BerkeleyHaas
Haas School of Business
University of California Berkeley

Regaining R&D Leadership:

The Role of Design Thinking and Creative Forbearance

California Management Review
2020, Vol. 62(2) 12–29

DOI: 10.1177/0008125619897395
journals.sagepub.com/home/cmr
SAGE

Melissa M. Appleyard[1], Albrecht H. Enders[1], and Herb Velazquez[2]

SUMMARY
This article examines how Siemens's molecular imaging group incorporated design thinking principles into R&D to regain market leadership. Marked departures from its past practice included a "universe of possibilities" for lifetime customer value; multi-iteration "leapfrog concepting" ahead of prototyping; and adherence to an "innovation metric" that enabled simultaneous consideration of customer value and business cost. These elements gave rise to a dynamic capability, "creative forbearance," which supported the innovation team's unbridled creativity while building in patience for introducing new features to its product platform. This case illustrates how design thinking can be integrated in settings replete with technological and customer complexity.

KEYWORDS: new product development, dynamic capabilities, technological innovation, R&D, design thinking, creative forbearance

Through the application of design thinking principles,[1] wide-ranging customer value has been created in sectors spanning consumer packaged goods to social ventures.[2] Less is known about the incorporation of these principles into technology-intensive research and development (R&D) settings. To extend the design thinking literature in this arena, we present a case study that analyzes how the molecular imaging group at Siemens first employed design thinking to reengineer their approach to R&D. The infusion of these principles altered many dimensions of the group's R&D process as detailed below. Changes included a much-expanded definition of the end-user and a system-level view of the new product platform that replaced the previous modular view. The incorporation of design thinking

[1]Portland State University, Portland, OR, USA
[2]Georgia Institute of Technology, Atlanta, GA, USA

allowed the innovation team to abandon their ingrained belief that customer value only could be created with an increase in manufacturing and other business costs.[3] A pronounced increase in the customer-value-to-business-cost ratio (Value/Cost) became a stretch goal as the team adapted design thinking principles to their industrial R&D setting. This integration also contributed to the group's creation of a new dynamic capability, which we call "creative forbearance." Creative forbearance is defined as the ability to patiently and persistently extend customer value when enabling technologies become feasible. Creative forbearance in effect allows an innovation team to plan the path of lifetime profit of a product platform. The group's execution of creative forbearance meant that competitors in the molecular imaging market could not catch up with the constantly improving features of Siemens's new platform, called E.CAM, resulting in Siemens's market leadership for more than a decade. This case study holds lessons for R&D teams who want to infuse their existing innovation process with design thinking principles in order to break out of incremental outcomes and achieve enduring market leadership.

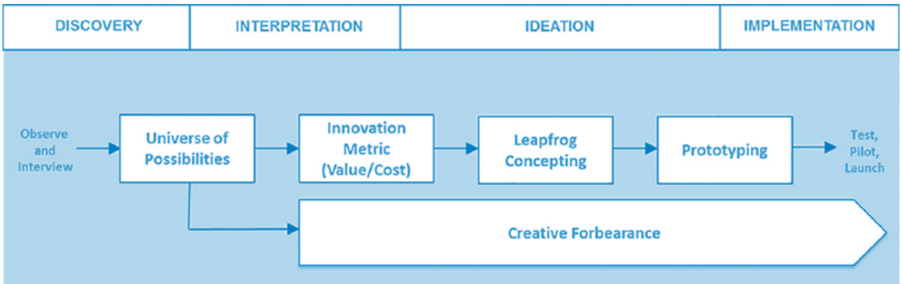
While the design firm, IDEO, popularized the term "design thinking" starting in the 1990s,[4] user-centered processes, human factors, ergonomics, empathic user research, and the digital tools and methods under the design thinking umbrella pre-dated the term. The diffusion of the term improved communication between designers and business partners to help explain what designers do and how these practices might be shared and utilized across functions within organizations. In this article, we use the term design thinking along with other design terms, such as empathic research, because these terms were known at the time of the E.CAM innovation program, and these terms and practices were used within Siemens's Design Department during the E.CAM era.[5]

The Basis for Change and the Move of Design to the Front End

By the early 1990s, Siemens's global share in the molecular imaging market had dropped from nearly 40% to just above 15%.[6] Up to that point, the innovation process in the molecular imaging group had followed a traditional stage-gate process.[7] The process would start with marketing communicating feedback from customers to the engineering team, and the engineering team would develop new product systems and components, which were typically incremental changes.[8] As R&D progressed, sequential handoffs would occur across the functional areas, or gates. The incremental improvements that resulted, coupled with the group's inability to incorporate new camera designs that other companies were bringing to market,[9] contributed to the market share decline.

To reverse this negative trend, the senior leadership restarted the entire product development process with a clean slate in 1992. As part of their new approach, the group VP brought in a new designer named Herb Velazquez. The prior designer in the group reported to the Mechanical Engineering Department and only had been involved at the end of the product development process to

FIGURE 1. The E.CAM innovation process.



select colors and textures, for example. Instead, Velazquez reported directly to the group VP, and this reporting structure meant he was included in meetings in which the market pressures and competitive realities were analyzed. Velazquez applied design thinking methods to assess the market and crafted design strategies that addressed the need for a new direction. The new direction included small, highly integrated systems that were driven by an intense focus on customer needs and rapid visualization. The leadership team embraced this new thinking, and they assigned Velazquez to the core innovation team. This meant that design and design thinking moved from a back-end process to the front end of product development.

The New Innovation Process

After scrapping the stage-gate process and signaling the importance of design by appointing a designer to the core innovation team, senior leadership broke from the past in three additional ways. First, the core team had, for the first time, cross-functional membership spanning marketing, research, engineering, manufacturing, sales, service, and design.[10] The core team members were relieved of all other duties, so they would have a singular focus on the development of the new E.CAM product platform. Second, a consultant, Dr. Jay Desai of IGC (Institute of Global Competitiveness), was brought in to set ambitious stretch goals and help implement the transformation of the product development process.[11] Desai led the team to adopt a "10×" stretch goal, where the controlling metric of the whole innovation program, Value/Cost, was expected to grow by a factor of ten, which shattered preconceptions and fully reset the team's thinking. Shattering preconceptions was critical to overcoming the incremental mindset that embodied the status quo at that time. Third, the core innovation team devised a new innovation process with four phases: Discovery, Interpretation, Ideation, and Implementation (see Figure 1). This new four-phase innovation process placed emphasis on the activities espoused by design thinking methodologies: careful user observation and needs discovery; reframing of the observational data to get at the essence of the user problem; the determination of complete system-level design imperatives to address the user needs; and the interlacing of logic and intuition to craft solutions.[12]

