long-term goals over time. These goals are generally driven by business development, not user needs or desires.

> "We do a lot of "6-month goal," "1 or 2-year goal," and "3-5 year goal," so we do a lot of that framework, but it's not structured as much as a roadmap, so it's very business development–oriented. So the problem with that is the business side of it is captured, but it's hard to put, for example, research and products or other activities [at] the same importance level as business, so it has a tendency of making the business aspect the driving factor. So I feel like that framework is helpful, but it doesn't give equal say to other people's positions. So I feel like it's a very CEO-oriented approach, not a designer- or engineer-acceptable approach." (D-13)

> "We haven't really called it roadmap. We didn't deliberately say, in my mind at least, "Let's sit down and draw a roadmap." We have called it, "What is our business strategy?" We've used words like business model canvas to come up with ideas of how these pieces fit together." (T-9)

Rather than developing a future plan driven by design or technology, Sproutel uses a business-oriented approach to strategic goal setting. This approach seems to be in contradiction to how they describe their product development process as being human-centered and design-driven. Sproutel was aware of this contradiction and was interested in a better framework to integrate design research, product, and design driven planning techniques.

6.4.7 Post surveys with workshop participants

After completion of second iteration of the design roadmapping workshop and the transfer of the deliverables, the follow-up survey questionnaires were sent to participants to ascertain their overall satisfaction rate and benefits and drawbacks (see Appendix H for a full list of questionnaires). We asked them to score on a scale of 1-5 (5 = strongly agree and 1 = strongly disagree). All participants (four out of four) completed the online survey. Due to the small sample size, open-ended questions were included to receive in-depth responses on the pros and cons, as well as suggestions for future implementation.

The workshop participants agreed that the workshop was very satisfactory and useful with the average score of 4.5/5 (See Figure 26).

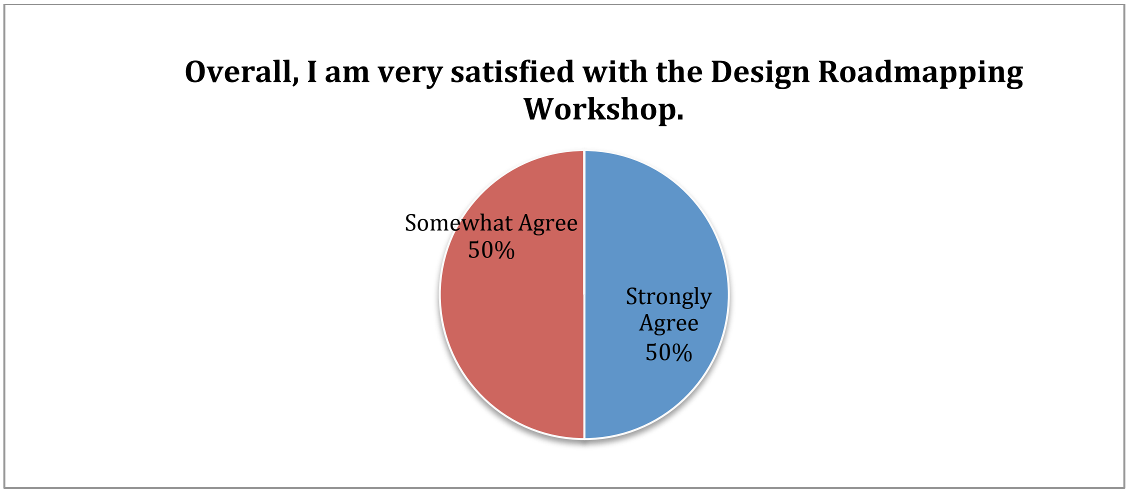


Figure 26. Satisfaction rate of the design roadmapping workshop (Sproutel)

Fifty percent of respondents strongly agree that the workshop was useful (5 out of 5). 50% of respondents somewhat agree that the workshop was useful (4 out of 5). Here is one response from a participant.

> "I think it helps our team to communicate clearly. The framework works really well to have all of our input. Have [an] equal level of importance. In the end of the workshop, I loved how our teammates started planning to hash out our tech roadmap and discussed…having a consistent vision and experience at our company. I think the design roadmapping workshop gave us a set of vocabulary that we can use where there is no confusion in what we are talking about." (D-13)

> "I like using an end user needs–driven approach to determine what is most meaningful to build technologically." (T-9)

I also asked the participants to rate which aspects of the design roadmap workshop were the most helpful. The results of the online survey are shown in Figure 27, disaggregated by value/usefulness of the design roadmapping process.

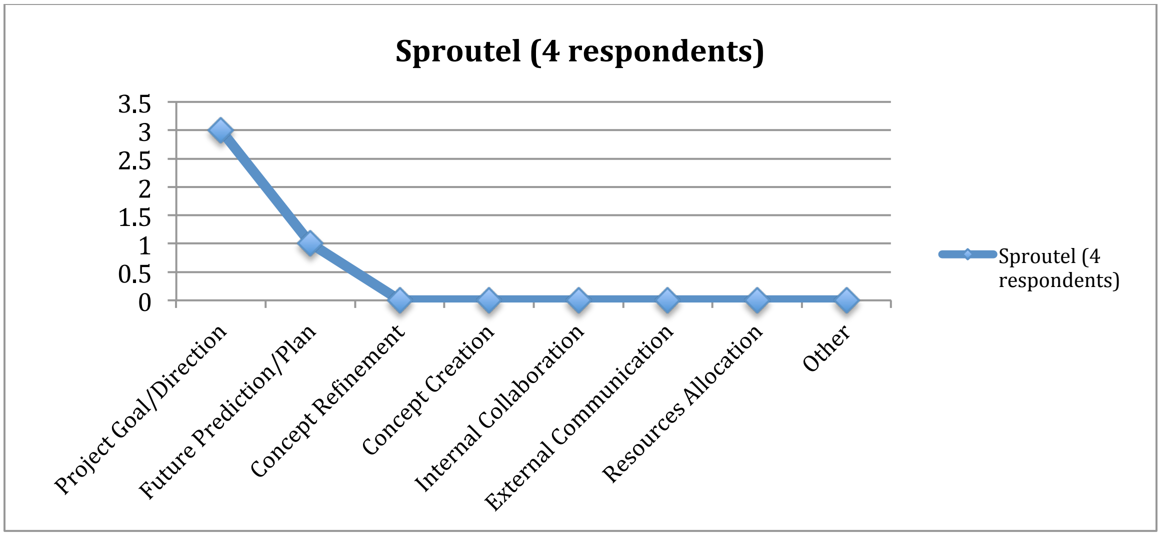


Figure 27. Online survey result for the number of responses disaggregated by the value/usefulness of the design roadmapping workshop (Sproutel)

Of the four survey respondents, three participants answered that they valued it as a medium to set project goals/directions. One of respondents described that it was helpful for future prediction/planning. While no one selected benefits of collaboration, I found several positive comments as to how the design roadmap helped the company improve internal collaboration. For example, one respondent answered that:

> "I'm extremely happy with the result of the workshop. I think it helped our company to collaborate better and understand the importance of process and documentation more than ever." (D-10)

6.4.8 Findings

This action research provides some insights as to how design roadmapping could benefit a small startup company in a competitive environment such as the child health-care market. The sections below summarize a few findings that address new opportunity areas for design roadmap implementation for small startups.

6.4.8.1 Developing shared team vision and goals

Vähäniitty et al. suggest the steps for creating roadmaps start with vision setting (Vähäniitty, Lassenius, & Rautiainen, 2002). Vision is positively related to the team's performance (Kantabutra & Avery, 2010; Quigley, 1994). A key advantage of applying design roadmapping in this case study was partially so the team could develop a unified shared vision and goals on their design project to help them create compelling holistic user experiences for their product line. Surprisingly, all three participants in the worksheet stage of the workshop came up with a similar definition of the company's vision.

Here are example vision statements excerpted from Table 16:

> "Creating educational healthcare products that empower users, alleviate stress, and are simply fun." (CTO, Sproutel)
>
> "Empower[ing] children with confidence and self esteem, to overcome whatever obstacles (disease, etc.), stand in the way [of them] living happy, healthy lives." (CEO, Sproutel)
>
> "Creating experiences/products that make health an empowering fun experience" (CCO, Sproutel)

In these vision statements, it is straightforward to find overarching themes over the statements from the three participants. All three address that their vision should be to create educational solutions that empower children with chronic diseases. Frequently used words were: experience, empowering, alleviating, fun, happy, healthy, etc. None of members used technical terms to qualify their vision for the company. Once the shared team vision was set at the beginning, it was easier to align other discussion points. One participant stated:

> "I felt that it was cool to see on the higher level what type of emotions or the experience we were trying to drive are consistent. When we talked about specifics it was cool to voice more easily without worrying if it was important or not because that was all aligned in the beginning." (D-13)

Participants valued the design roadmap's flexibility in allowing the vision statement to evolve over the process. Rather than requiring completeness of the vision statement at the start, the ability to go through the activities to advance their vision was considered beneficial.

> "I feel it was good that we moved through it even though each piece was not complete, like maybe our vision statements were not incomplete." [T-9]

6.4.8.2 Integrating individual design roadmaps into a shared roadmap with equal opportunity and no hierarchy

Design roadmap templates were used to "envision" the future of the Jerry the Bear product line at Sproutel. As with the large company example, the Sproutel example showed how possible integration of individual design roadmapping activities could be incorporated into the company's shared design roadmap. The architecture of individual design roadmaps served to introduce each member's vision and progressive roadmapping elements. Once conceptualized, these individual roadmaps were brought together. A single, group-synthesized design roadmap evolved from the progression of the collectively unified visions shared by the team that guided all concept paths towards one solid endpoint using the design principles, collected quotes, and user needs over three phases of future projection.

> "I think what's really interesting [about] the roadmapping process is that … it's a tool that helps you think long-term, but not putting preference on one aspect or the other, so I like the fact that the way we did the workshop today, even my voice or the other's voice is equal, and there's no hierarchy in it. So I really like that part, so I'd love to see more on how that can be used in the next step." (T-9)

6.4.8.3 Benefit of having a facilitator

I selected the action research (Sagor, 2000) approach because of its strength in promoting engaging interactions between researchers and case study participants. The action research enabled flexible and practical participation to the real-world situation and challenged the proposed design framework to be responsive to practical issues with real users (Brydon-Miller, Greenwood, & Maguire, 2003). Participants believed that the mediator (dissertation author) facilitated greater workshop engagement and better collective internal collaboration.

> "I think one of things that was beneficial was having you here as the mediator, because sometimes we got focused on single details. When we weren't making progress, you helped us move along and revisit or rethink different ideas. I think that was a really strong part of the discussion because I think when we had discussions in teams, that's where we'd get stuck discussing singular topics." (T-10)

Another participant reacted that inviting a facilitator was useful in encouraging equal opportunity to speak up during the team collaboration.

> "I felt that everybody was heard equally and everything on the board had the same level of importance." (D-13)

> "I enjoyed having you as a facilitator here. I think that your continuous asking of questions enabled us to articulate and get on the same page as to what we were talking about on lot of the things." (P-17)

6.4.8.4 Design roadmapping for external communication

Sproutel seeks partnerships with "external manufacturers" in the children's toy industry. They believe that an external partnership would help the company to expand their existing product lineup and create a new market opportunity space. The design roadmaps created by the team showed potential as a medium for communication with external partners. Sproutel would adapt it as a medium to “proactively” share the company’s interests to those who want to manufacture toy factors.

> “This made it more clear to me that this is one of…the first time[s] where we were starting to make our own plan rather than it being like a reaction to the stuff that was happening, whether it be investors or a money situation.” (T-10)

> “Let’s not be reactive to this partnership; let’s have our own strength and let’s be the catalyst, and that’s the only way we can give the counterpoint.” (D-13)

Rather than internally developing a complete version of a product, they are open to the idea that partners could assist them in strategic planning. A top priority was to identify the core experience and themes the prospective partner company regards most highly.

6.4.9 Action research implementation #2 conclusion

This action research demonstrates the use of the design roadmap framework as a method to enhance early-stage design and project exploration processes driven by “design principles” criteria—that is, by the end user’s experience. The design roadmapping process augmented the existing design process of an early-stage startup located in Providence, RI, US. Based on observations before, during, and after the workshops, as well as in-depth interviews, the design roadmap framework appeared to be of value in helping the management team evolve a shared vision driven by both business concerns and customer research. It also provided a mechanism for improved internal and external communication. The next chapter will provide insights drawn from comparisons between the two action research examples.