Adhering to the design thinking methodologies required the team to adopt new ways of going about innovation. First, by discovering and interpreting customer value, they created the so-called "universe of possibilities." The team triaged down the universe of possibilities to possible platform features that could enable the attainment of the 10× improvement in Value/Cost. Then, before a full physical prototype was built, the team created a new approach to system concepting called "leapfrog concepting," where they would use a state-of-the-art platform as their starting point but create whole new platforms from the features that would boost Value/Cost. Finally, by holding in reserve features that would raise Value/Cost, but were not yet technically feasible, led the team to develop a new dynamic capability called creative forbearance. Each of these new activities incorporated design thinking principles, and the innovation team considered these three areas the most pronounced ways in which they broke from their past stage-gate innovation process by incorporating design thinking.

The Universe of Possibilities

In the early 1990s, when this transformation was going on in the molecular imaging group at Siemens, companies typically relied on focus group data to understand what customers wanted.[13] The "voice of the customer" was in vogue and the marketing function was looked to for input about what the customer needed and wanted due to their interactions with the customer.[14] The innovation team learned from Desai, the consultant to Siemens, that a much more comprehensive mindset was required to get to the "real who" to guide extensive "need-finding."[15] All of the people who touched the system after it left the manufacturing facility needed to be included in the discovery process to capture a more complete set of customer requirements. This meant that the number of customers considered shifted from 2 (Procedure Technologist and Ambulatory Patient) to 25 (the prior two plus an extensive list of patient categories, physician categories, and hospital staff).

After the full customer list was compiled, the team undertook a journey into empathic customer research during the Discovery phase of the R&D program to understand and determine comprehensive customer needs.[16] The innovation team visited approximately 10-15 customer sites during the first six months of the program. The objective was to experience the customers' environments and observe the established ways equipment was being used. All applications and processes in the customers' environment were explored. This observational approach led the team to learn and identify short-term, medium-term (3-5 years out), and long-term (6-10 years out) needs. Another objective of this Discovery phase was to go beyond lower-level unmet needs and instead consider how to reinvent the entire customer experience. After their fieldwork, the team role-played the interactions with the platform from the vantage point of each of the 25 customer categories. This unique activity led the team to viscerally understand and value the customers' needs.

After this initial phase of the empathic research to understand customer needs, the innovation team engaged in a number of small-group internal brainstorming sessions. In these sessions, they challenged each other to go far beyond the needs synthesized from the customer visits and experienced through the role-playing. In total, the team generated a complete system-level set of customer need statements numbering in the hundreds, and these became the universe of possibilities. No prior innovation program in the molecular imaging group at Siemens had pursued customer needs discovery to this vast extent. By front-loading the innovation process in this way, the team laid the foundation for creative forbearance.[17]

As the team moved into the Interpretation phase of the program, they took the universe of possibilities back out into the field to meet with six customer groupings around the globe. At those customer sessions, the participants helped triage down the hundreds of need statements into the most critical customer requirements, resulting in roughly 120 vital customer requirements. By considering each of these requirements and aligning on the meaning of each, the innovation team developed 180 system-level design specifications with targets surpassing the competition. These design specifications were fine-grained customer needs statements and focused on measurable outcomes for customers (similar to outcome statements).[18] Examples of design specifications were "Minimize steps to change the collimator" or "Minimize the mental and physical effort needed to change the collimator." The innovation team created a 120 × 180 matrix of the vital customer requirements and the design specifications, which was nicknamed "the Million-Dollar Matrix," because of its perceived value by the senior leadership. Some senior leaders joked that it should be locked up in a vault because it was their "secret sauce."[19] Instead, the matrix was shared freely among the molecular imaging group to instill the vision and thinking of what was important to the customer not only at initial launch of the platform, but over the total life of the platform. The customer was viewed as a composite global customer, which avoided the complexity of creating numerous customer segments. Accounts from the core innovation team noted that people would dwell on the matrix and how to achieve the high-value specifications contained in it, triggering frequent spontaneous creative sessions.[20] Velazquez noted, "The creative energy could be seen and felt everywhere in the organization. Team members were constantly thinking about solutions and coming up with both practical and way-out ideas. It was vibrant and exciting to be part of it."[21]

Leapfrog Concepting Governed by the Innovation Metric

After nearly two years committed to customer needs discovery and interpretation, the innovation team shifted into the Ideation phase. During this phase, the team expanded to include staff from different functions and levels with the intent of integrating as diverse a set of ideas as possible. The team's approach to concept ideation departed from past practice in two primary ways. First, influenced by design thinking principles, the team framed ideation of the platform around the whole system rather than moving from one subsystem of the machine to the next. Second, the stretch goal of a 10× improvement in Value/Cost was *the* innovation metric that guided the team's work. It galvanized the E.CAM team's creative process by generating a strategic constraint.[22] Because the platform design challenge was done at a whole system level, this introduced more degrees of freedom into the process, which opened up new opportunities to increase customer value while reducing cost.

Consistent with the whole-system approach, the initial platform concept integrated the entire workflow. This meant that everyone on the expanded innovation team had an opportunity to contribute ideas, which ensured not only a diverse set of ideas, but a comprehensive buy-in.[23] The team adapted the Pugh matrix to organize the concept comparisons.[24] The Pugh matrix is a structured way to evaluate each platform concept relative to other concepts against specific criteria to arrive at a winning concept. The benchmark concept in the first iteration was the market leader at the time. The winning concept from the first iteration became the benchmark for the second iteration. And the process continued in this manner through five iterations. As concept sketches were presented by team members, both value and relative cost comparisons between ideas were captured in the Pugh matrix by considering the quantity of parts, the complexity of making them, and the materials and technology required. This was a fast and accurate way to assess cost on a relative cost basis. The cost analysis increased in rigor as the team progressed through concept iterations. One unique challenge for the team was in resolving opposing requirements, which were called a "double-x" challenge. These double-x challenges were true opportunities for innovation, which the team readily accepted producing double-x achievements. One example of a double-x achievement related to image quality. The relentless commitment to add value while driving down cost resulted in an innovation that improved image quality with a lower part count, reducing cost by approximately 50% relative to prior systems.[25]

To strive for the 10× stretch goal, the team had to embrace a new way of thinking, characterized as leapfrog concepting. To leapfrog the competition, the team needed to consider solutions that far surpassed the platforms in use. In other words, they needed to leap over the competition, with the goal of being 10 times better. The process started by identifying the best-in-class system in the market. Then the team brainstormed ideas to meet the customer and design requirements from the Million-Dollar Matrix better than the best-in-class system, thereby leapfrogging it. The concept that leapfrogged became the best-in-class concept that would be leapfrogged in the subsequent iteration. The team derived concepts that would add value and reduce cost in pursuit of the 10× goal. They generated 25 concepts in the first iteration, 15 in the second, 9 in the third, 3 in the fourth, and only 1 in the fifth iteration. One subtle but critically unique aspect of these five iterations was the impact they had on the team dynamic and size. At iteration 1, there were teams working on each concept. In iteration 2, the number of concepts fell to 15 because alliances were formed around concepts. By iteration 5, there was only one concept by one team. This unity of team members proved critical to subsequent development phases.

The lead designer, Velazquez, noted that the intensive iteration process was necessary to enhance customer value while not only containing costs, but reducing them:

> The E.CAM leapfrog concepting process forced the innovation teams to add functionally while reducing the overall platform cost and part count of Siemens's entire Molecular Medicine product portfolio. It is important to note that the shift in mindset and creativity of the innovation team came in iterations 3 and 4.[26]

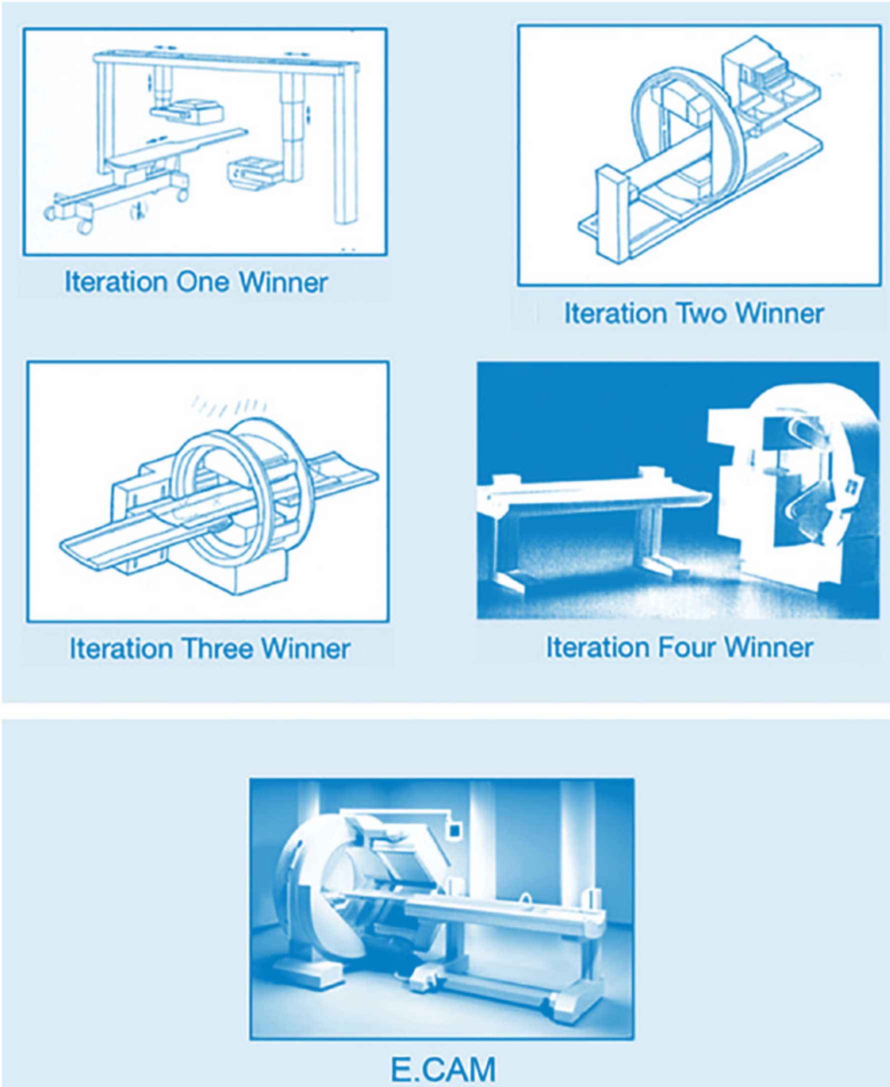
After four months and five iterations, there was only one concept that successfully leapfrogged the winner from the fourth iteration to become the E.CAM platform. The progression of the concepts is shown in Figure 2. Because of the active participation of multiple functions during the leapfrog concepting, when the winning concept entered the Implementation phase, the majority of the workforce willingly participated in the platform launch.[27] The team faced pressure from the executive leadership to move into Implementation at the end of the third iteration. The team decided against this course of action and continued to develop additional concepts for iteration 4. If the process had stopped at iteration 3, the results would have been suboptimal. There were nine concepts going into iteration 3 from nine different teams, and if the winning concept had been chosen at that time, the project team would not have achieved unity. Factions would have continued to pursue their ideas, silos would have arisen, and a common vision for the new system would not have emerged. This in effect would have constituted a reversion to previous development practices including top-down, schedule-driven decision making. The team leadership persevered to see the process through to the end to produce a truly optimal system-level solution. That was a unique moment for the innovation team and constituted the only path forward for a successful outcome.

Throughout leapfrog concepting, the team generated sketches and mock-ups of their ideas, but a functional prototype was not created until after the fifth iteration. Before they were ready for the functional prototype, Velazquez advocated for a break from past practice to create a full-size appearance model out of foam.[28] This request was met with skepticism because of the large price tag at the time ($100,000), but it actually turned out to contribute immeasurably to validation of the concept.[29] The foam mock-up allowed the team to approve the final form aesthetics and interfaces at full scale. The model could be rotated such that when the team brought back end-users for feedback, they could walk through all of the imaging procedures by manipulating the model. The novel open ring concept had a noticeable effect on the patient-customers who came to view the foam model. They approached the imaging system without being intimidated, and, whether they could walk up to it or were in a wheelchair, they could be accommodated by the adjustable bed height. The sales staff brought in leading hospital customers to get pre-market introduction sales commitments. The mock-up was further useful in the production of user manuals, training materials, service manuals, and promotional literature, before the actual functional prototype was developed at the end of the Ideation phase.