7 COMPARISON AND EVALUATION OF THE TWO ACTION RESEARCH EXAMPLES

Chapter Overview

This chapter evaluates findings from the two action research examples introduced in Chapter 6. Data sources from observations, interviews, and documentation from each case are examined with explicit comparisons.

7.1 Introduction

In action research example 1 (Chapter 6.3), the design roadmapping process was tested in a global company with corporate stakeholders located both in the Silicon Valley and in Asia. The action research involved a small-size internal innovation team that is part of a larger business division, playing in a mass market within the global marketplace. The mission of this innovation team was to initiate and promote a new product concept for a range of near- to long-term timespans driven by a mix of experience- and technology-driven approaches.

In action research example 2 (Chapter 6.4), the design roadmapping process was implemented with Sproutel, a small startup that is enthusiastic about its own child-centered innovation process for its single-product portfolio, Jerry the Bear. Sproutel aspires to expand its target market to a larger population. This example shows the potential for design roadmapping to help a small multidisciplinary team set a shared vision for moving forward.

The two action research examples presented herein have differences and similarities in terms of the benefits they derived from applying the proposed design roadmapping process. I note key differences in their design process, use of prototyping, goals for roadmapping, and role of roadmapping in project selection. The companies derived similar benefits from the roadmapping process in terms of use for developing shared vision, and facilitation communication, both internal (for the large corporation) and external (Sproutel).

7.2 Key Differences between the Asian-Silicon Valley Corporation and Sproutel

7.2.1 Design process

To better understand the similarities and differential impact of roadmapping in these two examples, I first step back and compare their design process, as summarized in Table 17. In the Asian–Silicon Valley corporation example, the roadmapping interventions occurred throughout the three stages of the company's existing design process in order to augment their continuing concept exploration, selection, prototyping, and refinement, and documentation. In the Sproutel example, the roadmapping process intervention was first applied after the team had already completed a certain number of iterations, and then again after their product was commercialized.

Table 17. Pre-existing design processes at the two action research companies

	Asian–Silicon Valley Corporation (Action research example 1)	**Sproutel** (Action research example 2)
Step 1	**Project scoping** Research user cases and scenarios in the real world to find high-value opportunities/ applications. Identify user experience principles to guide explorations.	**Identify opportunities** Start with needs finding by talking to children, families, medical experts, and companies to find opportunities for creating an impact.
Step 2	**Prototyping and testing** Evaluate scenarios to identify core user experiences and features that are required for designing new products and services. Build short-sprint MVPs (Minimum Viable Product) and test them with target user segments.	**Immersion** Dive in, work with families to understand how health is managed at home, directly with kids to understand what they perceive, and collaborate with medical experts to synthesize best practices in care. This spawns an iterative prototyping and testing process, refining our design with each turn of the crank.
Step 3	**Refining and documentation** Iteratively refine the seed products that demonstrate value and scale up to achieve a broader vision of the project. Prepare demonstrations and documentation to assure successful knowledge transfer.	**Evaluate Impact** After successful testing, products are released into the world, often with the help of the champions Sproutel worked with to initially identify a need. They aim for measurable impact and work with clinical partners to conduct outcomes research after product launch.

In the second application at Sproutel, the roadmapping was aimed at restructuring their strategic planning to benefit future product concept exploration, idea generation, and goal-setting. The differences in the design process between the two companies led to different forms and timing for our design roadmapping interventions.

7.2.2 Role of prototyping in the design process

Both the Asian–Silicon Valley corporation and Sproutel embrace a design process that values multiple iterations of prototyping to inform new concept generation or refine existing concepts. While both companies are committed to prototyping, their different paths and perspectives towards use of prototyping is of note and could influence the role of design roadmapping.

7.2.2.1 Asian–Silicon Valley Corporation

One major output for this company's design process is the delivery of a compelling prototype demonstrating essential functionalities associated with user scenarios. A prototype is crucial for communication with their internal collaborators as well as for collecting user feedback on rough product concepts (Zimmerman, Forlizzi, & Evenson, 2007). I observed that the engineers in this case study were reluctant to provide a functional prototype to design researchers for user testing until they had achieved a high-quality working prototype, whereas the designers were more interested in lower-fidelity prototypes for rapid user testing to make room for adjustments in the earlier stages of the design process. The internal members had different expectations for the role of prototyping in the design process, depending on their functional role. As cited by D-5 in Chapter 4:

> "The technology people are driving the prototype realm of things and the designers have been focused more on the long term, what is the vision of this thing. Sometimes, prototypes only cover small parts of a whole." (D-5)

7.2.2.2 Sproutel

Sproutel stressed that the human-centered design process (Kim, Kocsik, & Agogino, 2013; Gasson, 2003; Krippendorff, 2004; Giacomin, 2014) was crucial to their in-depth understanding of user needs, meanings, and nuances. Multiple prototyping sprints were identified as particularly effective:

> "One thing that we've done with the process is we've done a lot of quick prototyping sprints with the product so we learn through doing it three four times what worked and what didn't work well. So I think the thing that works well in our process is both the approach works well with the communication style of our team as well as identifying these things early, and I think the reflection part of our process has helped us get better every time. […] Over the past two years at Sproutel, there has been a lot of prototyping; the mechanicals and electricals are great, and even more software, web, and android development." (T-9)

As a practical tool, Sproutel adapted the sprint process to a weeklong rapid brainstorming and ideation processes. They keep a rule of thumb that requires making an initial prototype to only 20% fidelity to allow 80% user feedback in the early phases of the design process, followed by developing a 40%-fidelity prototype for obtaining 60% user feedback in later phases.

> "I think it's part of human-centered design process, but we call this as 20-40-60-80 rule, so that's a process I learned from outside, which means if you make a prototype 80% so early on, you only give 20% of room for users or feedback, so you want to make 20% first and then scale it up. If you have all the time we can do that really well, but a lot of the time we don't have that time and need to rush, so we have a tendency to jump from 20% to 80% and you have to compromise because with time, do we want to hit 60%, do we want to hit 80%, but what's the compromise? I think following proper human-centered design in a short amount of time with all these variables is the hardest part, and it usually happens in the prototyping stage." (D-13)

However, Sproutel occasionally confronts issues on testing their prototypes for/with investors, not real users (see Chapter 6.4 for detail). They expect that it will be a temporary issue that can be resolved once the financial issues are settled. As cited by P-17 in Chapter 6:

> "Instead of testing those prototypes with users, they are tested with investors to see whether they are attractive enough to raise money to continue the process, which is not right." (P-17)

All things considered, I identified significant differences between the Asian–Silicon Valley corporation and Sproutel in their perspectives on prototyping. The variation may be affected by not only their organizational structure and design processes but also the perceptional differences towards the value of prototyping between engineers and designers working together. In the Asian–Silicon Valley corporation, user testing was normally planned when the prototype was 70–80% complete, whereas Sproutel tested prototypes earlier when the concept was only defined at the 20% level. The lessons learned from analyzing the different approaches to prototyping taken in these two examples can inform where design roadmapping should be implemented during the new product planning and development process.

7.2.3 Motivation and goals for design roadmapping

In Chapter 4, I defined four primary purposes for roadmapping: *future prediction, resource allocation, internal collaboration,* and *external collaboration*. Below, I summarize the differences in motivation and goals for our design roadmapping intervention.

Both companies were motivated to employ roadmapping for more effective communication and collaboration. However, the large corporation was motivated by *internal* collaboration, whereas Sproutel was motivated by roadmapping's helpful role in *external* collaboration with potential partners.

7.2.3.1 Asian–Silicon Valley corporation

For product development, the innovation group studied in action research typically develops a series of materials to share with internal stakeholders. They primarily communicate with Headquarters and local collaboration teams. The results of their work are reported to top management as well as team-level collaborators such as Design, R&D, Marketing, and Advanced Product Planning. While the innovation group in the case study hadn't had a design roadmap until the action research was implemented, the interviewee from Headquarters, a counterpart internal collaborator, stated that they have a kind of design roadmap for internal use:

> "We use a design roadmap to…provide vision for designers within our group to say "this is a thing we are…heading [toward], so let's prepare for it. Another is… ike a foundation to work with other groups, so we show [them] videos…[and] roadmaps, and say, "Look, this is what we think users will like, [what] they will expect, what our competitors will probably be doing, so let's do this. Let's make it as delightful and fun as possible. We have to talk with the engineers, say you know that we think that this technology is possible, then can we speed up on the research, and can we have it and do it? And then we talk to them in product planning, and say that this is what we think that user research will be around, and how can we market this, how can we plan [a] product around this." (D-3)

Headquarters builds something other than a roadmap as a form of documentation for the purpose of conveying their ideas with their internal stakeholders within the large organization. Headquarters primarily uses various types of data sources—a roadmap, vision video, expert interviews. Their expectations for roadmapping went beyond technology projections, desiring a mix of social, design, economic, or green trends associated with people's lives:

> "Ideally, what we would want to do it to create roadmap and envision video, and then also do interviews with experts, key leaders in the industries to see if they agree with it or if there are disrupters because the roadmap is not just tech-based, but you are looking at social trend, design trend, economy, how people want to do things differently, there are green trend, maybe they don't want to buy the new one, but they just want to update software, maybe that' the purpose of the evolution for example." [An interviewee from Headquarters]

The three design roadmap examples developed by the innovation group as part of our action research appear to have increased the engagement of representatives from both parties early in the advanced planning process.

7.2.3.2 Sproutel

This company aspires to build a design roadmap for proactive collaboration with a potential partner company in the health industry. They expect the design roadmap to play an important role in enhancing their collaboration with potential partners who could guide Sproutel in addressing potential future toy markets.

> "The model is to join venture with revenue share. For example, twenty companies would partner with us and produces something similar to Jerry but deal with ADHD (Attention Deficit Hyperactivity Disorder). Then we are just in charge of creating the product. We are in our first iteration of our partnership with one of these people. We are being paid to help them build the roadmap, so it's kind of interesting. So they have no idea what they are going to do. And so basically, what they've said is like, we want to go into health. […] They've released one product. But they've said, we [Sproutel] are a very "kids" company. They released a product for the elderly. They were like, We know we need to go into kids' health. We don't know anything about kids' health. You guys are the experts in kids' health. What should we do? And presumably we are going to hire you to make the product. So I think it's really the right time. There are also some other companies in similar places for different verticals. And so we've just done a bunch of research. They are kind of cool because they are the research we wouldn't have done ourselves. Like we would never sit down and do this. It only took somebody to say we are paying you to do what we should've done four years ago to make a roadmap for our company. Our roadmap has been less linear." […] (P-17)

Partnerships may have limited funding for the product investment so that all aspects of Jerry the Bear cannot be implemented into a toy product. Thus it was important to ask the team: "What is the most important attribute if you could pick one of those?" Sproutel recognized the need to focus on a few key parts instead of everything. They saw this ability to focus and clarify directions as a major benefit for the design roadmap.

Sproutel also found that customers were not the direct users but instead potential partners and stakeholders. They have to decide the market to sell it to and understand what these partners want. They have mixed feelings about how much of a role these partners should have, but recognize that they are critical for financing and providing product channels.

> "Now we find that customers are not our users at all, the customers are large company or a non-profit that wants to buy and distribute [the products] for free. We kind of develop this cool product and try to figure out how to sell it." (D-13)

> "It can be scary when you have like two months' worth of financial runway and you are trying to build something and you have someone who wants you to do [it] in a certain way, or if you need to build something [just] to foster a partnership with another company." (T-9)

Although key stakeholders exist within a company, external influencers such as investors, partners, manufacturers, or other stakeholders can influence the company's direction.

> "But [it's] still kind of unclear, exactly where the tangible goal is where we want to go. Like one of partnerships popped up initially was a really strong plan in a single direction of working with a current product, but modifying a little bit, having bunch of them sent out. But that really didn't change, so that's currently not the plan anymore. Even when you have a sort of situation working with outsiders like you can't address change what you are doing" (T-9)

While the design roadmaps haven't been shown to their partners yet, the Spoutel team believes that having their own design roadmaps would greatly strengthen their capability to proactively lead an alliance between the company and external stakeholders.

7.2.4 Processes for project selection

After customer research helps a product design team identify opportunity spaces to create, prototype, and test concepts, the next step is to select the most promising projects to develop further (Ulrich & Eppinger, 2003). In the Asian–Silicon Valley corporation example, scoring the projects with human desires (Chapter 6.3), as a part of the design roadmapping process, assisted the team in selecting one of projects to recommend to Headquarters for further development and commercialization. In Sproutel, because the company was focused on only one product, Jerry the Bear (Chapter 6.4), the project selection process didn't apply. However, our research suggests that the team might benefit from design roadmapping when it comes time to compare several possible rough concepts, directions, and experiences to pursue in the future, as described below (Table 18).