Creative Forbearance

The three major elements of their new innovation process analyzed above enabled the innovation team to map out the desired functionality over the entire

FIGURE 2. Concept examples from the five-iteration leapfrog concepting.



life of the platform. These elements included their commitment to investing in the Discovery phase to create the complete system-level universe of customer needs; prioritizing the vital customer requirements and design specifications; and triaging the customer requirements and design specifications by assessing them vis-à-vis a 10× improvement in the Value/Cost innovation metric. A number of the underlying technologies that would enable some of the greatest gains, however, were either cost prohibitive or not yet invented at the time of the platform's initial release. The team's ability to not sacrifice creativity due to technology limitations and then patiently introduce features as they became feasible culminated in their creative forbearance dynamic capability. Creative forbearance can be classified as a dynamic capability, because exercising creative forbearance required continual reaction to the evolving technology landscape.[30] Creative forbearance became a differentiating innovation capability for Siemens, as it led the team to be extremely imaginative in discerning and projecting user needs yet be patient with the implementation of design specifications to address the vital customer needs. Creative forbearance is applicable in a host of settings characterized by uncertainty around foundational technologies, with current examples including artificial intelligence and blockchain applications. Instead of becoming anxious around providing a subpar solution to customers at the time of launch, creative forbearance allowed the innovation team to embark on a measured path to addressing high-value and latent user needs over a long time horizon. Creative forbearance allowed the team to plan the lifetime profit pathway of the platform. Competitors could not catch up to the market entrenchment of the E.CAM platform, because as they reacted to each new product release on the E.CAM platform, the Siemens's team was in the process of readying their next release.

The Timeline

The new innovation process front-loaded the team's work to allow time to thoroughly understand customer value and to develop global alignment and prioritization of customer value. The timeline placed on the process was not defined at the outset, because it was not clear how long it would take to gather and analyze customer requirements from a much greater pool of customers. It turned out that the Discovery phase required more than a year and a half to complete, which eclipsed how much time was spent on customer requirements in prior platform programs. The Interpretation phase during which the team defined the essence of customer value required about three months. The application of the Value/Cost innovation metric to guide leapfrog concepting ran about four months. The prototyping, testing, and ultimate market launch of the new platform lasted about 16 months. The group's prior product development programs weighted the back-end stages of engineering and manufacturing more heavily with adherence to strict deadlines. The new process was not schedule driven allowing time for innovation and design to reach breakthroughs aimed at the 10× stretch goal. In addition, while Figure 1 implies that the four phases—Discovery, Interpretation, Ideation, and Implementation—occurred sequentially, they actually overlapped to a much greater degree than the stages in the past stage-gate process. This overlap contributed to deeper trust across team members who had worked in different stages in the past without much cross-functional interaction.

Discussion

At the time of the E.CAM innovation program, design thinking principles were not new. What was new was to package the design thinking principles in ways that the whole organization could understand, implement, and accept as their own process. With this first comprehensive application of design thinking into the R&D function in the molecular imaging group at Siemens, the intent was to translate the principles into the responsibilities of each function such that everyone could be part of the transformation. Design techniques such as rapid visualization sketching were, for example, taught to all team members to enable ideation and sharing of ideas.

The resulting innovation process, which incorporated design thinking principles throughout all phases, profoundly changed the behavior of the innovation team. Prior innovation teams waited to be told what to do. Direction trickled down from the executive level to the department managers to the working subteams on a need-to-know basis. Team members would stay within the boundaries of their assignments and worked within their functional siloes, which stifled innovative thinking. Within the new process, the emphasis on the front-end customer value identification, universe of possibilities, and subsequent creation of the Million-Dollar Matrix revealed "the why" behind the need to deliver on the design specifications: because then vital customer needs would be met.[31] This freed the team to think expansively, and the 10× improvement goal in the Value/Cost innovation metric became the rallying cry for the team.

The innovation team never actually quantified the resulting Value/Cost ratio, but the final E.CAM platform gave rise to an immediate and intuitive confidence that the team achieved a new productivity frontier (a superior Value/Cost ratio) in the molecular imaging sector. This hypothesis proved to be accurate over the entire life of the product platform. At the start of the innovation program, the 10× stretch goal was met with disbelief, but it ultimately reframed the team's thinking allowing for vastly new, innovative ideas during the E.CAM program and in subsequent innovation programs.

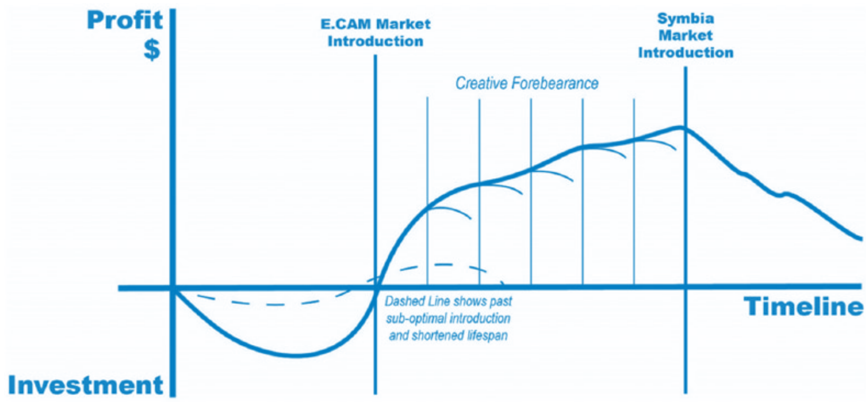
The foam, full-scale appearance mock-up encapsulated the importance of design for the whole program and organization. The engineering teams, the manufacturing teams, and the service teams all used the model extensively to help resolve uncertainty and plan activities needed to complete the system. The mock-up unified the vision of the entire molecular imaging group, bringing everyone into alignment to accelerate development and subsequent activities including engineering, functional prototyping, testing, pre-market introduction sales, and ultimately market launch. The alignment of cross-functional resources was critical in achieving design thinking and aesthetic goals.

A number of new design elements in the E.CAM platform, which were made possible by the team's cross-functional collaboration, immediately received favorable customer feedback. First, the system achieved improvements in image quality, because of the reduced thickness of the pallet upon which the patient rested. Through collaborations across design, engineering, and manufacturing, the thickness went from 3 to 0.06 inches. This allowed the detector (the camera) to be closer to the patient and image quality improved as a result. Second, customer comfort was enhanced by reshaping the pallet, which also improved image quality by reducing patient movement during the scan. Design proposed anthropometrics to test different curvatures and widths of the pallet; engineering conducted Taguchi experiments[32]; and manufacturing built pallet samples. Third, body scan imaging improved in quality because integrated arm holders helped patients stay in place. These arm holders served an additional function—when they were folded down, they would extend the width of the pallet and disguise the pallet's curvature making it easier for patients to slide onto the pallet. Again, design, engineering, and manufacturing worked closely together to create this new pallet design. A final example of a market-favored design element was improved serviceability of the equipment. Service was typically an afterthought, and on past systems, much disassembly was needed to get to components that needed maintenance, service, and replacement. In the E.CAM case, the service function scoped the requirements for component access, as well as wiring longevity; engineering led the failure mode and effects analysis (FMEA); and design collaborated on the servicing ergonomics. This resulted in all of the components and subsystems being easily and quickly accessible.

The E.CAM platform replaced Siemens's entire product portfolio in molecular imaging and created an efficient value chain with a significant reduction in overall part count, reducing product portfolio complexity. It was easy to service this multipurpose product family resulting in a long-term reduction in manufacturing and service cost. The design elements further allowed future modules to easily integrate into the initial product platform and aligned with evolving market needs. The unique bundle of functionality developed from a deep understanding of the customer's prioritized needs. The leapfrog concepting resulted in a highly differentiated product family across the composite global customer, leading the E.CAM platform to address 80% of the molecular imaging market and forcing major competitors to become followers as they worked to redesign their platforms.

Once the platform was launched, profit planning over the life of the platform made possible by creative forbearance contributed to a sustained competitive advantage. Creative forbearance allowed the team to explore exciting system elements with the potential of delivering continuous value to the market once available.[33] The complexity, technology, feasibility, and profit potential of these elements varied widely. Some were relatively easy to implement and others, such as the integration of computed tomography (CT) technology with molecular imaging, were further out. These high-value features were mapped on a timeline to provide a roadmap for planned continuous product improvements. This strategy enabled the product family resulting from the E.CAM innovation program to hold its market share for more than a decade. The product family shared more than 75% of the components, and each year, two new product releases occurred. Figure 3 depicts the conceptual lifetime profit of the E.CAM system for Siemens (solid curve) relative to the typical lifecycle path of prior systems (dashed curve). The lifetime profit could be thought of as the upper envelope of successive "S curves" or technology lifecycle curves with profit instead of performance on the vertical axis.[34] As shown, the E.CAM platform had a dominant profit profile attributable to its longer life, its superior Value/Cost profile, and the practice of creative forbearance. The successor platform was named Symbia, and market demand persisted for the E.CAM system even after the launch of Symbia. In terms of overall

FIGURE 3. Lifetime platform profit enabled by creative forbearance.



market performance, Siemens rebounded to a 30% market share a few years following the E.CAM's release. Consolidation in the industry ensued, and a competitor, Toshiba, ended up licensing the E.CAM technology.[35]

Extensions

The introduction of design thinking principles into an established innovation process was met with initial skepticism at Siemens. Over time, acceptance grew as the innovation team understood that the intent was to strike a balance between known methodologies and new design thinking ones to reach a more comprehensive approach to innovation, which we term "holistic innovation." This balance can be visualized as a level "innovation beam" with reliability-focused methodologies[36] on one end and validity-focused ones[37] on the other (Figure 4). The reliability end depends on methodologies rooted in objective measurement like Quality Function Deployment (QFD) and System Validation,[38] whereas the validity end is based on observation, intuition, and deep customer empathy achieved through such methodologies as field interviews, mock-ups, and user testing.[39] The Siemens holistic innovation process analyzed in this article represented an integration of the two approaches.

The E.CAM team had innovation experts that represented the two ends of the innovation beam—including Velazquez, the lead designer, at the validity end and Desai, the consultant, at the reliability end. Holistic innovation arose from the meshing of intuitive methods with analytical ones.[40] Reliability tools such as QFD were adapted and applied by the team in a highly structured process. The more design-oriented team members learned how to apply rigorous decision tools when facing a complex composite customer, and they adapted their ideation approaches in E.CAM's technology-intensive setting. Siemens's holistic innovation process that resulted relied heavily on design thinking principles to develop unique solutions that achieved superior performance. Prior to E.CAM, Siemens utilized consumer marketing approaches such as interviews and focus groups to define the

FIGURE 4. Holistic innovation balances validity and reliability methodologies.

Note: QFD = Quality Function Deployment.

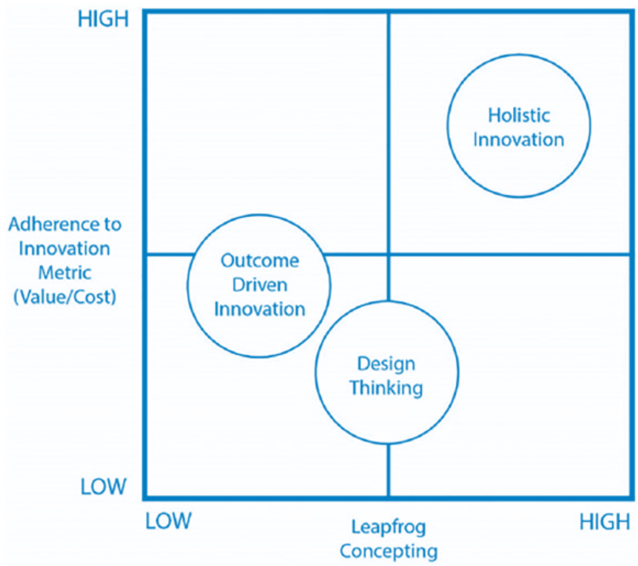
project brief along with a schedule-driven project plan for market introduction, which inherently compromised value and cost. Holistic innovation differentiated itself from design thinking because it valued and integrated elements of reliability-focused methodologies like outcome-driven innovation. The application of the Value/Cost innovation metric and leapfrog concepting by cross-functional teams distinguished holistic innovation from *both* design thinking and outcome-driven innovation (Figure 5).

The innovation metric has a much more refined articulation of where customer and business value can be generated. Design thinking methodologies, in contrast, focus the initial ideation process on a problem statement that usually lacks the depth of the innovation metric and therefore compromises a team's ability to holistically evaluate their creative ideas. This focus limits the creative process because of the team's narrow approach to the problem.