Table 18. Project selection processes of the Asian–Silicon Valley corporation vs. Sproutel

	Asian–Silicon Valley corporation (Action research example 1)	**Sproutel** (Action research example 2)
Project(s)	**Project P** Reflect on the flowing stream of everyday life to strengthen family connections and shared identity. **Project W** Explore various forms of (tele) presence, leveraging the screen's facility to mediate casual long-duration engagements between remote people and distant places. **Project M** Explore how full-body interactions, augmented reality, and faceted media manipulation can unlock realms of fantasy, storytelling, and imaginative play.	**Jerry the Bear** The first version of Jerry is designed for children with type 1 diabetes. Children care for Jerry by feeding him foods, administering insulin, and monitoring his blood glucose levels. (Sproutel, 2016) **Jerry the Bear 2nd version** A concept is not identified yet. Apply "sprint" exercises to enable quick ideation, brainstorming (see Chapter 6 results for details).

7.2.4.1 Asian–Silicon Valley corporation

Three design projects were simultaneously running towards the same goal to develop a compelling consumer display concept for the future. As part of the design roadmapping process, Projects P, W, and M were rated by the design principles developed by the internal team members working with the action research facilitator. Since the company required prioritizing the design projects as a recommendation to Headquarters, the evaluation criteria were built and scored in two different perspectives: a design perspective (see Table 10) and a technology innovation perspective (see Table 13). Interestingly, the project that scored high against technology innovation criteria scored low on design criteria. The project that had the lowest technological innovation levels, but the highest on design criteria, compared to the other two projects was selected as the final concept to be further developed. As a consequence, Project P led to the launch of a commercial product in a different form factor while keeping the core experience levels identified in this company.

7.2.4.2 Sproutel.

The company had one design product, Jerry the Bear, that was already commercially available. A week-long "sprint" process was used to initiate a new product concept at the same time as discussing the future of the Jerry the Bear product line. The dual paths of product development enabled the company to focus on making a gradual evolution of the current product (Jerry the Bear), while laying groundwork for next-concept development. Design roadmapping facilitated Sproutel's strategic thinking deeper into the future than before. Coupled with the sprint exercise, Sproutel was able to generate compelling customer-driven ideas for future product lines. During the design roadmapping workshop, participants were able to coherently connect the current Jerry the Bear to potential products by building the provided design roadmapping template.

7.3 Similarities between the Asian–Silicon Valley Corporation and Sproutel

While differences existed between the two action research examples, certain benefits of the design roadmapping intervention were shared by both organizations.

7.3.1 Shared team vision and communication

Multidisciplinary collaboration has been widely adopted for new product development processes (Dym, Agogino, Eris, Frey, & Leifer, 2005; Beckman & Barry, 2007). However, some researchers address its fragility and dissonance across participating members (Kuniavsky, 2003; Roschuni, Goodman, & Agogino, 2013; Dumas & Whitfield, 1989). In both action research examples in this dissertation, collaborators and product team members thought that they shared a common team vision, but found that there were still significant gaps in how they defined and scoped their projects throughout the collaborative efforts. The design roadmapping activities—from defining the team's overarching long-term goal to extracting common user experience themes over a timeframe—enabled the participants to learn about both agreements and disagreements among team members with different educational backgrounds and work experience.

> "I think that your continuous asking of questions [in the design roadmapping workshop] enabled us to articulate and get on the same page as to what we were talking about on lot of the things. I think that doesn't often happen. I found the first session we did was one of my favorites. They were all really helpful. That one was really enjoyable partly to see the similarities across the team." (P-17, Sproutel)

> "Throughout the roadmapping, our team could reach consensus and clarify misunderstanding on the vision/direction of the project" (P-1, Asian–Silicon Valley corporation)

The design roadmapping process therefore promoted active team communication and engagement as well as better documentation of ongoing project results, as illustrated by this comment from one of the participants:

> "What's really interesting [about] the roadmapping process is that…it's a tool that helps you think long-term, but not putting preference on one aspect or the other. So I like the fact that the way we did the workshop today, even my voice or the CTO's voice is equal, and there's no hierarchy in it." (D-13)

7.3.2 Identifying low-hanging experience to come next

Even when a firm is equipped with a well-developed technology roadmap relevant to its market sector, it can fail by miscalculating the trajectory of consumer adoption of those technologies over time (e.g., Google glass, Segway) (MIT Technology Review, 2014; Segway, 2016). The design roadmapping intervention for both action research examples was able to guide participants in defining captivating user experiences first, then in defining associated technologies. One of the benefits of the design roadmapping process was to discover "low-hanging experiences" that the team could achieve first while keeping a focus on core user experiences over time. This is a result that could not have been achieved with previously introduced technology and product roadmapping processes.

Technology and product roadmapping has typically been used to align technology development projections with future product platforms and features among these stakeholders. In contrast, design roadmapping has the potential to play a decisive role in connecting technology with user needs and expectations, as well as grounding a design team's shared vision. One participant from the Asian-Silicon Valley corporation commented:

> “As [I am] a project lead and user experience designer, it was my first experience of [creating] a Design Roadmap during my decade-long industry career. It was useful as we started with a design perspective, [iterated on] key opportunity spaces, then looked into associating different technologies at micro levels.” (D-11)

In the Asian–Silicon Valley corporation’s design roadmap, the level of experiences was defined prior to the phases of technology exploration (see Table 11 and Figure 15 - Figure 17).

During Sproutel’s design roadmapping workshop, similar to the Asian–Silicon Valley corporation, the participants were very enthusiastic about portraying current and forthcoming user experiences by their own definition. By setting aside technology considerations from the conversation during the workshop, rich descriptions of anticipating phases were collected from individuals and then integrated by the team.

For example, members of the Sproutel team delineated the first phase of the Jerry the Bear’s design roadmap by filling it with non-technology/non-feature-driven terminologies to explicitly describe where they would focus on a spectrum of emotional values. Example descriptions included terms such as “improve behaviors, building relationships, health, happy, stress, empower, methodologies to abstract curriculum,” etc. The content in Phase 1 progressively moved on to the next phases with “strengthen experiences, new user and/or market segments, expended partnership/collaboration with alternative products” (see the bottom three rows of Table 16 for detail).

7.3.3 Visual representation of design-driven roadmap elements

Supported by recent publications on the value of roadmap visualization (Simonse, Hultink, & Buijs, 2015; Kerr & Phaal, 2015), our design roadmap workshops encouraged the advancement of concepts incrementally and visually represented along with the time frame. Kerr and Phaal argued that:

> “Although roadmaps have been widely recognized as powerful visual devices for communicating strategy, their graphic design—the visual element—has been generally ignored by both practitioners and academic researchers, and often has been poorly executed.” (Kerr & Phaal, 2015)

In terms of the roadmapping process, Kerr and Phaal introduced four process steps: 1) defining the frame for the roadmap, 2) establishing the structure of the roadmap layout, 3) depicting relationships that connect various elements of roadmaps, and 4) articulating a direction for the strategic narrative captured by the roadmap (Kerr & Phaal, 2015). They proposed templates be built based on these four process steps to visualize the roadmapping activities.

The five steps of the proposed design roadmapping processes herein (Table 6) comprise components mapping across user needs, design elements, and technologies. The last step of this design roadmapping process utilizes the two-page worksheets that were beneficial to visually couple associated components (Figure 23), as illustrated in this comment:

> "I like using an end user needs–driven approach to determine what is most meaningful to build technologically." (D-13)

Furthermore—in addition to the visual representation of the process used during the design roadmapping workshops—I have observed participants who applied their own visual representations to illustrate anticipating concepts on a large white canvas. They used symbols such as straight lines to portray the gradual advancement of experience levels. The radii of circles were used to depict the magnifying degree of defined contents over a timeline (e.g., Figure 15 top).

The next chapter on Teaching Design Roadmapping provides more illustrations of both digital and tangible visualizations of design roadmapping, which were used in educational workshops.

8 TEACHING DESIGN ROADMAPING IN PRODUCT DEVELOPMENT CURRICULA

Chapter Overview

This chapter explores the application of design roadmapping in new product development classes as a supplementary project-based learning activity. This chapter examines one in-depth pilot test and in-class case studies with nine student teams in new product development (NPD) courses at UC Berkeley. It also illustrates some of the pedagogy and instructional instruments used and refined in industry workshops described in previous chapters.

8.1 Introduction

This chapter describes a pedagogical framework for design-driven roadmapping and its key elements in an attempt to teach general roadmapping processes in product design and development education. I gathered data from one in-depth pilot workshop with a product design development group consisting of five undergraduates. After the pilot research, I conducted the same workshop with 46 students (nine student teams) who were taking ME110 (Introduction to New Product Development) at UC Berkeley in Summer 2016. I examined the results of workshops with students who had been given the opportunity to practice design roadmapping tools in their team-based new product development projects. Both tangible and digital design roadmapping tools were built and provided to the students. I showed example design roadmaps developed by student teams to exhibit actual design roadmapping elements applied to their team projects. Additionally, the results in this study provide points for discussion on how design roadmap phases can evolve over a timeline. Lastly, lessons learned are discussed.

8.2 Related Work

Dym et al. review the history and the role of design in engineering education, and emphasize project-based learning (PBL) driven by design implementation (Dym, Agogino, Eris, Frey, & Leifer, 2005). New product development courses have been well formalized by engineering faculties in both undergraduate and graduate courses across a number of universities (Beckman & Leslie, 2006). For instance, UC Berkeley offers an undergraduate course called ME110 (Introduction to New Product Development), where students gain hands-on product development experience during a semester-long team project. The Capstone Project course for UC Berkeley's Master of Engineering program run by the Fung Institute for Engineering Leadership is another example where new product design processes play a crucial role in integrating students' learning and leadership skillsets to develop innovative solutions to major challenges (Capstone Experience, 2016).

The generic NPD process follows four distinct iterations of observation, framework, imperatives, and solutions that are cycled through at least twice during the course of the semester (Beckman & Barry, 2007). Using a human-centered design process, a series of design phases includes needs finding, concept generation, development, prototyping, testing and concept refinement. The final team deliverables in traditional NPD curricula, normally include the following components: 1) mission statement, 2) customer and user needs, 3) concept generation, 4) concept selection, 5) use of prototype and feedback, 6) product impact analysis, 7) business model canvas, and 8) final prototypes.

While significant effort has been made on the industrial application of roadmapping, fewer studies have focused on teaching this model in today's product development curricula. Ulrich and Eppinger introduce example technology and market segment roadmaps as part of product planning in their textbook, *Product Design and Development*, which is widely adopted in new product development courses (Ulrich & Eppinger, 2003). Their textbook covers a general introduction of product and technology roadmapping frameworks, including its definition and examples from industry. There appear to be few published academic papers explicitly dealing with how a roadmapping process could be taught in a new product development curriculum. However, as today's new product development becomes more agile and requires iterative processes (Martin, 2003; Olsson, Bosch, & Alahyari, 2013), it has become more important for product development teams to set their goals to clearly reflect their long-term direction. My research in this chapter is motivated by the potential implementation of design roadmapping within project-based learning (PBL) courses on new product development.

8.3 Building Design Roadmap Materials—Tangible Tools and Digital Tools

Visual aspects of roadmapping have been a neglected area of attention (Kerr & Phaal, 2015). Yet visualization features can make a roadmapping activity more engaging and visually attractive. Aimed at making the proposed design roadmapping activities more engaging and interactive, I built tangible design roadmapping tools made of flexible wood materials with laser cutters in the invention lab at UC Berkeley (CITRIS Invention Lab, 2016). Each step of the design roadmapping processes developed in Table 6 was duplicated into the tangible design roadmapping tools. Parallel online design roadmapping tools (Design Roadmap Online Template, 2015) were also developed to compare participant's learning progress under different conditions: tangible tools (Figure 28) vs. digital tools (Figure 29).

Figure 28. Example design roadmapping workshop materials: Tangible roadmap template

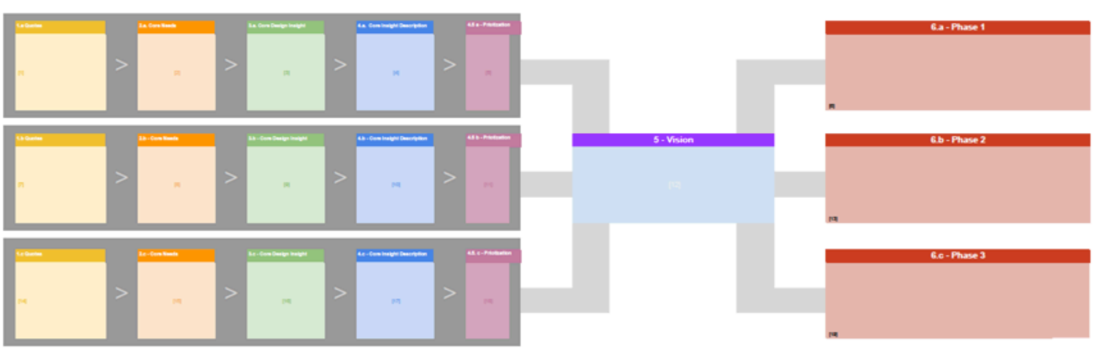


Figure 29. Example design roadmapping workshop materials: digital online roadmap template. See the full-size online tool (Design Roadmap Online Template, 2015)

8.4 In-Depth Pilot Research

8.4.1 Research design

Before conducting the pedagogic case study on a large scale, I conducted pilot research by applying the preliminary design roadmapping framework to a test-bed with similar academic background, a small team of students from ME110 in Spring 2015. ME110 is a new product development class for senior-year undergraduate students from various disciplines at UC Berkeley, such as engineering, business, or design. In a multidisciplinary team environment, students learn how to develop a new product or service through comprehensive human-centered design processes. The team projects are geared towards developing students' design abilities with an emphasis on hands-on creative components, teamwork, and effective communication. During the course of instruction, students are asked to realize their team project concept into prototypes, developed from the iterative human-centered design process. The students also exercise tools and methods of professional practice such as optimal design, solid modeling, life cycle assessment, and market analysis for their projects.

A group of five students was invited to the pilot research as a part of an optional workshop in the ME110 class of Spring 2015. This volunteer team was selected because they had requested further advice on their project. Although the class covered a curriculum based on human-centered design approaches to design (including design research, user needs extraction, concept generation and development), this team was struggling with extracting findings and connecting them into engineering feature sets. Through conversation with the team members, I found that the team had been focusing on technical/engineering components, while not developing an understanding of user experiences associated with their design challenge. From my personal experience mentoring over a dozen student teams at UC Berkeley over the last several years, I knew this kind of symptom was not uncommon in multi-disciplinary product development teams. This motivated me to apply the design roadmapping methods I had developed for industry into NPD education.

To my knowledge, this research is the first attempt to incorporate design roadmapping elements into a new product development class curriculum.

8.4.2 Implementation and discussion

I designed the pilot workshop to provide guidance and in-depth mentoring to an undergraduate NPD team (working on Internet of Things opportunities in the kitchen) in ME110 in Spring 2015. The workshop provided a comprehensive introduction to the roadmapping process and supported activities associated with design roadmap building; mapping the design elements to the technology lists was a crucial part of the activities. Their project vision evolved with several iteration of brainstorming and team discussion throughout the design roadmapping workshop. The final vision developed by this student team was:

> "Creating a new experience that enables new cooks to integrate social media and their existing entertainment features into a educational cooking experience."

Keeping this vision as an overarching theme for their concept development, five representative quotes from users, five core needs, design principles, and descriptions were defined (See Table 19). These progressive steps of the design roadmapping processes allowed the participants to connect the outcomes of their design research into their own language in order to describe the core design element that the team considered the most important.

During the pilot test, I observed that student teams were struggling with filling out some phases of the proposed design roadmapping process (see Table 19). For instance, while the connection between quotes and core needs was made smoothly, creating design principles and defining them in the team's own language was problematic.

Table 19. Example Design Roadmap (Part 1/2) - Quotes, core needs, design principles, and description

	Quotes	Core needs	Design principles	Description
1	You know what, it's always fun to watch a movie or listen to music while you cook. Hands are always dirty so you can't touch anything, can't change anything, or go online, and it's a pain.	Hands free control of device	Entertainment in chore	Cooking itself is not fun. Users play their own entertainment (music, video) to make the experience better
2	While cooking, sound level changes... It's a problem when watching a movie, so I just stop paying attention to the movie since I can't hear it.	Control of environment	Alienation	Most college students are not familiar with cooking. People do not cook often thus not confident in cooking
3	"I consider myself a hobbyist in cooking, above average, but I still [mess] up a lot. That makes me want to cook to improve."	Learning to cook better	Discourageme nt	College students are discouraged to cook because they cannot cook well. Cooking is therefore waste of money and time
4	I like cooking with people because it's fun and she can talk while cooking, so it's social.	Sharing experience	Sharing	College students enjoy activities that they can share with others. Cooking becomes more enjoyable when they posting pictures online, cook with others
5	I'll start off looking up a recipe...but then I'll just go off and do my own thing.	Become creative in cooking	Creativity/Ada ptability	People have different favorite tastes, some like sweeter, saltier etc. They want to adjust taste. Standard recipes do not allow space for creativity. Creativity requires familiarity with cooking first

It was clear that these parts were not fully developed based on what they had filled in for the previous steps. There was a disconnect between the quotes and their descriptions (see top three quotes and their descriptions in Table 19. For instance, the team came up with a design principle 'discouragement' from an extracted quote "I consider myself a hobbyist in cooking, above average, but I still [mess] up a lot. That makes me want to cook to improve" that was interpreted to the user needs as "learning to cook better." These two elements did not seem to exactly correspond to each other. This abrupt or incomplete transition hadn't been evidenced in the two industry action research examples in Chapter 6. This guided me to spend more time on providing a clearer description and illustrative examples in subsequent design roadmapping workshops with a larger group of students.

Building on their design research to date in the class, three phases of the design roadmaps (near-, mid-, and long term) were created by the students, and associated experiences and sub-experiences defined. The team then defined associated technologies, sub-technologies, descriptions, and key functions as an attempt to coherently map them into design elements in Table 20. The results show that the level of experiences defined in phase 1 gradually advances through the subsequent phases. In phase 1, for instance, the team aimed to make the cooking experience "fun" and "not feel cooking as chore." More adequate and advanced experiences of encouraging cooking are described in the phase 2. Finally, phase 3 describes the highest level of experience that the team fundamentally aspired to: increased creativity in cooking and sharing the experience with others in a community. I observed a logical connection between the list of design elements (experience elements in this pilot) and a list of technologies and associated key functionalities.

Table 20. Example Design Roadmap (Part 2/2) - Three phases of design roadmaps, experience, sub-experience, technology, sub-technologies, and key functions

Description of Experience	Sub-Experience	Technology/ form factor	Sub-technology	Description	Key function
Phase 1 Makes the cooking experience more fun so that people do not feel cooking is chore but something more entertainable	Enjoy music while cooking	Hardware/ Network communication	Physical buttons and Bluetooth	Each sensor has physical buttons so that users can control music while cooking.	Switch to next songs by pressing buttons on the side of the sensors, and control volume by buttons on the top and bottom of the sensors.
	Follow instructions easily, step by step. Not confused about which step user is on	Software (mobile app) and Hardware	Bluetooth and Internet	Sensors and smartphone communicate via Bluetooth. Smartphone gathers recipe information via internet.	User can flip the recipe by pressing the button.

Phase 2 User become adequate at cooking by using our product and feels encouraged to cook more	Step-by-step instruction naturally incorporated in the activity so that users do not have to keep going back to device to check recipe	Software (mobile app)	Audio control	Audio navigation and control. Accurate hearing of user's voice for instruction.	Users do not need to rely on visual information (words on recipe).
	Accurate description of each step, warns user to prevent any mistake from happening (too much of an ingredients etc.)	Hardware/ Software/ Network communication	-Internet and Bluetooth -Non-Contact infrared IR Temperature sensor for heat sensor	Improvements on the phase 1 sensors (smaller and improved accuracy) and software database. Better use of input information for instructions.	Updates database and sensor data collection. Better instruction by acquiring data from many users.
	Do not fail at heating food/no burnt or uncooked food	Hardware/ Thermal resistive casing	Food Temperature Sensor Probe	Sensors are used as inputs from the various cooking applied. Requires users to insert probe into the food to measure accurate temperature.	Reminds users to check the pan when the food reaches critical temperature to prevent burn.
	No water overflowing	Hardware	The Ultrasonic Level Transmitter	Measures how close water is from the rim of the pot.	Reminds user to check the pot or sink when water overflows.
	Measures weight of ingredients conveniently. No need for putting ingredients into separate dishes to measure	Hardware	Weight sensor + sensor pad	Attach sensor pad on the cutting board so that users can put ingredients on it to measure the amount needed. No need to putting food in separate dish to measure.	Users can measure weight of ingredients just on the cutting board.
	Not to forget about stirring food	Hardware	Accelerometer	Ensure that user mixes food well enough. Prevent food unattended.	Reminds users to check the food if user forgets to stir well enough.
	Sharing users' result (cooking experience and food) with others	Network communication	Internet	Post recipe and pictures on internet so that other users are encouraged to cook. Share tips among the community.	Able to share links to recipes and pictures on social networks such as Facebook and Instagram. Post tips and improvements on the recipe to refine the database.
Phase 3 Users become adapt at cooking and feel	No need for checking device (phone, tablet) for cooking	App/ Hardware	Projector projects screen on table and wall that	Users can check necessary information anywhere anytime in the kitchen.	Projecting screen onto surfaces that are convenient for users to see. Audio support where appropriate.

comfortable in the kitchen so that they become creative at cooking, such adjusting recipes, creating new recipes, and trying new tastes.			moves and follows wherever users go		
	Kitchen becomes aware of what user is doing and supporting his/her activity Any necessary information will be provided on demand (amount of ingredients, weight, etc.)	Sensors/ Network communicati on/ Machine learning	Audio control/inst ructions.	Kitchen is aware of user's cooking situation and offers appropriate information. i.e. Google Now.	Users do not need to press buttons to tell the device to indicate their cooking state. With improved AI & machine learning, device can determine the user's actions and intentions to offer appropriate support.
	Community that supports and encourages users to explore and try new tastes	Network communicati on	Internet	Strong community network, improve coking experiences by sharing ideas.	Users can easily edit their recipes to share online.

8.5 Teaching Design Roadmapping in NPD Curricula

8.5.1 Research design

After the in-depth pilot research was completed, I applied the design roadmapping process in the same undergraduate NPD class in Summer 2015. In this workshop, nine groups, consisting of three to six students each, were asked to perform unique team projects developing new products or services such as sanitizing door knobs, a cooking knife storage system, science education for kids, etc. I consulted with the course instructor regarding when we could fit the design roadmapping workshop into the new product development process. The instructor and I agreed to insert the design roadmapping workshop when the first cycle of the HCD process (design research, concept generation, concept selection, prototyping and testing) was completed (See Figure 30). At this point, the student teams were able to bring in their own data for the workshop and had already learned the necessary concepts of product development processes—observation, framework, imperatives, and solutions (Beckman & Barry, 2007).

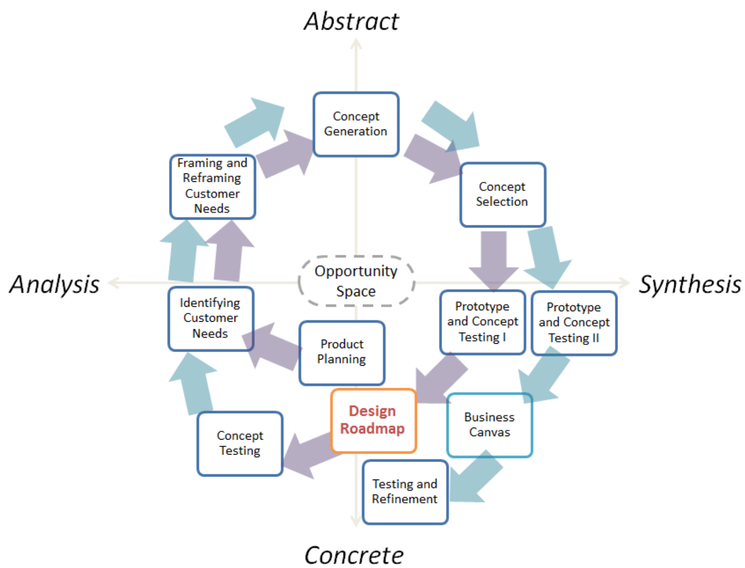


Figure 30. Human-centered design process with design roadmapping

8.5.2 Implementation and discussion

The five steps of the design roadmapping process as summarized in Table 6 were applied to the nine team projects in this experiment. Teams 1-5 received only online tools and teams 6-9 only the tangible tools. Both groups received the same direction, guidelines, and content, aside from the differences in the media type. As this was the first time the students in this course had ever attempted design roadmapping, the background and concepts of design roadmapping processes were introduced to the entire class, followed by in-class design roadmap workshops. Two assistants and the course instructor who were knowledgeable on design roadmapping participated in the workshop to provide appropriate support if needed. The workshop followed the five steps [7] of the design roadmapping process defined in Table 6. The course curriculum already covered a user research session, so student teams were asked to bring key quotes from their interviews and observations, and their interpretations of user needs from the previous session's learning. The steps and processes of the design roadmapping were part of the intervention, while the project topics had already been decided through previous course sessions. The workshop sessions included a one-hour lecture to introduce overall design roadmapping concepts and best-practices examples from my pilot research and industry case studies followed by two hours in class team activities. Figure 31 shows example photos taken during the workshop sessions.