The innovation metric encourages the innovation team to simultaneously ideate on customer value and business cost. Setting that strategic constraint is rare in both design thinking methods and outcome-driven innovation approaches. Outcome-driven innovation promotes a "focused brainstorming" strategy, targeted at pinpointing the innovation opportunity through precise outcome statements.[41] This approach promotes a rapid convergence process that is not desirable in complex technology settings. Design thinking methodologies are starting to apply more ideation rigor, but due to early prototyping strategies they also accelerate the convergence process prematurely. In contrast, Siemens's resulting holistic innovation process delivered a high value-to-cost platform from which to launch a family of products and innovative future system features, leading the E.CAM platform to achieve sustained lifetime profitability.

Once the Siemens's team committed to meshing methodologies, their adherence to and respect for the holistic innovation process enabled them to reach a new industry standard (or productivity frontier). The commitment extended far up into the organization. Department managers and company executives were trained in the process and understood their role. For example, if a company executive suggested an idea, the idea had to be run through the rigor of the Value/Cost innovation metric. Because of the breadth and depth of the adoption of the new

FIGURE 5. Distinguishing elements of holistic innovation.



process, a high level of trust was felt across the organization, which supported cross-functional collaboration and allowed the four phases of the process to overlap to a much greater extent than in previous innovation programs. According to team members, that bond of trust across the group also allowed them to weather changes in executive leadership that occurred in the middle of the E.CAM program.[42] Future research could assess strategies for meshing the validity and reliability methodologies to understand the underlying, interpersonal processes that most effectively contribute to holistic innovation. This would require cross-functional academic research to bridge the design thinking and the traditional reliability-heavy innovation communities. Such inquiry could lead to the development of more resilient methods to advance both cultures' capabilities.

A final consideration is as follows: when might design thinking not be necessary in a technology-intensive industrial R&D program? The E.CAM program required nearly two years for the Discovery and Interpretation phases to define high-value customer needs. While extensive customer value was created for more than ten years following the platform's release, would that kind of time investment lead to the same returns in other industrial R&D settings?

One setting where the return might be called into question would be a setting characterized by what we call "ecosystem compatibility."[43] Historically, the semiconductor industry, as an example, reflected a high degree of ecosystem compatibility, with the players in the market highly interreliant on other firms in adjacent industries such as computers or gaming consoles. Chip makers, like Intel, needed to stay on the technology roadmap roughly consistent with Moore's Law.[44] The technology roadmap was a way for the electronics industry to coordinate the release of new systems.[45] For example, the chip componentry needed to be ready when the next generation of laptops was scheduled to be released. Because of the technology roadmap known across the ecosystem, a company like Intel knew the primary dimensions of what their users needed, including chip size, clock speed, heat dissipation, and reliability. It was more important for a components company like Intel to focus attention on solving the technology barriers to release their chips in keeping with the roadmap, rather than spending excessive time with front-end customer sessions.[46] The historic focus by the semiconductor industry on ecosystem compatibility contrasts with the E.CAM case, where end-customer empathic design was central to the E.CAM's success.

Another setting where an advanced R&D company might want to forgo creating an E.CAM-type innovation process would be when open innovation can substitute for empathic design. Companies can open up parts of their product development to co-creation by user-developers.[47] Examples range from the replacement of proprietary software code by open source software (e.g., Cisco's OpenDaylight project[48]) to the creation of whole product categories by user-entrepreneurs (e.g., the juvenile products industry[49]). In this way, open innovation outsources the development to the user, so user needs are accurately captured.

The incorporation of design thinking principles created unrivaled customer value in the E.CAM case. However, careful consideration is required to understand design thinking's return on investment relative to alternative approaches to innovation. Future research is required to systematically assess when and how design thinking can ensure leadership across technology-intensive R&D settings.

Author Biographies

Melissa M. Appleyard is Ames Professor in the Management of Innovation & Technology and Associate Dean of Graduate Programs at Portland State University's School of Business (email: appleyard@pdx.edu).

Albrecht H. Enders is Principal of endersgroup, an innovation consulting firm in Portland, Oregon, and an adjunct faculty member at Portland State University's School of Business (email: albrecht@endersgroup.com).

Herb Velazquez is a Professor of Practice in the College of Design at Georgia Institute of Technology in Atlanta, Georgia (email: hvelazquez@gatech.edu).

Notes

1. By pursuing human-centered design, design thinking guides innovation teams to "discover the real problems" rather than surface-level product shortcomings. D. Norman, *The Design of Everyday Things* (New York, NY: Basic Books, 2013), p. 218. The global design firm, IDEO, helped popularize design thinking methodologies. For the phases of IDEO's product development process, see S. Thomke, *Managing Product and Service Development: Text and Cases* (New York, NY: McGraw-Hill/Irwin, 2007), p. 98. Regarding IDEO's internal learning processes across projects, see A. Hargadon and R. I. Sutton, "Technology Brokering and Innovation in a Product Development Firm," *Administrative Science Quarterly*, 42/4 (December 1997): 716-749.