7 While five steps of the design roadmapping workshop were covered in the workshop, data analysis in my dissertation focuses on the three phases of the design roadmap that the teams developed.

Figure 31. Photos from design roadmapping workshops in ME110 Summer 2015

The student teams' final deliverables were collected in in either physical format (from teams who worked with tangible design roadmapping tools) or digital format (from those who worked in digital design roadmapping tools). The original deliverables were digitalized for further investigation. During the design roadmapping workshops, students were asked to capture each step of their work and submit their documentation to instructors at the end of the workshop.

8.5.2.1 Three phases of the design roadmaps defined

Table 21 below shows three phases of the design roadmaps defined by each group of students.

Table 21. Three phases of design roadmaps from nine student teams

	Phase 1	Phase 2	Phase 3
Group 1 (Digital tool)	Create a working prototype to show the viability of a door-mounted UV Sanitation device.	Make the device retrofittable to different types of door knobs.	Develop a newer version of the product, which is smaller, cheaper, and uses less energy, while continuing to provide convenient and effective sanitization. Make it more compact. Make it a smart/programmable and secure lock.
Group 2 (Digital tool)	The device will be capable of disinfecting, and will be in as compact a form factor as is feasible while still allowing it to disinfect objects up to the size of a phone.	The device is available at an affordable price point, and will have a refined look, making it more attractive to the customer. It will feature revised internals to be more space efficient.	The device will be further refined to increase its desirability by making it more physically attractive, as well as by providing more variants to increase user choice. It may be adapted to purposes other than just small.
Group 3 (Digital tool)	A fully functional unit for most knives in the market: Making sure our product is compatible with the 3 general shapes of knives in the current market. Meanwhile, the product should stabilize and protect the knives.	A unit that can work well with most top kitchen drawers: Our product is able to work well with most kitchen drawers without causing damage.	Better Cooking Experience: With our product, more people would consider cooking an enjoyable experience. Thus more people would be willing to cook at home.
Group 4 (Digital tool)	Have a functional model that we can give to a student such that they can actually understand some new physics concept. The most fundamental basics of our prototype will be used to satisfy user needs and meet our vision statement (relatability, simplicity, interactivity).	The prototype will be further refined. A cleaner, more streamlined interface will further engage users. Hopefully we can implement a more innovative and intuitive UI design as well. More experiments will be added to further increase the size of the library. Possibly implement user-generated content with user moderation as well to allow user base and library to increase with one another.	Want to work to make a physical tool that will help implement our vision, although it may result in a slightly more expensive model.
Group 5 (Digital tool)	Improved housing search Through preference filtering, advanced search capabilities, dynamic map and a proprietary matching algorithm.	Students are able to find and rent housing on our service Through secured payment gateways, verified users and verified listings.	To be the one-stop solution for everything related to housing, through seamless P2P transactions and interactions and scheduled payments.
Group 6 (Tangible set)	Functional prototype ready for longitudinal case study (2-4 month) decomposing design insight.	Marketing: Polished product including and FDA approval and journal paper.	Widespread, feedback driven iteration for MK 2. Expand target market and functionality.

Group 7 (Tangible set)	Make a fully functioning prototype that works as it should, but may not be easily manufacturable or made of the final material.	Develop a way to manufacture on a large scale, having settled on a material to use for the device.	Make a secondary version that gives a choice between accessorizing and portability.
Group 8 (Tangible set)	Have a completed workstation that has proper storage, great surface space useful utilities and can be showcased.	Gain feedback from many test trials and change the product according to feedback.	Analyze successes and pitfalls from first generation. Emphasize successful features and fix pitfalls.
Group 9 (Tangible set)	A basic, functional table that students will make a point to use on a regular basis.	More than just a desk. Physical attachments improve the work experience.	The desk is used by not just students, but everyone uses the desk in their daily lives as it is integrated into their work and personal lives.

8.5.2.2 Patterns of phase development

I evaluated these deliverables to discover common patterns of phase deployment. During the workshop, I purposely allowed participants to use their own language to describe their three phases—be it language regarding features, product, service, or experience. One interesting pattern over the three phases can be seen in Figure 32, which looks at how many projects are feature-focused versus experience-focused in each phase.

Interestingly, in the first phase of their design roadmaps, all teams described their concepts in a physical feature–based form (100%, nine out of nine teams), none in an intangible form. In phase 2, a few teams described their evolved concepts in non-physical ways; three out of nine teams (33%) described their concepts in intangible formats such as experience, service, user, or market contexts. Finally, an increased percentage of teams used intangible formats in the third phase—four out of nine teams (55%).

While no statistical analysis is possible due to the small sample size, the increasing percentage of intangible form being used provides evidence that this is an appropriate area for further research. This looks promising because it displays a possible pedagogical approach for training students to think more about exploring the intangible elements/experiences associated new product development.

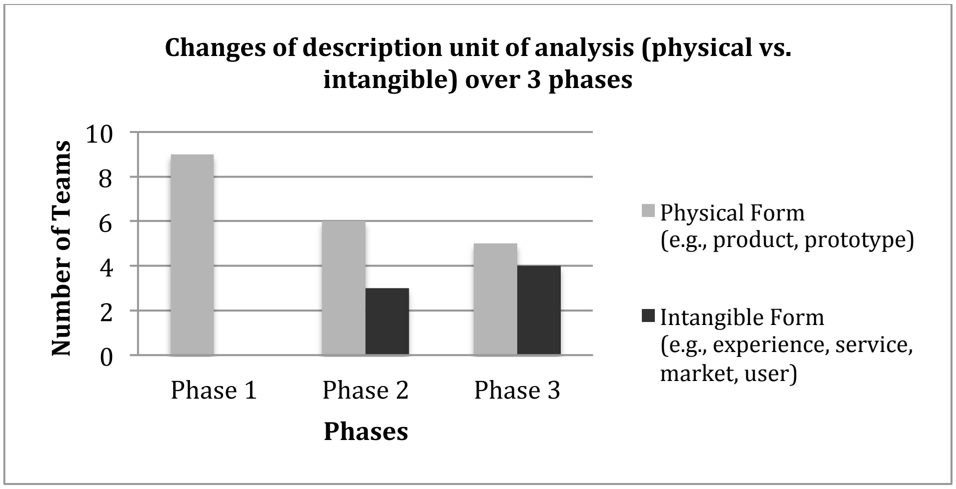


Figure 32. Changes of description units of analysis (physical vs. intangible) over 3 phases

8.5.3 Observations comparison between tangible tools and digital online tools

During the workshop, I observed more active physical engagement from the teams who were assigned tangible tools in comparison to the teams using online tools. The tangible design roadmap tools seemed to encourage more face-to-face communication and active team collaboration (moving pieces around, writing sticky notes, etc.). In contrast, the teams using digital tools were less interactive in person, but heavily relied on the computer for communication. For example, I observed one team with six members who didn't talk each other during the workshop, but just stared at their own laptops. It turned out that all team members were on the online chat messenger and were communicating about their project and the workshop through electronic media.

Digital online tools, however, allowed the student teams to have access to their design roadmaps at all times. As a consequence, I observed better "documentation" of outcomes from the workshops thanks to the increased accessibility to the datasets and prompt revisions regardless of their physical attendance or what digital devices (e.g., laptops or mobile devices) they might be using.

In addition, the teams with online digital tools showed richer descriptions of content in the online templates than those using the tangible tools. To analyze the richness of deliverables from the teams, we calculated the number of words in each cell (phase 1, phase 2, or phase 3). A t-test was conducted to compare the difference between the two groups (those using online tools and the other group with physical tools). Student teams using online tools filled each phase of their design roadmaps with an average 28.6 words. In contrast, the student teams with tangible tools filled each phase with an average of 15.3

words. The difference is statistically significant at the 5% significance level ($\alpha=0.05$, p-value=0.0013: the number of words in each phase was calculated independently). The difference might be attributed to the easier accessibility to the online tools during/after the workshop, allowing more refinement of the workshop work.

8.6 Lessons Learned

8.6.1 Streamlined design process from need finding to gradual concept development

Connecting user needs to a product's specifications is crucial for making a market success (Beckman & Barry, 2007; Brown T. , 2008; Ulrich & Eppinger, 2003). Student participants in the workshops report that the design roadmapping process facilitates a streamlined connection between revealed customer needs—via several touch-points on the way though—to the product specifications.

> "A benefit of this is mapping out these customer needs all the way to the end product, and how it's related to current products on the market." (S-10)

> "This workshop did a good job of making us analyze what our target customers were saying and to come up with product attributes based on what quotes we gathered. In addition, it got the group to think about how we could advance our prototype into a final product, and how we can further upgrade the product." (S-18)

> "I learned how to narrow down interview quotes and turn them into a vision statement." (S-22)

> "Through 'Design Roadmapping', our group could get some valuable insights from potential users/customers opinions, and finally integrating an overall vision." (S-7)

The feedback also indicates that making a concrete bond across design elements would help student teams to better understand how these are related and how they can be developed together along with the same objective.

> "I learned how complex the interconnections between aspects of our product are; there are plenty of features and ideas that we had that we could now visualize their connections much better." [S-2]

In a similar context, a considerable number of participants' shared their thoughts on how it was for them: data organization, refining a team mission, and grouping ideas etc. Overall, the design roadmapping process leveraged team alignment and mission/vision refinement.

> "[Design roadmap] It was a useful tool to consolidate all our ideas properly and group them up together based on their aim and how they link back to our mission statement." (S-8)

> "I learned that it makes the process a lot easier when things are organized to be placed into groups and everything is color coordinated." (S-20)

8.6.2 Project planning

Similar to the purpose of the roadmapping implementation in industry (Cooper & Edgett, 2010; Albright & Kappel, 2003; Phaal, Farrukh, & Probert, 2004), workshop participants described the workshop as useful for preparing future plans beyond the development of a single product. Answers from participants motivated me to consider ideal points where design-driven roadmapping would fit in the new product development process. The quotes below capture the general consensus on its purpose.

> "The design roadmap made a clear general plan without dates. I learned about how to form a vision statement and come up with future phase plans." (S-13)

> "This workshop did a good job of making us analyze what our target customers were saying and to come up with product attributes based on what quotes we gathered. In addition, it got the group to think about how we could advance our prototype into a final product, and how we can further upgrade the product." (S-18)

8.6.3 Struggle to anticipate new design concepts in phase 2 and 3

Many of the students struggled with putting elements into a timeline. Teams who didn't have concrete results from the user research and data-gathering stage had difficulty expanding their project vision on a time axis. Perhaps this is due to the fact that undergraduate participants live semester to semester and have relatively less knowledge, experience, and skills regarding the subject domain, which could lessen their ability to anticipate future concept developments. Consider this quote from one participant:

> "It was challenging to come up with future phase plans because I have no experience putting a product in the market. [Creating] Phase 1, 2, and 3 was hard" (S-4)

Furthermore, some teams seemed to be fixated on their initial concept or their current prototype. This tendency made it difficult for teams to think further beyond what they had on hand.

> "The challenge was to write about the next generation model or upgrade version because we were not even ready for the current prototype." (S-7)

Thinking forward to the future is not as easy as thinking backward to the past. In order to make design roadmapping more effective, it is clear that participants need further direction, and guidelines to effectively learn how to develop unexplored concepts gradually over the timeline. Nonetheless, the patterns of phase development observed in the design roadmapping workshops show potential for use within new product development education by enabling a shift from product-driven to experience-driven thinking.

8.7 Post-Survey

I asked workshop participants to score their satisfaction overall and usefulness to their project on a scale of 1-5 (5 = strongly agree and 1 = strongly disagree) (see Appendix H for a full list of questions). Eight students (out of forty-three students in class) responded to the online survey. While the response rate was small, their responses were valuable for us as a form of feedback. The participants who responded rated the workshop as satisfactory and useful in overall with an average score of 4.1/5 (see Figure 33). Thirty-seven percent of respondents strongly agreed that the workshop was useful (5 out of 5). Fifty percent of respondents somewhat agree that the workshop was useful (4 out of 5).

The one participant who answered 'somewhat disagree' recommended that the workshop should had been offered earlier in the course curriculum. He/she complained that the concept of their project team had already been set by the time the design roadmap workshop was held and wished the workshop had been held earlier (e.g., in planning and ideation phases) in order to have a larger impact on their project.

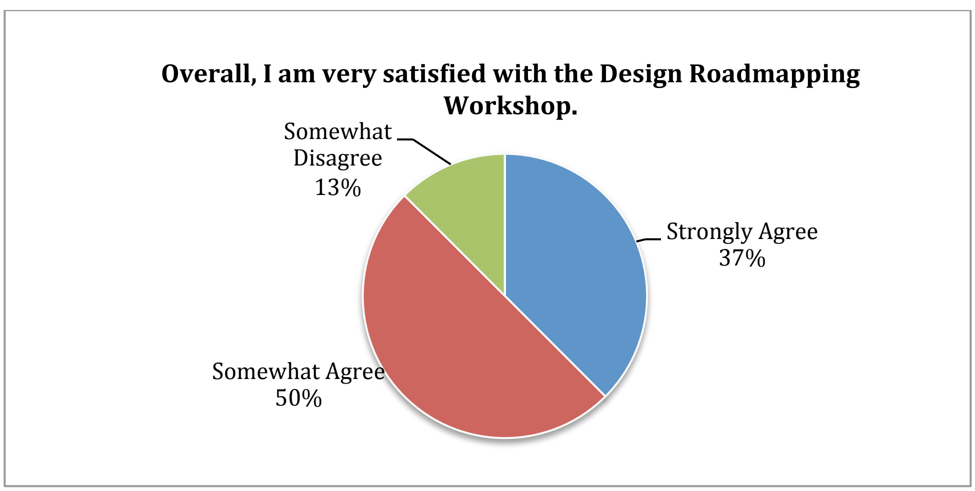


Figure 33. Satisfaction rate with the undergraduate design roadmapping workshop

We also asked which function of the NPD process most benefited from the design roadmap workshop. The results of the online survey are shown in Figure 34 disaggregated by value/usefulness of the design roadmapping process.

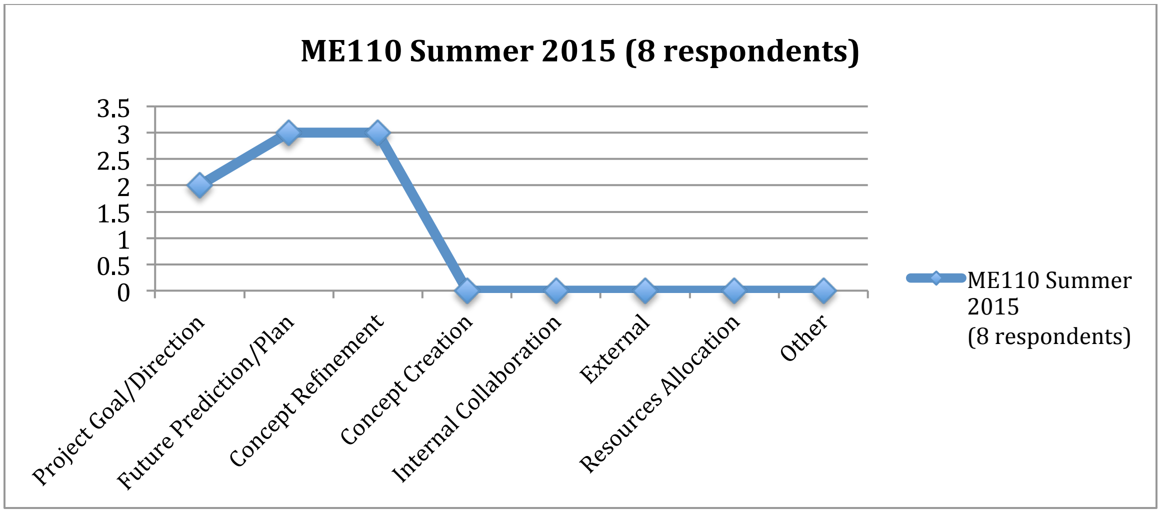


Figure 34. Online survey result for the number of responses disaggregated by the value/usefulness of the design roadmapping workshop

Of the eight survey respondents, three participants answered that they valued roadmapping as a means to predict and plan for the future. The workshop was also useful in concept refinement. Two of them noted it was helpful in setting project goals and direction. One participant, who said the workshop was useful in setting a project goal/direction, commented that the workshop was great particularly to share and organize the team's plan to develop a clearer direction in which to proceed. Some felt it was useful as they were able to refine a concept they had already come up with. However, the sample size is small and further research with a larger population is recommended.

9 CONCLUSION AND FUTURE RESEARCH

Chapter Overview

This chapter summarizes the results of the dissertation research and provides overall conclusions and recommendations to both academic scholars and industry practitioners. In this dissertation, I summarized current industry roadmapping practices, based on 46 interviews and on-site workplace observations, as well as a literature search—and identified key challenges and opportunities for roadmapping based on this research. I introduced a design roadmap framework, which was implemented in two action research studies at very different types of companies. Finally, I implemented a design roadmapping workshop in an undergraduate class in order to explore design roadmapping as a pedagogic element within a new product development curriculum. I also discussed how design roadmapping could be smoothly implemented in new product development processes in both industry and education, depending on the strategic goals for its use.

9.1 Summary and Findings

I introduced a conceptual framework for design roadmapping that aims to complement a company's existing product roadmapping and technology roadmapping processes (Chapter 5). This framework builds on the following three opportunity spaces identified in a descriptive study of forty product development professionals in different industries: 1) introduction of experience-driven roadmapping; 2) increased ownership of designers in planning and roadmapping processes; and 3) preparation for the future using an iterative roadmapping process (Chapter 4). Design roadmapping reconciles differences that arise when customer/user needs are not considered simultaneously with technology choices.

Based on these findings, I introduced a five-step design roadmapping process that explicitly connects the design research outcome to experience definition and technology prioritization (Chapter 5). In two action research examples, the entire five-step procedure implemented at two different companies to augment their existing product design and development processes. The action research examples highlighted the benefits of design roadmapping and how it helps teams to connect their design research outcomes into a list of technologies or desirable functionalities (Chapter 6). In the Asian–Silicon Valley corporation, the design roadmap addressed efforts to: 1) stimulate design-focused product development connected to a project selection process; 2) define user experience levels over time phases; and 3) weigh projects with criteria associated with design principles as opposed to technology innovation levels. As a result of the design roadmap-based decisions, the company further developed the project concept which had the highest score on design principles. The design roadmapping process led to the launch of a common household product the following year (Spring 2016) with enhanced functionality to improve family connection and engagement experiences (Brown R. , 2016). The main goal of this project—"reflecting the flowing stream of everyday life to strengthen family connections and shared identity" was a critical aspect of their design roadmap. This example illustrates the benefits for design roadmapping in strategic planning for high-tech products. In addition, design roadmapping also helped the team to proactively communicate with their internal collaborators, including top-level corporate officers.

Another benefit of the use of the design roadmap was its use as a medium to connect stakeholders. In the Sproutel example, design roadmapping helped the team to create a shared team vision and goals. By integrating individual design roadmaps, they learned how to develop a shared roadmap in a way that minimized disciplinary hierarchal silos. The facilitator's role was crucial in this particular case study. Sproutel expects more from design roadmapping when they initiate an expected partnership with outside toy manufacturers.

Finally, the design roadmap model was tested in undergraduate-level new product development courses (Chapter 8). The result from these classes highlighted how design roadmapping can leverage and enhance research by student design teams. The evaluation of these workshops suggests that they can be effective in changing the mindset of students to think beyond products attributes, going further by integrating intangible attributes such as user experience, services, and market opportunities.

Design roadmapping workshops offered in both industry and academic settings received high reviews. Workshop participants surveyed (n=59) scored their satisfaction rate overall and how useful the process was to their projects on a scale of 1-5 (5 = strongly agree and 1 = strongly disagree). The Overall satisfactions response rate was 39%, with 23 respondents out of 59 workshop participants rated giving an average score of 4.48 out of 5. Fifty-two percent of respondents strongly agreed that the workshop was useful (5 out of 5), while forty-three percent of respondents somewhat agreed that the workshop was useful (4 out of 5).

9.2 Recommendations for When to Introduce Design Roadmapping in the NPD Process

The academic workshops on design roadmapping were introduced after one cycle of the human-centered design process, i.e., after one cycle of design research, analysis of the research, concept generation, and initial prototyping. The thinking was that preliminary research available at this point could provide a solid basis for a design roadmapping exercise. It turns out that students felt that this was too late in the NPD process to be helpful, as at this point design had been fixed and strategic directions had been set.

> "I think it would have been super helpful to have this earlier in our process, maybe during concept selection, when we were trying to see where to focus." (S-2)

Figure 35 shows the results of the online survey of students (N=19) plus the four Sproutel participants disaggregated by value/usefulness of the design roadmapping process. Twelve of the 23 survey respondents reported that the most valuable contributions of design roadmapping were on developing project goals and future planning. A few thought that design roadmapping was useful for concept refinement.

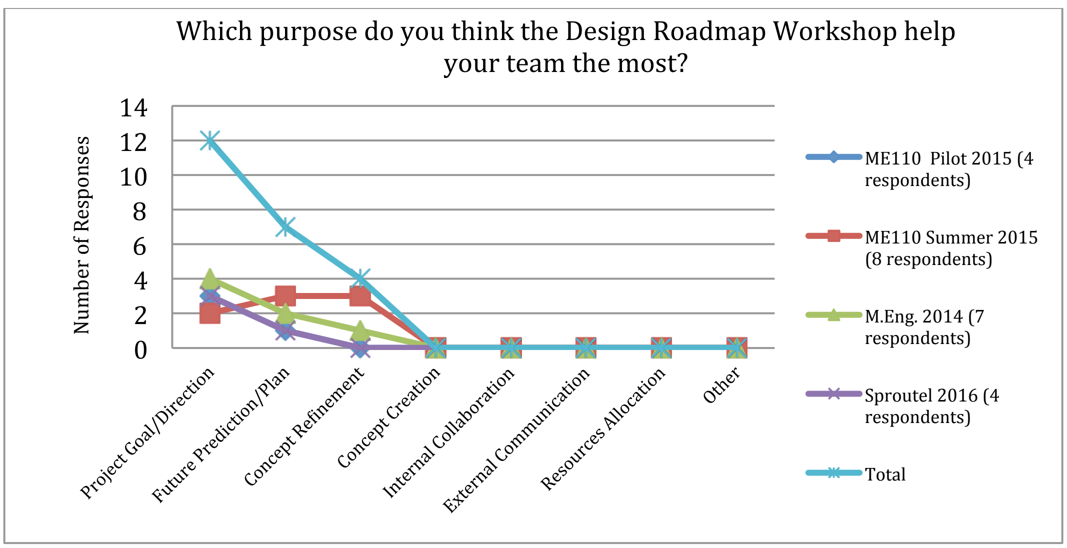


Figure 35. Online survey results for the number of responses disaggregated by the value/usefulness of the design roadmapping workshop participations

Although participants from the Asian–Silicon Valley corporation example did not take the survey (as requested by corporate management), it is clear from their interview quotes and results that the greatest impact was at the early project planning stage.

More details on where to insert design roadmapping into the NPD process are discussed below, with example quotes from participants in all research groups.