2. S. L. Beckman and M. Barry, "Innovating as a Learning Process: Embedding Design Thinking," *California Management Review*, 50/1 (Fall 2007): 25-56; A. Ignatius, "How Indra Nooyi Turned Design Thinking into Strategy," *Harvard Business Review*, 93/9 (September 2015): 80-85; T. Brown and J. Wyatt, "Design Thinking for Social Innovation," *Stanford Social Innovation Review*, 8/1 (Winter 2010): 30-35; T. Brown, *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation* (New York, NY: HarperCollins, 2009); E. B.-N. Sanders and P. J. Stappers, "Co-creation and the New Landscapes of Design," *CoDesign*, 4/1 (March 2008): 5-18.
3. This new understanding by the innovation team that customer value could go up while cost decreased is consistent with "Blue Ocean" strategy, where novel sources of value are pursued outside of established dimensions of competition. W. C. Kim and R. Mauborgne, "Blue Ocean Strategy: From Theory to Practice," *California Management Review*, 47/3 (Spring 2005): 105-121; W. C. Kim and R. Mauborgne, *Blue Ocean Strategy: How to Create Uncontested Market Space and Make Competition Irrelevant* (Boston, MA: Harvard Business School Publishing, 2005).
4. IDEO acknowledges the influential work of Buchanan (1992) and others in shaping the design thinking framework. IDEO, accessed August 2019, https://designthinking.ideo.com/history; R. Buchanan, "Wicked Problems in Design Thinking," *Design Issues*, 8/2 (Spring 1992): 5-21.
5. More than 25 years later, many of these terms are still in use, though some may soon give way to new terminology such as experience design including augmented reality, user experience, attentional experience, and virtual reality.
6. Diagnostic Imaging, "E.Cam Spurs Market Resurgence at Siemens' Nuclear Medicine Unit," October 1, 1997, accessed March 2019, https://www.diagnosticimaging.com/articles/ecam-spurs-market-resurgence-siemens-nuclear-medicine-unit.
7. For additional information about the stage-gate product development process, see R. G. Cooper, *Winning at New Products: Accelerating the Process from Idea to Launch*, 3rd ed. (Cambridge, MA: Perseus Books, 2001): 113; R. G. Cooper, "The Stage-Gate Idea-to-Launch Process—Update, What's New and NexGen Systems," *Journal of Product Innovation Management*, 25/3 (May 2008): 213-232; R. G. Cooper and A. F. Sommer, "The Agile-Stage-Gate Hybrid Model: A Promising New Approach and a New Research Opportunity," *Journal of Product Innovation Management*, 33/5 (September 2016): 513-526.
8. Limited direct customer contact by the innovation team and relying on the marketing function to be the go-between has known shortcomings. G. Bacon, S. Beckman, D. Mowery, and E. Wilson, "Managing Product Definition in High-Technology Industries: A Pilot Study," *California Management Review*, 36/3 (Spring 1994): 32-56.
9. Diagnostic Imaging (1997), op. cit.
10. Evidence for the benefits of cross-functional participation to facilitate concurrent engineering can be found in C. Terwiesch, C. H. Loch, and A. De Meyer, "Exchanging Preliminary Information in Concurrent Engineering: Alternative Coordination Strategies," *Organization Science*, 13/4 (July/August 2002): 402-419.
11. D. Destler, "Siemens E.CAM: A New, Clear Image of Holistic Design," Industrial Designers Society of America, 2009, pp. 1-22, accessed December 2010, www.idsa.org.
12. Beckman and Barry (2007), op. cit.
13. E. F. McQuarrie and S. H. McIntyre, "Focus Groups and the Development of New Products by Technologically Driven Companies: Some Guidelines," *Journal of Product Innovation Management*, 3/1 (March 1986): 40-47.
14. A. Griffin and J. R. Hauser, "The Voice of the Customer," *Marketing Science*, 12/1 (Winter 1993): 1-27.
15. The Siemens team sought understanding of unmet and unspoken customer needs by considering a much broader customer range to get at a comprehensive "who." This broad customer view is consistent with the notion of considering all customers in a bell curve distribution including those in the tails. M. Blanding, "Pay Attention to Your 'Extreme Consumers,'" *Working Knowledge*, July 14, 2014, accessed March 2019, https://hbswk.hbs.edu/item/pay-attention-to-your-extreme-consumers.
16. For examples of the lengths that designers go to seek empathy, see K. Battarbee, J. F. Suri, and S. G. Howard, "Empathy on the Edge," 2014, accessed April 2019, https://www.ideo.com/news/empathy-on-the-edge; D. Leonard and J. F. Rayport, "Spark Innovation through Empathic Design," *Harvard Business Review*, 75/6 (November/December 1997): 102-113.
17. While the Siemens team front-loaded their innovation process with customer needs, other companies like Toyota have benefited from front-loading problem identification and problem solving

to help shorten product development lead time, reduce cost, and increase quality. S. Thomke and T. Fujimoto, "The Effect of 'Front-Loading' Problem-Solving on Product Development Performance," *Journal of Product Innovation Management*, 17/2 (March 2000): 128-142.

18. A. W. Ulwick, *What Customers Want: Using Outcome-Driven Innovation to Create Breakthrough Products and Services* (New York, NY: McGraw-Hill, 2005), p. 30.
19. Author interview with Herb Velazquez, March 23, 2019.
20. Author interview with Herb Velazquez and Albrecht Enders, April 1, 2019.
21. Author interview with Herb Velazquez, March 23, 2019.
22. An anonymous reviewer pointed out that breaking constraints is a common quest in design thinking processes. See J. Liedtka, "In Defense of Strategy as Design," *California Management Review*, 42/3 (Spring 2000): 8-30.
23. Divergent and imaginative ideas were encouraged across all group members to instill "creative confidence" (T. Kelley and D. Kelley, "Reclaim Your Creative Confidence," *Harvard Business Review*, 90/12 (December 2012): 115-118) and avoid stifling creativity (T. M. Amabile, "How to Kill Creativity," *Harvard Business Review*, 76/5 (September/October 1998): 77-87; D. Leonard-Barton and W. C. Swap, *When Sparks Fly: Igniting Creativity in Groups* (Boston, MA: Harvard Business School Press, 1999)).
24. S. Pugh, "Concept Selection—A Method That Works" (Proceedings of the International Conference on Engineering Design, Rome, Italy, March 1981), pp. 497-506; S. Pugh, *Total Design: Integrated Methods for Successful Product Engineering* (Harlow, UK: Addison-Wesley, 1991), p. 73.
25. Destler (2009), op. cit.
26. Author interview with Herb Velazquez, March 23, 2019.
27. The group achieved a deep common understanding of what the platform was trying to achieve for the customer or "concept coherence." V. P. Seidel and S. O'Mahony, "Managing the Repertoire: Stories, Metaphors, Prototypes, and Concept Coherence in Product Innovation," *Organization Science*, 25/3 (May/June 2014): 691-712.
28. The mock-up pre-dated the first functional prototype, but it was not a so-called "pretotype," because it was a full-scale representation of the final concept. For a discussion of pretotypes, see A. Savoia, *The Right It: Why so Many Ideas Fail and How to Make Sure Yours Succeed* (San Francisco, CA: HarperOne, 2019).
29. Destler (2009), op. cit.
30. D. J. Teece, G. Pisano, and A. Shuen, "Dynamic Capabilities and Strategic Management," *Strategic Management Journal*, 18/7 (August 1997): 509-533.
31. S. Sinek, *Start with Why: How Great Leaders Inspire Everyone to Take Action* (New York, NY: Penguin Group, 2009).
32. D. Clausing, "Taguchi Methods to Improve the Development Process" (IEEE International Conference on Communications—Spanning the Universe, Philadelphia, PA, June 12-15, 1988), pp. 826-832.
33. The value of the Million-Dollar Matrix was its ability to extend beyond the design of the initial E.CAM system and to reduce the time-to-market of subsequent programs. For example, the Design team took the lead to collaborate with Sales, Customer Support, Training Specialists, and Software Developers to apply the insights and priorities from the initial E.CAM work to the development of a next-generation concept for the E.CAM user interface. This allowed fast tracking through the iteration process and in a period of three months led to a working mock-up of the proposed interface concept using Adobe Director. The system-level user interface concept featured an iPad-like touch screen with a highly intuitive graphical interface that received positive user feedback. This was an example of creative forbearance, because the touch screen graphical interface was introduced 15 years prior to the iPad development.
34. P. Kotler, "Competitive Strategies for New Product Marketing over the Life Cycle," *Management Science*, 12/4 (December 1965): B-49-C-112; E. M. Rogers, *Diffusion of Innovations*, 5th ed. (New York, NY: Simon & Schuster, 2003), p. 272.
35. Diagnostic Imaging (1997), op. cit.
36. Griffin and Hauser (1993), op. cit.; J. R. Hauser and D. Clausing, "The House of Quality," *Harvard Business Review*, 66/3 (May/June 1988): 63-73; L. A. Bettencourt and A. W. Ulwick, "The Customer-Centered Innovation Map," *Harvard Business Review*, 86/5 (May 2008): 109-114; A. W. Ulwick, "Turn Customer Input into Innovation," *Harvard Business Review*, 80/1 (January 2002): 91-97; G. Katz, "A Critique of Outcome-Driven Innovation," September 2008, accessed March 2019, https://ams-insights.com/our-latest-thinking/articles/critique-outcome-driven-innovation/.