9.2.1 Design roadmapping for project goal/direction setting

Participants in the design roadmapping workshops greatly valued the role that design roadmapping played in rethinking their project goals and directions. Of the 23 survey respondents, 12 participants (52%) answered that they valued it most as a means to set project goals and direction. Many of respondents addressed internal misalignment to set a shared project goal and direction within an interdisciplinary collaboration environment. Here is an excerpted comment from a participant:

> "It works well for reaching consensus and clarifies misunderstanding of the direction of the project. It helps us get a bit of a clean slate and get a plan for the future of the product." (T-10)

Participants from the multidisciplinary student teams particularly emphasized the workshops usefulness in developing longer-term goals and directions for their projects beyond the class schedule. Two comments explain:

> "Perhaps doing the roadmap earlier in the design would help everyone understand the direction of our product -- there are many user needs competing for priority, but with the roadmap, we would all know which ones we are focusing on at which phase." (S-8)

> "It helps us shape our goal, especially our long-term goal so that our project has more significant meaning. It helped our team make alignment." (S-3)

The design roadmapping process led meaningful conversations within teams by establishing a structured procedure for figuring out a vision, goal, and direction *before* selecting product features. As one respondent mentioned:

> "It helped us A LOT in figuring out what direction our project is going in. We kept arguing over features and exactly what our product would do, and this workshop helped us focus on a vision to work around, and see our customer's pain points. Once we wrapped our heads around this, it became a lot easier to see what features we should focus on and where our concept should move in the future." (S-2)

As with the industry examples, participants in the academic workshops replied that design roadmapping was beneficial to product planning. The results reconfirmed that one of reasons for roadmapping (e.g., technology roadmaps or product roadmaps) is to strategically plan for future market conditions (ASME Manufacturing Engineering Division, 2015; Albright & Kappel, 2003; Cooper & Edgett, 2010) and to introduce products with new technologies and functions ahead of the competition (Ulrich & Eppinger, 2003; Phaal, Farrukh, & Probert, 2004).

> "I thought it was a very interesting way to visualize the project. It injects life into it and gives the team a reference frame of what the project can become. We are not looking at just one product here. There are many facets to that product and many iterations before it becomes what we intend it to be in the first place." (S-5)

> "The workshop helped our team to extract all the information little by little from the project and project that onto the future paths." (S-1)

Another participant describe design roadmapping as a tool to visualize future interactions of a product step by step over the guided timeline.

> "It works well in the ability to visualize a conceptual project in future interactions instead of one huge project with one deadline." (S-6)

9.2.2 Design roadmapping for concept refinement

A few participants identified design roadmapping as advantageous for concept refinement. An agile development model has achieved mainstream implementation, particularly in the software industry (Martin, 2003; Olsson, Bosch, & Alahyari, 2013). Agile development focuses on flexible, effective, and speedy iteration of product refinement. Highsmith and Alistair state that:

> […] Agile development is not defined by a small set of practices and techniques. Agile development defines a strategic capability, a capability to create and respond to change, a capability to balance flexibility and structure, a capability to draw creativity and innovation out of a development team, and a capability to lead organizations through turbulence and uncertainty. […] (Highsmith & Alistair, 2001)

Similarly, we found that design roadmapping allows participants to bring their findings from design research and use them to refine concepts over a timeline. Participants addressed that:

> "It was a structured way to refine a concept. I feel it would have had a larger impact on our project if it were done earlier in the session. By the time we did this we had already come up with a design." (S-19)

> "The workshop was great to share and organize our group's plan, and it showed a clear direction to proceed in. This has helped us refine about how we think about future products" (S-14)

9.3 Future Research

This dissertation highlights possible future research areas where fellow scholars and practitioners may collaborate to further develop the design roadmapping framework.

9.3.1 Expanding the design roadmapping into product, service, and system integration

PSS (Product-Service-System) is an integrated approach to consolidate product, services, and systems together (Baines, Lightfoot, & Evans, 2007). Maussang et al. note that engineers tend to focus on the physical design and user interaction rather than the services or systems level (Maussang, Zwolinski, & Brissaud, 2009). The initial goal of my dissertation research was to build a design roadmapping framework to smoothly guide new product development teams to consider not only product features but also intangible attributes such as experience, user needs, or services. Workshop results show a positive pattern in that participants progressively expanded the scope of their concept over future stages by factoring in intangible attributes. In a next step, research to see how design roadmapping can leverage a PSS framework would be valuable.

9.3.2 Developing deviated roadmapping frameworks and mapping with traditional roadmaps

Design roadmaps require extracting human values, meanings, and key insights acquired from human-centered design research. These findings should be converted to core criteria and attributes for design road mapping through internal synthesis efforts. The overarching philosophy in the design roadmapping process is to subordinate technology roadmapping to those elements that would support the experience-driven goals of design roadmapping. However, it would be useful to develop practical techniques for explicitly integrating traditional product and technology roadmapping into the design-driven roadmapping process.

9.3.3 Making design roadmapping agile

Recent new product development processes have adapted more agile approaches for prompt reaction to fast-changing market conditions (Martin, 2003; Olsson, Bosch, & Alahyari, 2013). Although iterative new product processes have become more prevalent in new product development, roadmapping processes have not yet become as flexible as the agile product development process. In traditional approaches, roadmapping is part of product planning and strategic planning (Cooper & Edgett, 2010; Ulrich & Eppinger, 2003) using a linear predication approach driven by technology and/or product projections with little knowledge of customer research trends.

By formalizing the design roadmapping framework outlined in this dissertation into a more streamlined process, practitioners in various positions—from designers, design researchers, and engineering designers to engineers and product managers—could benefit from design-driven roadmapping. In the future, I aim to further formalize the design roadmapping process outlined in this dissertation with agile design principles that allow more room for flexibility and responsiveness at each stage.

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Appendix

Appendix A

INTERVIEW GUIDES FOR PRODUCT MANAGERS FOR STUDY OF "FRAMING IN DESIGN AND INNOVATION"

This study involves short interviews conducted by 1-2 researchers with Product Management professionals from a range of industries. The interviews will be conducted with participants in the "Product Management" Program hosted by the "Center for UC Berkeley Executive Education" from Feb. 3-7, 2014 and Mar. 17-21. 2014. One or two researchers will be attend each of the week-long programs and do the interviews during breaks between sessions.* For details about the event, please visit: http://executive.berkeley.edu/programs/product-management. It is expected that the interviews will follow more or less the themes outlined below but allow room for exploration of additional topics that seem relevant to both the interviewee and the interviewer. The guide is not intended to provide a comprehensive list of questions; instead, it highlights the main themes and key questions of this portion of the study.

Main questions will revolve around the following topics:

1. Background:
   a. Which company are you from?
   b. What is your responsibility in your company?
2. Does your company create and/or use roadmaps?
3. What kinds of roadmaps does your company have?
   a. Product Roadmap
   b. Technology Roadmap
   c. Design Roadmap
   d. Other
4. What purpose(s) do your roadmaps serve?
5. How frequently does your firm update these roadmaps?
6. Who owns the roadmaps?
   a. Product Roadmap -
   b. Technology Roadmap -
   c. Design Roadmap -
   d. Other -
7. Please describe the process used to create, update and review the roadmaps.
8. e.g. When (how often) do they have meetings?, Where do they have meetings (online/offline)?
9. How are conflicts among the parties resolved in the process?
10. Who are the most influential person(s) to decide roadmaps?
    a. PM, Engineers, Designers, Marketers, Sales, or else
11. What works well about the current process?
12. What doesn't work well about the current process?
13. What design features would your company like to bring into your product roadmap?

* **Additional Questions**

1. How does your firm gather users' needs?
2. Are you interested in how user needs are taken into account in the process?

Appendix B

INTERVIEW GUIDES FOR STUDY OF "FRAMING IN DESIGN AND INNOVATION"

This study involves short interviews conducted by 1 researcher with professionals in (Asian-Silicon Valley Corporation). We will perform interviews with professionals with experience in new product development at the firm both locally, for in-person interviews, and internationally, for interviews by Skype or phone. Euiyoung Kim will be working full-time in here over this summer to conduct the interviews during June to December, 2015.

It is expected that the interviews will follow more or less the themes outlined below but allow room for exploration of additional topics that seem relevant to both the interviewee and the interviewer. The guide is not intended to provide a comprehensive list of questions; instead, it highlights the main themes and key questions of this portion of the study.

Main questions will revolve around the following topics:

1. Background:
    a. Which group are you from?
    b. What is your responsibility in your group?
2. Does your group create and/or use roadmaps?
3. What kinds of roadmaps does your company have?
    a. Product Roadmap
    b. Technology Roadmap
    c. Design Roadmap
    d. Other
4. What purpose(s) do your roadmaps serve?
5. How frequently does your firm update these roadmaps?
6. Who owns the roadmaps?
    a. Product Roadmap -
    b. Technology Roadmap -
    c. Design Roadmap -
    d. Other -
7. Please describe the process used to create, update and review the roadmaps.
   e.g. When (how often) do they have meetings?, Where do they have meetings (online/offline)?
8. How are conflicts among the parties resolved in the process?
9. Who are the most influential person(s) to decide roadmaps?
    a. PM, Engineers, Designers, Marketers, Sales, or else
10. What works well about the current process?
11. What doesn't work well about the current process?
12. What design features would your company like to bring into your product roadmap?

* **Additional Questions**

13. How does your firm gather users' needs?
14. Are you interested in how user needs are taken into account in the process?

15. What kinds of information do inter-disciplinary teams share in their formal and informal interactions or communications with their collaborators?
16. What mechanisms do they use to share information, assumption, and deliverables? (e.g., email, instant messaging, face-to-face communication, tele-conference, skype) and in what form do they use to share this information? (e.g., text, images, ppt, prototype, videos, a like)
17. How are individual roles assigned in a disciplinary team? How diverse are the roles assigned?
18. How do HCI practitioners and designers choose to include in formal communications? How do they convey information about users? How do forms of communication influence the new product design and team outcomes?
19. What personal and shared tools could support design teams in maximizing contributions for each team role to achieve successful design?
20. How do designers understand users' frames and apply that to affect new product design and team outcome?
21. What user research methods provide the best insights for designers to build solid frameworks?
22. What user research methods are best for implicit or explicit understanding of a users' frame?
23. How do designers decide which user research methods are appropriate for a given design problem or domain?

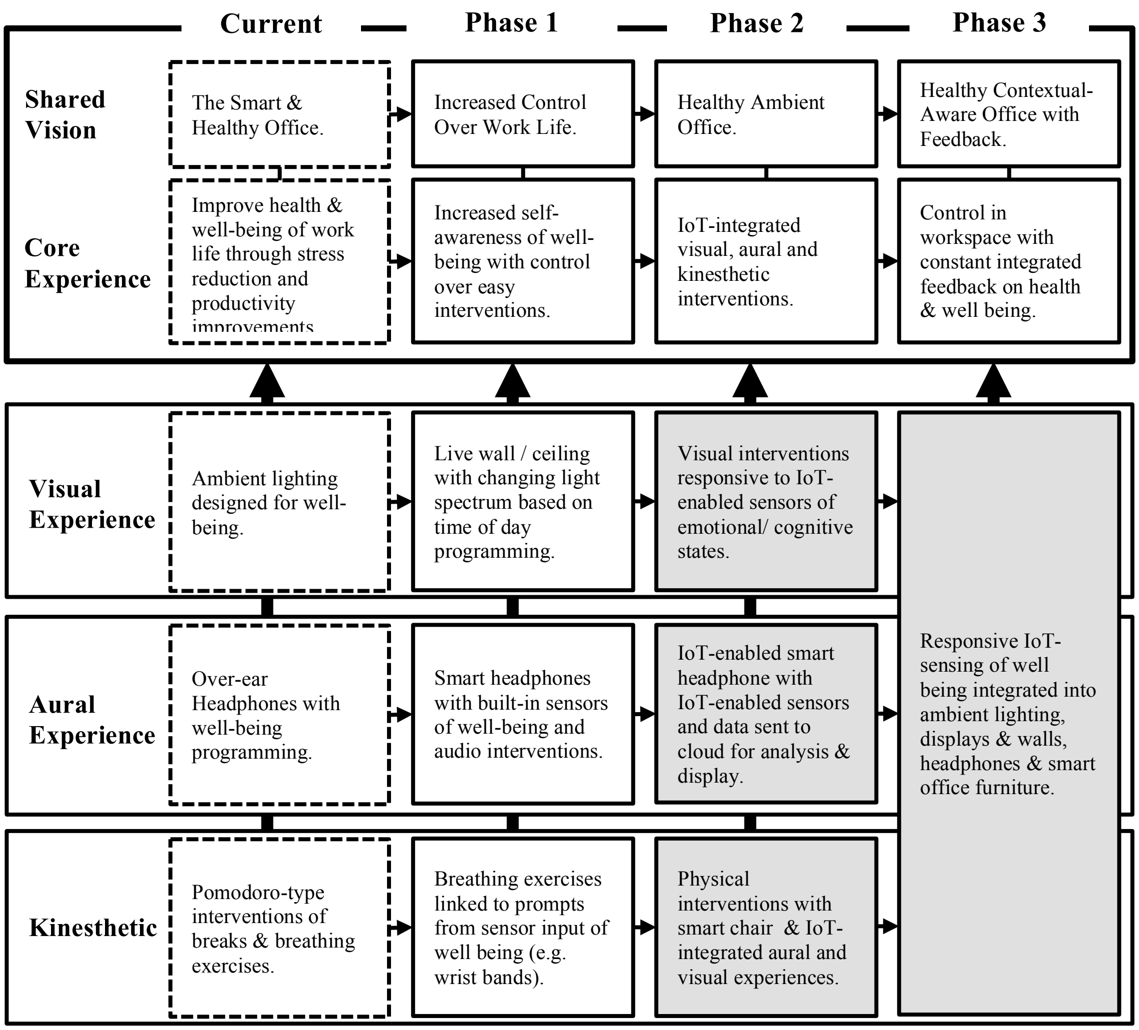
Appendix C

Pilot-Test—Five-design principles, user needs, and key quotes captured by the capstone design team