37. The validity end emphasizes exploration, whereas the reliability end represents exploitation. R. Martin, *The Design of Business: Why Design Thinking is the Next Competitive Advantage* (Boston, MA: Harvard Business Press, 2009), p. 26. Historically, limited attention had been paid to industrial design in the new product development literature. V. Krishnan and K. T. Ulrich, "Product Development Decisions: A Review of the Literature," *Management Science*, 47/1 (January 2001): 1-21.
38. R. R. Inman, D. E. Blumenfeld, N. Huang, and J. Li, "Designing Production Systems for Quality: Research Opportunities from an Automotive Industry Perspective," *International Journal of Production Research*, 41/9 (2003): 1953-1971.
39. For design thinking methods, see Beckman and Barry (2007), op. cit.; W. R. Spillers and S. L. Newsome, "Another Look at Design Theory," *IEEE Transactions on Systems, Man, and Cybernetics*, 20/1 (March/April 1990): 528-530; D. E. Whitney, "Designing the Design Process," *Research in Engineering Design*, 2 (1990): 3-13; Brown and Wyatt (2010), op. cit. To illustrate how the two ends might produce different prescriptions, one can consider the example of the Aeron chair described by Roger Martin. Martin (2009), op. cit., p. 111. If Herman Miller had concentrated on focus group data (high reliability), the company would have developed a traditional executive armchair. Instead, the novel design of the Aeron chair better addressed true customer needs (high validity). An anonymous reviewer suggested that the poles of the innovation beam could be representative of the different logical thinking modes where the parallel to the validity end would be an abductive logic that would represent exploratory thinking, whereas the other end would be deductive logic representing analytical thinking. We thank the reviewer for this insight.
40. In the end, there was widespread acceptance of the customer-centric holistic design approach across the group. Destler (2009), op. cit.
41. Ulwick (2005), op. cit., p. 137.
42. Author interview with Herb Velazquez and Albrecht Enders, April 1, 2019.
43. For an illustration of complementarities among ecosystem participants, see H. Ozalp, C. Cennamo, and A. Gawer, "Disruption in Platform-Based Ecosystems," *Journal of Management Studies*, 55/7 (November 2018): 1203-1241. For an example of how ecosystem actors collaborate during technological generational change, see R. Adner and R. Kapoor, "Innovation Ecosystems and the Pace of Substitution: Re-examining Technology S-curves," *Strategic Management Journal*, 37/4 (April 2016): 625-648.
44. Extensive cross-company collaboration in the semiconductor industry, for example, between chip makers and their equipment suppliers, has been required to keep pace with "Moore's Law." M. M. Appleyard, "The Influence of Knowledge Accumulation on Buyer-Supplier Codevelopment Projects," *Journal of Product Innovation Management*, 20/5 (September 2003): 356-373, at p. 357. For an overview of Moore's Law, see R. R. Schaller, "Moore's Law: Past, Present and Future," *IEEE spectrum*, 34/6 (June 1997): 52-59; M. J. Bowden, "Moore's Law and the Technology S-curve," *Stevens Alliance for Technology Management*, 8/1 (2004): 1-4.
45. To understand the criticality of the "collective" technology roadmap in the semiconductor ecosystem, see K. Lange, G. Müller-Seitz, J. Sydow, and A. Windeler, "Financing Innovations in Uncertain Networks—Filling in Roadmap Gaps in the Semiconductor Industry," *Research Policy*, 42/3 (April 2013): 647-661; M. M. Appleyard, C. Y. Wang, J. A. Liddle, and J. Carruthers, "The Innovator's Non-dilemma: The Case of Next-Generation Lithography," *Managerial and Decision Economics*, 29/5 (July 2008): 407-423.
46. Recent literature has questioned the adherence to past technology roadmaps without creating complementary design roadmaps (E. Kim, S. L. Beckman, A. Agogino, "Design Roadmapping in an Uncertain World: Implementing a Customer-Experience-Focused Strategy," *California Management Review*, 61/1 (Fall 2018): 43-70) and without asking how the market *should* evolve given customer needs (M. Schilling, "What's Your Best Innovation Bet?" *Harvard Business Review*, 95/4 (July/August 2017): 86-93).
47. C. Baldwin and E. von Hippel, "Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation," *Organization Science*, 22/6 (November/December 2011): 1399-1417; E. von Hippel, *Democratizing Innovation* (Cambridge, MA: MIT Press, 2005).
48. M. M. Appleyard and H. W. Chesbrough, "The Dynamics of Open Strategy: From Adoption to Reversion," *Long Range Planning*, 50/3 (June 2017): 310-321.
49. S. K. Shah and M. Tripsas, "The Accidental Entrepreneur: The Emergent and Collective Process of User Entrepreneurship," *Strategic Entrepreneurship Journal*, 1/1-2 (2007): 123-140.