Design Principles	Description	User needs	Key quote
1. Non-intrusive	A device that is invasive is an alarm from a clock radio, where it forces you to react. A non-intrusive device does not force you to do anything; it empowers you to do something on your own terms.	Time needs not be a stress inducer.	*"It's ok if I'm late. Everything I do I do it where the optimizing factor is time"*
2. Acknowledgement	Allow the user to acknowledge a smart goal without making it a stressful endeavor, these goals can be spread over the focus and distraction settings of a cycle.	Users need to have a sense of control in order to feel that they are doing something productive.	*"Focus to her is something that is associated with stress and work, she has no word or term for focusing on something she enjoys (like pottery)"*
3. Invisible interaction	A thing that doesn't need to be in line-of-sight or need manual interaction with users.	Users need to limit the amount of distractions around them.	
4. Natural/ inherent	The interaction between device and user must feel natural, organic, not forced and interruptive.	Users need to use the device in a way that does not negatively disrupt their flow or routine.	*"I tend to not use technology when I workout because it doesn't feel natural. I have to input information and then it spits out numbers at the end of the day, not what I associate with working out like feeling good and that sort of stuff"*
5. Empowered recognition	The recommendation given by device should allow user to do something with the data acquired. Rather than telling them what to do, it gives options that allow the user to make their own choice.	Users need to feel in control of their own actions and not feel like they are being told what to do, even if it is for their betterment.	*"I tend to not use technology when I workout because it doesn't feel natural. I have to input information and then it spits out numbers at the end of the day, not what I associate with working out like feeling good and that sort of stuff"*

Appendix D

Pilot-Test—A simplified schematic example of an integrated design roadmap (Capstone design team)



Appendix E

MAP PROJECT TO DESIGN PRINCIPLES & USER EXPERIENCE (UX) THEMES

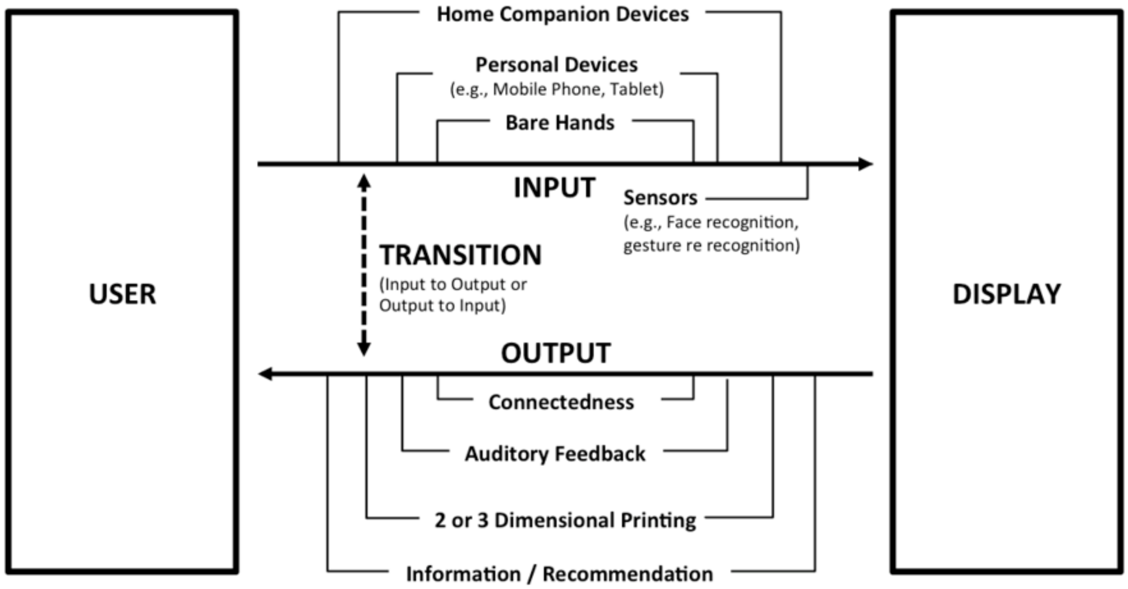
Source	#	User Experience Theme	Design Principles Criteria	Project-P	Project-W	Project M
Expert Interview (2014)	1	Analog-Digital Open Flow	Co-Existence/Mixture/Transition (Input & Output, Analog & Digital, Inside & Outside, Internal & External)	4	5	2
	2	Hybridization	Co-Existence/Mixture/Transition (Input & Output, Analog & Digital, Inside & Outside, Internal & External)	4	5	3
	3	Authenticity	Authenticity (Genuineness)	3	5	3
	4	Humanization	Authenticity	5	3	2
	5	Simplicity	Minimal Interaction	5	5	3
	6	Ambient Atmosphere	Minimal Interaction	5	4	3
	7	Me-Powered	Empowered data	5	3	2
	8	Meaningful Data	Empowered data	5	2	3
	9	Tactile Interaction	Physical Representation	4	5	2
	10	Tweak Reality	Technology Empowered Experience	2	1	1
	11	Neo-cyberpunk	Technology Empowered Experience	3	4	3
UX Report (2014)	1	Mobile Device Diversity and management	Mobile Experience	5	3	2
	2	Mobile Apps and Applications	Mobile Experience	2	3	2
	3	IoT	Mobile Experience	4	3	2
	4	Hybrid Cloud and IT as service broker	Co-Existence/Mixture/Transition (Personal cloud & Public cloud)	4	2	3
	5	Cloud/Client architecture	Data Storage	4	3	3
	6	The era of personal cloud	Technology empowered experience	4	3	1
	7	S/W-defined anything	S/W based Device Control	3	4	2
	8	Web-scale IT	Data Storage	4	2	1

	9	Smart Machines	Technology Empowered Experience	5	5	2
	10	3D Printing	Co-Existence/Mixture/Transition (Input & Output, Analog & Digital)	4	1	0
User Research (2014)	1	Morning Rituals	Anticipatory Computing	5	3	1
	2	Smart Watches/Wearable Devices	Technology Empowered Experience	3	1	0
	3	Anticipatory Decision/Automation	Empowered Data	5	3	0
	4	Sensors Everywhere Could Mean Privacy Nowhere	Privacy/Security	2	4	0
	5	Anticipatory Sensor-Embedded Technologies	Empowered Data	5	4	0
	6	-	Communication Network	5	4	2
Intel Trend Report (2014)	1	Shared Awareness	Empowered Data/Authenticity	5	4	2
	2	Programmable Lifestyle	S/W based Device Control	4	3	2
	3	Open Sources Access	Empowered Data	4	3	1
	4	Behavioral Nudge	Empowered Data	3	5	0
	5	Emotional Response	Physical Representation/Authenticity	3	5	1
	6	Contextual Experience	Anticipatory Computing	5	5	1
	7	Adaptive Machines	Empowered Data (Connected)	5	4	1
	8	Distributed Intelligence	Empowered Data (Connected)	5	5	2
	9	Environmental Whisper	Empowered Data (Connected)	4	4	1
	10	Anticipated (Orchestrated) Action	Anticipatory Computing	4	5	1
Parenting in the Age of Digital Technology (2013)	1	TV as educational tool	Authenticity/Physical Representation	5	2	4
	2	TV as educational tool / positive effect	Technology Empowered Experience	4	2	5

	on Children's reading				
3	Co-viewing on TV more, mobile less	Communication Network, Parental CO-Engagement (Family Activity)	5	2	5
4	Low-income/less highly educated parents are more media centric	Technology Empowered Experience	5	2	3
5	Opportunities on other parental concerns	Empowered Data	5	2	3
6	TV as a center of media environment	Communication Network	5	4	3
7	Activity Recognition	Technology Empowered Experience	5	5	3
8	Parents' sources of advice about media content	Communication Network	5	5	3
Total			**190**	**157**	**90**

Appendix F

ILLUSTRATION OF INTELLIGENT DISPLAY ECO-SYSTEM: A CONNECTION BETWEEN USERS AND ARTIFACTS BY TECHNOLOGY CATEGORIZATION



Appendix G

EXAMPLE DESIGN ROADMAP WORKSHOP SCHEDULE: Sproutel

Days	Time	Agenda	-
Day 1	Morning Session (9:30am-Noon)	Introduction Presentation - Research Background - Case Studies 1) Berkeley IoT Research Projects 2) Design Roadmapping Project	: 2 hours
	Afternoon Session (1pm-5pm)	Interviewing Member 1 Interviewing Member 2 Observation 1 - Sproutel's unique design processes, approaches	: 30min – 1hour : 30min – 1hour : 2 hours
Day 2	Morning Session (9:30am-Noon)	Interviewing Member 3 Interviewing Member 4	: 30min – 1hour : 30min – 1hour
	Afternoon Session (1pm-5pm)	Design Roadmapping Workshop (All team members' participation recommended) Observation 1 Observation 2	: 2hours : 1hour : 1hour
Day 3	Morning Session (9:30am-Noon)	Design Roadmap Refinement Follow-up Observations and Interviews	: 2hours : 1.5 hours
	Afternoon Session (1pm-5pm)	Open Discussion Wrap-ups (De-brief)	: 1hour : 30 min.
Day 4	Morning Session (9:30am-Noon)	Observation : User Test Observation	: 2hours
	Afternoon Session (1pm-5pm)	Departure	

Appendix H

EXAMPLE DESIGN ROADMAPPING WORKSHOP SATISFACTION SURVEY

Thanks for participating the Design Roadmapping workshop on [date] in [Location]. This is a post-satisfaction survey regarding your participation. Please feel free to answer to questions below to share your experience with workshop organizers. The result of this survey will be only used for the purpose of improving our educational materials and/or research publication only. Data will be collected anonymously and the result will not contain any identifiable information. Normally, It will be short and take no longer than 5-10 minutes. Thanks for your participation again and hope this design roadmap workshop helped your better understanding and learning in your class. * Required

(Background) Which group were you in? *
Group 1 Group 2 Group 3 Group 4 Group 5 Group 6 Group 7 Group 8 Group 9

(Background) Which form of Design Roadmapping tool was assigned to your team? *

Physical Tool (Puzzle)
Digital Tool (Google Doc.)

1. Overall, I am very satisfied with the Design Roadmapping Workshop.

Strongly Agree
Somewhat Agree
Neither Agree nor Disagree
Somewhat Disagree
Strongly Disagree

2. Of the categories on the list below, which purpose do you think the Design Roadmap Workshop help your team the most? You can select up to TWO answers.

Future Prediction/Plan
Project Goal/Direction Setting
Concept Creation
Concept Refinement
Internal Collaboration (as a team)
External Communication (beside your team)
Resources Allocation (Human, time, materials, etc)
Other:

3. What works well about the Design Roadmapping Workshop?

4. What doesn't work well about the Design Roadmapping Workshop?

5. Please describe the process used to capture user's insight in your project before workshop? e.g. observations, interviews, surveys, online articles, academic papers, or etc.

6. Were there any conflict among your team members to collaborate during this workshop? If, yes. Please describe it briefly.

7. What was the biggest challenge during the Design Roadmapping workshop? Please describe it briefly.

8. If you would like to share any additional comment, thought, or reflection on this workshop, please write them below. e.g suggestion on the workshop process, a way to gather data, etc.